NEWSLETTER
IRE Professional Group on ULTRASONICS ENGINEERING

THE PROFESSIONAL GROUP ON ULTRASONICS ENGINEERING (PGUE) IS AN ASSOCIATION OF IRE MEMBERS WITH PROFESSIONAL INTEREST IN THE FIELD OF ULTRASONICS ENGINEERING. ALL IRE MEMBERS ARE ELIGIBLE FOR MEMBERSHIP AND WILL RECEIVE ALL PGUE PUBLICATIONS UPON PAYMENT OF THE PRESCRIBED ASSESSMENT.

Number 23 September 1962

OFFICERS AND ADMINISTRATIVE COMMITTEE MEMBERS

The following PGUE members were recently elected to the Administrative Committee for a term of three years:

[illegible]olf Beckman	Hans Jaffe	William F. Konig

Other members presently serving on the Administrative Committee are:

A. H. Meitzler, Chairman	O. E. Mattiat, Trans. Editor
R. S. Woollett, Vice-Chairman	J. J. G. McCue
Arthur Rothbart, Secy-Treas.	R. L. Rod
W. J. Fry	R. N. Thurston

CALL FOR PAPERS - 1963 IEEE INTERNATIONAL CONVENTION

The PGUE will sponsor two sessions in the 1963 IEEE International Convention, March 25-28, to be held in New York City. A general call for papers is extended at this time. Papers on all aspects of ultrasonics engineering, submitted by members or nonmembers of the IEEE are welcome. A prospective author must [illegible]nit, prepared in triplicate, a 100-word abstract and a 500-word [illegible]mary. Indicate in the covering letter that the paper is intended for presentation in one of the sessions sponsored by the PGUE. All material should be sent to:

Dr. Donald B. Sinclair, Chairman
1963 Technical Program Committee
The Institute of Radio Engineers, Inc.
1 East 79th Street
New York 21, New York.

The deadline for submitting papers in response to the general call is October 19, 1962.

In the event that the program is not filled by papers submitted in response to the general call, it may be possible to have a paper in[illegible]ed in the program even though the abstract and summary are not [illegible] by the deadline date of October 19. If an abstract and summ[illegible]y can be prepared by December 1, then it may be possible to have the paper scheduled by contacting directly the session organizer and discussing the matter with him. The session organizer for the PGUE is:

Mr. Ralph S. Woollett
United States Navy Underwater Sound Laboratory
New London, Connecticut.

The activity and effectiveness of the PGUE depend to a large ex[illegible] [illegible]pon the quantity and quality of the papers submitted at sessions sp[illegible]ored by our professional group. The PGUE Administrative Committee would like to encourage increased participation in the group's technical meetings and in this connection invites all members (and non-members) who are doing research or development work in the various areas of ultrasonics engineering to report their results [illegible]apers presented at PGUE sessions.

1962 ULTRASONICS SYMPOSIUM
NOVEMBER 28-29-30
HORACE MANN AUDITORIUM
BROADWAY & 120TH STREET - NEW YORK CITY

Host - Columbia University School of Engineering and Applied Science

Included in this Newsletter is a complete program of the 1962 Ultrasonics Symposium. In addition to the technical sessions, the committee has arranged for a Social Hour and Banquet to be held at the Columbia University Faculty Club on Thursday evening, November 29th. Speaker will be Dr. Winthrop N. Kellogg.

Because the banquet is on the second day of the Symposium, it will be advisable to register in advance in order to be assured of a ticket. See the detailed notice on the last page of this Newsletter.

SYMPOSIUM COMMITTEE

J. E. May, Jr.	General Chairman
A. H. Meitzler	Vice-Chairman
W. F. Konig, Jr.	Arrangements
A. Rothbart	Publicity and Finance
R. N. Thurston	Technical Program Chairman
S. E. Jacke W. F. Konig, Jr. J. E. May, Jr. A. H. Meitzler	Technical Program Committee

CALENDAR

WEDNESDAY, NOVEMBER 28

9:00 a.m.	REGISTRATION (Fee $3.00)	
10:00 a.m.	Session A: "Ultrasonic-Optic Devices and Phenomena"	
	Invited Papers:	Hiedemann; Kiis; Haneman, Hornbostel; Small; Konig, Lambert; Arm
	Contributed Papers:	Cook; Jacobs; Berger, Collis.
2:00 p.m.	Session B: "Industrial and Biological Ultrasonics"	
	Invited Paper:	van der Burgt and Pijls.
	Contributed Papers:	Berlincourt; Balamuth; Litsios; Cottell; Kirsten; Reid; Zinsser.

THURSDAY, NOVEMBER 29

10: a.m.	Session C: "Ultrasonic Delay Lines and Transducers"	
	Invited Paper:	Tehon.
	Contributed Papers:	Thaxton; Galligher; Foster; Onoe; Tiersten; Perry; Ramamoorthy; Rote; Gerson; Peterson.
2:00 p.m.	Session D: "Ultrasonic Waves in Solids"	
	Invited Papers:	Bommel; Dransfeld; Tucker; Jacobsen
	Contributed Papers:	Bernstein; de Klerk; Bolef, Bolef; de Klerk.
6:00 p.m.	Social Hour	
7:00 p.m.	Banquet	(Fee $5.00) "Porpoise and Sonar" Speaker: Dr. Winthrop N. Kellogg.

FRIDAY, NOVEMBER 30

10:00 a.m.	Session E: "Magnetoelastic Interactions in Solids"	
	Invited Papers:	Seavey; LeCraw; Denton; Spencer.

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	Invited Papers:	Seavey; LeCraw; Denton; Spencer.

Contributed Papers: Morganthaler, Olson, Morganthaler

2:00 p.m. Session F: "Ultrasonic Phenomena and Devices"
Invited Papers: Shiren, Truell, Hutson, White; Becker.
Contributed Papers: Hsu; Brouillette; Wanuga.

SESSIONS WITH ABSTRACTS

SESSION A "Ultrasonic-Optic Devices and Phenomena" Wednesday Morning, November 28th, at 10:00 a. m. Chairman: Lawrence H. O'Neill.

Invited Papers

A1. Optical Effects of Ultrasonic Waves, E. A. Hiedemann, Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan. (45 minutes)

Light diffraction by ultrasonic waves in liquids: wide and narrow light beams. Geometric optical theory. Experimental studies of the light intensity distribution over the diffraction orders showed the significant parameters used in the physical-optical theory of Raman and Nath; phase modulation instead of amplitude modulation of emerging wave-front of light. Doppler effect of moving gratings. Modulation of light. Dependence on standing wave ratio. Some applications of the diffraction effects. Simultaneous diffraction. Non-sinusoidal waves and the two diffraction phenomena. Finding the waveform of finite-amplitude waves.

Limited range of validity of Raman-Nath theory and different approaches for a more general theory.

Light diffraction by ultrasonic waves in solids. Line spectra and point patterns. Resonance and forced vibrations. Birefringence. Photo-elastic analysis. Mueller's theory and the determination of the ratio of photo-elastic constants. Light modulation. Simultaneous diffraction. Secondary interference patterns in the Fresnel region. Visibility methods for progressive and stationary ultrasonic waves in transparent liquids and solids.

Special schlieren methods for ultrasonic gratings. Focus pattern of an ultrasonic lens. Beam pattern of transducers.

A2. A High-frequency Ultrasonic Spectrum Analyzer, A. Kiis, F. G. Haneman, D. Hornbostel, and B. Small, Airborne Instruments Lab., Division of Cutter-Hammer, Incorporated. (30 minutes)

A spectrum analyzer was developed that provides a frequency resolution varying from 20 to 60 kc over the 10 to 16 Mc operating range. The analyzer used ultrasonic and optical techniques to accomplish the separation and display of the signal frequencies to be analyzed. The electrical energy was converted to sonic energy in a water medium by a quartz transducer. This energy was diffracted by an echelon reflecting diffraction grating and then focused by a focusing reflector. The display was obtained using a schlieren readout system. Collimated light is transmitted through the region containing the focused sonic energy that is distributed in space as a function of frequency. The light is diffracted at the positions where the sonic energy is present. This diffracted light is used to form an image of the focused sonic energy thereby providing a self contained display.

A3. Electro-optical Spectrum Analyzers and Correlators Employing Ultrasonic Delay Lines, Louis B. Lambert, Moses Arm, and William F. Konig, Jr., Columbia University School of Engineering, Electronics Research Laboratories, New York 27, New York.

A transparent ultrasonic delay line is employed to instantaneously convert an electrical input signal to a proportional spatial pattern in the form of a traveling pressure wave. This results in a corresponding change in the index of refraction of the delay medium. By illuminating the delay line (light modulator) with partially coherent light, the signal information is transferred to the light carrier in the form of a spatial variation in phase and amplitude. A diffraction limited [illegible]al configuration is then employed to obtain the Fourier transform [illegible]ctrum) of the input signal as a distribution of light amplitude in the focal plane of a lens. Cross correlation is obtained by extending the optical configuration and including a diffraction grating for a second ultrasonic delay line light modulator. The spatial distribution of output light intensity is detected by a suitable photosensitor to provide an electrical output signal which is proportional to the instantaneous power spectrum or the magnitude-squared of a "real-time" cross correlation function of the input signal.

Typical optical configurations are presented, first for a spectrum analyzer and then for a cross correlator. Linearity and drive constraints on the ultrasonic delay line light modulator are introduced and interpreted in terms of the maximum input signal amplitude that can be used. The ratio of the maximum to the minimum input signal amplitudes that can be processed (the inherent display range) is then obtained by considering the detection characteristics of the photosensitor. The light source power required to illuminate the light modulator is then determined as a function of the inherent display range that is desired. Additional light source parameters, related to the temporal and spatial coherence that is required, are discussed. Limitations on the inherent display range that can be obtained by collimating certain noncoherent light sources are presented. Optical maser (laser) characteristics are reviewed and it is shown that both the pulse ruby laser and the continuous-wave gas laser are capable of significantly extending the inherent display range. The power level and the temporal and spatial coherence characteristics that are typically required from the laser are discussed. Typical experimental results will also be presented.

Contributed Papers (20 minutes)

A4. Determination of Ultrasonic Waveforms by Optical Methods, Bill D. Cook, Department of Physics and Astronomy, Michigan State Univ., East Lansing, Michigan.

Recently, several optical methods have been developed to determine ultrasonic waveforms, particularly those waveforms produced by finite amplitude distortion. A review of the basic principles involved in these methods will be given. Emphasis will be placed on the one method which gives the most direct determination of the shape of the wave. (This work was supported by the U. S. Army Research Office, Durham).

A5. An Investigation of the Limitations to the Maximum Attainable Sensitivity in Acoustical Image Converters, J. E. Jacobs, Department of Electrical Engineering, Northwestern University, Evanston, Illinois, H. Berger, Argonne National Laboratory, Argonne, Illinois, and W. A. Collis, Department of Electrical Engineering, Northwestern University, Evanston, Illinois.

The acoustical Image Converter, whose operation is based upon the modulation of secondary electron emission by an image excited piezoelectric plate, has been extensively investigated with regard to its maximum obtainable sensitivity. It has been stated that the maximum sensitivity is limited by the value of noise voltages produced by the load impedance of the input circuit. The limiting sensitivity determined by these considerations is in the order of 10^{-9} watts/cm^2; however, measured performance is reported to be in the order of $10^{-[illegible]}$ watts/cm^2. Investigations as to the exact mechanism of limiting sensitivity have been carried out in tubes in which the modulated secondary emission beam is amplified by means of an electron multiplier. This mode of operation of the tube removes the limitation imposed by the load impedance of the input circuits. Using tubes of this configuration one would expect improvements in the order of some 100 times in ability to detect acoustical energy; however, this is found not to be the case. Through the use of multi-element targets, the minimum potential differential on the target that may be detected by a change in secondary emission due to a scanning beam is found to be in the order of 50 millivolts. This value of potential is approximately that produced by the commonly used target plates when subjected to fields in the order of 10^{-7} watts/cm^2. The use of the electron multiplier Image Converter does contribute to the performance of the image system as a whole since it greatly simplifies the shielding problem encountered when using continuous wave excitation of the ultrasound field. Cine-sonograms illustrating performance of the tubes will be shown.

This work supported in part through N. I. H. Contract GM-08522-02 and AEC Contract, 31-109-38-1497.

SESSION B "Industrial and Biological Ultrasonics", Wednesday afternoon, November 28th, at 2:00 p. m., S. E. Jacke, Chairman.

Invited Paper (30 minutes)

B1. Motional Positive Feedback Systems for Ultrasonic Power Generators, C. M. van derBurgt, Philips Research Labs., Eindhoven, Netherlands, and H. S. J. Pijls, N. V. Philips' Gloeilampenfabrieken, Eindhoven, Netherlands.

The post-war advance of ultrasonics in industry raised the problem of how to combine a high-power electronic generator with an electroacoustic transducer system in order to keep the electroacoustic efficiency at the highest possible level in the presence of a varying acoustic load. Neither single-tube generators with one or another classical form of positive feedback, nor multi-stage generators excited by a variable LC or RC oscillator, meet the requirements. Since the open-circuit and short-circuit natural frequencies of a transducer may vary rapidly within wide limits under normal operating conditions, means should be provided for automatically and instantaneously adjusting the operating frequency. Motional positive feedback systems provide this, because the amplitude and the phase of the feedback voltage or current continuously represent a true picture of a motional variable (deformation, acceleration, etc.) Numerous acoustical types of motional feedback, e.g. piezoelectric pickups, have been proposed and are or have been used. In all these types the electric feedback variable is obtained through a separate conversion of an acoustical variable. However, several purely electrical types of motional positive feedback exist, in which the use of only electrical elements provides the motional feedback signal. A survey of both classes will be presented.

Contributed Papers (20 minutes)

B2. Power Limitations of Piezoelectric Ceramics in Radiating Transducers, Don Berlincourt, Electronic Research Division, Clevite Corporation, Cleveland, Ohio.

Two commerical lead titanate zirconate compositions, PZT-4 and PZT-5, and two barium titanate compositions, commercial Ceramic B (a barium calcium titanate), and the composition 80 w% barium titanate, 12 w% lead titanate, 8w% calcium titanate, are compared with regard to their power handling capacities in sonar-type transducers. These comparisons are made with regard to efficiency dissipated power and mechanical strength. PZT-4 is found to be superior to the other compositions, and best results are obtained using the parallel mode. A properly oriented bias compressive stress must be used in order fully to utilize the high electric energy densities available with PZT-4. It is quite likely that more power is dissipated as a result of mechanoacoustic losses not attrigutable to the ceramic than as a result of dielectric losses in PZT-4. Mechanical losses in PZT-4 and the two barium titanate compositions, even at high dynamic stress levels, are quite negligible in well loaded transducers.

B3. The High Speed Ultrasonic Rotor, a New Mechanical Rotary Drive Principle, Dr. Lewis Balamuth, Cavitron Ultrasonics, Incorporated, 51-02 21st Street, Long Island City 1, New York.

Dr. Balamuth will discuss a means for producing high speed rotary motion by the use of ultrasonic vibrations. The novelty of the method lies in the fact that no air or water turbine is used. High frequency longitudinal vibratory motion is used to produce rotary motion directly, without the use of complex bearings or turbines. Problems of wear and strain are thus greatly reduced. In addition, the high-pitched whine associated with the air-turbine type of drill is eliminated. This is of great importance in the application of the process to dentistry.

Basically, the technique used consists in producing high frequency elliptical mechanical vibrations; these vibrations are applied tangentially to a shaft, which is thus caused to rotate. The elliptical vibrations are produced as follows: if mechanical vibrations are imparted to a tool which is asymmetrical about the axis of vibrations, the imbalance in the mass distribution sets up a component of vibration perpendicular to that axis; the combination of these two types of vibrations creates the elliptical motion of the tool. The shaft to be rotated is inserted in a hole in the elliptically vibrating tool; one can see that contact between the shaft and the hole will be at one point, and that force will be applied to the shaft tangentially causing it to rotate. The entire transducer assembly is built into a handpiece for ease of manipulation.

B4. Industrial Applications of Gas Jet Sonic Generators, John Lysios, Sonics Products Laboratory, Kearfott Division, General Precision, Incorporated, 1150 McBride Avenue, Little Falls, New Jersey.

With the development of improved gas jet, high intensity, sonic and ultrasonic generators, the application of airborne sonic energy to industrial processes has become economically feasible. Outputs of 150 watts of acoustic power are obtained with jet generators driven with 22 psig air and a flow of 15 scfm operating at a frequency of 10,000 cps. Sound pressure levels of 150 db are measured 10 inches from the sonic generator. The generator, a resonant cavity whistle, has no moving parts, resulting in a unit that requires very low maintenance. It can be operated by gases other than air, as well as by dry steam. A major industrial application of sonic generators is the destruction or stabilization of undesirable foam. By mounting the sonic generators in special defoaming tubes, high volumes of foam can be destroyed without the need of chemical additives. The high intensity sonic energy ruptures the bubble walls, releasing the trapped gases which are then vented off and the liquid contents recovered. Industrial processes such as pharmaceutical fermentation, paper pulp manufacturing, and gas stripping are all plagued with high foam generation as an undesirable by-product which can now be economically destroyed by the use of sonic energy.

B5. Development in Liquid Whistles and Associated Systems, E. [illegible] Cottell, Sonic Engineering Corporation, Norwalk, Connecticut.

Development by the writer and his co-worker over the past few years has been directed towards higher acoustic energy and more intense cavitation effects. The most important single discovery was the effect of back pressure in the chamber when using high velocity jets to drive the vibrating element. If was found that heavier vibrating elements than had been used hitherto could be shattered in a finite length of time which suggested a new method of fatigue testing in a streaming environment. The importance of infinitely adjustable jet to blade distance is also reviewed.

In step with improvements of the whistle itself important advances have been made in the associated equipment e. g. pumps to drive liquid whistles and methods of feeding to allow for fully automatic in line processes.

B6. Effect of One Megacycle Ultrasound on Genetics of Mice, Edward Kirsten, Department of Urology, College of Physicians and Surgeons, New York 32, New York, John Reid, Department of Bioengineering, University of Pennsylvania, Philadelphia, Pennsylvania, and Hans H. Zinsser, Department of Urology, College of Physicians and Surgeons, New York 32, New York.

While ultrasonic radiation has been used by the physician in both research and general practice, it has never been shown that adverse genetic effects will not arise after successive generations. A long term study deals with the controlled breeding of LaF_1 hybrid mice after irradiation with high intensity ultrasound.

LaF_1 mice between the ages of 1-7 days were radiated at a frequency of 1 megacycle for a total radiation time of 5 minutes. Whole body radiation was administered both continuously and in pulses at intensities ranging from 1/7 to 4 watts/cm^2.

Ultrasonic burning and paralysis were noted directly following radiation and appeared indiscriminately among the mice radiated at one power level. These disorders were found to be not only a function of intensity but also dependent upon the age at the time of radiation. The unaffected mice were bred brother x sister for six litters with the average litter size being comparable with that of the control group. Microscopic examination of the gonads show no resulting tissue damage.

The first litter offspring of the radiated mice were studied through 5 generations. No genetic damage was noted either by direct observation or by microscopic examination of ovarian tissue.

SESSION C "Ultrasonic Delay Lines and Transducers" Thursday Morning, November 29th, 10:00 a. m., Oskar E. Mattiat, Chairman.

Invited Paper (30 Minutes)

C1. Development and Application of Dispersive Ultrasonic Delay Lines, S. W. Tehon, Electronics Laboratory, General Electric Co., Syracuse, New York.

Maximum radar range capabilities are limited by average transmitted power; resolution is determined by pulse duration. With given resolution requirements, pulse duration is fixed and range is limited by peak power. Pulse compression systems utilize long transmitted pulses and means for compressing the duration of received pulses, to achieve narrow-pulse resolution with long-pulse range capabilities. A linear-FM system requires means for generating a linearly frequency modulated transmitted pulse, and means for compression. Components with complementary group-delay slopes, or parabolic phase characteristics, are required. Matched networks for these functions have been described in the literature.

This paper is concerned with dispersive ultrasonic delay lines for linear-FM generation and compression. Selection of propagation modes will be discussed, with performance data for lines operating at frequencies up to 60 megacycles. Design methods which take into account phase velocity dispersion in transducers will be outlined, and computed delay errors for linear applications will be presented. Permissible errors will be discussed, for received signals which have undergone Doppler shift from moving targets. From analysis of frequency shift and computed delay error, maximum compression ratios for realizable dispersive delay lines will be derived.

Contributed Papers (20 minutes)

C2. The "Depletion Layer" Transducer as a Frequency Variable Ultrasonic Driver, H. Mack Thaxton and O. L. Galligher, Engelhard Industries, Incorporated, Amersil Quartz Division, Hillside, New Jersey, and Engelhard Hanovia, Incorporated, Hanovia Lamp Div., Newark, New Jersey.

The use of transducers of various types, for the propagation of ultrasonics, including quartz crystals, ceramic, ferrites, etc., requ[illegible] the dismantling of the system for each driving frequency, or the [illegible]ostitution of another system with the required transducer driver. In either case, the process is costly. In the frequency range from 5 to 100 megacycles per second, the "depletion layer" transducer has been used for the purpose of changing the driving frequency. A mathematical method has been developed for the calculation of the bias voltage to be applied to a gallium arsenide type transducer, for example, such that the driving frequency required may be obtained. Theoretical analysis of the process is given and the appropriate mathematical relationships are derived. The experimental application of the system and theory to the propagation of ultrasonics in quartz is given. A comparative analysis of the response characteristics of this system with other ultrasonic driving systems is also given.

C3. The Diffusion Layer Ultrasonic Transducer, N. F. Foster, Bell Telephone Laboratories, Inc., Whippany, New Jersey.

The fabrication of transducers with fundamental resonant frequencies above 100 mc/s from insulating materials by the conventional grinding techniques presents considerable difficulty due to the extreme thinness required. This paper describes new techniques which have enabled the construction of transducers with resonant frequencies well above 100 mc/s from piezoelectric semiconductor materials using relatively simple processes. The design of this transducer is similar to that of the depletion layer transducer of D. L. White and consists of a highly conductive electrode region and a thin resistive active region, the thickness of which determines the transducer's resonant frequency. The transducers are made from highly conductive single crystal cadmium sulphide and the thin active region formed by diffusing in copper which compensates the material forming a resistive layer. Short delay lines are then made by bonding these transducers onto each end of 1-inch-long quartz bars and the transducer characteristics determined by both single ended (reflection) and do[illegible] ended (straight through) measurements. Transducers with res[illegible]ant frequencies up to 150 mc/s have been made with bandwidths of approximately 70% when tuned at each measurement frequency and 10% with fixed tuning. The insertion loss of these complete delay lines has been as low as 30 db at 175 mc/s. Admittance measurements have also been made and show the pronounced effects of the series resistance introduced by the electrode region.

C4. Resonant Frequencies of Finite Piezoelectric Ceramic Vibrator with High Electromechanical Coupling, Morio Onoe and H. F. Tiersten, Bell Telephone Laboratories, Inc., Whippany, New Jersey.

The vibration of transducers made of piezoelectric ceramic materials with high electromechanical coupling differs considerably from that of geometrically similar, purely elastic bodies. Rigorous analyses are available for only a few special cases. This paper presents an approximate method for the determination of the resonant frequencies of finite, strongly piezoelectric, ceramic vibrators of various shapes as a function of the configuration ratio. The method is an extension of the coupling theory which Giebe and Blechschmidt successfully applied in the determination of the frequency spectra of finite purely elastic bodies. One coupling mechanism is found to be adequate for the following geometries: a wide rectangular plate, a thin strip, a solid cylinder and a thin cylindrical shell. Three coupling mechanisms are required in the case of a parallelepiped. The method enables a simple, quick determination of the frequency spectrum for a limited number of branches with reasonable accuracy. It turns out that the frequency spectra of piezoelectric ceramics nearly coincide with the spectra of geometrically similar, purely elastic, isotropic bodies; but the anisotropy and the piezoelectric interaction should be taken into account if elastic (or other) constants are to be determined from these spectra.

C5. The Distributed Transducer - A Method of Improving the Gain-Bandwidth Product of Solid Ultrasonic Delay Lines, Bernard D. Perry The Mitre Corporation, Bedford, Massachusetts.

A major disadvantage of solid ultrasonic delay lines is their large insertion loss. In short lines (500 μs or less) this loss is largely transducer loss which, in turn, is a function of the electro-mechanical coupling coefficient of the material and the "matching" of the transducer to the delay medium via a bonding substance.

Assuming optimum bonding techniques, transducer loss can be reduced by increasing the transducer area or using material having a high electro-mechanical coupling coefficient. Either technique results in a higher transducer capacity. Thus for a given bandwidth, the voltage gain (inverse of loss) will be unchanged. An important figure-of-merit for delay lines is therefore the "gain-bandwidth product" (as for wideband amplifiers).

To improve the gain-bandwidth product, distributed amplifier techniques can be adapted to the transducer problem. Instead of one large transducer several smaller ones are used and their capacities become the shunt elements in a lumped-parameter delay line. Thus the characteristic impedance of the lumped-parameter line replaces the large single transducer capacity as the input and output impedance of the device.

A quartz delay line 20 μs long, operating between 37 Mc and 55 Mc was built with four input and output transducers connected in this fashion. A 10 db improvement in the gain-bandwidth produce was observed with no apparent degradation in other delay line characteristics.

This so-called distributed transducer technique can be extended to long ultrasonic delay lines provided certain compromises are made. Significant improvement in the gain-bandwidth product can, it is felt, still be obtained.

C6. A Class of Digital Storage Schemes for High Frequency Ultrasonic Delay Lines with Known Peak Resolvable Jitter, C. V. Ramamoorthy, Minneapolis Honeywell Regulator Co., Newton Highlands, Massachusetts.

A new generation of ultrasonic digital delay lines using a time-invariant glass as a delay medium and ceramic or quartz transducers is becoming increasingly important as memories for commercial and aerospace computers.

Under steady state temperature conditions, the peak jitter of an ultrasonic delay line is very small. But the major restrictions imposed on the recording system are:

a. The successive transitions in the RZ (or NRZ) waveforms must be at least one nominat bit time. This restriction is imposed in particular by the reading and the writing circuitry.

b. The peak resolvable jitter in the ultrasonic delay line requir that the transitions must occur within specified intervals.

A mathematical model is set up which analyzes the problem of constructing the maximum number of distinct RZ type waveforms under the above constraints. The enumerating structure indicates that the number of distinct waveforms in a nominal k-bit interval of time (i.e., at maximum RZ bit rate) is greater than 2^k and is given by a recursive difference equation of the form $g_k = g_{k-1} + g_{k-c}$ where c is a function of maximum peak resolvable jitter. The class of waveforms specified by the solution of the equation are studied.

When the maximum jitter is small (e.g., <33 1/3%) schemes can be derived such that the digital storage of the ultrasonic delay line can be increased by 50% without increasing the frequency bandwidth. Or the line can be made considerably shorter (decreasing the access time) to store the same amount of information.

The class of waveforms suggested by this technique can be encoded and decoded economically for small k. The practical design of one such encoder-decoder is given and discussed.

C7. High Frequency Dielectric Properties of Lead Titanate Zirconate Ceramics, Donald M. Rote, Western Reserve University, Robert Gerson, and James M. Peterson, Electronic Research Division, Clevite Corporation.

The dielectric constant and dissipation factor of lead titanate zirconate piezoelectric ceramic samples were studied in the frequency range from 500 to 2000 megacycles. The results showed a 25% reduction in dielectric constant (to about 800) which seemed to continue above the frequency range studied and a rise in dissipation factor to about 0.4 at 2000 megacycles. Cole-Cole plots indicated the presence of a simple relaxation spectrum. An attempt is made to explain these results in terms of the following model: The grains or subdivisions of grains into which the sample is divided (as indicated by microphotographs) are treated as piezoelectric resonators loaded by a surrounding medium which is a close acoustic match. Because of the strong electromechanical coupling in these piezoelectrics, the electrical response of the resonators is partly determined by their mechanical characteristics. It is shown that the radiation reaction of the medium upon these resonators can account for a rise in dissipation and a relaxation of that component of the dielectric constant associated with the mechanical motion of the resonator.

SESSION D "Ultrasonic Waves in Solids" Thursday Afternoon, November 29th, 2:00 p. m. Chairman: Warren P. Mason

Invited Papers (30 minutes)

D1. Microwave Ultrasonic Absorption in Solids I (Metals and Vitreous Silica), H. E. Bommel, University of California, Los Angeles, Calif.

D2. Microwave Ultrasonic Absorption in Solids II (Dielectric Crystals and Ferromagnetic Materials), K. Dransfeld, University of Calif., Berkeley, California.

D3. Interactions between Microwave Phonons and Electron Spins in Solids, E. B. Tucker, General Electric Research Laboratory, Schenectady, New York.

D4. Anomalous Dispersion of Ultrasonic Waves by Electron Spins, E. H. Jacobsen, University of Rochester, Rochester, New York.

The interaction between paramagnetic atoms and elastic waves at microwave frequencies is discussed in terms of a total Hamiltonian comprising sound field, interaction, and spins. From this Hamiltonian the Heisenberg equations of motion are derived for the atomic displacements and the spin operators. The resulting set of coupled equations show that for sound waves close to a paramagnetic resonance frequency the disturbance which propagates is in reality a mixture of elastic and spin waves. As expected the velocity of propagation shows anomalous dispersion rear resonance in addition to other phenomena such as Raman scattering, rotary polarization, loss, and amplification.

Contributed Papers (20 minutes)

D5. *Ultrasonic Investigation of Physical Properties of Solids at Temperatures in the 2000 C Range*, B. T. Bernstein, American-Standard Research Division, Union, New Jersey.

The use of ultrasonic pulse-echo techniques in the MC/sec range for the study of elastic moduli, atomic relaxation phenomena, precipitation reactions and phase diagram determinations at temperatures in the 2000°C range is discussed. It is shown that by suitable specimen design the effects of axial and radial temperature gradients are eliminated as well as the transit time error due to impedance mismatching between specimen and transducer. The results of experiments on polycrystalline tungsten[1] are reviewed and preliminary results for single crystal tungsten specimens to 2000°C presented. The experimental results are discussed in terms of the formation of sub-carbide phases of tungsten as determined from transmission electron microscopy and mechanical property measurements.

[1]B. T. Bernstein, J. Appl. Phys. 33, 2140 (1962).

D6. Improved Hypersonic Techniques and Some Attenuation Measurements in Quartz at Low Temperatures, J. de Klerk and D. I. Bolef, Westinghouse Research Laboratories, Pittsburgh, Pennsylvania. *

Conventional pulsed surface excitation of quartz in the kilomegacycle range of frequencies almost invariably produces nonexponentially decaying echo envelopes, making reliable attenuation measurements difficult This difficulty can frequently be overcome by the use of conventional transducers and by careful bonding techniques. This transducer technique and some of the methods of bonding will be described. Methods of simultaneously generating compressional and shear mode in quartz at hypersonic frequencies have been developed and a preliminary investigation of the interaction between the modes has been conducted.

A study of attenuation vs transmitter power at several low temperatures has shown an anomalous behavior in the power dependence of attenuation of hypersound. The attenuation of hypersound in quartz decreases with decreasing transmitter power. Measurements of attenuation, α, of compressional and shear waves in quartz at temperatures below 20° K have indicated that a single value of n in the expression $\alpha = A + BT^n$ does not hold for this temperature range.

*This work was supported by the U. S. Air Force through the Air Force Cambridge Research Laboratories, Bedford, Mass.

D7. CW Techniques for the Measurement of Attenuation and Velocity of Ultrasound in Solids, D. I. Bolef and J. de Klerk, Westinghouse Research Laboratories, Pittsburgh, Pennsylvania.

Several cw ultrasonic techniques have been developed, covering the frequency range of 1 mc/sec to 1000 mc/sec, for the purpose of measuring attenuation and velocity of sound in solids. These include, in addition to the previously described Q-meter technique, a differential power or voltage monitoring technique, swept-frequency cw oscillator techniques, and lock-in oscillator techniques. In the latter, the rf oscillator is coupled to the ultrasonic probe in such a way that the oscillator frequency is locked to one of the cw mechanical resonances characteristic of the specimen. A change in the sound velocity in the specimen, e.g. as a function of temperature, is then reflected as a change in oscillator frequency.

For the measurement of extremely small changes of attenuation, frequency or magnetic field modulation, together with synchronous detector chart recorder techniques, has been used. In several of the cw ultrasonic techniques mostly commercially available equipment can be used. Applications to the measurement of elastic constants and internal friction of solids, as well as to the measurement of spin-phonon interactions in paramagnetic materials, will be described.

SESSION E "Magnetoelastic Interactions in Solids" Friday Morning, November 30th, 10:00 a.m., Chairman: John E. May, Jr.

Invited Papers (30 minutes)

E1. Microwave Phonon Generation by Thin Magnetic Films, Marden H. Seavey, Jr., Air Force Cambridge Research Laboratories, Bedford, Massachusetts.

The magnetostrictive generation of microwave phonons in thin magnetic films is described and experimental results are discussed. A single rectangular cavity resonant at 9 KMcps is employed in the experiments and a DC magnetic field is applied either parallel or perpendicular to the film surface. On ferromagnetic resonance (FMR) or spin wave resonance (SWR) in the thin film, phonons are generated and then are observed as echoes from the far end of a single crystal substrate. It is shown that on SWR the phonon generation occurs throughout the interior of the film while on FMR the generation is at the film surfaces. In the former case interference effects predict a shift of the phonon peak off the SWR peak and this is experimentally observed. The dependence of the phonon generation efficiency and magnetic field behavior on film thickness and composition is discussed. The splitting effect due to spin wave-phonon crossover is shown to be small in permalloy films due to low phonon Q. Hence the generation occurs principally through the dm/dz driving term. Finally, a comparison of magnetostrictive with piezoelectric phonon generation is made.

E2. High Frequency Acoustic Losses in Yttrium Iron Garnet, R. C. LeCraw, Bell Telephone Laboratories, Inc., Murray Hill, N. J.

With the recent discovery of the unusually high Q of yttrium iron garnet (YIG),[1] and its use as a highly efficient microwave acoustic transducer,[2] the sources of possible losses in YIG have become of considerable importance. Measurements thus far have demonstrated room temperature Q's of $\sim 10^7$ at 10 Mc and 2×10^5 at 1000 Mc. In neither case are these values known to be intrinsic.

Loss mechanisms in YIG which have to some degree been identified are (1) Fe^{++} impurity ions, which at 1 Mc produce a large relaxation-type peak in Q^{-1} at $\sim 225^\circ$K, (2) rare earth and other impurity ions with unquenched orbital angular momentum, which introduce loss by the strong coupling of acoustic modes to dissipative spin wave modes, and (3) surface irregularities, which cause much greater losses in YIG than in quartz. This loss essentially vanishes below $\sim 150^\circ$K. *Its nature is not fully understood at present.* The above sources must be understood and eliminated before the intrinsic losses of perfect YIG can be observed.

[1]LeCraw, Spencer and Gordon, Phys. Rev. Letters, 6, 620 (1961).
[2]Spencer, Denton and Chambers, Phys. Rev., 125, 1950 (1962).

E3. Microwave Acoustic Measurements in Garnets, R. T. Denton and E. G. Spencer, Bell Telephone Labs., Inc., Murray Hill, N. J.

Considerable interest has been generated in the microwave acoustic properties of yttrium iron garnet by the recent discovery of the low acoustic losses of this material and the efficient generation of microwave ultrasonics which can be obtained. Further data have been obtained on the microwave acoustic losses of yttrium iron garnet over a range of temperatures and on the input power level at which nonlinear processes occur in the transducer for several different crystal orientations. Measurements have been made on other magnetic garnets which also have low acoustic losses.

Acoustic data have been obtained on the characteristics of several nonmagnetic garnets by bonding piezoelectric transducers onto samples of these materials. These measurements show that the nonmagnetic garnets can also have low microwave acoustic losses at room temperatures. The acoustic properties of the magnetic and nonmagnetic garnets indicate that these materials should be useful in a number of device applications.

Contributed Papers (20 minutes)

E4. The Parametric Excitation of Magnetoelastic Waves in Magnetically Ordered Single Crystals, Frederic R. Morgenthaler, Department of Electrical Engineering, Massachusetts Institute of Technology Cambridge, Massachusetts.

The magnetic and/or elastic excitation of magnetoelastic waves in ordered magnetic solids of cubic or uniaxial symmetry is considered. The case of magnetoelastic waves propagating at right angles to the dc magnetic field is treated in detail, the level of longitudinal parametric excitation[1,2] required to drive them unstable is derived and the threshold calculated as a function of the dc field. It is found that phonon contribution[3] to the threshold curve gives rise to an asymmetric line shape and that the cross-over from the lower to the upper branch of the magnetoelastic wave spectrum does not occur at the point of intersection between the unperturbed spinwave and phonon spectra. Failure to account for this fact can lead to an overestimation of the exchange constant;[4] the error increases with increasing phonon Q. The peak and width of the phonon contribution is obtained as a function of the phonon Q, magnetoelastic energy coefficient, and the exchange constant.

Phonon pumping of magnetoelastic waves is also considered as is the interaction between this form of excitation and longitudinal pumping.

[1]F. R. Morgenthaler, J. Appl. Phys. Suppl. 31, 95S (1960); PhD Thesis Proposal, MIT, Department of Electrical Engineering, May '59.
[2]E. Schlömann, J. J. Green, and U. Milano, J. Appl. Phys. Suppl. 31, 386S (1960); E. Schlömann, Tech. Rept. R-48, Research Division, Raytheon Company, October, 1959.
[3]E. H. Turner, paper No. 82, Sixth Symposium of Magnetism & Magnetic Materials, New York, Nov. 14-17, 1960; Phys. Rev. Letters, 5, 100 (1960).
[4]R. C. LeCraw and L. R. Walker, J. Appl. Phys. Suppl. 32, 167S (1961).

E5. Microwave Magnetoelastic Measurements by Parallel Pumping, Frank A. Olson, Air Force Cambridge Research Labs., Bedford Mass

Measurements of acoustic loss and of the magnetoelastic coupling of phonons and spin waves in a ferrimagnetic insulator have been made at microwave frequencies. The technique consists of a high resolution measurement of the spin wave-phonon interaction first observed by Turner[1] in parallel pumping experiments (microwave magnetic field applied parallel to the dc magnetic field). This method provides a determination of the magnetoelastic properties, from the magnitude and line shape of the interaction, at high microwave frequencies where other techniques have not been successful due to transducer and bonding problems.

Studies have been made of the interaction in oriented spheres and disks of single-crystal yttrium iron garnet at 5 kMc and at 12 kMc. At room temperature and a (100) orientation these have yielded phonon Q's of up to 5×10^4, a f^{-1} variation of the Q, and a value of $\sim 10^6$ joule/m^3 for the magnetoelastic coupling coefficient. From measurements performed at 77°K and 4°K the temperature dependence has been observed, including the low-temperature peak of the phonon loss. The results have been correlated with lower frequency measurements, and the marked differences with the quantities from a higher frequency parallel pumping experiment[1] have been resolved. Finally, the magnetoelastic coupling for various crystalline orientations and the practicality of generating phonons by this technique have been considered.

[1]E. H. Turner, Advances in Quantum Electronics (Columbia University Press, New York, 1961), p. 427.

E6. Conditions for Coherent Phonon Generation in Ferrimagnetic Single Crystals, Frederic R. Morgenthaler, Department of Electrical Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

Conditions have recently been given[1] for the parametric excitation of both longitudinal and transverse microwave phonon standing waves by the uniform precession of the magnetization undergoing ferromagnetic resonance in a ferrimagnetic single crystal. The possibility of generating phonons in crystals having cubic or uniaxial symmetry by this form of volume excitation is explored in this paper, and the potential advantages over other methods of generation are outlined. The excitation of phonons which lie below the spinwave (magnon) band is considered in detail. Such vibrational modes are not magneto-elastically coupled (in the usual sense) to the magnons, and it may therefore be possible to extract appreciable coherent phonon power from the crystal before other unstable phonons, magnetoelastic waves, or magnons can interfere with the generation process.

A power theorem and the relevant boundary conditions satisfied the phonon displacement vector in a parametrically active crystal e d ed and used to determine the maximum phonon power which ay b adiated from a given geometry. The theory is applied to the se of a rod or disk.

The suitability of any given ferrimagnetic crystal can be as-rtained from a knowledge of certain of the higher order magneto-astic energy terms[1] and the appropriate phonon and magnon Q's. he possibility of engineering a material with the appropriate char-teristics (in the event that one is not already available) is explored ; is the possibility of doping a material to selectively favor a parti-ılar phonon propagation direction.

*This research was sponsored by the Ford Foundation under rovisions of a Ford Postdoctoral Fellowship.

[1]F. R. Morgenthaler, "Microwave Phonon Instabilities Associa-d with Ferromagnetic Resonance", to be published in the Proc. of e Institute of Radio Engineers.

ESSION F "Ultrasonic Phenomena and Devices", Friday Afternoon, November 30th at 2:00 p. m. Chairman: R. Bechmann.

Invited Papers (30 minutes)

1. Detection of Microwave Ultrasonics by Phonon-Photon Double Quantum Transitions, N. S. Shiren, International Business Machines Corporation, Thomas J. Watson Research Center, Yorktown Heights, New York.

A new detector of pulsed microwave ultrasonics, which makes use of double quantum transitions, will be described. The detection method consists in the measurement of electro-magnetic microwave power absorbed in double quantum transitions, in which a microwave photon and an ultrasonic phonon are simultaneously absorbed. Using the ground state Zeeman transitions of Fe^{2+} in MgO, the practi-calit the method has been verified.

Since the transition probability is proportional to the ultrasonic ntensity the double quantum method is capable of detecting spatially ncoherent radiation, unlike the piezoelectric method which is sensi-ive only to spatially coherent radiation. Also the new detector is ensitive to all polarizations of the ultrasonics and since, for Zeeman ransitions, the variation of transition probability with magnetic field ngle is a function of the polarization, it is possible to determine the olarization mixture as well as the amplitude of the radiation. Other pin resonance ultrasonic detectors also have the above mentioned roperties, but unlike them, the double quantum method is capable of etecting fast pulses because the long time constant relaxation effects re not observed.

Using inhomogeneously broadened transitions, such as those of Fe^{2+} in MgO, the detector may be operated with microwave and ultra-sonic frequencies which differ by as much as 1000 mc/s.

As an example of the use of the detector, a measurement of small angle refraction will be described.

2. Title to be Announced, Rohn Truell, Brown University Metals Research Laboratory, Providence, Rhode Island.

3. Traveling Wave Ultrasonic Amplification, A. R. Hutson, Bell Telephone Laboratories, Incorporated, Murray Hill, New Jersey.

Acoustic loss or gain resulting from the interaction between traveling acoustic waves and mobile carriers will be discussed for piezoelectric semiconductors and for a semimetal such as bismuth. The linear (small-signal) theory will be developed in terms of: the carrier bunching forces (piezoelectric fields and deformation poten-tial gradients); the carrier debunching mechanisms (space charge, carrier, diffusion, trapping, and recombination); and applied drift el hich control the relative phases of carrier bunches and bunch-ng es. It will be shown that the nonlinear terms in the theory ive rise to the traveling-wave mixing, the acousto-electric effect, nd non-ohmic behavior in amplifying media. The choice of material nd operating parameters of acoustic amplifiers as influenced by ower dissipation, self-oscillation, and noise temperature, will be iscussed.

F4. The Piezoelectric Ultrasonic Amplifier, D. L. White, Bell Telephone Laboratories, Incorporated, Whippany, New Jersey.

The large amplification of ultrasonic waves which has been ob-served in piezoelectric semiconductors such as CdS, ZnO, and CdSe has a number of possible applications, both as electrical and ultra-sonic devices and as laboratory tools. Most experimental data to date has been taken with short bursts of ultrasonic energy amplified by short voltage pulses, but in a useful device the amplifier should oper-ate continuously. To make such an amplifier, spontaneous oscilla-tion must be suppressed and dc heating should be minimized. Methods of accomplishing these ends will be discussed.

The full potential of the ultrasonic amplifier cannot be used in ver high frequency devices becauses of the inadequacy of present day ultra sonic transducers. For instance the amplifier has a much greater bandwidth than that of the transducers attached to it. The high inser-tion loss of currently available transducers at the higher frequencies seriously limits the use of the ultrasonic amplifier in amplifying elec-trical signals. New transducers under study should greatly extend the capabilities of ultrasonic amplifier devices.

An ultrasonic amplifier can be used to generate intense ultrasonic waves and to detect very weak waves. In the detecting process a pie-zoelectric semiconductor generates a direct current when it absorbs an ultrasonic wave, and when the semiconductor is used as an ampli-fier, the wave changes the dc level. Thus the semiconductor can be used as a square law or power detector of ultrasonic waves which is very useful at high frequencies.

F5. Quartz Optical Phonon-Masers, C. H. Becker, Precision Instru-ment Company, San Carlos, California.

Emission of optical phonons in the Teracycle frequency range of 10^{12} cycles persecond can be stimulated in alpha-quartz by means of strong ultraviolet optical pumping.

This phenomenon results from the quantum-mechanical excitation of the vibrational molecular modes of the alpha-quartz unit cell during second-order inelastic light-scattering processes. During the excita-tion period, optical phonon-maser action takes place in the alpha-quartz causing inversion of the intensities of the quartz Raman spectrum when the critical intensity of optical pumping is achieved.

Thus, optical phonons in alpha-quartz can be detected by measur-ing the intensity distribution of the Anti-Stokes and Stokes lines during the inversion processes.

The quantum electronics of optical phonons may be conceivably established on the basis of this new phenomenon, and a radically new approach to molecular energy transport is expected. If successfully accomplished, it will occur at optical (infrared) frequencies, but will be strictly mechanical in nature.

Principles of and first experimental approaches to such a new dis-cipline will be presented at the Symposium, with alpha-quartz as the quantum-mechanical amplifier medium. These results will be com-pared with present knowledge regarding the generation, propagation and detection of microwave acoustical phonons.

Contributed Paper (20 minutes)

F6. Field Enhancement Techniques for the Generation of Microwave Phonons, H. Hsu, W. Brouillette, and S. Wanuga, General Electric Company, Electronics Laboratory, Syracuse, New York.

Much improved electromagnetic transducer coupling has been achieved by enhancing the electric field in case of piezoelectric trans-ducers, and the magnetic field in the case of magnetostrictive trans-ducers. These transducers also couple to both transverse and longi-tudinal phonons.

The contribution of this paper pertains to the idea of enhancing the field intensity in a microwave cavity. By using perturbation measure-ments, we have studied the enhancement of electric or magnetic field in the vicinity of the crystal and have developed cavity structures for much improved piezoelectric or magnetostrictive transducer coupling

For both piezoelectric and magnetostrictive couplings, we have found that the field intensity can be much enhanced by properly shaping the center port of a re-entrant cavity. In each case, the distribution of the electric or magnetic fields in the cavity is purposely perturbed by the special post structure so that the field intensity becomes much higher in the vicinity of the crystal.

With these structures, it is possible to selectively couple to either longitudinal or transverse mode, or to both simultaneously. For example, we have obtained 180 longitudinal echoes and 380 transverse echoes using a special piezoelectric cavity.

In this paper, the perturbation techniques, various cavity structures, and some wideband structures will be disclosed. Experimental results of the excitation of microwave phonons from liquid helium temperatures to room temperatures will be presented for a variety of propagation media.

REGISTRATION FOR TECHNICAL SESSIONS AND BANQUET

Registration will be required in order to gain entrance to the technical sessions. Registration desks will be set up at the entrance to the auditorium. It will be helpful to the Symposium Committee to know in advance the number of persons planning to attend. Please fill out and send the form at the bottom of this page to Mr. William F. Konig, Arrangements Chairman.

Because of the limited facilities available for holding a banquet, we urge those interested in attending the Social Hour and Banquet to register in advance. This can be done by mailing the accompanying form and a check for $5.00 to:

Mr. William F. Konig
Columbia University
Electronic Research Laboratories
632 West 125th Street
New York 27, New York

Tickets for the Banquet, if available, will be on sale at the registration desk until 2:00 p. m., Wednesday. Tickets paid for in advance can be picked up at any time before the Banquet at the registration desks.

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