ACOUSTICS AND NOISE CONTROL IN CANADA

THE CANADIAN ACOUSTICAL ASSOCIATION

L'ACOUSTIQUE ET LA LUTTE ANTIBRUIT AU CANADA

L'ASSOCIATION CANADIENNE DE L'ACOUSTIQUE

A C A

Avril 1977
Vol. 5, N° 2

April, 1977
Vol. 5, No. 2

ACOUSTICS AND NOISE CONTROL IN CANADA

L'ACOUSTIQUE ET LA LUTTE ANTIBRUIT AU CANADA

CONTRIBUTIONS

Articles in English or French are welcome. They should be addressed to a regional correspondent or to a member of the editorial board.

SUBSCRIPTIONS

Acoustics and Noise Control in Canada is distributed free. To have your name put on the mailing list, please contact the Noise Control Division, Environmental Protection Service, Department of the Environment, Ottawa, Ontario K1A 0C8. Postal codes must be provided for all addresses in Canada.

This newsletter is published by the Canadian Acoustical Association. Printing and distribution are provided by the Department of the Environment. The contents of the newsletter and any opinions expressed are the responsibility of the authors and do not necessarily represent the views of the Canadian Acoustical Association or the Canadian Government, its departments or agencies.

(continued on inside back cover)

o o o o o o o o o

CONTRIBUTION

Vous êtes invités à faire parvenir des articles en anglais ou en français. Prière de les adresser à un correspondant régional ou à un membre de la rédaction.

SOUSCRIPTION

L'acoustique et la lutte antibruit au Canada est distribué gratuitement. Veuillez communiquer avec la Division de la lutte antibruit, Service de la protection de l'environnement, Ministère de l'Environnement, Ottawa (Ontario), K1A 0C8, pour faire inscrire votre nom sur la liste d'envoi. Il est nécessaire que tous les résidants du Canada indiquent leur code postal.

Ce bulletin d'information est publié par l'Association canadienne de l'acoustique. Le Ministère de l'Environnement s'occupe de l'impression et de la distribution. Le contenu du bulletin ainsi que les avis exprimés ne représentent pas nécessairement l'opinion de l'Association canadienne de l'acoustique ou du gouvernement du Canada et des ministères et organismes fédéraux; ce sont les auteurs qui en assument la responsabilité.

(suite au recto de la couverture inférieure)

Contents/Table Des Matieres

Notice Board

Acoustics Measurement Seminar

The Physics Division of the National Research Council is sponsoring a seminar in acoustics measurements. The seminar will provide a forum for discussion and dissemination of some of the major advances in knowledge in Outdoor Sound Propagation, the External Ear and Hearing and Noise Measurement Techniques. It should appeal to professional acousticians in Industry Government, University and Consulting.

Proposed Subjects

1. Outdoor Sound Propagation

2. External Ear; Acoustical Measurements and Their Applications

3. Critical Review of Sound Level Measuring Techniques

The seminar will be held on October 24-25, 1977 at N.R.C. Labs Building M-36 Montreal Road, Ottawa. Details concerning registration will be available from the Physics Division.

CAA Annual Meeting and Symposium

The annual symposium and meeting of the Canadian Acoustical Association will be held in Ottawa on Wednesday, October 26 and Thursday, October 27, 1977. The schedule is as follows:

Symposium: mornings and afternoons of October 26 and 27

Dinner and annual meeting: evening of October 26

All events will take place in the Inn of the Provinces, 360 Sparks Street, Ottawa, Ontario K1R 7S9. An application form for reservation of overnight accommodation at the Inn of the Provinces is enclosed.

Contributions to the symposium on

physiological acoustics, psychological acoustics, speech communications, attitudes and human factors electroacoustics

noise control legislation, occupational noise and community noise

and on other topics in acoustics are invited. Abstracts should be sent to:

Dr. T.F.W. Embleton
Acoustics Section
Division of Physics
National Research Council of Canada
Ottawa, Ontario K1A 0S1

The deadline for receipt of abstracts is June 30.

The printed program of the meeting will contain a Consultants' Directory. Business-card type advertisements, with maximum dimensions of 2-1/2" by 3-3/4", are acceptable at a fee of $30.00 per piece. These should also be sent to Dr. T.F.W. Embleton at the above address.

Electrical Noise Contract

The Sound and Vibration Laboratory of the Faculty of Engineering Science, The University of Western Ontario, has recently been awarded a research contract by the Canadian Electrical Association to undertake a program of physical measurement and analysis of audible noise from high voltage transmission lines and transformer substations, and an assessment of attitudinal reaction of people to this form of noise. This information is required in order to provide certain guidelines in the design and development of future high voltage transmission lines in Canada.

The project, which will cost $185,000, will involve automatic recording of noise and other environmental data on digital monitors over a period of one year at selected test sites in Ontario and Quebec. Operating personnel from Ontario Hydro and Hydro Quebec will cooperate with the Laboratory in this phase of the study. The data obtained in the field will be processed with the aid of the University computing facilities.

A second phase of the study concerns testing and correlation of the reaction of a representative cross-section of the public to audible noise from various types of transmission lines and a typical transformer substation, through playback of specially prepared test tapes. The facilities of the Laboratory, including a "quiet" room for subjective testing, will be used in this part of the project. These tests will be carried out in close cooperation with the Department of Psychology at the University.

Position Available

Applications are invited for a newly established position in the Division of Speech Pathology, University of Toronto. The Division plans to offer a 2-year Master's degree in the fall of 1978 which will replace the existing postgraduate diploma programme. The position involves teaching, research, possibly thesis supervision, and collaboration with the Divisional faculty in developing a Speech Science Laboratory.

Ph.D. with proven research and teaching capabilities are required. A strong background in Speech and Voice Science and/or Experimental Phonetics which includes an understanding of instrumental quantification of speech and voice data, the psycho-acoustics of communication and the physiological substrates of language. Applicants should possess, or have in interest in developing, extensive insight into all aspects of disordered communication.

Rank: Assistant or Associate Professor
Salary depending on experience and qualifications.
Effective date of appointment: September 1st, 1977 or as soon thereafter as possible.

Enquiries should be address to:

Professor Jean F. Walker, Director
Division of Speech Pathology,
Faculty of Medicine,
University of Toronto,
Toronto, Ontario. M5S 1A1

CENTRE DE RECHERCHE
INDUSTRIELLE DU QUÉBEC

CRIQ

333, rue Franquet,
C.P. 9038, Ste-Foy, Québec
G1V 4C7

(418) 659 1550, telex: 051 2273

Le 1er avril 1977

Dr. C.W. Bradley
Dept. of Electrical Engineering
McGill University
Montréal, Qué.

Monsieur,

Nous préparons un guide pour le contrôle et/ou la réduction du bruit dans l'industrie de la transformation première du bois (atelier de sciage ou de rabotage). Je vous saurais gré de me donner le nom de compagnies canadiennes, que vous connaissez, susceptibles de nous fournir du matériel (outil de coupe, silencieux, amortisseur, enceinte, etc.) conçu pour réduire le bruit dans ces ateliers. Les noms d'organismes (centres de recherche, associations, universités, etc.) dans ce domaine me permettraient d'aller chercher aussi d'autres informations.

Je vous remercie de l'attention que vous portez à ma demande et je demeure,

Votre tout dévoué.

Dear Sir

In order to provide Quebec sawmill and planermill owner's a guide for the reduction and/or control of noise in primary woodworking industry, we are looking for names and addresses of canadian companies who might supply devices designed to do so (cutting tool, muffler, damper, acousti-cab, etc.). Name of organisms (research center, associations, universities, etc.) in this field would be very helpful to find out other information (e.g. scientific publication, standard, law, etc.).

Thanking you in advance for your prompt collaboration, I remain,

Yours truly

Claude Carrier

Claude Carrier, Analyste
Service d'Analyse de
l'Information Technologique

CC:lm

MOUNT
SINAI
HOSPITAL

600 UNIVERSITY AVENUE — TORONTO, ONTARIO M5G 1X5

Otolaryngologist-in-Chief
P.W. ALBERTI, M.B., Ph.D., F.R.C.S., F.R.C.S.(C)

DEPARTMENT OF OTOLARYNGOLOGY
Telephone (416) 596-4319

April 4th 1977

Mr. C.W. Bradley,
President,
Canadian Acoustical Association,
William Bradley & Associates,
3550 Ridgewood Ave.
Montreal, Que.

Dear Mr. Bradley,

I was extremely interested to read in the January issue of "Acoustics and Noise Control in Canada" the correspondence between Dr. Jones, Robert Andras and Romeo Leblanc.

The situation concerning acoustics and consulting engineers exactly parallels a problem being faced in their psychological correlate audiology and hearing testing. The field of audiology is slowly evolving in a Canadian as opposed to a U.S. way, and more or less surviving the various setbacks produced by influx of foreign audiologists. It is also proving quite difficult to pioneer innovative compensation schedules for noise induced hearing loss without constant harping back to American standards promulgated by peripatetic consultants from across the border. Continue the good work!

Yours sincerely,

P.W. Alberti

PWA/dmb
c.c. Dr. H.W. Jones

National Research Council Canada | Conseil national de recherches Canada

Division of Physics | Division de physique

7 April 1977.

The Editor,
Acoustics and Noise Control
in Canada,
Mechanical Engineering Dept.,
University of Alberta,
Edmonton, Alberta
T6G 2G8

Sir:

In the January issue of your Journal, p. 10, J.S. Bradley attempts to provide simplified methods of graphically predicting L_{eq} due to traffic noise. I have seen no data that agree with his low speed corrections in Fig. 2. If we use DOT data (s/v Feb. 1977, p. 14) a change of speed from 30 to 55 m.p.h. would increase the noise for an individual truck by 7.5 dBA. Olson's data, to which Bradley refers, would give a 7.0 dBA increase for trucks as well as passenger cars. Taking the lower figure, and taking into account the increased spacing that results from the increased speed, we get a correction of 7.0 - 2.6 = 4.4 dBA compared to the value of 2 decibels in Fig. 2.

The other point of disagreement is perhaps more serious. Figure 2 shows the same increase in level for each 4% increase in percentage of trucks. This contradicts the last sentence of the second last paragraph of Bradley's paper as well as the logic of the problem. Figure 2 would lead the unwary to conclude that 100% trucks would raise the level by 37 decibels when the proper value is only 15.

The actual spacings between the parallel lines should be 3.4, 1.9, 1.4, 1.0, 0.8 and 0.7 decibels.

One more comment if I may. At the top of p. 11 Bradley suggests a method of obtaining L_{eq} by integration. This is more readily achieved graphically. The level of the average vehicle (average in energy output) is plotted on graph paper where the abscissa is log (distance) for any distance for which this level is known - usually 50 feet or 15 metres. The ideal level vs distance is drawn (20 decibels drop per decade of distance). The vehicle spacing is then calculated (speed over vehicles/hour). When this is divide by π we get the distance at which L_{eq} is the same as the level for a single vehicle. If a slide rule is not handy simply move up 5 dB from the single vehicle line, at the distance corresponding to the vehicle spacing, and you are on the L_{eq} line. Drawing a line through this point with a slope of 10 dB per decade of distance gives the ideal for the line source. Corrections must then be applied at greater distances for ground, air, barrier etc. attenuation. But that is another problem.

Ottawa, Canada
K1A 0R6
Telex 053-4322

Yours truly,

G.H. Thiessen

The University of Western Ontario

Faculty of Engineering Science
London, Canada
N6A 5B9

April 21, 1977

Mr. G. Faulkner, Editor
Acoustics and Noise Control in Canada,
Mechanical Engineering Dept.,
University of Alberta,
Edmonton, Alberta
T6G 2G8

Dear Sir:

Dr. Thiessen's comments seem to relate to one of the major points that I was trying to make in my previous article (1). Perhaps the much condensed form of the paper has caused it to be less clearly understandable than would be desirable. In the paper several traffic noise prediction schemes were compared and the relative merits of analytical and empirical equations were indicated. Briefly, analytical equations were seen to be more desirable, but are only easily and exactly derivable for L_{eq} values; empirical equations are only as good as the data from which they are derived. Empirical equations are further limited by the usual somewhat arbitrary form of most of these equations, and certainly should not be used for extrapolations outside the range of the original data. They can be useful for predicting other noise measures (other than L_{eq}) and for simplified prediction methods.

Figure 2 of the article (1) is simply a graphical form of an empirical equation of a form originally used by Delany. This equation has a term indicating a linear dependence on the percentage of trucks, and so figure 2 contains a set of equally spaced parallel lines. The fact that this is a reasonable approximation is seen from the low overall prediction error of this equation ($\pm$ 1.92 dBA). The fact that it is not an entirely satisfactory prediction equation was illustrated in figure 1. In figure 1 it was clearly shown that this empirical equation and that of Hajek do not correctly consider the effect of percentage of trucks. It must therefore be concluded that the analytical equation is a more satisfactory prediction method.

Dr. Theissen's extrapolation to 100% trucks very dramatically illustrates the folly of making extrapolations from such empirical prediction equations.

.../2

Mr. G. Faulkner, Editor
Acoustics and Noise Control in Canada

April 21, 1977

The question of the speed correction on this same figure 2 again relates to the problems of empirical equations. It is simply the best fit of a given equation form to measured data. As the number of data points at speeds above 45 mph were quite small one should make inferences at 55 mph with some caution. It must be remembered that the work was concerned with predicting urban traffic noise levels, and was not for free-flow highway traffic noise as practically all previous predictions schemes have been. It is thus reasonable to expect some differences in the speed dependence. Indeed Fisk developed an urban traffic noise prediction equation in Britain that contained no dependence on speed. (2).

I do not appreciate the merits of Dr. Thiessen's prediction technique, and indeed it seems a little cumbersome. His method seems to be mathematically essentially the same as the analytical equation discussed in my paper. It would seem quite satisfactory to simply enter all the relevant variables into one equation and calculate the resulting L_{eq} value. Figure 2 of my paper was plotted solely to provide a simplified "quick and easy" prediction procedure that would avoid the cumbersomeness of techniques such as Thiessen's and the various traffic noise nomographs. Of course it has its limitations (see above) but it would appear to excell in simplicity. It has been used quite successfully in choosing sites with desired noise levels for a major study of the effects of exterior vehicle noise.

(1) "Predicting L_{10}, L_{50}, and L_{eq} For Urban Traffic Noise" J. S. Bradley, Acoustics & Noise Control in Canada, Vol. 5, No. 1. (Jan. 1972)

(2) "Prediction of Urban Traffic Noise" Fisk D. J. et al. 8th ICA (London 1974).

Yours sincerely,

J. S. Bradley

J. S. Bradley
Assistant Professor
Part-time

JSB:cw

The Regulation of Noise

William M. Crawford
Supervisor Industrial Hygiene Department
Workers' Compensation Board of B.C.

Ladies and Gentlemen, welcome to the forum on industrial noise. This being the last day of the symposium I promise you some very informative data on the recent regulation revisions, regarding industrial noise, proposed by the Workers' Compensation Board of British Columbia. It goes without saying that without the support of management and labour, it would be difficult to effectively enforce such regulations on all industries.

Let me explain a little about what is presently in force and then what is envisaged for the future.

Our present regulations, effective May 1, 1972 require that:

a. the employer shall first take appropriate measures to reduce the noise intensity to approved levels, or
b. if it is not practical to reduce the noise to approved levels or isolate the workmen from the noise, the workmen shall wear personal protective equipment which will effectively protect their hearing.

We then apply the criteria for permissible noise exposure. This is the familiar time weighted scale of 90 dBA for 8 hours with the provision for halving the allowable exposure for every 5 dB increment of noise intensity.

At the start of this program the obvious step was to protect the work force. To this end, the provision of personal hearing protection became widespread. Industry was made aware of the first requirement and I am happy to say that extensive noise control programs were initiated. It took some convincing nevertheless, but I am pleased to relate, that sanctions were not too numerous.

The Board published its policy statement regarding industrial noise in February 1975 wherein the concern about industrial deafness was expressed and preventive measures were outlined. Included was a statement that "as a temporary measure when exposure of workers to noise above the permissible level cannot be avoided, hearing protection must be worn." This then intimated that personal hearing protection would not be accepted as the panacea for all noise exposures.

Personal hearing protection was acceptable as an interim measure while other steps were taken to reduce the noise at the source or isolate the workers permanently from the source of noise. This then is our present policy but, as I intimated earlier, there are other improvements envisaged.

The proposed revision to the regulations have taken a new title, that of Industrial Health and Safety Regulations. These proposals have gone through the process of first and second draft and public hearings, and the cut-off date for additional written submissions to the drafts was July 30, 1976. All submissions are now being studied in preparation for final regulations. As stated in the published Second Draft Amendments, the proposed regulations require:

1. Noise levels to which workers are exposed shall not exceed:

    a. 90 dBA of steady state noise, or
    b. daily exposure to impulsive noise in excess of 100 impulses at 140 dB.

in circumstances in which the noise could have been reduced by methods that are known to the employer, or which he could have discovered upon reasonable inquiry, except;

    a. where the excessive noise level occurs solely in a location to which human access is either impossible or not necessary and not permitted; or,
    b. where the excessive noise level occurs solely at a time at which access is not necessary and not permitted; or
    c. in emergency or other transitory exposure situations where anyone presently is wearing hearing protection.

Where an employer could not and cannot reduce the noise to 90 dBA or below, or cannot isolate the worker from the noise, then all workers who are so exposed shall be provided with and shall wear adequate hearing protection devices. Where hearing protection is required by this regulation, but for medical reasons hearing protection devices should not or cannot be worn by any individual, the employer shall notify the Board and shall follow the directions of the Board concerning the permissible noise exposure.

In a nut-shell then, the Board is proposing a MAC of 90 dBA steady state noise, and 140 dB peak. The permissible excursions from these values will be, "not normally manned positions," emergency conditions, and medical considerations. It has been proposed that where medical considerations are involved we could then relate back to the familiar time weighted scale.

Where impact noise is concerned, it is intended to limit this to 100 impulses at 140 dB, 1000 impulses at 130 dB, and 10,000 impulses at 120 dB. With a little bit of research it will become obvious that we are not too different from the OSHA proposed new noise standard. Included also is a requirement for audiometric testing of the work force. The requirement here will be for base line and periodic audiograms for workers who are exposed to noise in excess of 85 dBA of steady state noise, or in excess of impulse noise of 120 dB.

The proposed requirement for this audiometric testing program is that the conditions be met not later than January 1, 1978. It is envisaged then that every worker exposed to noise shall receive an initial hearing test and shall then receive an annual hearing test thereafter.

It is obvious that the testing of workers' hearing is an integral part of any overall program for the prevention of industrial deafness.

Measuring the hearing of workers at the time they begin their employment and at periodic intervals thereafter assists a program of noise measurement and noise control enforcement.

To enforce such a program it is prudent to assist the industrial community in its implementation. To that end, then, the Workers' Compensation Board of B.C. has established a Hearing Branch in Richmond for the purpose of hearing loss claim adjudication, provision of clinical facilities for the determination of hearing loss, the training and subsequent follow-up of the industrial audiometric program. In addition, it is the function of the Board's industrial hygienists to monitor noise through the Province and assist industry in their noise abatement programs.

I relaize this just a key-hole sketch of the regulations pertaining to noise in B.C. However, my two speakers will elaborate on the problems confronting industry and illustrate some of the work that has been done for compliance with present regulations and with ears to the ground, the proposed regulations.

My first speaker then will be Mr. Don Blake, and I must admit that there is no one in B .C. so well equipped as Mr. Blake to "lay on you" the trials and tribulations that the hearing conservation and noise control program inflicts on industry, especially a large industry which Don represents. As he goes through his presentation it will become obvious that considerable effort and analysis has been attributed to the requirements for noise control. It gives me pleasure therefore to introduce the manager of Acoustical Engineering Control for MacMillan Bloedel Ltd., Mr. Don Blake . . . .

(Editors Note: Mr. Blake's paper appeared in the last Newsletter, Vol. 5, No. 1).

Reprinted from Vol. 90--Acousto-Optics--Device Development/Instrumentation/Applications

STATUS OF RESEARCH IN ACOUSTIC IMAGING AND HOLOGRAPHY

H. W. Jones
Acoustics Group, The University of Calgary
Calgary, Alberta, Canada, T2N 1N4

Abstract

This paper reviews the results of research in imaging reported in the last two years approximately. The emphasis is placed on the high frequency applications of this subject and very little reference is made to sonar and none to geological applications. The subject is discussed under three main divisions, direct (pulse echo) imaging, holography and finally particular devices. Emphasis has been placed on the physical principles used. It is assumed the reader is conversant with the outlines of earlier work in the field.

Introduction

In reviewing the situation in ultrasonic imaging and holography one is faced with the task of choosing material for omission because the work which has been done is so remarkably extensive (even though it is mainly the achievement of the last ten years or so).

The methods of ultrasonic holography and imaging are a generalization of the processes which are used in conventional optics and high frequency electromagnetism. This state of affairs arises because of the special properties of sound waves. First, sound has several modes of transmission, both longitudinal and transverse waves exist. Second, the velocity of propagation is low and, usually, the frequencies used are low enough that detail processing of signals presents no problems, which is not the case with light for example. Consequently, methods which can only be imagined in other fields can be practised in acoustics. Finally, the absence of any acoustical receiving system which has such special virtues that it can be regarded as unique has presented experimenters with a challenge. Now an almost bewildering array of alternatives present themselves, each with its own special advantages. It is difficult to say at this time how much acoustical research has contributed to the general field of "imaging" and how far it has taken its ideas from its close physical relatives. I think that future assessments will show that acousticians have made a fairly substantial contribution to recent advances in the general area; a point that might be demonstrated in part in this review.

The subject will be discussed here first by reference to general principles and secondly by reference to particular applications. Of necessity, low frequency imaging related to geological surveying and sonar scanning is not generally discussed.

Receivers

Table 1[1] summarizes the many methods of detecting the ultrasound from which the image is to be formed. This table probably requires two additions, (i) the AOCC converter of Greguss[2] which uses nematic liquid crystals, and (ii) use of the pyroelectric effect in a Sokolov tube (Jacobs[3]).

The methods which have proved more popular are based on the piezo-electric effect, liquid and solid surface deformation and the optical detection of density variations. It is, of course, very possible that another method might become active again. The history of the topic almost suggests this will happen as is instanced by the considerable improvement in the Pohlman Cell[4] which arose from the work of Campolattoro *et al.*[5].

Non-holographic Imaging

Direct pulse echo visualization systems are widely used, particularly in medicine. Many different modifications of the simple single transmitting and receiving transducer system have been made. The most important developments in this field probably relate to the phasing of arrays. Some of the Australian work reported by Kossof[6] is perhaps of interest in this regard. He observed that there are three basic limitations to the techniques in use and lists them as:

i. lack of lateral resolution;
ii. the inability of mechanically moved (or hand operated) transducers to cope with mass screening of the population together with the inability of such systems to examine fast moving structures, such as the heart;
iii. "artifact echoes" related to multiple reflections which obscure the genuine echoes from the smaller internal organs.

He discussed methods of overcoming two of the difficulties starting from the use of a concentric annular phase array, see Figure 1. If the array is used for transmitting, then the relative phase between the elements will decide where the focal point of the energy will be. The quality of the focussing action is another and much more complex matter which will be discussed later. The reflected sound waves on their return

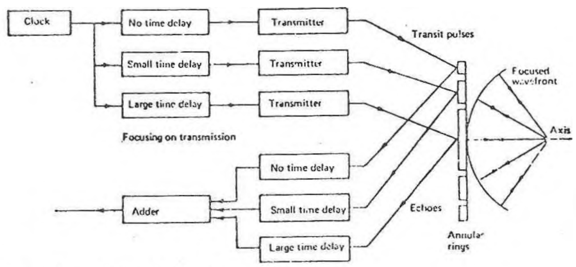


Fig. 1. Annular phased array

can be focussed on reception by introducing suitable time delays to the signals after their reception and prior to their summation; thus the phased array can be focussed on any point by introducing the correct delay in signal processing. The practical difficulties associated with this system led him to suggest linear phased arrays should be used. He concluded with the discussion of the crossed phased array transducer, see Figure 2. The ideas of using phased arrays are not new and have been the subject of interest in other fields for quite some long time. Halvice, Kino and Quate[7] described an elegant method for an electronically focussed two dimensional array, see Figure 3. From this they produced some very good images. This process is clearly capable of much extension and elaboration. Focussing can be achieved by any means of summing the elements of the wavefront which takes proper account of the phase relationships. Electronic, digital or refraction processes all allow this summation to be undertaken. It is not obvious which method has the greatest advantage because work on this topic is developing so rapidly. In more recent work, Macovski and Norton et al[8] considered segmented annular arrays, see Figure 4, and showed that very high resolution can be obtained from their use. This work is closely related to that of a Vilkomerson [9&10] who also demonstrated and discussed the properties of annular arrays of piezo-electric elements. Thurstone et al[11] discussed the use of sampled apertures and the summation of received signals to produce images of brain tissue using programmable delay lines, see Figure 5. The object was to correct for the phase abberations introduced by the skull. We can neglect the causes of the variations and treat the phase compensation as a general problem. If we do so, then

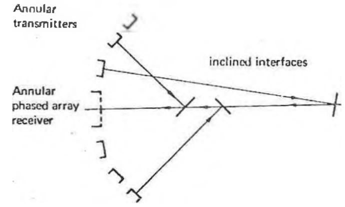
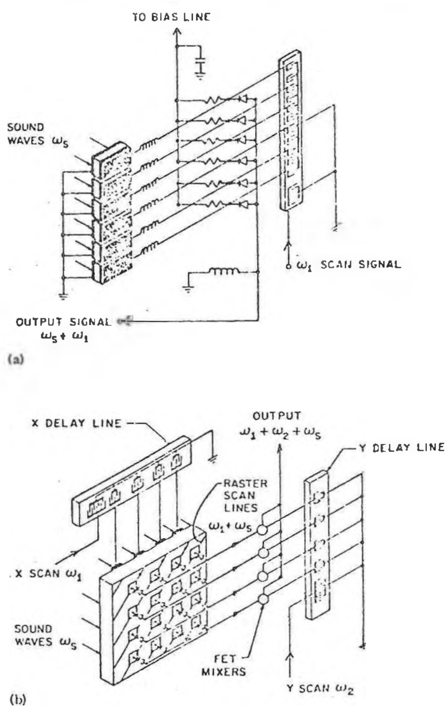


Fig. 2. Wide aperture array



←Fig. 3. Electronically focussed imaging device

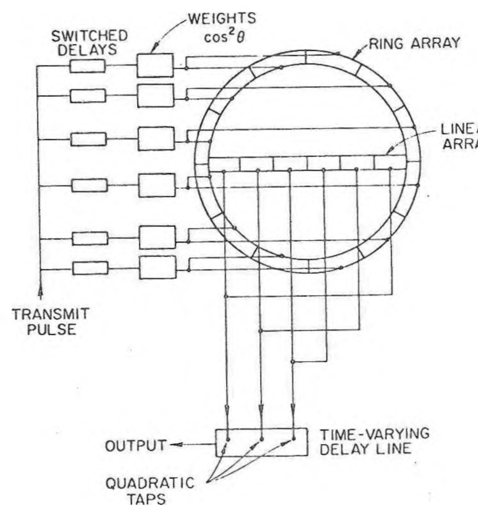


Fig. 4. → Sector scan system using a weighted ring transmitter and dynamically focussed line array receiver

we find that this leads us back to classical optics and to the work of Wild[12], Toraldo di Francia[13] and Luneburg[14]. The latter two authors demonstrated that any aperture can achieve any chosen resolution limit provided we satisfy two theoretical considerations and solve two practical problems. Theory demands that we must be able to modify the phase and amplitude of an incoming wavefront (shading) in any way which we choose after it has passed through a receiving aperture. If we can do this, then provided we can solve a massive set of simultaneous equations, we can decide on the shading characteristics. In practice we may find, unfortunately, that we are left with an image which is of nearly zero intensity. Remarkably, we can show that for any given aperture there is no unique solution for the shading. Luneburg demonstrates this very elegantly by providing three alternative solutions for a given aperture problem. The point can be explained by reference to the Fresnel-Kirchoff diffraction integral[43]

$$U(P) = -\frac{Ai}{2\lambda}\iint_A T\frac{e^{ik(r+s)}}{rs}\left[\cos(n_1r) - \cos(n_1s)\right]dS \qquad (1)$$

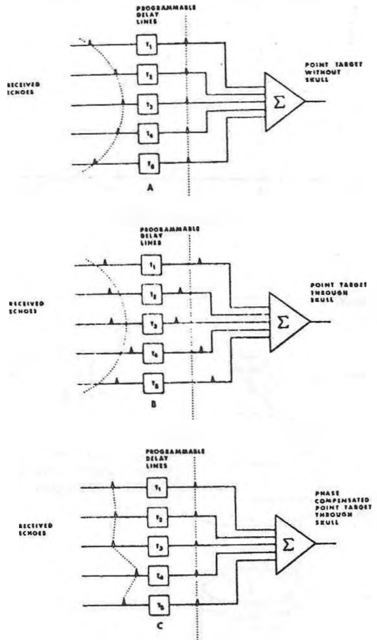
(See Figure 6) where U is the amplitude of the diffracted wave. If we choose to introduce a factor

$$T(x,y) = T'(x,y) + i\,T''(x,y) \tag{2}$$

then it becomes

$$U(P) = -\frac{Ai}{2\lambda}\iint_A T\frac{e^{ik(r+s)}}{rs}\left[\cos(n_1 r) - \cos(n_1 s)\right]dS \tag{3}$$

By a suitable choice of T we can produce any value we wish for U(P). Consequently we can, by "shading" the aperture in some arbitrary way, produce any diffraction patter we like at a given image plane. Toraldo di Francia described a method for choosing T' and T" for a circular aperture and provides examples of some of the difficulties which can arise.



←Fig. 5. Phase compensation technique in receiver mode

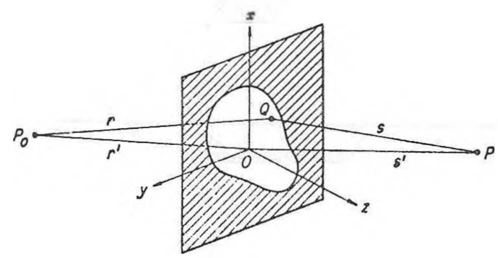


Fig. 6. → Diffraction at an aperture in a plane screen

If it is supposed that some ideal pressure diffraction pattern has been obtained and we have to use this information without degrading it, then the angular response of the receiver is important and this has been explored by Jones[15] and Ahmed[16]. Figures 7 and 8 show this response of PZT and quartz. The use of the Kirckoff integral as it is presented in Equation 3 implies that the receiver response is independent of the angle of incidence; if this is not the case then it has to be modified.

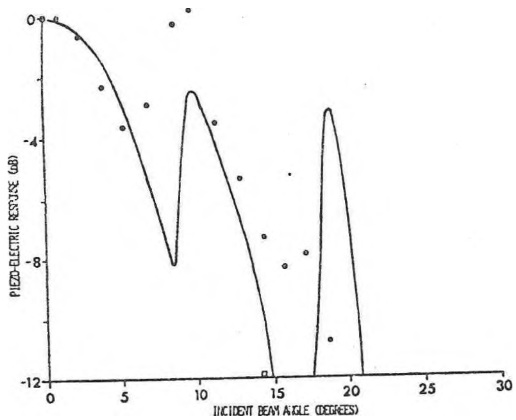
The effect of the aperture is clearly of considerable general concern and here it should be said that in principle there is no reason for an actual physical aperture to exist. Its existence can be inferred or synthesized by the use of suitable receiving and transmitting arrays. Much work has been done in this area, the purpose of which has been to produce the best resolution with the minimum number of piezo-electric elements. Examples of such work, apart from that already mentioned are given in reference 17, 18, 19.

At this point it is probably appropriate to digress sufficiently to mention a related point concerning scanning. Wade and Wang[20,21] discussed this question from the point of view of sensitivity and contrast and introduced the terms Positively Scanning Transmitter (PST), Positively Scanning Receiver (PSR), Negatively Scanning Receiver (NSR) and Negatively Scanning Transmitter (NST). They investigated the relative advantages of each system. These systems can perhaps be briefly explained by reference to the PST and NST systems. In the PST system the transmitter provides a beam which is focussed at and scans the object plane. A transducer (or array) at the receiver records the signal and the temporal output signal corresponds to the spatial structure of the object. In the NST system the only part which is not illuminated is that part of the object for which information is required, i.e., it is the negative version of the PST (and is only of theoretical interest). The authors show that the PST system allows the average intensity of the ultrasound used to be less than that required in other systems. They also discussed the use of an opto-acoustic transducer as the ultrasound source. This transducer switches on in the regions which are illuminated by a light beam. Several rather ingenious methods of scanning were introduced which depend on the use of holographic illumination patterns on the transducer to produce focussed scanning beams, see Figure 9.

Returning to Kossof's list of limitations, it can be noted that mass screening apparatus still appears to be a distant hope in spite of the ingenuity which has been applied to detail designs of direct imaging system.

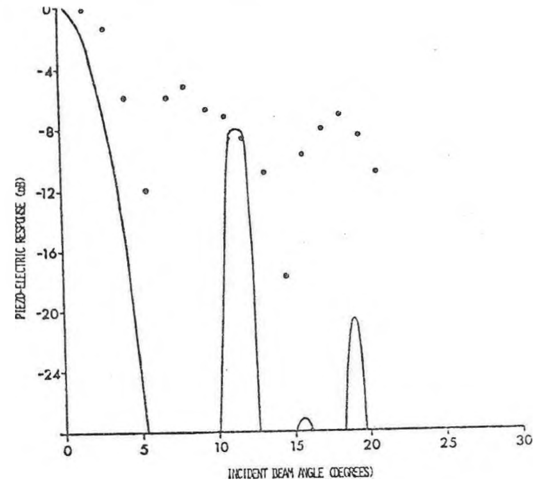
The question of artifact echoes has been addressed by several workers; that of Thurstone et al[11] has been mentioned. Korpel et al[22] have explored the effects of frequency modulation and concluded that for an experimental situation a "10% frequency sweep is, however, sufficient to eliminate these spurious images." There can be little doubt that this is a promising approach to the problem but it poses problems if phase correction and receiver response is a critical factor in an imaging system.

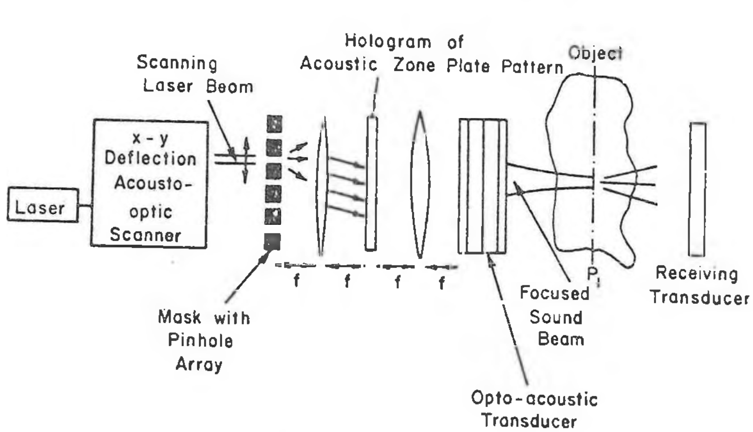
Perhaps before leaving the topic of direct "amplitude only" imaging a recent example of a system nonmedical application ought to be presented and that by C. H. Jones[23] is shown in Figure 10.



←Fig. 7
Angular response
of a quartz receiver

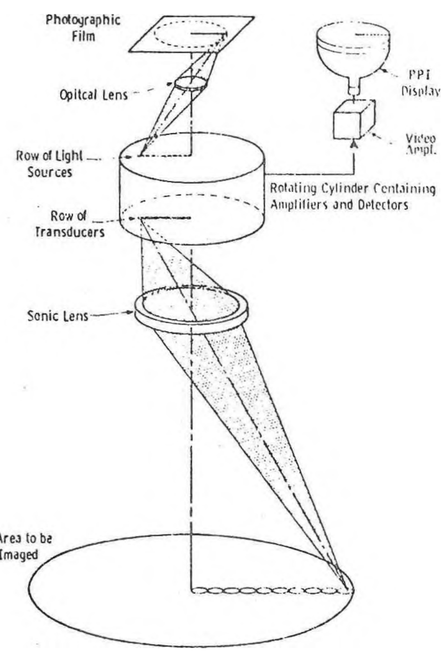
Fig. 8→
Angular response
of a PZT receiver





↑Fig. 9. Schematic of Zone Plate approach to generate a scanning focussed beam

Fig. 10. Schematic of circular scan camera→



Acoustical Holography

Essentially holography concerns itself with reconstructing wavefronts which carry the information about the objects; this requires that knowledge of both the phase and amplitude variation of the wavefront should be available. It may be of assistance to mention the differences between optical and acoustical holography. Because acoustic imaging generally concerns itself with frequencies which can be relatively easily processed by electronic systems it is possible to identify and record the amplitude and the phase of a received signal. Further, it is also possible to arrange, very readily, either linear or square law detection when this is required.

A linear electro-acoustic receiver allows the use of an electronic process to synthesize the reference beam.[44] It is possible to simulate any required reference, off axis or point source for example, simply by varying the phase (and if necessary, the amplitude) of the electronic reference in a suitable way during the scanning process. The two methods of using the reference are available as the following shows:

It can be written for the received signal[24]

$$s(\nu t,y) = a_1(\nu t,y) \cos (\omega_1 t + \phi_1(\nu t,y)) \qquad (4)$$

(Refer to Figure 11 for the definition of the terms.)

Using the circuit shown in Figure 11a, the received signal is multiplied by a reference at the same frequency (i.e., that driving the transmitter) and the resulting signal is:

$$y(t) = a_0 a_1(\nu t,y)\cos(\omega_1 t + \phi_1(\nu t,y))\cos\omega_1 t \qquad (5)$$

which after passing through a low pass filter gives:

$$z(t) = \frac{a_0 a_1(\nu t,y)}{2}\cos\phi_1(\nu t,y) \qquad (6)$$

which provides the information required for a reconstruction. Using the alternative system, Figure 11b, it follows that output will be given by:

$$z(t) = \tfrac{1}{2}(a_0^2 + a_1^2(\nu t,y)$$
$$+ 2a_0 a_1(\nu t,y)\cos(\phi_1(\nu t,y)) \qquad (7)$$

which contains the information (c.f. Equation 6) for reconstruction together with two unwanted terms.

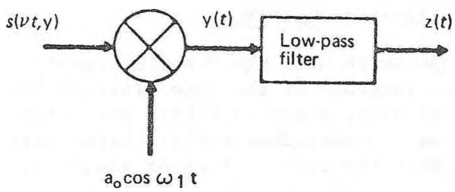
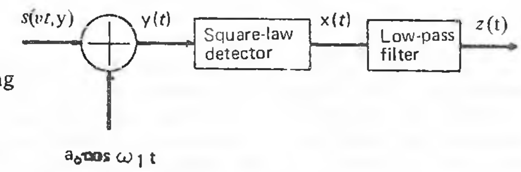


Fig. 11a & 11b.
Detection methods for producing a hologram using a linear receiver and an electronic reference



New developments have taken place in several areas; i) some development of scanning methods, ii) improvements in signal processing, iii) detailed studies on particular aspects of existing apparatus, and iv) work on holographic interferometry.

Concerning items (i) and (ii), Keating[25] discussed the relationship between phased array and holographic receivers and showed that the only difference between them lay in the order in which the temporal and spatial processing operations were carried out. He was able to show that compared with multibeam sonar the holographic approach had a decided signal to noise ratio advantage. It would be interesting to see how far his ideas applied to some of the existing medical ultrasonic apparatus.

Mueller et al[26] described a holographic "weak signal enhancement technique" (WSET) which was applied by M. J-M Clément[27,28] to a translated circular scanned system. The following is Clément's description of (WSET):

"(1) linear detection of the object field (e.g. by scanning) leading to an electronic signal:

$$s(x,y,t) = S(x,y)[\cos\omega_s t + \phi(x,y)] = \text{Real}\{\underline{S}(x,y)e^{i\omega_s t}\}$$

where S is its amplitude, ϕ its phase, $\underline{S}$ its corresponding complex amplitude and $\omega_s/2\pi$ the ultrasound frequency.

(2) point by point formation of the intensity $|\underline{S}(x,y)|^2 = |\underline{S}_1 + S_2|^2$

(3) temporal high pass filterings of $|\underline{S}|^2$ (denoted $|\tilde{S}|^2$).

(4) multiplication of s by $|\underline{\tilde{S}}|^2$.

(5) record of $s.|\underline{\tilde{S}}|^2$, as in conventional holography, multiplied by a reference signal R.

(6) reconstruction (e.g. optically) of the "weak-signal" hologram obtained in step (5).

The multiplication in step (4) being performed onto electronic signals, it effectively represents electronic holographic reconstruction, where the reconstructed field of representation $|\underline{\tilde{S}}(x,y)|^2.s(s,y,t)$ is obtained point by point as a time varying electronic signal.

The analysis remains similar, although the space dependent complex amplitudes (1) - (4) become implicitly dependent on the scanning time τ. For simplicity, the calculations are done with complex amplitudes (i.e. exponential form) rather than with the electronic signal representation (i.e. cosine form). This gives a reconstructed complex amplitude (eq.(4)) (step 5):

$$\underline{S}_p(\tau) = S_p(\tau)e^{i\phi_p(\tau)} = (|\underline{S}_1|^2 + |\underline{S}_2|^2)S_2 + 2|\underline{S}_2|^2 S_1 + S_1{}^* S_2{}^2 + S_1{}^2 S_2{}^* \qquad (5)$$

As the steps 1 to 4 are performed electronically, the wanted reconstructed wave of complex amplitude $\underline{S}_p$(eq.5)) is not available physically. Instead, a signal $s_p(t)$ analog to it is obtained, whose amplitude and phase correspond to that of the complex amplitude (5), i,e,:

$$s_p(t) = |\tilde{S}(\tau)|^2 . s(t,\tau) = S_p(\tau)\cos[\omega_s t + \phi_p(\tau)] \quad (6)$$

This signal is then mixed (e.g. multiplied) with a reference signal R as in conventional ultrasonic holography, yielding the weak-signal enhanced (W.S.E.) hologram:

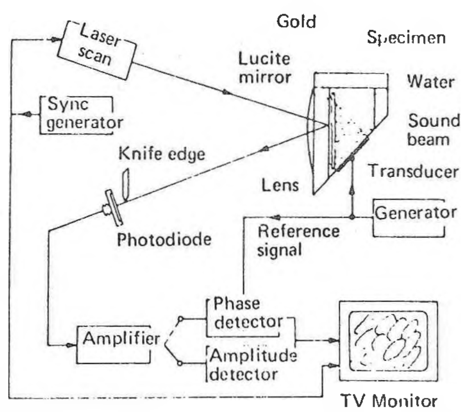
$$H_{wse}(x,y) = C + (\underline{S}_p \underline{R}^* + \underline{S}_p^* \underline{R}) \quad (7)$$

where C is a constant and the implicit time dependent complex amplitude $\underline{S}_p(\tau)$ has been converted into a space varying one by a suitable hologram recorder. When illuminating the W.S.E. hologram (7) with a reconstructing wave $\underline{U}\, e^{i\omega t}$, and for simplicity assuming that the hologram has not been demagnified, the complex amplitude of the reconstructed wave of interest would be:

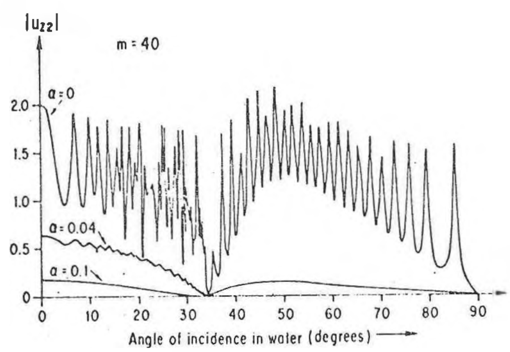
$$C\underline{U}^{i\omega t} + \underline{S}_p(\underline{R}^*\underline{U})^{i\omega t} + \underline{S}_p^*(\underline{R}\ \underline{U})e^{i\omega t} \quad (8)$$

Assuming $\underline{R}^*\underline{U}$ to be real (e.g. by taking the reference and reconstructing waves as identical plane waves), then it can be seen that the second term of the complex amplitude (8) is identical to that of (5) and (4), in which we find the enhanced image $(|\underline{S}_1|^2 + |\underline{S}_2|^2)\underline{S}_2$."

Korpel et al[29] have done much detailed work on their acoustic microscope which uses the dynamic ripple technique, see Figure 12. Ahmed et al[30] published a detailed study of the response of the face plate of this system, see Figure 13, showing the complex response which occurs. This analysis, which is fairly extensive and has its origins in the work of Brekhovskikh[31], treats the face plate as a homogeneous solid. Later this work was extended to non-homogeneous solids[32] and has, consequently, become a formidable piece of analysis; unfortunately the details of this have not yet been published.

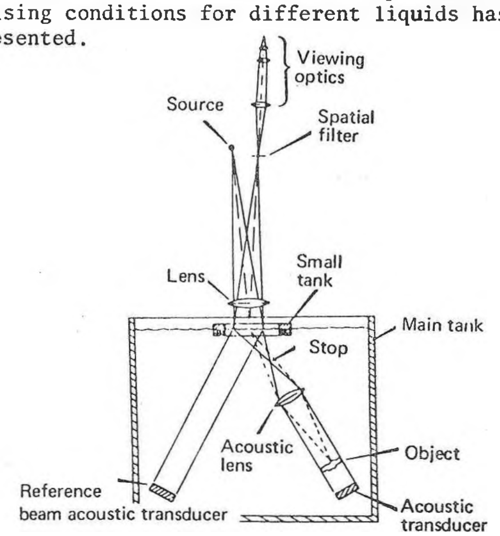


←Fig. 12. Dynamic Ripple Imaging System



↑Fig. 13. Amplitude response of solid-air interface of 20A thick plate.

Liquid surface holography[33], Figure 14, has, to quote one of its originators, "matured". Pille and Hildebrand[34] have published a rigorous analysis of the liquid surface behaviour including the effects of the presence of the "mini-tank." The previous analyses were confirmed and somewhat better information on optimum pulsing conditions for different liquids has been obtained; Figure 15 shows an example of the information presented.



←Fig. 14. Liquid surface imaging system.

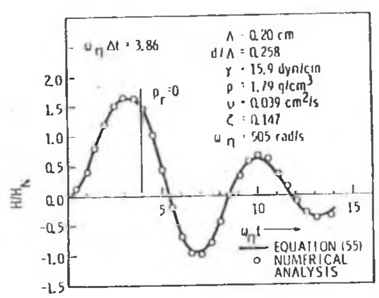


Fig. 15→
The response of liquid surface to pulse of radiation pressure.

Interest in interferomic holography has quickened somewhat as is instanced by references 35 & 36. Metherell[35] extended his earlier work to investigate a number of methods of using interferomic techniques. He derived conditions for "linearized subfringe holographic interferometry" which required suitable phased modulation of the optical illuminating beam; Figure 16 shows the image intensity which is produced as a function of the liquid surface displacement. Metherell develops the argument to show how vibrational phase and amplitude information can be recorded. He estimates that using an argon laser at 5145Å holograms can be recorded at 1 MHz with a (surface) acoustic intensity of 0.00165 w/cm^2. He shows a reconstructed hologram of a forearm which was recorded by this process. The application of this work to stroboscopic holography is discussed.

Fox et al[36] discusses the principles of acoustic holographic interferometry and performed some pilot experiments in air at frequencies in the 15 - 20 KHz region.

Other Topics

Three other topics require mention in even the tersest of reviews; GHz microscopy, Bragg imaging and image contrast.

The high frequency ultrasonic microscopy work of Quate and Lemons[37], see Figure 17, is based on a scanning method in which the object is moved to produce the image. The rigid requirements of the lens system led to this choice of geometry. Resolution is sufficient for the shape of individual red blood corpuscles to be clearly identified. A major part of their future programme of work is identifying the special advantages of acoustic micrographs in relation to their optical equivalent. It is pointed out that contrast arises in the acoustic images from the usual ρ c differences and also, at these frequencies, from the viscous differences in the specimen.

Bragg imaging is too large a subject to be covered adequately in a paragraph, consequently only one or two topics are mentioned. Wade's[38] activity in this field continues with the recent publication of work on acoustic lenses and low velocity fluids for improving images[38]. A distinction between Raman Nath and Bragg imaging was made by R.A. Smith[39] in which he shows that low frequency imaging is of the former type if the light interaction length is greater than about 35 cm. Tobochnik et al[40] evaluated Bragg imaging in the 1 - 5 MHz region for medical purposes by comparing it with radiography. They concluded among other points that "a simple imaging model indicated that one must balance resolution and depth of field considerations in the design of an ultrasonic system."

In presenting visual information, contrast in the image is a factor of vital importance. Much imaging has suffered from a lack of contrast which has been associated with limitations of the dynamic range of the overall system (often the oscilloscope). Mention of this point was made at the beginning of this paper. Sutton et al[41] reported work on various methods of electronic processing of signals from an array and demonstrated the usefulness of active integrator circuits in this regard. Further work in this general area on standard phantom objects was reported by Nigam[42] in which he discussed the performance of three such objects in relation to high resolution pulse echo imaging.

Conclusion

It is hardly possible to summarize the foregoing. If a general comment is appropriate, then it appears that the nature of the scientific endeavour is changing from an emphasis on general principles to the development and exploration of particular areas in greater depth. Finally, I emphasize that the reader must be cognizant of the omissions required to meet the limitations of the publishing requirements.

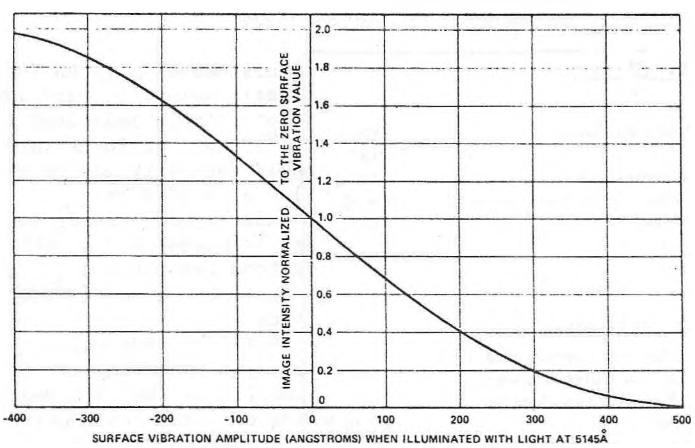


Fig. 16. Linearized subfringe holographic interferometry (modified Powell-Stetson)

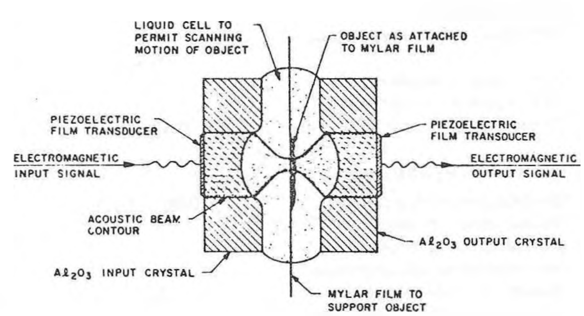


Fig. 17. Schematic diagram of acoustic system (acoustic microscope) showing the lens configuration

References

1. Berger, A. H., "Acoustical Holography"*, Vol. 1, pp. 27-45. Edited Metherell & El Sum, Plenum 1969. *Subsequently referred to as A.H. followed by a number indicating the volume.
2. Greguss, P., "Ultrasonics International 1973", pp. 265-269. I.P.C. Science and Technology Press Ltd.
3. Jacobs, J. E., A.H. 6, Edited Booth, pp. 661-669, 1975.
4. Pohman, R., Z. Phys., Vol. 113, 697, 1939.
5. Campolattoro et al, Il Nuovo Cimento, XXXVI, Vol. 1, pp. 1281-1289, 1965.
6. Kossof, G., "Ultrasonics International 1973", pp. 199-255 ibid.
7. Havlice, J.F., G.S. Kino and C. F. Quate, "Applied Phys. Letters, Vol. 23, 11, pp. 581-583, 1973.
8. Macovski, A. and S. J. Norton. A.H. 6, pp. 121-143.
9. Vilkomerson D. and B. Hurley, A.H. 6, pp. 145-163.
10. Vilkomerson D, A.H. 5, pp. 283-316, Edited P. S. Green, 1974.
11. Phillips, D.J., S. W. Smith, O.T. von Ramm, F. L. Thurstone, A.H. 6, pp. 103-119.
12. Wild, J. P., Proc. Roy. Soc. 286A, p. 499, 1965.
13. Toraldo di Francia, G., Supplemento Al Vol. IX, Serie IX, Del Nuovo Cimento, pp. 426-438, N3, 1952.
14. Luneburg, R. K., Mathematical Theory of Optics, U. of California Press, 1966.
15. Jones, H. W., 8th Intl. Cong. on Acoustics Proc., Vol. 2, p. 712, 1974.
16. Ahmed, M., A. H. 6, pp. 671-687.
17. Hayward, R. A., E. L. Rope, G. Tricoles and O. C. Yue, A.H. 6, pp. 469-484.
18. Keating, P. N., R. F. Koppelmann, T. Sawatri and R. F. Steinburg, A.H. 6, pp. 485-506.
19. Johnson, S. A., J. F. Greenleaf, F. A. Duck, A. Chu, W. R. Samayo and B. K. Gilbert, A.H. 6, pp. 193-211.
20. Wang, K., and G. Wade, A.H. 4, pp. 431-462, 1972.
21. Wang, K., and G. Wade, A.H. 6, pp. 213-228.
22. Korpel, A., R. L. Whitman and M. Ahmed, A.H. 5, pp. 373-390.
23. Jones, C. H. and G. A. Gilmour, J.A.S.A., Vol. 59, 1, pp. 74-85, 1976.
24. Hildebrand, B. P. and B. B. Brenden, An Introduction to Acoustical Holography, Plenum Press, New York, 1972
25. Keating, P. N., A.H. 5, pp. 231-238
26. Keating, P. N, R. K. Mueller and R. R. Gupta, A.H. 4, pp. 251-265
27. Clément, M. J-M., A.H. 6, pp. 557-576
28. Clément, M. J-M., and J. W. R. Griffiths, "Ultrasonics International 1973", Conf. Proc. pp. 270-274, ibid.
29. Korpel, A., L. W. Kessler and P. R. Palermo, "Nature", Vol. 232, 110., 1971
30. Ahmed, M., R. L. Whitman and A. Korpel,"I.E.E.E. Trans. Sonics and Ultrasonics," SU-20, p.233, 1973
31. Brekhovskikh, L. M., Waves in Layered Media, Academic Press, New York, 1970
32. Ahmed, M., A.H. 6, pp. 671-687
33. Brenden, B. B., A.H. 1, pp. 57-71, 1969
34. Pille, P., and B. P. Hildebrand, A.H. 5, pp. 335-372
35. Metherell, A. F., A.H. 5, pp. 41-58
36. Fox, M. D., W. F. Ranson, F. R. Griffin and R. H. Pettey, A.H. 5, pp. 103-120
37. Lemons, R. A. and C. F. Quate, "Science", Vol. 18, pp. 905-911, May 1975
38. Wade, G., A. Coello-Vera, L. Schlussler and S. C. Pei, A.H. 6, pp. 345-361
39. Smith, R. A., A.H. 6, pp. 363-383
40. Tobochnik, N., P. Spiegler, R. Stern and M. A. Greenfield, A. H. 6, pp. 327-343
41. Sutton, J. L., J. V. Thorn and J. N. Price, A.H. 5, pp. 573-590
42. Nigam, A. K., A.H. 6, pp. 689-710
43. Born, M. and E. Wolf, Principles of Optics, p. 382, Pergamon Press, 1965
44. Metherell, A. F. et al, A.H. 2, Editors, Metherell and Larmore, pp. 69-85, 1970

TABLE I showing approximate threshold sensitivity (W/cm²)

PHOTOGRAPHIC AND CHEMICAL METHODS			
Direction action on film	1 – 5	Liquid surface deformation	10^{-3}
Photographic paper in developer	1.0		10^{-5}
	0.1*	Solid surface deformation	10^{-6} ‡
Starch plate in iodine solution	1	Mechanical alignment of flakes in liquid	2.8×10^{-7}
Film in iodine solution	1	Acoustic birefringence	10^{-1}
Colour change effects	0.5 – 1†		
THERMAL TECHNIQUES			
Phosphor persistence changes	0.05 – 0.1	**ELECTRONIC METHODS**	
Extinction of luminescence	1		
Stimulation of luminescence	–	Piezoelectric detector – mechanical movement of transducer or object, or use of an array of transducer to form an image	10^{-11} ** 5×10^{-12}
Thermosensitive colour changes	1		
Change in photoemission	0.1		
Change in electrical conductivity	0.1		
Thermocouple and thermistor detectors	0.1	Probe detection of potential on back of piezoelectric receiver	(*)
OPTICAL AND MECHANICAL METHODS		Electron scan of piezoelectric receiver	2×10^{-11}
		Electron scan of piezoresistive receiver	10^{-7} ††
Optical detection of density variations	10^{-3}	Piezoelectric – electroluminescent phosphor detector	
	3×10^{-4}		10^{-6}

*This value is given for a 'satisfactory picture quality'. It is indicated in (12) that the lower threshold intensity can be as low as 0.05 W/cm².

†Under special conditions (15) indicates that this method can respond to intensities as low as 0.07 W/cm².

‡This technique was brought up during the discussion at the 74th Meeting of Acoustical Society of America, Miami Beach, Fla., Nov.13-17, 1967, by A. Korpel, Zenith Radio Corp., Chicago, Ill.

(After Berger)

Question submitted by A. A. Read, Iowa State University:

Would you comment on the use of shock waves from explosive charges for the generation of holograms?

Answer: This has been the subject of a study by G. L. Fitzpatrick (Denver Mining Research Center, U.S. Bureau of Mines, Denver, Colorado) who concerned himself with geological applications of the subject. I have an informal communication on the topic and I would suggest that he be approached by the questioner. The information I have indicates that a complete and cohesive study of this subject has been made by him. Related relevant work could be that of J. F. Farr, Chapter 16 "Acoustical Holography", Vol. 2, Plenum; A. Fontanel and G. Grau, 39th Annual International Meeting of the Society of Exploration Geophysicists, Institute Francais du Petrol, reprint ref. 17.353, Sept., 1969; J. B. Farr, "Acoustical Holography", Vol.6, 435 etseq. Plenum.

Question submitted by Glen Wade, University of California:

Would you comment on the differences in the character of the focusing available from phased arrays if continuous waves are used as opposed to pulses?

Answer: The primary difference appears to arise from the frequency spectrum differences. The use of phased arrays implies the choice of delay times which relate to a particular frequency. If a pulse train is used, the Fourier components could well be at frequencies which did not relate to the original intent with consequences for shape of a transmitted beam pattern and probably a defocussing effect for the received signal. It would be interesting to see a general theoretical treatment of this problem.