JSB.

ACOUSTICS AND NOISE CONTROL IN CANADA

THE CANADIAN ACOUSTICAL ASSOCIATION

L'ACOUSTIQUE ET LA LUTTE ANTIBRUIT AU CANADA

L'ASSOCIATION CANADIENNE DE L'ACOUSTIQUE

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CONTRIBUTIONS

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

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(continued on inside back cover)

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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.

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(suite au recto de la couverture inférieure)

Contents/Table Des Matieres

Papers:

NOTICE BOARD

CAA MEETING

The fourteenth annual meeting of the Association will be held in Vancouver on the 6, 7 and 8 of October, 1976. Contributions on all aspects of acoustics and noise control are invited and abstracts are being accepted by Doug Whicker, Barron and Strachan, 3284 Heather Street, Vancouver, B.C. V5Z 3K5. Please submit your abstracts as soon as possible. For more information concerning the meeting contact Doug Whicker at the above address.

A group air travel plan is being arranged for those members coming from or through Toronto to Vancouver to help hold the airfare costs down. For information regarding this group flight contact our "Travel Advisor"

John Manuel
Supervisor Noise Pollution Control Section
Pollution Control Branch
Ministry of the Environment
135 St. Clair Ave. W.
Toronto, Ontario. (416 - 965-2~~17~~1)
2425

UNIVERSITY OF WESTERN ONTARIO GRADUATE PROGRAM

The Sound and Vibration Laboratory of the Faculty of Engineering Science, The University of Western Ontario, will be offering a program of graduate studies dealing with noise, vibration and control in transportation, communities, buildings and industry. The program will begin in September, 1976.

The program will lead to the Master of Engineering (M.Eng.) degree, and is designed primarily to provide advanced specialized training beyond the baccalaureate level leading to increased professional competence in various areas of noise assessment and control.

For further information and/or application forms, write to:

Student Liaison Office
Faculty of Engineering Science
The University of Western Ontario
London, Ontario, Canada, N6A 5B9

CONFERENCES IN ACOUSTICS

The 15th International Conference on Acoustics, Ultrasound, to be held on the 5th to 9th of July 1976 at the Electrical Engineering Building, Prague, Suchbatarova 2, Praha 6-Dejvice. The themes of the conference will deal with technology and medicine. For information write

Assoc. Prof. Dr. Ing. Oldrich Taraba CSc.
Chairman of the Subcommission for Ultrasound
of the Acoustic Commission of the CSAV

XIII International Congress of Audiology

on the 18th to 22nd of October, 1976, in Florence, Italy. For information write the congress President

Prof. E. Bocca
Viale Regina Giovanna 15, Milan

Acoustical Society of America

meeting in San Diego on the 16th to 19th of November, 1976. Chairman of the conference is

Fred N. Spiess
Marine Phys. Lab.
Scripps Institute
Box 109, La Jolla CA
92037

The Institute of Acoustics is organizing the next FASE Symposium on the subject of European Noise Legislation to be held from the 14th to the 17th of November, 1977 in London. The technical programme itself will include consideration of criteria, instrumentation, standards, laws and regulations, their nature, enforcement and effectiveness. If any member of the association would like to make a contribution to one of the subject headings please contact

Mr. R.A. Waller
Vice-President
Symposium Organizer
Institute of Acoustics
47 Belgrave Square
London SW1X 8QX

Ultrasonics International will be held at Imperial College, London at the end of June 1977. Subjects include high-power ultrasonics, instrumentation, medical and biological applications of ultrasound, non-destructive testing, physics of ultrasonics, transducers, underwater ultrasound and visualization.

Authors offering papers for presentation should sent abstracts of 150-250 words plus one illustration to:

Dr. Z. Novak
Conference Organizer
Ultrasonics International 1977
IPC House
32 High Street
Guildford Surrey GU1 3EW UK

General inquiries should be sent to: Mrs. Mabel Stacey, Conference Secretary at the same address.

Government of Canada Gouvernement du Canada

Department of Communications Ministère des Communications

Ottawa, K1A 0C8

26 August, 1975

Dr. H.W. Jones,
Chairman, Canadian Acoustical Association,
Physics Department,
University of Calgary,
CALGARY, Alberta.
T2N IN4

Dear Hugh:

In a recent telephone conversation, you suggested that I might write you a letter to be read out at the CAA meeting.

First of all, I would like to say how sorry I am that I cannot be with you all at this meeting, especially as pressure of other business has kept me from several previous ones; but you have chosen the exact dates when I will be packing up my Ottawa home, and moving to sunny Florida. This move is the result of a decision to retire from my regular occupation to devote myself full time to consulting in architectural acoustics and noise control. By moving to the United States, naturally with considerable regret, I plan to broaden the base of my practice, while still keeping, I hope, as many of my Canadian clients as possible!

That's enough about myself; what of the future of the Canadian Acoustical Association now that it has become a teen-ager. For it is just over thirteen years ago that eighteen of us got together in Ottawa, at what the minutes described as a "meeting of Canadian Acousticians", to start the ball rolling. In the course of that meeting, to quote the minutes again, "the general problem of establishing and using (noise) criteria was discussed at some length". It seems to me that that discussion is still going on!

. . . /2

A later quotation from the same minutes suggests that we have in fact made some progress in the intervening years. A representative from the mechanical engineering division of NRC said: "It appears, in fact, that noise control is just too far down the list of considerations in the design of aircraft, trucks or even in buildings. One important task for acousticians is to educate designers to the point where they will consider noise, or rather quiet, as a basic design factor, rather than something to be looked at after other design objectives have been met". Although we still have a long way to go, I believe that the question of noise has been raised quite a few notches on the designer's list of priorities. It may be a straw in the wind, but I am told that in California the drawings for a hotel or an apartment building must be signed off by an acoustical consultant before construction can start.

That first meeting also discussed landzoning ordinances based on allowable noise, another subject in which I believe advances have been made. Quite recently, I have been consulted, at the behest of CMHC, by three different developers planning housing close to railway tracks. Ten years ago, such a firm requirement for an acoustical analysis would have been unheard of, and it is a move which should be encouraged. This type of situation, however, raises one very interesting question of human rights. Does a source of noise acquire, as it were, squatters' rights by having existed for a long time? The present answer seems to be that if you are a large powerful organization like a nation-wide railway, no one can touch you, or even expect your assistance in controlling the noise you produce, however much it trespasses on other people's property. On the other hand, if you are, for example, a small manufacturer, you must control your noise output to the satisfaction of your most finicky neighbours, or risk being put out of business. There is still plenty of scope for the socially-minded acoustician!

I believe that the Canadian Acoustical Association has a very important and valuable future ahead of it, if it can convince governments at all levels that it is an accepted, reasonable and neutral representative of acoustical thought in Canada. And here I would like to emphasize "reasonable" and "neutral". If CAA takes a stand too far in advance of technical possibility, it will rapidly lose its credibility. On the other hand, if it adopts the somewhat one-sided and moralistic approach of some of our present day environmentalists, it will cut itself off from any support which otherwise will be forthcoming from the more conscientious and public spirited members of Canada's industrial world.

. . . /3

In conclusion, I hope that, in spite of my defection, you will retain me as a member of CAA. May I wish you all a very successful meeting.

Yours very sincerely,

Bob

Robert H. Tanner

P.S. My new address will be:

2105 Sheepshead Drive
Naples, Florida
33940, U.S.A.

From the President and Council of The Institute of Acoustics

47 Belgrave Square
London SW1X 8QX
Tel: 01-235 6111
Telex 918453

29th July, 1975.

Professor H.W. Jones,
President,
Canadian Acoustical Association,
Ottawa,
Ontario,
Canada K1A 0R6.

Dear Professor Jones,

I am delighted to hear from Dr. Kolmer of the acceptance of the Canadian Acoustical Association into the International Commission on Acoustics. As a Canadian myself, the pleasure is doubled for me. Please give my greetings and congratulations to your colleagues.

Yours sincerely,

W Allen

W.A. ALLEN,
President.

A note on incorporation of the C.A.A.

A study of the purposes and requirements of Federal Incorporation has been made and an outline of the findings as they apply to the Association has been prepared.

The appropriate steps for incorporation could be taken under the Canada Corporations Act by making application to the Department of Consumer and Corporate Affairs (Corporation Branch). The relevant part of the regulations is that applying to charitable organizations. Full details of the procedures can be found in the Department's Information statement number 5 and its immediately associated forms 1 and 2.

The reasons for incorporation can be summarized as:

a) Limitation of liability of the officers (directors) of the Association and therefore of the Association.
b) The acceptance by Income Tax authorities of donations for the purposes of tax rebate.
c) The creation of an ability to receive grants and enter into contracts with government(and other) agencies.

A further advantage, seen by some authorities, is the need for the creation of an identifiable structure to the Association.

First a search has to be made to show that the name of the Association has not been acquired by others, i.e., that it is therefore available to us for our exclusive use. Dr. McLaren, Dean of Law at the University of Calgary, has volunteered to conduct this search for us. Subsequently an affidavit has to be filed certifying that the name is not "objectionable" that the other statements (to be) submitted are true and making similar undertakings of a like kind. This is followed by an application in which detailed information on the by-laws of the (proposed) Corporation are submitted. Typical of the requirements is that contained in Appendix A to this note.

The cost of incorporation is $150.00 approximately.

Three people have been of great assistance in collecting the information and assisting me to put it together. They are Dough Allen and Neil Gold of the University of Windsor and John McLaren of the University of Calgary. Their assistance is gratefully acknowledged.

H.W. Jones

APPENDIX A SPECIMEN ONLY

The following shall be the By-Laws of the Corporation:

CORPORATE SEAL

1. The seal of the corporation shall be in such form ...

CONDITIONS OF MEMBERSHIP

2. Membership in the corporation shall be available to ...

3. The membership fee for an individual shall be ...

4. Any member may withdraw from the corporation by ...

5. Any member may be required to resign by ...

HEAD OFFICE

6. The head office of the corporation shall be located at ...

7. The corporation may establish such other offices ...

BOARD OF DIRECTORS

8. The property and business of the corporation shall be managed by ...

9. Directors shall be eligible for re-election at the annual meeting of members.

10. The office of director shall be automatically vacated

(a) if ...

(b) if ....

provided that if any vacancy shall occur for any reason in this paragraph contained, the directors may by resolution fill the vacancy ...

11. Meetings of the board of directors may be held at any time and place ...

12. Directors, as such, shall not receive any stated remuneration for their services.

13. A retiring director shall remain in office until ...

14. The directors may exercise all such powers of the corporation as are not by the Canada Corporations Act or by these by-laws required to be exercised by the members at general meetings.

15. Upon election at the first annual meeting of members, the board of directors then elected shall replace the provisional directors named in the letters patent of the corporation.

16. A majority of the directors shall have power to ...

17. The board of directors shall take such steps as they may deem requisite to enable the corporation to receive donations ...

OFFICERS

18. The officers of the corporation shall be ...

19. The president and vice-president shall be elected at ...

20. There may be such honorary officer or officers as the board of directors may from time to time consider advisable and ...

21. The board may appoint such agents and ...

22. The officers of the corporation shall hold office for one year and ...

DUTIES OF OFFICERS

23. The president shall be the chief executive officer of the corporation. He shall ...

24. The vice-president shall ...

25. The treasurer shall ...

26. The executive secretary shall ...

EXECUTIVE COMMITEE

27. The board of directors, whenever it consists of more than six, may ...

28. During the intervals between the meetings of the board of directors the executive committee shall ...

29. Subject to any regulations imposed from time to time by the board of directors, the executive committee shall ...

30. Meetings of the executive committee may be held ...

MEETINGS

31. The annual meeting of the members of the corporation shall be held ...

32. _________ days' prior written notice shall be given to each member of any annual ...

AMENDMENT OF BY-LAWS

33. The by-laws of the corporation may be repealed or amended ...

34. At all meetings of members ... shall be determined by at least two-thirds of the votes cast ...

35. The financial year of the corporation shall be ...

AUDITORS

36. The members shall at each annual meeting appoint an auditor to audit ...

SIGNATURE AND CERTIFICATION OF DOCUMENTS

37. Contracts, documents or any instruments in writing requiring the signature of the corporation, shall be signed by ...

RULES AND REGULATIONS

38. The board of directors may prescribe such rules and regulations not inconsistent with these by-laws relating to the management and operation of the corporation as they deem expedient, provided that ...

39. In these by-laws the singular shall include the plural and the plural the singular; the masculine shall include the feminine.

IN WITNESS WHEREOF we have ...

Applicants

SOUND PROPAGATION OUTDOORS

T.F.W. Embleton, J.E. Piercy, N. Olson
Division of Physics, National Research Council
Ottawa, Ontario K1A 0S1

Introduction

In problems of sound propagation outdoors it is usually assumed that the ground is infinitely hard, and that sound from a point source spreads in the space above the ground according to the inverse square law. At large distances molecular absorption plays a significant role. Because sound levels at ranges greater than a few hundred feet are often 10 or 15 dB less than expected, from the mechanisms so far mentioned, sound levels are often reduced empirically by this amount in prediction schemes and attributed to a "terrain effect", or some such name. Meteorological effects, caused by gradients of wind or temperature are more difficult to allow for, and are often ignored. These gradients and related instabilities also result in turbulence, which causes fluctuations in the sound levels that are quite significant, depending on sound frequency, even a few hundred feet from the source.

There is much relevant material in the technical literature that has not yet been applied to the practical problems of outdoor sound propagation; but which can be very significant for such things as the standard testing of motor vehicles or snowmobiles at ranges of 25 or 50 feet, and at longer ranges are important for the prediction of airport or highway noise at distances of a mile or two. Precise mathematical theory of wave propagation in near-horizontal directions over a surface of finite impedance goes back to Sommerfeld in 1909 and was extensively developed by about 1940 at least for electromagnetic waves. The theory was put into acoustical form about 1950 by both Ingard and Rudnick, and the latter also confirmed the main features experimentally in the laboratory. In the last twenty years there have been several experimental studies outdoors, whose principal strength has been the careful reporting of results rather than the discussion of mechanisms. The reasons most of this is not yet applied are twofold: firstly the scarcity of measurements of ground impedance particularly for the near-grazing angles of incidence that are of practical importance; and secondly the complexity caused by several phenomena that usually coexist, although sometimes one or another can predominate.

This paper briefly summarizes some of this un-applied experimental knowledge, with a view to replacing parts of the present widely used empirical prediction methods by more quantitative schemes.

Basic Theory

The equation in Fig. 1 represents the elements of the Weyl-van der Pol solution. The first term is the direct field from the source.

It embodies only the inverse square law. The second is the familiar term for a reflected wave. Its magnitude is directly determined by the plane wave reflection coefficient R_p which is dependent on the grazing angle ϕ and the impedance ratio β. When source and receiver height are small or distance is large, sin ϕ eventually becomes small compared with any β ($\beta > o$), the value of R_p approaches minus one for all impedance ratios, r_1 and r_2 become nearly equal and the first two terms cancel. This produces a shadow zone because the value of ground impedance is not infinite, and the sound field inside the shadow zone is determined mainly by the third term of the equation. This we shall call the ground wave, following the terminology of electromagnetic-wave propagation - it is how one hears the local AM radio station and we shall show that it determines how low-frequency sound propagates outdoors in most situations of practical importance.

Ground Wave

Figure 2 shows eight spectra at a progression of distances from 2 to 50 feet. Source and receiver are both on the ground. At low frequencies the signal level decreases at the rate of 6 dB per doubling of distance — as expected from the inverse square law. At high frequencies it starts at 6 dB per doubling of distance at very short range, but beyond a few feet changes to 12 dB per doubling distance. A rough calculation will show that what happens for electromagnetic waves at frequencies of a megahertz and distances of miles, will be similar for acoustic waves of a kilohertz and distances of several feet.

The spectrum is that of the ground wave, and it can be regarded as a transmission filter between source and receiver. Taking each curve in turn, in Fig. 2, and reading off the frequency at which this filter is 3 dB down from its low-frequency value, one obtains the result shown in Fig. 3. The values at distances less than 100 feet are from measurements at N.R.C. and those beyond 100 feet are from Parkin and Scholes in Britain for neutral wind and neutral or temperature lapse conditions. There is a fair degree of agreement between the measurements. The distance at which the ground wave is 3 dB down, for any given frequency, depends on the magnitude of the ground impedance and so can be used to estimate this impedance.

This procedure produces the results shown as the shaded area in Fig. 4. It gives the magnitude of the ground impedance as a function of frequency. These results are for a grass-covered surface, and Fig. 4 also shows the degree of agreement achieved between this and other techniques. To compare the results at essentially grazing incidence with those from the impedance tube (at normal incidence) and the inclined track (generally a grazing angle of 15 to 21^0) the surface has been assumed to be locally reacting.

Ground Wave plus Direct and Reflected Waves

So far the results discussed have been for both source and receiver on the ground. Being a grass-covered surface the impedance is low enough that one then measures essentially a ground wave isolated from other effects. Figure 5 indicates that as the receiver is raised from the ground to a height of 4 feet, at a range of 50 feet, the high frequency part of the spectrum is progressively recovered. Below about 500 Hz the signal comes via the ground wave, and this is the same for each receiver height. About 500 Hz the ground wave is sharply cut-off and the signal is recovered because with increasing receiver height there is no longer perfect cancellation between the direct and reflected rays, since the reflection coefficient is no longer -1. Note though that the two paths are still equal, and there are no path-length interference effects. This comes next.

Direct and Reflected Waves

Figure 6 shows the effects of interference due to a path length difference between the direct and reflected waves. The receiver is 4 feet above the surface, 50 feet from the source and the interference pattern changes with changing height of the source. These measurements were made over asphalt, and Fig. 6 illustrates the effect of path length interference in fairly pure form because the surface impedance is too high for there to be much of a ground wave. The dotted curves are theoretical predictions, and the solid curves are experimental results. The zero of sound level is the value expected from inverse square law at this range of 50 feet.

Figure 6 is relevant to the measurement of motor vehicle noise using the standard SAE test procedure because the latter uses the same surface and microphone position. The sound of the vehicle has to pass through this transmission filter between vehicle and microphone. The shape of the transmission filter depends on the source height as shown, and also on horizontal distance, not shown. As a vehicle drives by, the interference pattern moves down from very high frequencies, looks like this at the point of closest approach, and then goes back to high frequencies (as if the frequency scale is written on a piece of elastic rubber). Obviously this process is not going to aid the reliability of vehicle noise measurements and the extrapolation of noise levels to other distances.

Figure 7 summarizes many of the ideas so far illustrated. In the top graph, the transmission filters for grass and asphalt are compared for the same source and receiver heights, 1 and 4 feet respectively and 50 feet apart. The minimum at about 3 kHz over asphalt represents a half-wavelength path length difference and a hard surface having essentially zero phase change on reflection. Over grass (the solid curve) the geometry is the same, so the path length difference between direct and reflected waves is still half-a-wavelength. But the transmission filter now has a maximum at this frequency. The difference between grass and asphalt shows that for these source and receiver heights, and separations, the grass surface provides at 180^0 phase change on reflection. This phase change is responsible for the decreasing signal below 2 kHz for grass, and the dip that has its minimum near 800 Hz. This loss of signal would persist to zero frequency except that below 800 Hz the signal exists because of the ground wave. That this is so can be verified by comparing with the middle graph of Fig. 7; this shows the ground wave free of other effects.

This broad minimum in the spectrum of outdoor sounds in the region of 500 to 1000 Hz has been observed over plowed ground, vegitation, air-fields, etc., by many workers but its explanation until now has been a bit of a mystery. An interesting feature is that it doesn't change frequency significantly for different horizontal ranges, although all the minima at higher frequencies due to path length differences do change. These effects are shown in the bottom graph of Fig. 7 by comparing results for ranges of 15 and 50 feet over grass.

Shadow Region Due to Ground Impedance

In Fig. 5 for a source on the ground, at high frequencies where the ground wave was strongly attenuated the signal level increased progressively as the receiving microphone was raised. Other results indicate that at still higher microphone locations the high frequencies are completely recovered, and the spectrum then is identical with that measured very close to the source.

The relevant geometrical parameter is the sine of the grazing angle of incidence for the reflected wave. One can look upon the vertical coordinate in Fig. 8 as the height of the receiver for a source on the ground; the horizontal coordinate indicates in decibels how the sound field near the surface is reduced because the impedance of the surface is finite - under good measuring conditions the reduction can be as much as 40 dB.

The results in Fig. 8 show a considerable scatter because the horizontal ranges are now greater than in earlier figures. This leads to the next topic, which is fluctuations in measured sound levels caused by atmospheric turbulence.

Fluctuations

Near the ground there are vertical gradients of temperature and horizontal wind. Instabilities are very common and so the air is usually an uneven propagation medium, composed of turbulent eddies having a broad spectrum of sizes. As these are convected by the wind through the sound field between source and receiver, so the sound level at the receiver fluctuates.

There is now an extensive theory of propagation in turbulence to help calculate the effects of these eddies, and it has been verified by a small number of acoustic experiments. Two major questions need to be answered, however, before this theory can be applied to most practical noise problems. The first has to do with assumption in the theory. The propagation paths are usually close enough to the ground for a number of assumptions to be very questionable, for example that the turbulence is isotropic, and that the largest eddies are greater than the wavelength.

The second question concern the phenomenon of saturation, which is best illustrated by some optic measurements.

Measurements of the propagation of light in the turbulent atmosphere are much more plentiful than those of sound, see Fig. 9. Measurements of the standard deviation of the light intensity σ_X are plotted here on the vertical scale versus σ_1, the value calculated from theory for equivalent meteorological conditions, on the horizontal scale. For $2\sigma_1$ less than 1 the values on each scale roughly correspond, indicating the theory is correct. For $2\sigma_1$ greater than about 3, however, the measured values $2\sigma_X$ saturate at a value of about 1.4, independent of σ_1. Thus if you follow a light ray in the atmosphere, be it from a star or a laser, the fluctuations in intensity caused by turbulence (traditionally called twinkling!) at first increase in a predictable manner, but then saturate.

Returning now to sound, Fig. 10 summarizes experimental results at NRC in a form that can be compared with other peoples' work. One of the principal predictions of theory, that has been confirmed experimentally, is that the fluctuations of sound level have an approximately gaussian distribution after propagation through a turbulent medium. The σ that is plotted on both ordinate and abscissa is the standard deviation of the gaussian distribution of sound level, and the numbers are decibels. The solid line on the left is the unsaturated fluctuation theory for isotropic turbulence of Tatarski - it is also the theory used to obtain the calculated values of $2\sigma_{DB}$ for all the plotted experimental results, where sound measurements at low frequencies are used as a "probe" to compute according to Tatarski what the fluctuations should be for higher frequencies. The horizontal dashed line copies from Fig. 9 the experimental results from optics in the saturated region. The only theories in the saturated region are by Brownlee, shown dotted, and within the last year by Wenzel (not shown) that lies close to the dashed line. There is definite evidence from these measurements that saturation occurs in the acoustic case and at the level predicted by theory.

Figure 11 summarizes results for six days picked at random during the three summer months in Ottawa. On these six occasions the wind speed was quite low, up to about 6 mph but with gusts sometimes to 10 or 12 mph. Propagation directions covered all possibilities - up, down and cross winds. Temperature gradients near the ground at the time of measurements was always neutral of lapse, never inversion. Going down the table we have increasing horizontal range from 50 to 1000 feet, across the table is frequency from 150 to 5000 Hz. An X in the table indicates that the fluctuation of sound level of a particular frequency at a particular distance was <u>not</u> satured, and a 0 indicates that the corresponding fluctuation <u>was</u> saturated. No entry means no measurement, and several entries means that the measurements were repeated on several different days. At low frequencies or shorter distances the fluctuations are not saturated, at high frequencies and larger distances the fluctuations are always saturated. There is a transition region between these extremes where the fluctuations can be either saturated or not, depending on the weather conditions. We found that the non-saturated X's towards the lower right hand corner of the table were associated with low wind speeds, and were independent of its direction.

Penetration of the Shadow Region During an Inversion

We saw earlier that the impedance of ground was finite, and was quite small for a grass-covered, see Fig. 4. This resulted in a shadow region near the ground that under neutral atmospheric conditions could have sound levels as much as 40 dB below what was expected, see Fig. 8. This plus the inverse square law and molecular absorption is often sufficient to make even intense sources like aircraft on the ground, highways and locomotive whistles inaudible at ranges of a mile or two, during most of the daytime hours. However the ground-impedance shadow region can be penetrated by a variety of propagation mechanisms under appropriate conditions. One example of this, where we have made some progress towards a quantitative analysis, is during propagation in a temperature inversion. Inversions occur many nights and early mornings in most parts of the world.

In an inversion sound rays follow paths between source S and receiver R that are curved and concave downwards, Fig. 12 a. If the inversion is uniform, these are arcs of circles. In addition to the direct ray, here labelled path 1, and the first reflected ray called path 2, there are other multiply-reflected rays called path 3, and so on. These form an infinite series when source and receiver are both on the ground.

This picture is more complicated when the source and receiver are not on the ground. However we can still think of sound following the same rays provided the simple source S is replaced by a composite source, see Fig. 12b. This is valid provided the source is not too far above the ground. The composite source consists of the simple source S, its image I, and the impedance of the surface which determines the amplitude and phase of the reflected waves. One change is that the series of ray paths is no longer infinite, but terminates after a relatively small number of terms - how many terms depends on the source and receiver heights compared with the height of the ray path. The strength of the composite source is different for the different ray paths 1, 2, 3 etc., because ϕ is different for each path. (ϕ enters into both the ground reflection coefficient and the path length difference $2h_S\sin\phi$).

As a brief digression, the amplitude and phase lag of the plane-wave reflection coefficient for an average grass-covered surface are shown in Fig. 13 for several small values of the grazing angle that are appropriate for propagation in an inversion to a range of the order of a mile or two.

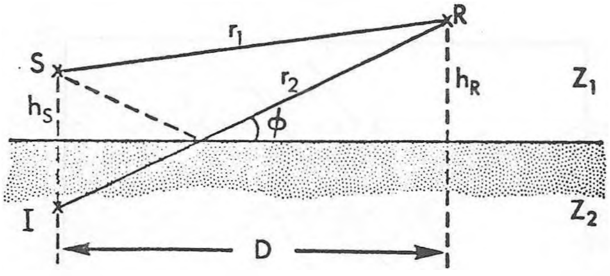
Normally at these ranges, in a neutral atmosphere, the excess attenuation beyond inverse square law and molecular absorption would be about 30 or 40 decibels. Using the theory outlined by Fig. 12, the excess attenuation for path 1 under conditions of temperature inversion are as shown in Fig. 14

for three different strengths of inversion. Between 100 and 1000 Hz the excess attenuation is between 0 and 10 decibels. The maximum correction to these curves when one adds the contribution from all other paths 2, 3, etc., is only 2.2 dB for an infinite series of paths and a reflection coefficient of unity: more typically, summing only the first 6 or 7 paths and using the reflection coefficient for a grass-covered surface for the appropriate and changing angle of incidence, given by Fig. 13, the correction is only 0.5 dB. This theory for inversions is consistent with general experience that one hears distant sources louder during an inversion, and with measurement that their sound levels rise approximately to the value calculated by inverse square law and molecular absorption alone.

Conclusion

To sum up, it is suggested that simple but accurate predictions of sound levels and spectra can be made by assuming that an excess attenuation due to finite ground impedance exists when either the source or (by reciprocity) the receiver is near the ground. Its vertical extent and magnitude increases with horizontal range and depends on the value of the impedance. This shadow region is then always penetrated by a ground wave at low frequencies, the upper-frequency limit being determined by horizontal range and ground impedance. At higher frequencies any one of several specific mechanisms can provide penetration of this shadow region: three discussed in this paper were (a) changing reflection coefficient with angle as either the source or receiver were raised above the ground, (b) path length interference when both source and receiver were above the ground, and (c) the propagation of sound under meteorological conditions of temperature inversion.

Figures



Pressure at receiver R is given by

$$\frac{p}{p_o} = \frac{e^{-ikr_1}}{r_1} + \frac{R_p e^{-ikr_2}}{r_2} + (1-R_p)F\,\frac{e^{-ikr_2}}{r_2}$$

where reflection coefficient $R_p = \frac{\sin\phi - \beta}{\sin\phi + \beta}$

and impedance ratio $\beta = Z_1/Z_2$.

R_p and β are complex and depend on angle ϕ and frequency.

Fig. 1

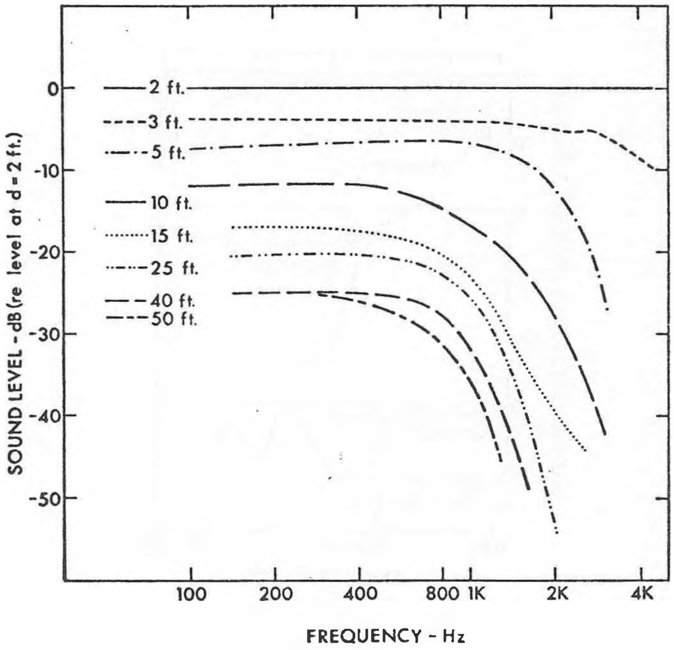


Fig. 2

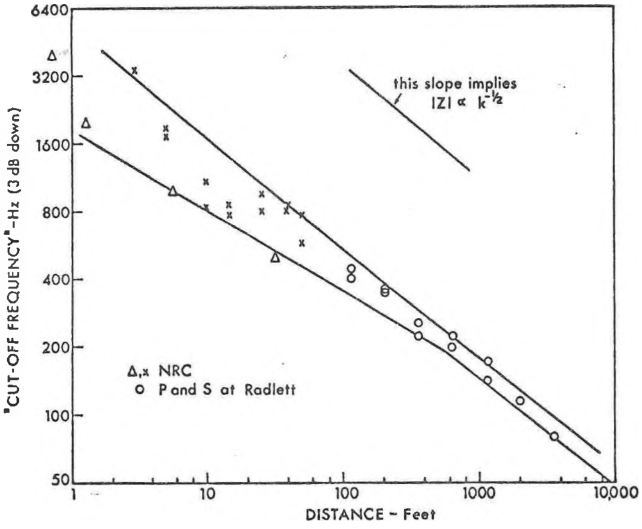
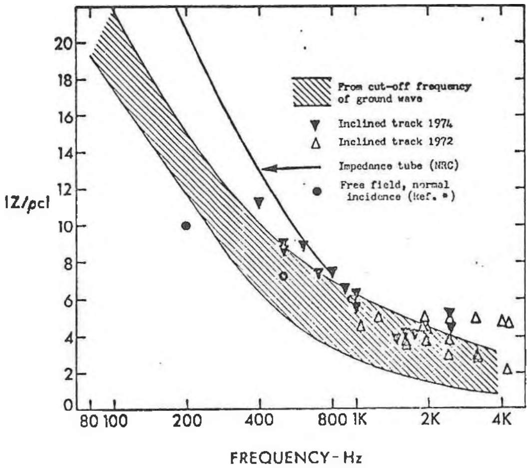


Fig. 3



*Dickinson and Doak, J. Sound Vib., 13, 309-22 (1970)

Fig. 4

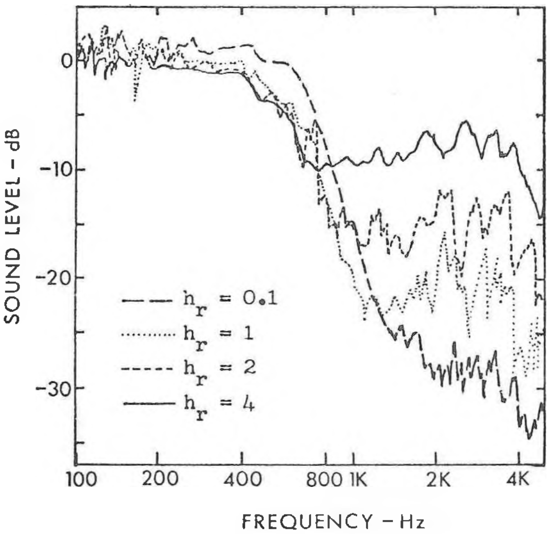


Fig. 5

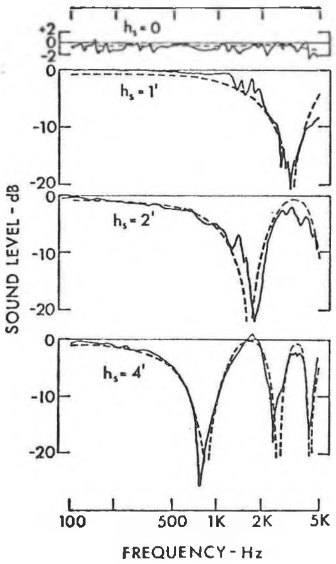


Fig. 6

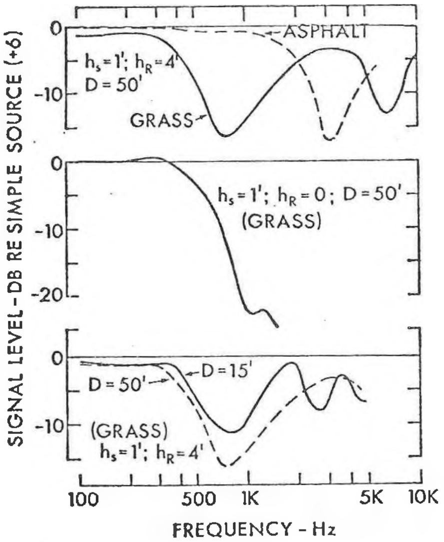


Fig. 7

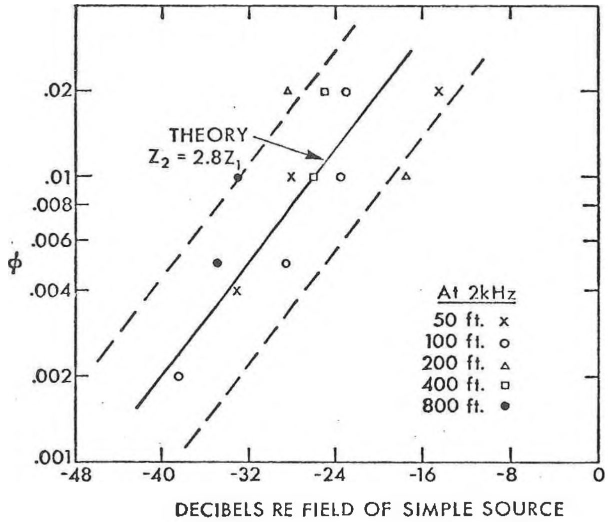


Fig. 8

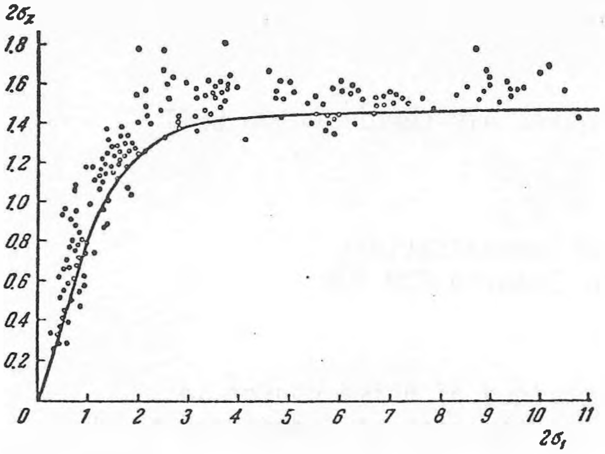


FIGURE 60. Comparison of the experimentally obtained values of the mean square of the log intensity fluctuation ($2\sigma_\chi$) with the corresponding quantity in the first approximation of the method of smooth perturbations ($2\sigma_1$).

(From V.I. Tatarskii, "Effects of the Turbulent Atmosphere on Wave Propogation" Keter Press, Jerusalem, 1971)

Fig. 9

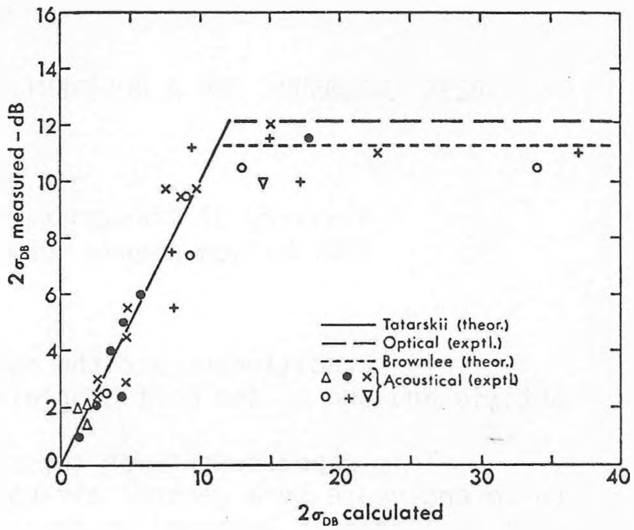


Fig. 10

Measurements on Rockcliffe Airport, Six Summer Days

H_S = 1 ft, H_r = 4 ft

Wind speed varies from < 2 to 6 mph - cross, down and upwind.

Temperature varies 16 to 31 °C.

Temperature gradient varies from neutral to 0.7 °C/m. (lapse).

Humidity moderate to saturated.

Freq.(Hz) Distance (ft)	150	300	600	1250	2500	4000	5000
50	XXX	XXXX	XXXXX	XXXXX	XXX	XXX	XX
100	XX	XXX	XXX	XXX	XXX	X	XX
150		XX	XXX	XXO		XXO	
200		XX	XX	XX	XX	O	X
250		XX	O	X		O	
400	XX	XXXX	XXXX	XXXO	XOO	OO	OO
500		XX	XO	OO		OO	
600			X	X	O		O
1000		X	X	X	O		O

X = non-saturated, O = saturated.

Fig. 11

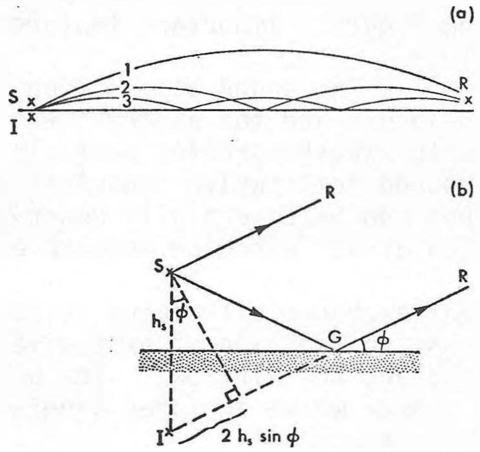


Fig. 12

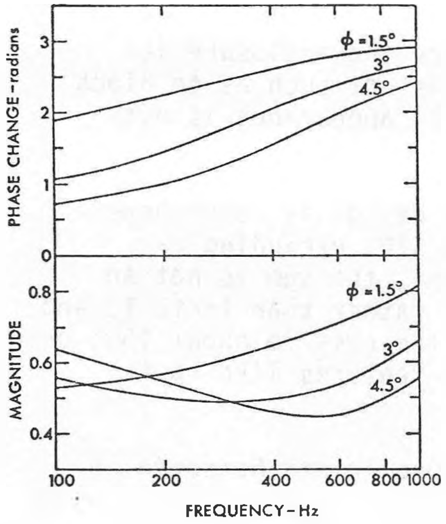


Fig. 13

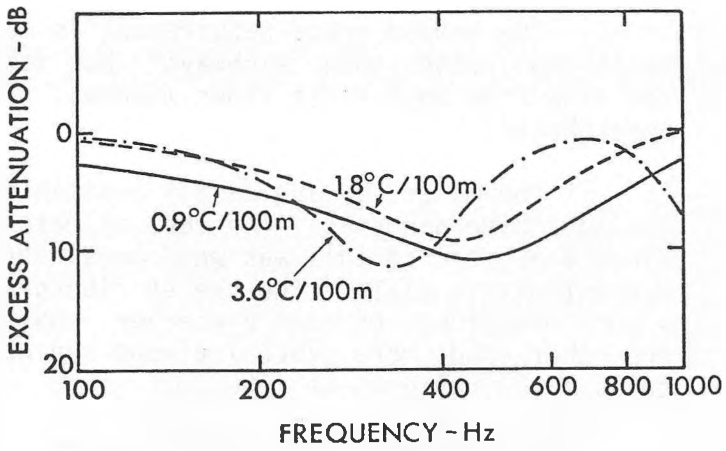


Fig. 14

A NOISE ENCLOSURE FOR A RESIDENTIAL, CENTRAL AIR-CONDITIONING UNIT

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Air conditioners are the most complained of noise source in Ontario and one of the most complained-of in the rest of Canada and the U.S.

This paper reports on the construction of a lowcost demonstration noise enclosure on a central air-conditioning condenser unit, the first step in a program intended to result in a do-it-yourself brochure for home handymen and others. The work was performed while the author was with the Ministry of the Environment, and was carried out in collaboration with L. Butko, D. Fumerton, E. Granell and R. Purchase.

The essential details of the enclosure are given in the accompanying figure. Important features are as follows.

The sound attenuation it achieved was 14 dBA. The sides of the enclosure and the absorptive silencers to achieve this were, respectively, 11/16" weatherproofed particle board and 1/2" tentest boards. Though grouped into twelve "modules" of two boards each, the absorptive arrangement can be essentially described as that of 24 sheets of 1/2" tentest with a 1/2" airspace between each.

Heat exchange efficiency is preserved by avoiding undue flow constriction from the addition of excessive backpressure, and by well-separating the cold and hot airflows. The air conditioner worked satisfactorily through a summer which included several consecutive days of 30°C (90°F) peak temperatures.

To permit maintenance of the air conditioner, and winter storage of the enclosure, the enclosure is easily removable. The roof also lifts off to allow the absorption materials to be inspected and replaced. The tentest material is cohesive enough to withstand the airflow and not clog the machine.

The ground space requirement is modest since the enclosure is built "up" rather than "sideways", but its height is not such as to block the view from most first floor windows. The overall appearance is not unaesthetic.

The materials are easily available and the design is comprehensible to a home handyman. The cost of materials was $78, excluding tax. Since a quarter of this was wood preserver and paint, the sum is not an overoptimistic claim. The use of fiberglass batts rather than tentest, and a more modest use of wood preserver, could reduce the cost to about $50; on the other hand, more expensive wood and decorative features like roof tiles could raise it to $100.

Fuller details of the enclosure are available in the Noisexpo 76 proceedings, in a paper of the same title.

AIR-CONDITIONER NOISE ENCLOSURE DESIGN CONCEPT

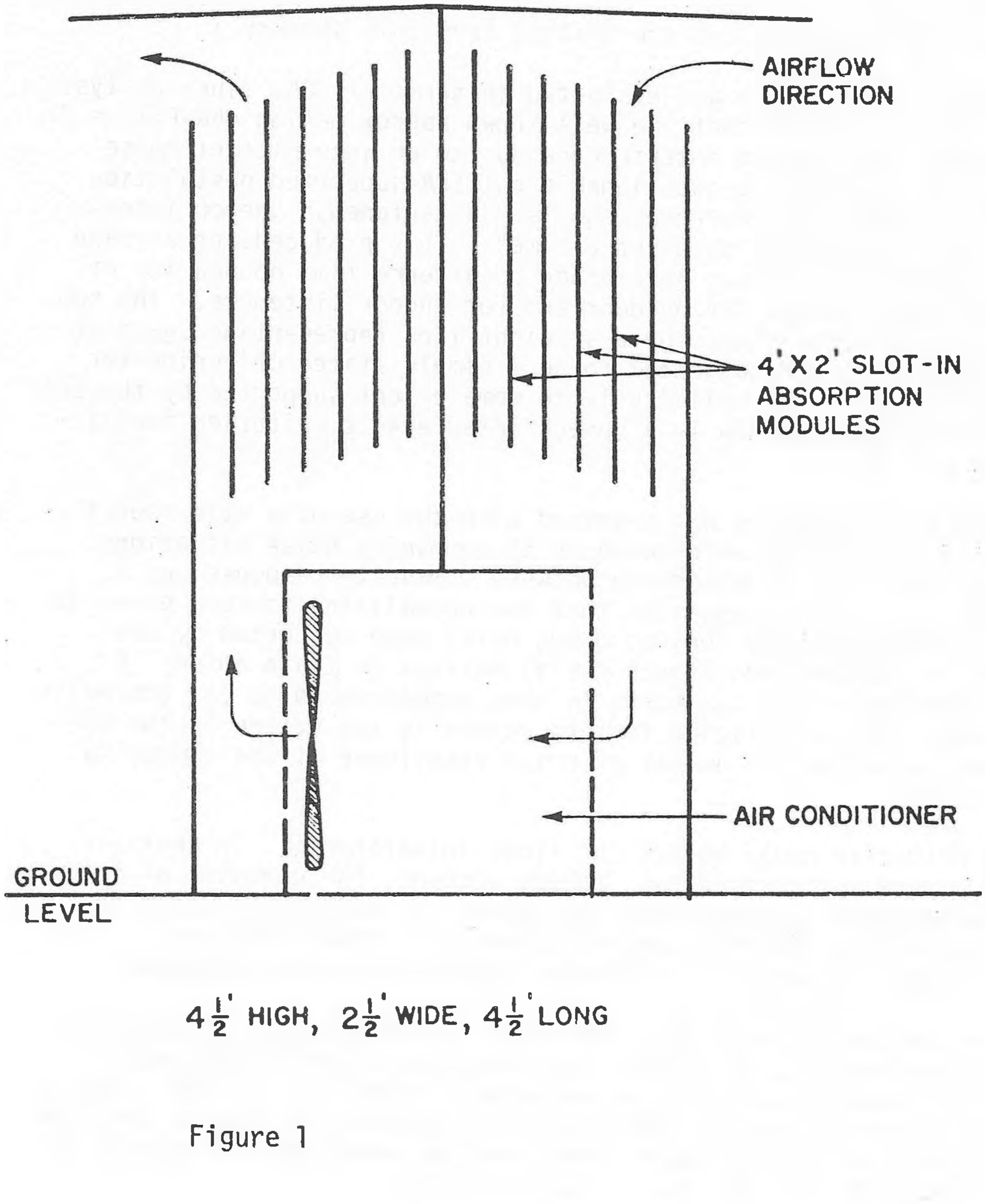

Figure 1

CRITERIA AND LIMITS FOR WAYSIDE NOISE FROM TRAINS

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There has been comparatively little study of train noise acceptability. This paper reviews state-of-the-art knowledge on the subject, and suggests criteria in terms of L_{eq}. (Existing limits were also reviewed in the presented paper, but are omitted from this summary.)

Speech interference was evaluated in terms of dBA, since analysis of several spectra showed that the well-known approximation dBA-PSIL = 7 was applicable. The speech interference due to an intermittent noise was examined by accepting a questionable but EPA-supported postulation that "overall speech interference" equals "instantaneous speech interference" times "percentage occurrence time". This produced, on a graph of outdoor sound level versus percentage occurrence time boundaries of speech interference level for outdoor and for indoor listeners. The two boundaries can be approximated by a straight line representing L_{eq} = 60 dBA, which was therefore suggested to be a simply-stated criterion for speech interference. Its validity is to some extent supported by the EPA conclusion that L_{eq} = 65 dBA is a speech interference criterion for aircraft noise.

Community annoyance was examined with the use of a Wyle report for EPA whose conclusions were based on 55 community noise situations and take the form of a relationship between community response and a "normalized" L_{dn}. It is suggested that the normalizing factors given in that report (which are too long to quote here) were supported by the conclusions of Japanese and French social surveys on train noise. A criterion translated into L_{eq} terms is then suggested to be L_{eq} (normalized) = 55 dBA. The normalizing factors relate to the nature of the adjoining land usage and the amount of prior experience of the community with train noise.

No criterion could be set for sleep interference. An analysis of hearing hazard was carried out, taking account, for example, of the likely indoor/outdoor exposure and the amount of time people might be exposed; the various criteria suggested were all higher, but not enormously higher, than those for speech interference and annoyance.

The conclusions were that the speech interference criterion is an outdoors-measured L_{eq} of 60 dBA, and that the community annoyance criterion is a normalized L_{eq}, also measured outdoors, of 55 dBA. The normalizing factors depend on the specific situation, and may be obtained in the full version of this paper provisionally scheduled for Journal of Sound and Vibration, Vol 47, No. 1, July 8, 1976.

AN INVESTIGATION OF THE SUBJECTIVE RESPONSE OF OCCUPANTS TO INTERIOR CAR NOISE

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INTRODUCTION

The work described in this paper represents a continuation of a project initiated by the Vehicle Research Group of Ford Motor Company, England, the long term objective of which was to arrive at a means of predicting subjective response to interior car noise from objective measurements[1].*

The work conducted by Ford Motor Company involved the development of a high quality recording and replay system to allow subjective testing to be conducted in the laboratory, rather than in the field, and the subsequent proving of the experimental procedure by means of the comparison of results from subjective tests carried out in both environments. Attempted replication by the author, using the same tape recordings, showed the Ford results to be reasonably reproducible, although slight modification to the test procedure was found to be desirable. In these proving tests, recordings made inside five different vehicles were used, the frequency content and sound levels of each being different, thus considerable difficulty was experienced in attempting to use these results to isolate the effects of frequency and sound level upon subjective response.

Further subjective tests using controlled levels and spectrum shaping of the interior noise of a selected vehicle were therefore conducted. The results of these tests suggested that standard indices, such as dB(A), dB(B), dB(LIN) and PNdB, were not satisfactory for the prediction of subjective response of occupants. The results also suggested that, provided extremes were not encountered, interior car noise in which low frequencies predominated was preferable to that in which high frequencies were predominant, and that a weighting scale similar to the A-scale, but not attenuating the very low frequencies so much and attenuating the medium low frequencies more, may be applicable for rating 'annoyance' of interior car noise.

It was subsequently found that such a curve was recently proposed by Spring[2], based upon considerable subjective experimentation, and that the objective measures obtained by weighting the present author's spectrum shaped recordings according to Spring's curve were in complete rank order agreement with the corresponding subjective results.

RECORDING/REPLAY SYSTEM

The recording system, developed by Ford Motor Company, comprised a high quality, two channel tape recorder, together with a weighting device to improve the dynamic range over the spectrum of the interior noise, recording through 1/2 inch condenser microphones located in the ears of a dummy head. The dummy head was in turn located in the position of a typical passenger's head in the vehicle under consideration. Replay was through high quality electrostatic

+ The work described in this article was carried out by the author whilst on sabbatical leave at the Institute of Sound and Vibration Research, Southampton University, England.

* Numbers in brackets designate References at the end of paper.

headphones, with account being taken of the effect of the frequency weighting device.

CONDUCT OF SUBJECTIVE EXPERIMENTS

The subjective tests conducted in the laboratory involved the use of tape recordings comprising 25 eight second samples of interior car noise, each sample separated from the next by a period of approximately four seconds. The 25 samples were made up of noise, recorded as described, from each of five different vehicles (or, in the case of the spectrum shaped tapes, five different spectra). The last 21 samples were arranged in a balanced order such that each of the five different noises was twice adjacent to each of the other noises, once preceeding and once succeeding the other noise. The last four samples were repeated at the beginning of the tape and were treated as an adjustment period for the judges (that is, the first four decisions made by each judge were discarded during analysis of the results).

The judges, all of whom were volunteers from the post-graduate students and academic, research and secretarial staff of the Institute, were fitted carefully with the headphones and seated comfortably in a room shielded from exterior noise and remote from the remainder of the playback system.

In order to gain experience and to establish the reliability of the approach to be used, the author initially conducted a series of tests aimed at replicating the results obtained by Ford Motor Company in proving their in-laboratory arrangement to be representative of the in-car situation. The Ford work involved the use of five vehicles (1. Ford Cortina 2.0L - THK500L, 2. Renault 4L, 3. Opel Rekord, 4. Vauxhaull Victor, 5. Ford Cortina 2.0L - XVX 395L) their in-car tests being conducted in these vehicles whilst being driven at 30 mph in third gear over a special tar and chip surface. Tape recordings were made in the same vehicles under the same conditions and a master tape prepared, for in-laboratory subjective tests, comprising 25 samples of the five recorded noises in the order 2, 3, 4, 5, 1, 3, 5, 2, 4, 3, 2, 1, 5, 3, 1, 4, 2, 5, 4, 1, 2, 3, 4, 5, 1. The replication tests used this original five car tape and the same playback system as that used by Ford.

In all, four tests were conducted in the replication investigation, there being minor variations in each, and at least twelve judges participated in each test. The first was identical to that used by Ford and involved each judge listening to the playback of the master tape and making two judgements on each sample of noise, as indicated by the following questions:

(1) Which noise causes you less annoyance - the one you have just heard or the previous one?

(2) What rating would you give the noise you have just heard using the 1 to 10 scale given? (The scale ranged from 1. Exceptionally poor to 10. Excellent).

The judges were asked to record their replies on 25 prepared answer sheets, each of which was turned face down upon completion to avoid subsequent reference. In this way, each judge gave a numerical rating for the annoyance of each noise and, simultaneously, underwent a paired comparison test.

A second set of judges were subjected to the same test but, in order to assist the judges to imagine themselves being seated in a vehicle, an introductory tape was provided, comprising a recording (made with the same dummy head system) of a vehicle accelerating from rest to 70 mph and decelerating back to standstill.

The data from these two tests were processed using a computer program which, briefly, calculated the mean and median scores for each vehicle from the numerical ratings assigned by the judges and, from the scores, computed the rank order of the noises in terms of annoyance. In addition, a rank order was derived from the paired comparison 'table of agreements'. The mathematical basis for the analyses performed by the program may be found in Moroney[3] or Kendall[4]. Application of significance tests described by Kendall[4] showed that the probability of any of the sets of subjective results occurring from random decisions by the judges was less than 1% (the limit of the tables provided), which was also the situation for all subsequent tests conducted and reported in this article.

Examination of the processed results showed that the rank orders determined from the numerical ratings were inconsistent with each other and with the Ford in-car and laboratory tests. The paired comparison results were consistent with each other but only partly with the Ford and objective measurement results. It was recognized that replication of the Ford results had not been achieved and that further tests were necessary. In view of the general inconsistency of the numerical rating results and of comments from a number of judges - to the effect that there was insufficient time allowed for the performance of both rating and comparison tasks, the former being the more difficult to complete reliably - it was decided that all subsequent tests should involve only paired comparisons.

At this stage it was discovered that the noises presented to the judges during these first two tests had been about 4dB down on their true levels. On an annoyance basis, this should not have significantly affected the rank ordering but the inclusion of a test to check this was prompted. It was thus decided to run two further attempted replication tests, using paired comparisons only, the first having sound levels as in the previous two tests and the second having levels 4dB up (that is, as recorded), the introductory acceleration/deceleration tape being retained in both cases. The rank orders obtained from these two tests were totally consistent with each other and correlated well with the in-car and laboratory tests conducted by Ford, thus it was considered that the subjective approach adopted was satisfactory for the conduct of such tests. Comparison of both the Ford subjective rankings and those from these latter two tests with objective measurements made by Ford suggested that conventional measures such as dB(A), dB(B) and PNdB would to some extent, though not completely, allow rank order to be predicted.

In an attempt to learn more about the annoyance of interior car noise, narrow band frequency analyses were performed on the five vehicle noises recorded but this analysis proved to be of little value, since the variation in the spectra together with the variation in sound pressure levels caused interpretation of the results to be very difficult.

SPECTRUM SHAPED TESTS

In an attempt to reduce the number of variables, two new test tapes were prepared, one for which all the sample noises had the same sound level on the linear scale (used for Test A) and the other for which all samples had the same A-weighted sound level (used for Test B). The tapes took the same form as the Ford five car test tape but, this time, the five different samples were all prepared from one channel of one sample of one of the vehicle noises on the Ford tapes. The vehicle chosen (number 2) was that having the widest spectrum of noise and, incidentally, the one consistently adjudged the most objectionable. The five different samples were obtained by shaping the spectra of the single selected channel using a B & K one-third octave spectrum shaper and re-recording on both tracks of a stereo tape, adjusting the levels as required.

The unmodified spectrum of the base sample and the five frequency 'windows' used are shown in Figure 1, the numbers 1 to 5 being subsequently adopted as identifiers for the resulting shaped samples.

Twenty judges, most of whom had been involved in the earlier tests, were persuaded to assist in the conduct of Tests A and B and the tests were run consecutively, each judge undergoing both tests at one sitting. In order to establish whether the order in which the tests were taken affected the result and, if so, to minimize such an effect, ten judges took the tests in order A, B and ten in order B, A. The order of presentation of the samples was 1, 3, 2, 5, 4, 1, 2, 4, 3, 5, 2, 3, 1, 4, 2, 1, 5, 3, 4, 5, 1, 3, 2, 5, 4 and no introductory tape was provided.

The results of Tests A and B are summarised in Tables 1 and 2 respectively, where objective measurements derived from the tapes are also given. Table 1 shows complete correlation to exist between the rank order obtained from the subjective test and that which would be predicted using the objective measures dB(A), dB(B) or PNdB for the noise samples of Test A. This is to be expected since, in order to keep all linear levels the same, it was necessary to considerably attenuate the signals having high low-frequency content, thus the apparent loudnesses were significantly affected. The judgment of annoyance thus became based essentially upon loudness alone. It is evident that the order of presentation of the tests did not affect the decisions of the judges for Test A.

The results for Test B, Table 2, are rather more interesting. It appears possible that the order of presentation of the tests did affect the subjective ranking in this test, in as much as the order of noises 1 and 5 are reversed depending upon whether Test A or B preceeded the other. Examination of the Tables of Agreement and Tables of Preference from which these results came suggested that noises 1 and 5 were ranked quite differently and that this discrepancy was not likely to be due solely to inter-judge variations. The combined result showed noises 1 and 5 to be ranked about equal last. With respect to the objective measurements, the PNdB values calculated from the tape were all between 82 and 83, thus it was not considered reasonable to extract a rank order from these results. The order suggested by the dB(B) and dB(lin) values does not agree at all with the subjective ranking and are thus considered to be unsatisfactory for response prediction.

It should be noted that the noises 1 and 5 were chosen so that each was just on the limit of sounding like the interior noise of a motor vehicle, and consequently would not be likely to be encountered in practice under the supposed conditions of the test. (Noise 1 would be approached by driving over loose chippings and Noise 5 by driving at speed with one or more windows open.) Noises 2, 3 and 4, however, were considered to be quite representative of noises possible under the test conditions. These three were ranked quite consistently by the judges in the order shown in the table and consistently as more acceptable than noises 1 and 5. This would suggest that there is a preference for low frequency noise, provided that 'buffeting' is not experienced.

The fact that a fairly consistent rank ordering was obtained even with dB(A) and, incidentally, PNdB held constant suggests that these two measures are not ideal for subjective response prediction but are considerably better than dB(B) or dB(lin), which gave essentially inverse rank ordering.

CONCLUDING REMARKS

From the meagre results obtained thus far, it did not seem reasonable to attempt to quantify suggestions but, since it appeared that if extremes were not reached (such as in Noise 5) low frequency noise was more acceptable than high, then a weighting scale similar to the A-scale but not attenuating the very low frequencies so much (for example up to about 50 Hz) and attenuating medium low frequencies more may be applicable for rating 'annoyance' of interior car noise.

Subsequent to the completion of this work and arriving at the above conclusion, it was found that such a curve had been proposed by Spring[2] - referred to as the "Computer Tested Car" curve - arrived at by optimizing the frequency weighting used in objective measures of interior car noise used in extensive subjective experiments. Using this curve, the characteristics of which are presented in Table 3, the values tabulated under dB(CTC) in Tables 1 and 2 were obtained from the tapes of Tests A and B. Virtually complete agreement is seen to exist between the subjective and objectively predicted rank orders, suggesting that employment of the CTC weighting curve would give a good indication of the likely subjective response of occupants to interior noise of European cars. The author hopes to conduct a similar study involving typical North American cars.

ACKNOWLEDGEMENTS

The author would like to thank the Vehicle Research Group, Ford Motor Company, for their cooperation and assistance in the conduct of this project and to thank the Institute of Sound and Vibration Research for the privilege of spending a sabbatical year at the Institute, and for the use of their facilities. The assistance of the numerous judges is also gratefully acknowledged, and particular thanks are due to M. Oldman, Lecturer at the Institute, for his advice and encouragement.

REFERENCES

1. A.V. PHILLIPS and D. CHRISTIE, "Techniques of Vehicle Interior Noise Evaluation", Eighth International Congress on Acoustics, London, 1974, p.29.

2. H.W. SPRING, "Characterization of Acoustic Comfort in Motor Vehicles", Interkeller Gap, 1975.

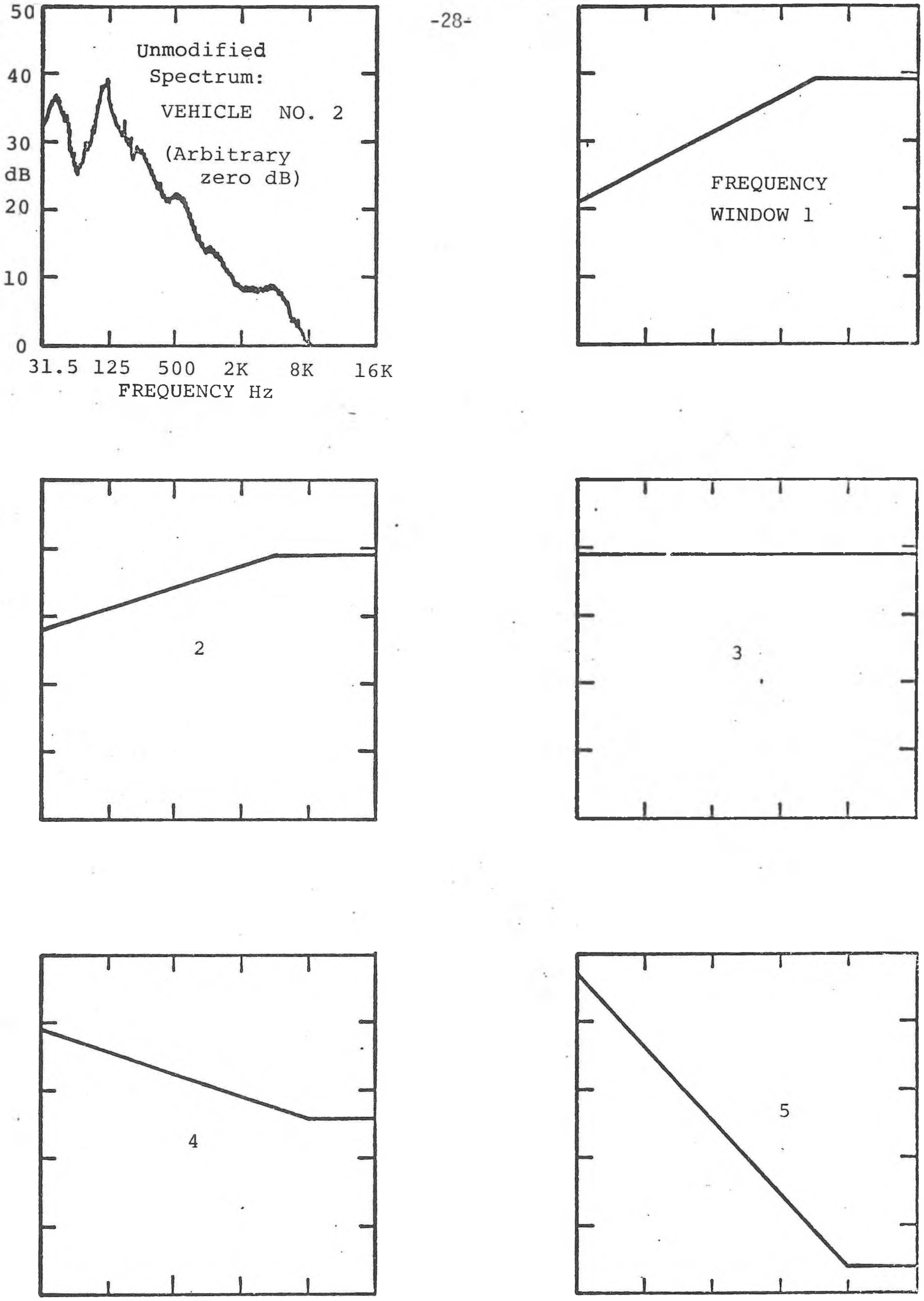

FIGURE 1 SPECTRUM SHAPED SAMPLES

Table 1 Test A - Five Spectra, All Linear Levels Equal

	Order of Test Presentation		All Judges	Objective Measurements and Predicted Rank Order				
	A:B	B:A		dB (A)	dB (B)	dB(lin)	PN dB	dB(CTC)
Least ↑	5	5	5	(59) 5	(73) 5	82	(72) 5	(61) 5
	4	4	.4	(64) 4	(75) 4	82	(78) 4	(64) 4
Annoyance	3	3	3	(68) 3	(76) 3	82	(82) 3	(67) 3
	2	2	2	(71) 2	(78) 2	82	(85) 2	(71) 2
Most ↓	1	1	1	(72) 1	(78) 1	82	(86.5) 1	(74) 1
Coef. of Agr.$^{\underline{t}}$	0.519	0.533	0.533					
Deg. of Freed.	11.7		10.8					

Table 2 Test B - Five Spectra, All A-Weighted Levels Equal

	Order of Test Presentation		All Judges	Objective Measurements and Predicted Rank Order				
	A:B	B:A		dB (A)	dB (B)	dB(lin)	PN dB	dB(CTC)
Least ↑	4	4	4	68	(73) 1	(77) 1		(67.4) 4
	3	3	3	68	(76) 2	(80) 2	82	(67.8) 3
Annoyance	2	2	2	68	(77) 3	(83) 3	to	(68.6) 2
	5	1	5	68	(78) 4	(88) 4	83	(69.8) 1
Most ↓	1	5	1	68	(81) 5	(93) 5		(69.8) 5
Coef. of Agr.$^{\underline{t}}$	0.172	0.126	0.155					
Deg. of Freed.	11.7		10.8					

Table 3 Characteristics of the C.T.C. Curve[2]

Frequency (Hz)	25	31	40	50	63	80	100	125	160	200	250	315	400	500
Weighting (dB)	-31.5	-30	-28	-27.5	-25	-23	-20	-17	-15	-13	-11	-10	-9	-8
Frequency (Hz)	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	
Weighting (dB)	-6	-4	0	+4	+6	+6	-6.5	+6	+7	+6	+6	+4	+2	

NANOSECOND ACOUSTIC STRAIN PULSES FROM CdS PHONON MASERS

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Observations of nanosecond strain pulses generated by a mode-locked CdS phonon maser are reported. Peak strains exceeding 5×10^{-5} have been measured. An analogy is drawn between the observed mode-locked operation and a repetitive pulse generator.

In the presence of a D.C. electric field, acoustic cavities, defined by polishing the faces of CdS single crystals accurately flat and parallel, form high Q resonant structures which are strongly analogous to lasers. Maines and Paige[1] reported that CdS phonon maser (PM), operated under certain experimental conditions, exhibited sharp current spiking. The frequency display of the current consisted of a harmonic series having amplitudes constant in time, and a frequency spacing equal to the reciprocal of the round trip transit time of the crystal cavity. From these observations Maines and Paige[1] concluded that the PM was operating in a mode-locked regime, and, by analogy with mode-locked optical lasers, predicted that the acoustic output should consist of narrow, high strain pulses. The validity of this prediction is however, far from obvious, since the mode-locked regime is strongly nonlinear so that there is no one-to-one correspondence between the frequency spectrum of the acoustoelectric current and that of the acoustic fields. When the piezoelectric potential associated with these fields is much larger than the thermal energy, a sinusoidal acoustic wave can result in a strongly nonsinusoidal electron distribution[2]. The strong D.C. current saturation observed in the mode-locked regime indicates that the electrons are constrained to move with the velocity of sound and are thus trapped in the potential wells associated with the acoustic wave. This establishes the strongly nonlinear nature of the mode-locked regime[2], and suggests that the prediction of Maines and Page[1] should be verified by direct observation of the acoustic fields.

By acoustically coupling a CdS PM to a passive cavity, we have directly observed nanosecond acoustic strain pulses using optical filtering techniques. Our experimental set-up is shown schematically in Fig. 1. The CdS crystal was oriented so that the b-axis was perpendicular to the polished cavity surfaces. For this orientation the active acoustic modes consist of shear waves whose K-vectors lie along the b-axis.

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The R.F. current signal from the active crystal could be displayed either in the frequency regime, by means of a spectrum analyzer, or in the time regime by means of a sampling oscilloscope. The active crystal was coupled to a passive fused quartz cavity by means of a high quality acoustic bond[3]. Since the two materials have nearly the same acoustic impedance for the chosen CdS orientation, the double cavity modes are nearly harmonic[4]. The passive cavity provides a convenient means of examining the acoustic field of the PM, since high power laser light may be passed through it. Such a high intensity probe may not be used in the active cavity since the large photocurrents produced would disrupt or prevent oscillation.

For our experimental configuration (see Fig. 1) the focal plane diffraction pattern consisted of a vertical row of 30-40 spots symmetrically arranged about the zero order or undiffracted beam. A focal plane spatial filter was used to remove certain diffracted orders before the optical signal was imaged on a 25 micron slit coupled to a photomultiplier. The photomultiplier could be driven transverse to the optical axis, as indicated in Fig. 1, in order to investigate the spatial variation of light intensity in the image plane. The nature of the spatial filter depended upon the particular experiment performed.

Acoustic strains introduce local variations in refractive index, thus presenting a phase grating to the incident light. The relation between the local strain and refractive index variation is linear[5], so that the phase variation profile of the acoustic grating directly yields the strain profile. If we describe the phase variation of the acoustic cavity by $\Phi(x,t)$, the near field light amplitude, just after passing through the cavity, is given by

$$A(x,z,t) = e^{i\phi(z,t)}\, e^{i\Phi(x,t)} \approx e^{i\phi(z,t)}\, [1 + i\Phi(x,t)] \qquad [1]$$

where $\phi(z,t) = \omega t - kz$ is the phase of a unit amplitude plane light wave incident on the passive cavity. For the strains we have observed $\Phi(x,t)$ has a maximum value of ~ 0.01 radians which allows one to expand the second exponential in Eq. [1] as shown. If the optical system following the acoustical phase grating is distortion free, then Eq. [1] also applies to the image plane, except for a spatial magnification factor. Since the acoustic cavity alters only the phase of the incident light, the strain field is not directly visible in the image plane. However, removing the zero order or undiffracted beam (represented by the factor 1 in $(1 + i\Phi)$, see Eq. [1]) in the focal plane we obtain the dark field image[6]. In this case phase variations in the object plane produce intensity variations in the image plane. The first order dark field image is

$$I_{DF}(x,t) \simeq \Phi^2(x,t) \qquad [2]$$

In mode-locked operation the acoustic output of the PM consists of many harmonically related frequency components. The optical phase variation in the passive cavity will then be due to a superposition of an incident wave train coupled from the PM, and a wave train spatially reflected from the free surface $(x = L)$ of the passive cavity. Assuming no losses, the resulting phase function may be written in the form

$$\Phi(x,t) = \sum_{n=1}^{N} V_n \{ \sin[nKx-n\Omega t+\alpha_n] + \sin [nK(x-2L)+n\Omega t-\alpha_n]\} \qquad [3]$$

where N is the number of active modes and Ω,K are the frequency and wave vector of the fundamental component. The coefficients V_n are Raman-Nath parameters and are proportional to the corresponding strain amplitudes[5]. The set of phases α_n determine the exact profile of the strain pulses. If Eq. [3] is substituted into Eq. [2], the resulting expression may be cast into a form where the various frequency components may be extracted. The D.C. term may then be shown to be

$$I_0 = \sum_{n=1}^{N} V_n^2 [1 - \cos 2nK(x-L)] \qquad [4]$$

Fig. 2(b) shows the experimental image plane intensity variation of the D.C. term for mode-locked PM operation. The corresponding time and frequency displays of the RF current signal are given in Fig. 3. The reciprocal round trip transit time for this particular double cavity corresponded to a fundamental frequency of 325 KHz. By changing voltage and current conditions for the PM, it was possible to vary the frequency separation from this fundamental to about 60 MHz. The separation of the frequency components in Fig. 3(a) is about 11.71 MHz, corresponding to the 36th harmonic of the double cavity fundamental frequency.

The pulse width from Fig. 2(b) is about 23 microns (see caption of Fig. 2 for effective resolution) which corresponds to about 6 nanoseconds for the velocity of sound in fused quartz. Peak strains in excess of 5×10^{-5} have been inferred from typical diffraction intensities. By spatially filtering the diffracted spots corresponding to different frequency orders, we could examine each component of the sum in Eq. [4] individually. In Fig. 2(c) and 2(d), the profiles of the components for n=1 and n=2 are given. If we choose a reference at a maximum of the n=1 component, the cosine components for n odd are found to be (nearly) π out of phase with those for n even, as is predicted by Eq. [4].

While the intensity profile of the D.C. term tells us the strain pulse width, it contains no information about the exact form of the strain profile, since the phases α_n are not present in Eq. [4]. However, our apparatus also allows us to examine the spatial intensity variation of each A.C. term in the image plane. By a combination of spatial and temporal filtering of the optical signal all the phases α_n can, in principle at least, be determined. Preliminary experiments indicate that this determination is practical at least for smaller values of n, where the diffracted intensities are relatively large.

It is useful to make a comparison between the PM operated in a mode-locked regime and a regenerative pulse generator (RPG). It is well known that a feedback loop containing an amplifier, filter, delay line and a saturable absorber behaves as a RPG[7]. In the PM, most of the required elements may be readily identified. The piezoelectric coupling of the acoustic field to drifting electrons provides an amplifying mechanism, a combination of the cavity resonances and the gain profile of the PM constitute the filter, and the round trip transit time of the resonant cavity serves as the time delay. In the case of an optical laser, which also contains these three basic elements, the saturable absorber must be added to the system for it to function as a RPG[8]. For the PM, however, the saturable absorber is an implicit part of the oscillator itself. Theoretical expressions for acoustic gain as a function of strain amplitude have been derived for piezoelectric semiconductors by Butcher and Ogg[9,10]. Based on their results for a simple sinusoidal strain[9], we have obtained an expression for round trip gain in a PM, including lattice and end losses, and have computed theoretical curves for gain vs strain amplitude at the frequency of maximum gain. Such curves indicate that, under typical operating conditions, the net round trip gain increases with strain amplitude. One is thus able to draw a direct analogy between the mode-locked PM and its optical counterpart, the mode-locked laser. For the laser and RPG's in general, the pulse rate is usually equal to the reciprocal of the round trip transit time or loop delay, i.e. there is only one pulse in the system at a time. In our double cavity configuration, the repetition rate was usually some harmonic of the cavity fundamental frequency. An additional distinction may be seen if one considers the product of center frequency and pulse width. A laser pulse having a center frequency of 5×10^{14} Hz (λ = 6000 Å) and a width of 10^{-12} sec contains 500 optical cycles. On the other hand, our PM has a center frequency of about 10^{8} Hz and a pulse width of 6×10^{-9} sec. In both cases the center frequency corresponds to the frequency of maximum gain and the pulse width corresponds to the reciprocal of the bandwidth over which net gain exists. In contrast to an optical laser, the PM produces "D.C." pulses which only contain about 1/2 cycle of the carrier. Such pulses should prove to be of interest in a variety of ultrasonic and acousto-optic applications.

The support of the National Research Council and the Defence Research Board of Canada is gratefully acknowledged.

Figure Captions

Fig. 1 Configuration for optical experiment. The PM c-axis was perpendicular to the incident light which was provided by an Argon-Ion laser.

Fig. 2 Intensity variation for D.C. term. On the left are photographs of the image plane optical field. The traces on the right give intensity profiles. Lengths indicated refer to the object plane. The corresponding slit width (resolution) in the object plane is about 1.5 microns. Shown are (a) the bright field image of the double cavity; and dark field images corresponding to (b) all frequency components, (c) n=1 component and (d) n=2 component.

Fig. 3 R.F. current signal: (a) frequency display, 20 MHz/div, (b) time display, 10 nanoseconds/div.

References

1. J.D. Maines and E.G.S. Paige, Sol. State Comm. 8, 421 (1970).

2. V.L. Gurevich, Soviet Physics-Semiconductors, 2, 1299 (1969).

3. E.K. Sittig and H.D. Cook, Proc. I.E.E.E. L. 56, 1375 (1968).

4. R.C. Hughes and R.R. Haering, to be published.

5. J. Vrba and R.R. Haering, Can. J. Phys. 51, 1341 (1973).

6. M. Born and E. Wolf, Principles of Optics, Pergamon Press (1959).

7. C.C. Cutler, Proc. I.R.E. 43, 140 (1955).

8. A.J. DeMaria, W.H. Glenn, M.J. Brienza and M.E. Mack, Proc. I.E.E.E. 57, 2 (1969).

9. P.N. Butcher and N.R. Ogg, J. Phys. D. 1, 1271 (1968).

10. P.N. Butcher and N.R. Ogg, J. Phys. D. 2, 333 (1969).

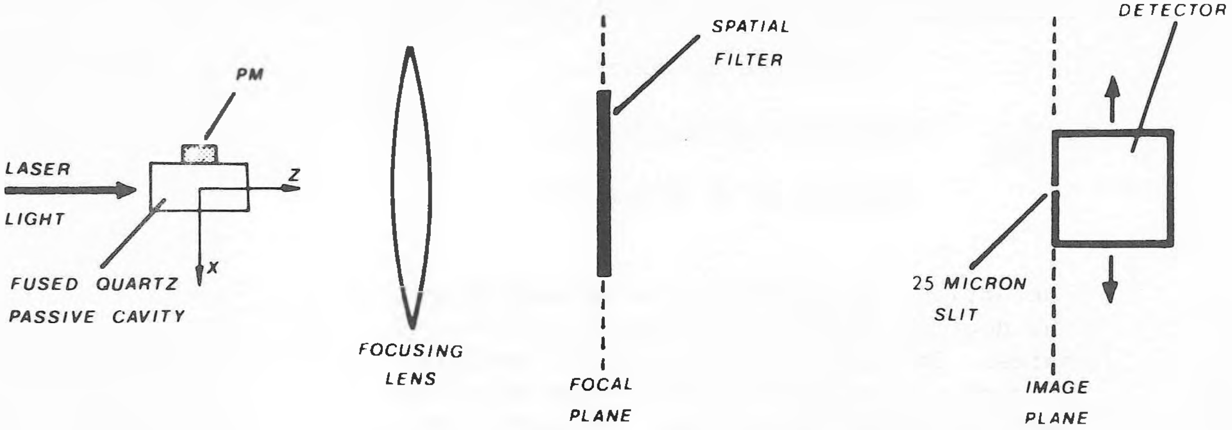


Fig. 1

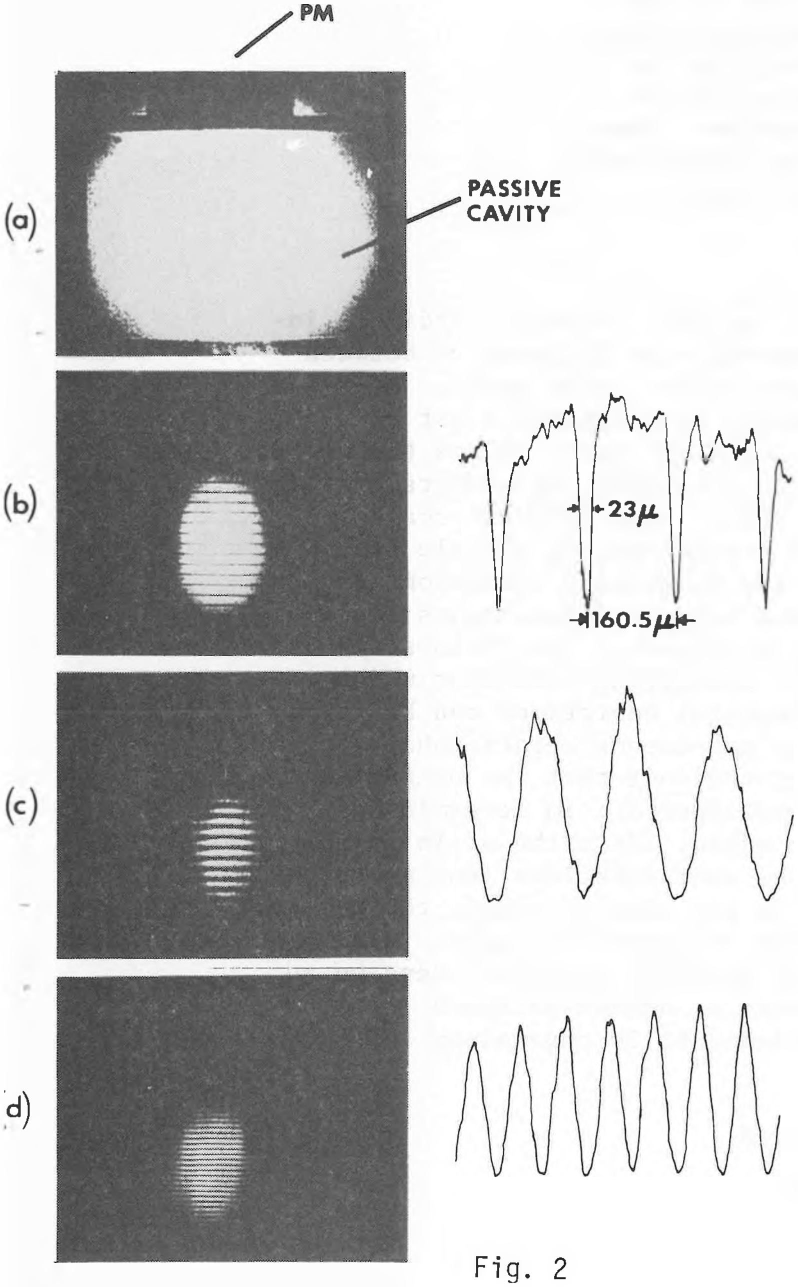
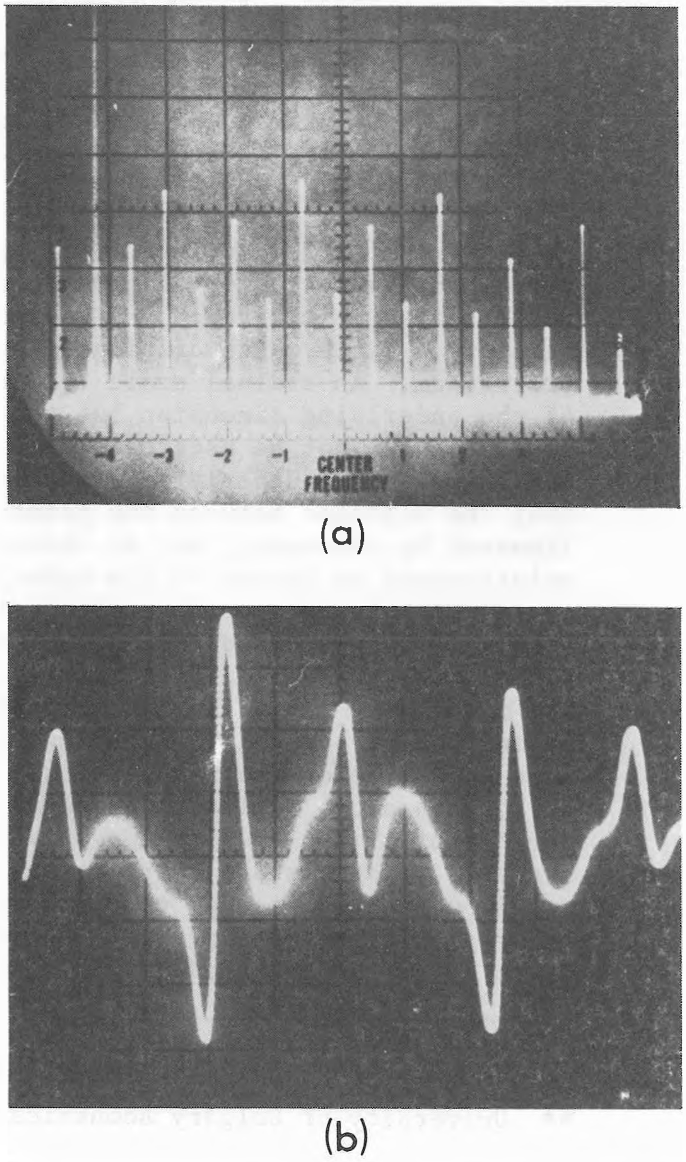


Fig. 2



(a)

(b)

Fig. 3

AMPLITUDE AND LOUDNESS: A SCALING PROBLEM

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The article discusses the relationship of the decibel scale to good scaling procedures. It points out the initial utility of such a scale for problems such as power loss in transmission lines. However, the point is made that when the decibel is used for purposes related to such variables as hearing loss and annoyance the scale properties of the decibel change due to the nature of the underlying variable. Certain problems exist when the decibel is used without taking into account the nature of these changes. Some implications of the power law relationship between sound and psychophysiological variables are discussed.

Stevens (1951) defined four types of scales: nominal, ordinal, interval and ratio scale. Although in many ways the delineation between these scales is arbitrary, he was making a rather valid point. A nominal scale is a scale which distinguishes members of a dimension but does not order them. An ordinal scale is one in which the scale orders the members of the underlying dimension but the distance between the members of the dimension can not be ascertained by the scale. The interval scale is one in which the underlying dimension is represented by a scale such that the distance between the points on the underlying dimension is delineated by the scale, but in which ratios between scale values bear no relationship to ratios in the underlying dimension. The ratio scale is a scale which bears a correspondence to the underlying dimension which is both interval and which all normal mathematical operations can be performed upon the scale while maintaining a one-to-one relationship with the underlying dimension. Dunn (1967) pointed out that the operational definition of the underlying dimension was important in determining what type of operations may be performed on a scale. Thus the scale is not any of the above scales independent of the considerations leading to the definition of the underlying variable. In the case of sound, the decibel scale is a ratio scale as power and intensity ratios are used. Also equal decibel steps tend to be thought of as equal interval steps on an underlying dimension involving the strength or amount of sound (from now on to be called amplitude). In most experiments in psychology and many

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** University of Calgary Acoustics Group in physics where the experimenter presents stimuli at several amplitude levels presumably in equal interval steps, equality of intervals is almost always defined by equal decibel steps. Clearly, these are not equal interval steps if one were considering either pure power or intensity, rather than log power or log intensity, as the scale most directly related to amplitude. There is nothing absolute about either of these measures. There is nothing necessarily wrong with treating equal decibel intervals as equal amplitude intervals. However, if this is done simply as a matter of tradition rather than with a consideration of the objectives defined by the situation, it is a procedure that leads to confusion and misconception about the underlying dimensions being studied.

TRANSFER UNIT

The history of the development of the current units of measurement of amplitude is marked by a very important step in 1924. In that year, the International Advisory Committee on Long Distance Telephoning in Europe was established (Martin, 1929). Part of the purpose of this committee was to propose a universally standardized unit for telephone transmission work. This meeting was also attended by representatives of the Bell System. At this meeting, two power ratios were established, the Neper based upon neperian logs and the Bell based upon the power ratio of 10^1. Here is an example of a decision about units which was primarily pragmatic. This unit was extremely useful for the measurement of power loss in transmission lines (Martin, 1924). It had the distinct advantage that it was independent of frequency and parameters of standard cables (the cable mile was the unit previously used by the Bell System). Martin (1924) also points out that the unit was useful in that it described the hearing function of the human ear. This usefulness was based upon an assumption of the validity of the well-known Fechner Law (Boring, 1942). This law, of course, asserts a logarithmic relationship between sensation and the intensity of a stimulus. Again this assumption about Fechner's Law further added to the pragmatic nature of the decision that was made. Clearly, the new unit appeared to have properties of a ratio scale with respect to two useful dimensions of sound. In fact, the reference value of the decibel scale was chosen to be close to the human threshold for 1000 Hz.

Clearly, the unit which became the decibel was a highly successful unit of measurement. A vast majority of the concerns of people in acoustics were those of electronics, sound transmission, and perhaps architecture. In many respects the size of the Bell System probably guaranteed the transmission concerns would dominate acoustic concerns, at least in North America. The concern with loudness was somewhat later than the concern with transmission. As late as 1929, Watson (1929) was just suggesting that loudness units perceived by the ear should be considered when dealing with the decay of sound in a room. He stated that until that time, decay was always measured in intensity units.

HEARING LOSS

Since that time, the development of acoustics applied to the human organism has proceeded rapidly. The study of the human ear and its relationship to hearing loss was one of the more important of these developments. As more was known about the nature of the ear, and the nature of hearing, it became evident that there were primarily two varieties of peripheral deafness: conductive deafness and nerve deafness. In the case of conductive deafness, the auditory impulse suffers a transmission loss in the outer and middle ear prior to reaching the hair cells. Since in pure conductive deafness, there is nothing wrong with the hair cells, the hearing loss is determined totally by the transmission loss in the outer and middle ear. Thus, hearing loss should follow the rules of a power ratio as does transmission loss. This implies that if a person's threshold is raised by 20 dB, the loudness of the tone 80 dB above his threshold (that is 100 dB) should appear as loud as a tone 80 dB above the threshold (that is 80 dB) of a person with normal hearing. Fig. 1 illustrates this. This indeed is true up to sound pressure levels of near 130 dB (Newby, 1964). The reason for the 130 dB catch-up is probably due to the phenomenon demonstrated by the micro-electro work of Howes (1974) which showed that at near 120 dB the auditory neurons of a squirrel monkey are firing at approximately maximum capacity.

Nerve deafness presents a very different picture. A phenomena usually known as recruitment occurs in the pure nerve deafness case. Recruitment means that if a person's threshold is raised, for instance, by 20 dB, then a tone 40 dB above his threshold (that is 60 dB) may sound just as loud as a tone 60 dB above the threshold (that is 60 dB) of a person's normal hearing. That is, the loudness function of the person with nerve deafness catches up to the loudness function of the person with normal hearing. Since the effect on hearing by white noise masking comes very close to duplicating that of nerve deafness (Hellman & Zwislocki, 1964), the phenomena has been most definitively studied by the technique of using a white noise masker in one ear and no masker in the other ear and having subjects match the two ears for loudness (Fig. 1 is an example of the kind of results obtained). All studies show essentially similar results (Scharf & Stevens, 1959; Lockner & Berger, 1961; Gleiss & Zwicker, 1964; Hellman & Zwislocki, 1964).

A number of people have tried to describe the effect of recruitment in neurological terms. However, a much more parsimonious explanation lies in the nature of the transfer function of the inner ear. This, of course, is a neural transfer function. If one looks at the data of Howes (1974) in which microelectrodes were placed in the neurons of the auditory nerve of a squirrel monkey, one can see that the transfer function is certainly not logarithmic. In fact, it is close through most of the hearing range to a power function with sensation being related to intensity raised to some power less than one. This, of course, is Stevens' well-known Power Law. Although it differs with Fechner's Law, it is

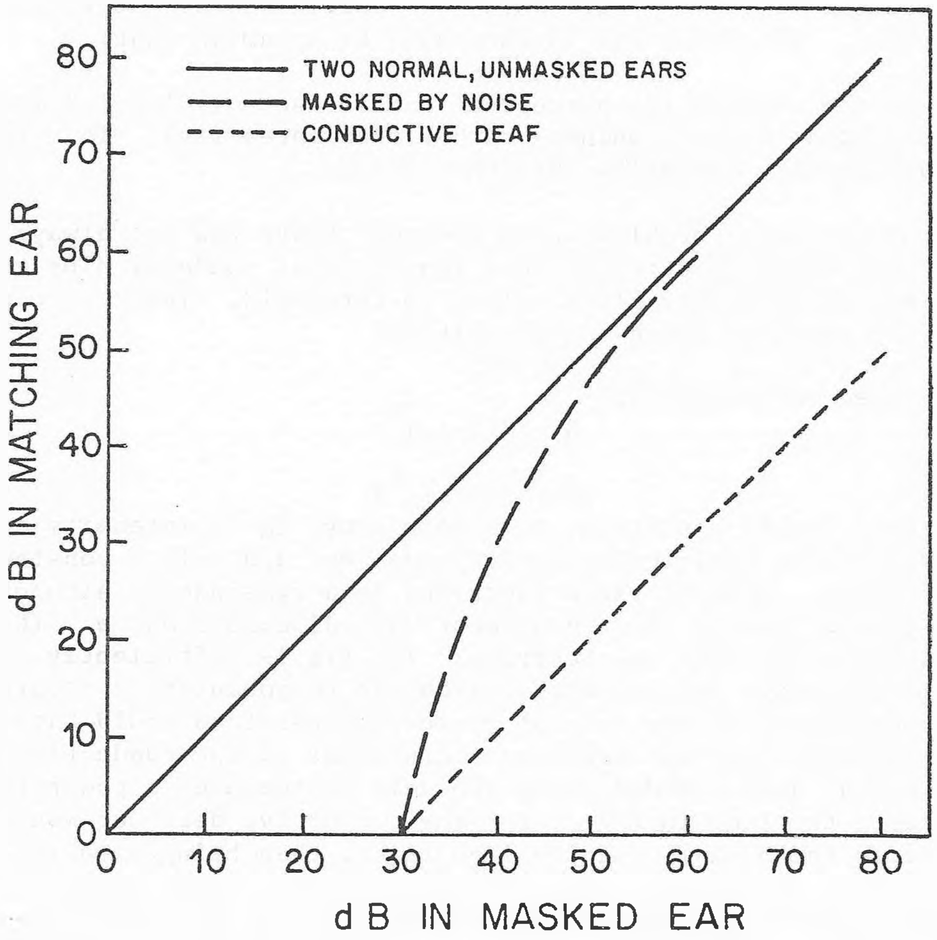

Fig. 1. Including anticipated results from three matching experiments. In all experiments a tone in the "masked ear" is matched in loudness in the other ear by a subject manipulating an attenuator. The solid line represents the case where both ears are unmasked and normal. The long dashes represent the case where the "masked ear" is truly masked by noise. The short dashes represent a case where the "masked ear" is "masked" by the faulty conductive mechanism in the outer or middle ear.

derivable from the Weber fraction (Boring, 1942):

$$\Delta I/I = K \qquad (1)$$

where ΔI is the difference threshold for hearing at intensity I, and K is a constant. The Power Law is derivable by assuming that:

$$\Delta S/S = K \qquad (2)$$

where ΔS is the size of the perceptual unit at sensory level S (sensory level implying perceived loudness rather than intensity). This implies that ΔS varies with intensity (Stevens, 1960).

One of the major problems with Stevens' Power Law has always been that the line which is straight on a log-log plot suddenly dips towards the abscissa at intensity levels close to threshold. This has caused the standard equation which can be written:

$$S = KI^n \qquad (3)$$

to be modified variously to:

$$S = K(I-I_o)^n \qquad (4)$$

or:

$$S = K(I^n-I_o{}^n) \qquad (5)$$

where S again equals sensation, I is intensity, I_o is intensity at threshold, where n is an empirically derived exponent and K is a constant of proportionality. Both of these functions do a reasonable, although not perfect, job of fitting the recruitment data discussed above. (Howes' 1974 data shows why this may be true.) The fit is sufficiently good that it is certainly not any more reasonable to postulate a separate law for recruitment in the case of nerve deafness than would have been to postulate special laws for negative recruitment in the conductive case had the initial unit decided on by the Bell System been a power function. In that case, the line in Fig. 1 for the conductive deaf ear would have diverged from the normal-unmasked line rather than being parallel to it. Would a special concept for that phenomenon have come to exist? Probably. What value would such a concept have had? Clearly, it would have been in defiance to any attempt at parsimony. Incidentally in Menieve's disease a type of recruitment that is in no way artifactual exists.

One implication of all of this is that although a hearing aid which amplifies on a logarithmic basis is ideal for conductive deafness, a hearing aid which amplifies a power-law basis is ideal for pure nerve deafness. It is true that the experiments which have attempted to determine the exponent for the power function have come up with somewhat different results depending upon the experimental paradigm. However, the ear-matching experiments give very straight forward and rather similar types of exponents for given amounts of hearing loss as produced by white noise masking. Even if there were some inexactitude in the nature of the exponent, the protection against auditory overload which can occur with a normal hearing aid would be much greater with an aid being based upon a power function than with an aid being based upon logarithmic amplification.

ANNOYANCE

Another area in which acoustics has become increasingly interested in the human response is in the area of annoyance. Noise has become a considerable environmental problem and has obtained the interest of engineers, physicists, and psychologists. A great deal of time has been spent on obtaining measures of sound which will correlate well with ratings of annoyance by people who are exposed to the sound. A book by Schultz (1972) deals exclusively with the research used to obtain measures and the validity of these measures in predicting annoyance. This implies that the underlying dimension of interest in these measurements is no longer that of transmission loss, but rather that of change in annoyance level. The implication is that a scale related to annoyance in a manner that can be considered interval or ratio should follow the rule that equal steps on the scale should imply equal steps in annoyance. However, the work of Kryter and his associates (see Kryter and Pearson, 1963) indicate that annoyance and sound intensity are related as a power function. In fact, if correction is made for the fact that the sound was calibrated externally to the auditory meatus rather than at the ear drum, the annoyance figures of Kryter and Pearson look very much like the sone scale. This is a scale of loudness. Then decibels are certainly not related to annoyance in a one-to-one interval relationship. Nonetheless all the more prominent measures of noise meant to be related to annoyance are logarithmic scales. This is true of L_{eq}, L_{50}, Noise Pollution Level, Traffic Noise Index, etc. (Schultz, 1972). Once more, there is very little evidence that researchers in a serious way are concerned with the effects of these deviations from proper scaling procedures on the correlations which will be or are likely to be obtained with the underlying variable annoyance. Fortunately, the fact that a power function can be translated into a log-log scale means that the currently used measures are linearly related to log annoyance. Knowing this will certainly improve correlations, but nonetheless will produce interesting statistical problems when averaging over responses. For instance, if a researcher carefully measures log annoyance for each individual interviewed, averages over individuals and then takes the anti-log, he will, of course, have the geometric mean of the annoyance levels, rather than the arithmetic mean. This, of course, will underestimate the annoyance level. This is just a minor point, but illustrates problems that lack of concern with the property of scales can have. In fact, much data (Schultz, 1972) shows that although the above-mentioned measures when used in conjunction with an A-scale give fair correlations for fairly homogeneous sound spectrums, the correlations deteriorate badly for very heterogeneous sound spectrums. This would not happen using a power function rather than a log function.

Another implication of the log-log relationship is that a constant decibel decrease in sound intensity will have a greater effect upon actual annoyance levels for high intensities than it will on annoyance levels for low intensities. This is a useful consideration when one is considering the construction of sound barriers in an area in which traffic volume is apt to increase, for it implies that the relative effectiveness of the barrier will increase with an increase in traffic volume.

CONCLUSIONS

The solution to these problems is not necessarily one of actually changing sound measurement units, although the problems in converting L_{eq} to a power measure are not that great (one could imagine an annoyance level meter based upon the power function, but in every other way using parameters exactly like those meters now measuring L_{eq}). The solution to the major problem is an awareness of the relationship between the current units and the underlying variables being measured. The solution simply implies an awareness of the basic laws of measurement and the functional nature of the units of measurement that are used. When one speaks about equal intervals of units for the presentation of stimuli or for the measurement of stimuli, one should be very careful to ask what is the underlying dimension which is of interest. The example above of the parameters underlying hearing aids makes the problem more than hypothetical.

In the case of annoyance, it is possible to take the process one step further. One may ask what is the underlying dimension that is being measured when one talks about the annoyance level. Is one talking about the probability of complaint? If one is, what is the relationship between the scale of annoyance as measured by an interview and the probability of complaint. If we know this, we have gone one further step towards relating intensity level of the noise to the probability of complaint. If probability of complaint is not the underlying variable, we should decide what it is and apply proper measurement rules to it as well. Essentially sometime one must ask what is it about noise such that we wish to reduce it? How can such a dimension be scaled? What kind of scale of sound will enable people interested in the problem to work most efficiently?

REFERENCES

BORING, Edwin G. (1942). Sensation and Perception in the History of Experimental Psychology (New York, Appleton-Century-Crofts).

DUNN, Bruce E. (1967). "Another Look at Scales," The Can. Psych. 8a, 354-356.

GLEISS, Norman, and ZWICKER, Eberhard (1964). "Loudness Function in the Presence of Masking Noise," J. Acoust. Soc. Amer. 36, 393-394.

HELLMAN, Rhona P., and ZWISLOCKI, J. (1964). "Loudness Function of a 1000-cps Tone in the Presence of a Masking Noise," J. Acoust. Soc. Amer. 36, 1618-1627.

HOWES, W. L. (1974). "Loudness Function Derived from Data on Electrical Discharge Rates in Auditory Nerve Fibers," Acustica 30, 247-259.

KRYTER, Karl D., and PEARSONS, Karl S. (1963). "Some Effects of Spectral Content and Duration on Perceived Noise Level," J. Acoust. Soc. Amer. 35, 866-883.

LOCHNER, J. P. A., and BURGER, J. F. (1961). "Form of the Loudness Function in the Presence of Masking Noise," J. Acoust. Soc. Amer. 33, 1705-1707.

MARTIN, W. H. (1924). "The Transmission Unit and Telephone Transmission Reference Systems," B.S.T.J. 3, 400-408.

MARTIN, W. H. (1929). "Decibel--The Name for the Transmission Unit," B.S.T.J. 8, 1-2.

NEWBY, Hayes A. (1964). Audiology (New York, Appleton-Century-Crofts).

SCHARF, B., and STEVENS, J. C. (1959). "The Form of the Loudness Function Near Threshold," Proc. Third Intern. Congr. on Acoust., Stut gart, Germany.

SCHULTZ, Theodore John (1972). Community Noise Ratings (London, Applied Science).

STEVENS, S. S. (1951). "Mathematics, Measurement and Psychophysics," in Handbook of Experimental Psychology, S. S. Stevens, Ed. (New York, Wiley) 1-49.

STEVENS, S. S. (1960). "The Psychophysics of Sensory Function," Amer. Sci. 18, 226-253.

WATSON, F. R. (1929). "Graphical Representation of the Reverberation Equation," Abstract of paper, J. Acoust. Soc. Amer. 1, 29.

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