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PGA NEWS

CONTRIBUTIONS

CORRESPONDENCE

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IRE PROFESSIONAL GROUP ON AUDIO

The Professional Group on Audio is an organization, within the framework of the IRE, of members with principal professional interest in Audio Technology. All members of the IRE are eligible for membership in the Group and will receive all Group publications upon payment of an annual fee of $2.00.

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World Radio History

PGA News

FINANCIAL AND MEMBERSHIP STATEMENT

IRE Professional Group on Audio
For the Period from January 1 to December 31, 1957

Financial

Balance from January 1, 1957		$11,159.27
Receipts during period:		
IRE matched funds	$3,788.00	
Assessments	7,894.62	
Advertising	300.00	
Sale of publications	1,067.09	
Surplus from meetings	—	
Other sources	200.00	
Total receipts		$13,249.71
Total balance and receipts		$24,408.98
Expenses during period:		
Publications	$7,328.07	
Membership service charges	245.33	
Other	858.79	
Total expenses		$ 8,432.19
Balance as of December 31, 1957		$15,976.79

Membership

Paid	3,754
Paid students	570
Affiliates	2
Unpaid	16
Total	4,342

NEW SOUND ROOMS AT ARMOUR RESEARCH FOUNDATION

The Armour Research Foundation of the Illinois Institute of Technology has announced the completion of two new sound facilities, one a reverberation room and the other an anechoic chamber.

Housed in the Physics and Electrical Engineering Research Building, 3440 South State St., Chicago, Ill., the two facilities will be used for research in the areas of acoustic design and sound and vibration control and in the investigation of the acoustic properties of a wide variety of devices.

Used primarily to create relatively high noise levels and to integrate acoustic energy, the reverberation room is designed to reflect 98 per cent of the sound, with less than 2 per cent absorption.

This low absorption level permits the build-up of sound energy for studies concerned with noise reduction in machinery, appliances, and industrial areas; noise surveys, and vibration problems.

On the other hand, the anechoic chamber is designed to absorb 99.99 per cent of the sound within the room. It will be used for research in the areas of architectural acoustics, electroacoustic transducers, acoustical properties of materials, calibration of acoustical instruments, ultrasonics, and musical instruments.

Built within a concrete shell, the reverberation room is designed with splayed, or slanted, walls and ceiling, painted alternately green and white to define the splays. A minimum of two inches of dead air space is provided between the shell and the walls.

The wall splays and angles are staggered in width, creating a giant sawtooth effect. They are made of six-inch cinder block covered with scratch coat plaster, cement base plaster, and two coats of oil base paint to cut absorption.

The anechoic chamber is of a conventional design and constructed of glass fiber wedges, $2\frac{1}{2}$ feet long, to form 30-inch-deep walls on all six surfaces of the room. Woven airplane-type cable, strong enough to support about 20 persons, is used for the floor construction.

Both rooms are air-conditioned all year and maintained at a 70° temperature through the central heating and cooling system of the building.

A track is provided for activity near the center of either room.

A "quiet" listening room separates the two facilities. In addition to the anechoic chamber and reverberation room, the Foundation maintains the Riverbank Acoustical Laboratory at Geneva, Ill., where studies are conducted in sound absorption, sound transmission, physical properties of acoustical materials, and acoustical calibration.

WILLIAM G. TULLER MEMORIAL AWARD

Purpose of the Award

The award is presented by the IRE Professional Group on Component Parts to stimulate student interest in the component parts which form the basic building blocks of electronic equipment as a career of engineering activity, and to act as a memorial to Dr. William G. Tuller, one of the organizers and member of the original Administrative Committee of the Professional Group on Component Parts. This award shall be known as the William G. Tuller Memorial Award.

Eligibility to Receive the Award

Any student in the senior year of an accredited engineering or scientific school or in any graduate school of study will be eligible to receive this award. A graduate student is defined as one who achieves graduate status within three years after receiving the baccalaureate degree.

Subject of Award

The award will be made on the basis of a paper published in the IRE STUDENT QUARTERLY or any other IRE publication, or presented at any national meeting or symposium sponsored or supported by the IRE.

Eligibility of the Subject

The paper to be considered for this award may be upon any component part subject and may relate to operational theory, materials, construction, design, testing, or application.

Basis for Judging the Award

The criteria for judging the award will be:

1) Originality of approach,
2) Comprehension of subject,
3) Analytical approach and manner of presentation,
4) Novelty, invention, or advanced engineering approach.

Proposals for Award

Papers to be considered for this award may be proposed by any or all of the following:

The Editor of the IRE STUDENT QUARTERLY.
The Editor of any IRE Professional Group TRANSACTIONS.
The Editor of the IRE PROCEEDINGS.
The National Administrative Committee of any IRE Professional Group.
The Technical Program Committee of any IRE sponsored or supported symposium.

Judges

The judges who determine the winner of this award will be members of the Scholarship and Awards Committee of the Professional Group on Component Parts and the National Chairman of this group. Any questions regarding winners, suitability of paper for award, or any conflicts, will be resolved on appeal to the National Administrative Committee of the Professional Group on Component Parts.

Nature of the Award

Each award will consist of a cash sum not less than $250 and a suitably inscribed scroll which will be presented to the winner at the National Components Symposium, or at a major IRE Section or Regional Meeting nearest the school of attendance or home of the winner. The place and time of making the award will be established by the Professional Group on Component Parts Awards Committee.

General Procedure

The availability, nature, and requirements of the award will be publicized through the engineering and scientific schools during the spring semester of each calendar year. To be considered, the paper must be submitted for publication not later than December 31 of the same year. The Awards Committee will receive recommendations between January 1 and March 1 of each calendar year based on the papers received up to December 31 of the year immediately preceding and will determine the winner for that year not later than April 1. The winner will be notified not later than April 15 of the award to be made at the National Components Symposium held annually in May.

The Awards Committee will have sole discretion in omitting an award for any year if the submitted papers are considered unsuitable and may make multiple awards in the following year upon approval of the Administrative Committee.

CHAPTER NEWS

Baltimore, Md.

Kenneth W. Betsch reports the Baltimore Section held its first meeting of the year on October 16 at WBAL's Studio A.

George N. Webb, of the biophysical division of The Johns Hopkins University, described the spectralphonocardiograph, an analyzer developed at the university to obtain a better representation and permanent record of the quality of the human heart sounds. The intensity, tonal quality, and rhythm of the normal sounds, and the quality and placement of any murmurs, are recorded.

A second paper was presented by Wilbur Visher, who described and demonstrated his system of motional feedback as applied to a 50-watt high-fidelity amplifier. The only added requirement for this technique is a speaker with two voice coils, one for driving the speaker and the other for obtaining a signal generated by the motion of the speaker. Fortunately, a few speakers with dual voice coils are available.

Mr. Visher, employed by Bendix Radio Corporation, is engaged in airborne radar research.

At the January 16 meeting held in the Mergenthaler Vocational High School Auditorium, a talk and demonstration of the new Westrex Stereo Disc System was presented. It was pointed out that the phonograph record industry is expected to market many of their future microgroove records as single-groove stereophonic recordings. The change-over probably will begin in 1958.

Two single-groove stereophonic disk recording systems have been seriously considered by the record industry. In both systems, a special cutter is used which actuates the recording stylus in a complex motion having components in two planes corresponding to the two sound channels. The playback head resolves the motions and generates separate output voltages for reproduction through two amplifier and speaker chains. In one of the two systems considered, the record is cut simultaneously vertically and laterally. In the other system, a 45°-45° symmetrical stylus motion is used; this is the method employed in the Westrex System. Both are compatible for monaural playback on existing equipment; however, only the 45°-45° system gives reproduction of both channels combined in monaural playback.

Boston, Mass.

Meetings were held October 3, November 25, and December 12.

At the October meeting, Richard S. Burwen, PGA Chapter Chairman for this year, described a high-quality transistor power amplifier. In this power amplifier circuit, all audio transformers and interstage coupling capacitors are eliminated by dc coupling, even to the loudspeaker. Its transistor output stage is operated in push-pull class B and delivers 20 watts from a standard 45-volt battery and four mercury flashlight cells. Because of its excellent overload characteristics, the amplifier is capable of producing listening levels, with unnoticeable distortion, equivalent to the output of a 100-watt amplifier. Distortion below the overload point is held to an extremely low value of 60 db of feedback around eight stages.

The power amplifier is installed, together with batteries and an efficient 15-inch woofer and a horn tweeter, in a 2-cubic-foot cabinet. Contrary to usual practice, the enclosure is deliberately made highly reverberant.

This system is fed from a compact transistor remote-control preamplifier incorporating mixing and tone controls and equalization for the acoustic response of the speaker system. A demonstration using recorded and taped program material will show the results of the equalization, acoustic treatment, and the direct-coupled circuit overload characteristics.

At the November meeting, a sound film "The Acoustic World of the Grasshopper" by R. G. Busnel was shown, and an accompanying discussion was presented by Prof. Walter A. Rosenblith of M.I.T.

The film was produced at the request of the French Secretary of State for Scientific Research, by a team of scientific workers in the Laboratory of Physiological Acoustics of the French National Institute for Research in Agronomy. This laboratory is under the direction of Mr. Busnel, and from it has come, during the last several years, an impressive group of papers on the behavior of animals in relation to acoustic stimuli. A French introduction to the film has been written by B. Dumortier (June, 1956, issue of *La Nature*).

The film itself is in color with sound in English. The following discussion, which serves as an introduction to the film, is drawn from a paper by Busnel in Volume 15 of the *Journal of Scientific and Industrial Research*, pages 306–310:

> The study of animal phonoreactions is a relatively new branch of acoustics which has developed during the past fifteen years, as a result of newly perfected magnetic recording techniques and the introduction of mobile equipment facilitating field work for biologists. Newly acquired knowledge in ultra-sonics has also opened up new possibilities Research is being carried out in a number of countries, principally France, Germany, U.S.A., U.K. and U.S.S.R. The pioneers in this field are Griffin and Galambos of Harvard University who have carried out interesting work on bats, and Everest who has studied the ultra-sonic waves emitted by marine crustaceae. The experimental animals which have been employed for study in various laboratories include mosquitoes, butterflies, grasshoppers, porpoises, fish, frogs, snakes, birds, bats, and monkeys. The general trend of research in animal acoustics is summarized below.
>
> To start with, the mechanism responsible for the emission of signals and the morphology of the organs connected with it are studied. Then comes the recording of the emitted signals, which have a bearing on a particular behavior of the animal, i.e., courtship, distress, rivalry, alarm, joy, assembly, etc. The recordings are then analyzed and physical data such as frequency spectrum, waveform, intensity, and rhythm are determined. The variations in these data may then be studied with respect to factors such as temperature, humidity, vegetation, state of the animal, etc. From these static but necessary data, the semantic character of the acoustic information is deduced. For example, it would be very interesting to study the acoustical variations in signals in different geographical races of the same animal species.

The article goes on to discuss animal reactions to both natural and artificial (*i.e.*, man-made) signals.

The December meeting was held in the Parish House of Christ Church in Cambridge.

The subject for the paper presented was that many modern churches and auditoriums lack the reverberation characteristics so essential to the performance and appreciation of many types of music. In particular, the pipe organ traditionally is associated with the highly reverberant conditions typical of buildings within which it evolved. The successful design of an organ installation depends as much on the acoustical environment as on the design and construction of the instrument itself. Many buildings of frame construction, and auditoriums in which sound absorbing materials have been introduced to control reverberation for speech intelligibility, are not suitable for organ installations unless the necessary additional reverberation can be provided.

This paper described a practical solution to this problem. Sound picked up in the organ chambers is recorded on magnetic tape and played back from multiple heads, with suitable feedback and time delays, to loudspeakers distributed throughout the church. Six independent amplifier channels are employed, with a total of eleven wide-range loudspeakers. The level and equalization of each channel is carefully tailored to provide realistic sound diffusion throughout the building.

By judicious adjustment of the system parameters, it has been possible to simulate natural conditions so successfully that the listener is unaware that artificial means have been employed. At the same time, the additional reverberation has permitted a considerable extension in the variety of organ registration and musical literature which can be successfully presented on the existing instrument. Applications of the system to choral and orchestral music also were discussed.

The installation at Christ Church, Cambridge, is the first system in regular operation in the United States and probably in the world. Following the meeting in the Parish House, a demonstration concert provided an opportunity for direct comparison of the listening conditions with and without the reverberation system.

Robert G. Breed, who presented the paper, is responsible for the engineering design and construction of the system, with the advice and assistance of Dr. Jordan

Baruch of Bolt Beranek and Newman Inc. Mr. Breed is a graduate of the Massachusetts Institute of Technology in 1953 with the B.S. degree in electrical engineering. Since he has been associated with Aeolian-Skinner, he also has been actively concerned with the production of a twelve-volume series of organ recordings called "The King of Instruments." Additional volumes of this series are currently in preparation.

Cleveland, Ohio

Jack Goldfarb reports that "Stereo Disk Recording" was the topic at the January 16 meeting of the Cleveland Section. Curtis Rex Carter, Jr., of Electro Voice, Inc., discussed the stereo effect, the advantages of stereo disks over stereo tape, and the details of the four types of stereo disk recordings. He explained the reasons why the 45-45 standard was adopted and followed this with a demonstration of stereo disk operation. There was an excellent attendance.

Dayton, Ohio

Harold Souther, of Electro Voice, Inc., talked on the subject "New Developments in Very High Frequency Drivers" at the February 12 session of the Dayton Section.

San Francisco, Calif.

The San Francisco Chapter met November 19 in the Ampex Corporation Demonstration Room in Redwood City. John Leslie, chief engineer of the professional products division, gave a talk on "Loopholes in Magnetic Tape Recorder Specifications." The following account of the meeting was written by Lambert T. Dolphin and is reprinted from the *San Francisco Section Grid*.

How to Beat the System

John Leslie, Jr., chief engineer of the professional products division of Ampex, presented an intriguing and stimulating talk in the Ampex Demonstration Room during the November meeting of PGA on the subject, "Loopholes in Magnetic Tape Recorder Specifications."

Leslie began by presenting "specifications" of two tape recorders originally both Ampex model 601's. Unit A was unmodified off the production line, but unit B had been altered to illustrate points of the talk. These alterations did not keep the unit from meeting the "Specifications" which were not typical of those listed by many recorder manufacturers. The modifications made to unit B were realistically planned and were of types which could easily occur if the design and engineering of a machine had in mind only the realization of this set of specifications without regard for loopholes in these specifications. Leslie felt that most recorder manufacturers were sincere in their attempts to make good tape recorders but often failed to recognize loopholes in their specifications because of lack of thorough engineering and lack of industry standards.

Recorders A and B both had an over-all frequency response flat within 2 db from 50 to 10,000 cycles. Both had very low noise levels in the band 0 to 300 cycles, low total harmonic distortion at 400 cycles, and low flutter and wow.

Clearly, however, recorder B was a completely unsatisfactory recorder to listen to and had striking and obvious defects.

While the over-all noise level of recorder B was as low as recorder A, a good portion of this noise occurred at capstan period and was extremely objectionable to listen to. Here, as Leslie pointed out, was the first loophole. Noise components of considerable amplitude at low frequencies, such as the capstan period, are more annoying than higher-frequency components which pass almost unnoticed. For this reason it is not sufficient to merely hold the total noise level over a wide frequency range below a certain value but to see that low-frequency components which might arise, for example, from a deformed capstan, are kept to an extremely low value.

Using a microphone whose high-frequency response could be peaked, Leslie had prepared two tape recordings of a woman's voice, which he played on the two recorders. Recorder A reproduced the sound of the woman's voice with typically good Ampex quality, but recorder B was almost painful to listen to, due to extreme distortion. The crisp high-frequency sounds in the voice were accompanied by strong low-frequency components, clearly the result of high intermodulation distortion.

When measured with two frequencies, 100 and 6000 cycles, the IM distortion of recorder B was still within specifications, however, using the difference frequency method (signals at 6500 and 7000 cycles) the intermodulation distortion in recorder B exceeded 25 per cent at signal levels 10 db below program level! Harmonic wave analysis confirmed the existence of very high distortion in this machine at the high-frequency end.

Such high distortion can easily arise in practice from overdriven amplifiers since tape equalization results in large record-amplifier signals at high frequencies.

Leslie's very interesting talk stimulated many questions from the group and an informal discussion period followed.

WITH OTHER ACOUSTICAL AND AUDIO SOCIETIES

The October, 1957, issue of the *Journal of the Acoustical Society of America*, contains eleven articles and three Letters to the Editor, which are of unusual interest to acoustical people. The following papers are of special importance to the members of the Professional Group on Audio.

In an article entitled "On the Interpretation of Certain Sound Spectra of Musical Instruments," Robert W. Young, U. S. Navy Electronics Laboratory, and H. K. Dunn, Bell Telephone Laboratories, write on the problem of computing sound power from measurements of average rectified sound pressure, with particular reference to "Absolute Amplitudes and Spectra of Certain Musical Instruments and Orchestras" published by Sivian, Dunn, and White in 1931.

Experimental data are introduced on the distribution of instantaneous pressure amplitudes of music in a wide band and on relations between rms and average pressure in octave and half-octave bands for speech. These data suggest, for example, that in a half-octave band in the vicinity of 1000 cps the rms sound-pressure level during a 15-second interval of music exceeds the average pressure level by 9 db. Means are described for converting the old data based on "pressure per cycle" to a form that would be obtained with the modern octave band analyzer and sound level meter. In place of the steeply sloping spectra suggested by the original figures, the two kinds of corrections lead to an average sound power spectrum, for the 15-piece orchestra, with a broad peak between 100 and 4000 cps.

W. P. Mason and R. N. Thurston, Bell Telephone Laboratories, are authors of the "Use of Piezoresistive Materials in the Measurement of Displacement, Force, and Torque" (received June 10, 1957).

They discuss the use of piezoresistive materials as strain gauges and in the measurement of displacement, force, and torque. A torsional transducer which has been constructed from *n*-type germanium is described, and the experimentally obtained voltage-torque characteristic is given.

Of increasing interest is the subject of shock. In "Response Spectra by Means of Oscillograph Galvanometers," Robert W. Conrad and Irwin Vigness, U. S. Naval Research Laboratory, make an important contribution to this subject.

A response spectrum (shock spectrum) is the response of a series of single-degree-of-freedom systems of given damping to a shock or vibratory motion, as a function of the frequencies of the simple systems. An oscillographic galvanometer is a single-degree-of-freedom system having a rotational response to an exciting current. If the exciting current is made proportional to the amplitude of the motion, the response of the galvanometer to the current will be proportional to that of a single-degree-of-freedom system to the motion, provided their natural frequencies and damping properties are the same. A commercial galvanometer-type oscillograph has been obtained that has twelve undamped galvanometer elements with natural frequencies in the range between 10 and 2500 cps. Damping, by electrical means, has been made adjustable between about 3 and 50 per cent of critical. Associated circuitry has been constructed so that electrical playback of recordings of shock and vibratory motions can be analyzed conveniently. Calibration techniques are described and examples given for analysis of simple and complex shock motions.

The issue contains several book reviews and the usual "Reviews of Acoustical Patents," by Robert W. Young.

BENJAMIN B. BAUER

* * *

A New Determination of the Equal-Loudness Contours*

D. W. ROBINSON†

Summary—**The results of a redetermination of the equal-loudness contours for pure tones, carried out at the National Physical Laboratory, Teddington, England, are discussed in relation to earlier data. The new measurements cover a wider area of the auditory diagram and were obtained by a comparatively large number of listeners. This has enabled the results to be classified into sex and age groups. The latter factor is shown to dominate high-frequency hearing. Some data are presented on the reliability of laboratory measurements of loudness and on certain features of a well-known discrepancy between the thresholds of hearing under free-field and earphone listening conditions.**

INTRODUCTION

ACOUSTICS is commonly defined as the science of sound, and if we seek further for a definition of sound we shall get, at least in the English language, the ambiguous answer that it is both a mechanical disturbance propagated in a medium and the sensation of hearing produced by the disturbance. This duality is reflected in the work of the acoustical engineer. Largely by manipulations of a purely physical character, he aims to achieve a desired sensation within the hearing processes of a listener. To bring about a satisfactory junction between the dual aspects of sound, the engineer must have, as an essential part of his equipment, a proper knowledge of the relations between the physical and psychological aspects of sound—the so-called psychoacoustical data.

It is possible to visualize a multidimensional relation between the various physical magnitudes (sound pressure, frequency, direction of wave propagation, duration, spectral distribution, harmonic distortion, and so on) on the one hand, and a set of psychological correlates (loudness, pitch, brilliance, annoyance, "presence," and so on) on the other. In one or two cases there is a fairly direct correspondence between members of each set, whereas others involve many factors. Early in the development of modern acoustics, it was appreciated that the relations between frequency and intensity of pure tones and their loudness have a leading place in this connection.

There are various reasons why loudness has received more attention than other factors in spite of the obvious fact that other attributes of a sound can be of importance. It is perhaps true to say that this emphasis stems from the experimental fact that loudness is amenable to fairly precise measurement. In the case of pure tones, the loudness depends primarily on the frequency and intensity of the tone. Other factors such as the wave direction, duration, previous history of sound exposure, and the mode of listening have some effect. These, however, can be experimentally controlled and handled as "corrections" to a set of primary data.

As with any psychological magnitude, the loudness necessarily is personal to each listener and can be determined only by subjective experiments. Differences between the judgments of different listeners can be attributed partly to physical causes (such as variations in bodily dimensions), partly to physiological differences giving rise to different patterns of neural activity for the same sound stimulus, but in the last resort to differences in the perceived sensation. With some "perceptual continua" such as annoyance, there seems to be no limit to variability in the third of these categories. In the case of loudness it has been shown convincingly over a number of years that the judgments of different listeners fall within limits narrow enough to justify the concept of a statistical "normal listener," at least for practical purposes. Some experimental data on the reliability of loudness measurements are presented in this paper.

In addition to their scientific interest in connection with the mechanism of hearing, the equal-loudness relations are concerned in a variety of practical applications. A familiar example is the reproduction of music using frequency weighting networks selected according to the level. Aside from entertainment there are important applications to the measurement of sound level, to various methods of calculating the loudness of complex sounds from objective measurements of their spectra, to certain methods of diagnosis of hearing impairment, and so on.

The well-known curves of Fletcher and Munson[1] have been in use for these purposes for a number of years, but their results had been challenged as long ago as 1937 by Churcher and King[2] who carried out their experiments in a rather more direct manner. Differences were apparent in all parts of the auditory diagram, and amounted in places to 30 phons or more, errors which are greatly in excess of the internal consistency of the respective determinations. It was impracticable to resolve these discrepancies on paper, and as a result of repre-

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* Manuscript received by the PGA, January 30, 1958. The work described was carried out as part of the research program of the National Physical Lab., and this paper is published by permission of the Director of the Laboratory.

† National Physical Lab., Teddington, Middlesex, England.

[1] H. Fletcher and W. A. Munson, "Loudness, its definition, measurement and calculation," *J. Acoust. Soc. Amer.*, vol. 5, pp. 82–108; October, 1933.

[2] B. G. Churcher and A. J. King, "The performance of noise meters in terms of the primary standard," *J. IEE*, vol. 81, pp. 57–90; July, 1937.

sentations by the committee of the British Standards Institution charged with preparing national standards for noise measurement, the National Physical Laboratory undertook to redetermine the relations taking advantage of improvements in technique since the 1930's. The opportunity also would be taken to extend the intensity and frequency range of the earlier work. By employing a comparatively large group of listeners, it was intended to provide a basis for possible standardization of a set of loudness relations acceptable to all workers in the field. These objectives are now within sight largely through the encouraging progress made at a meeting of the International Organization for Standardization (ISO) in 1957 at which provisional acceptance of the new results was secured.

This paper is concerned principally with the results of the new determination of the pure-tone equal-loudness contours of which a full description has been published elsewhere by Dadson and the author,[3] and it is relevant to discuss the results in relation to other work in the psychoacoustic field with which National Physical Laboratory has been associated in recent years.

Scope of Investigation

Every audible pure tone can be represented, using its frequency and intensity as coordinates, by a point of the so-called auditory diagram. In this representation the equal-loudness contours are the loci of sets of such points representing tones of constant loudness. The set of all possible audible tones is represented by an area on the diagram which is bounded by the absolute threshold of hearing at the lower end of the intensity scale, and by the greatest intensities which the ear can tolerate at the other.

The frequency range over which the auditory area extends amounts to 11 octaves or more, though the boundaries between what is heard and what is perceived by other senses are somewhat blurred. A range of some 9 octaves from 25 to 15,000 cps was studied in the present investigation, and contains nearly all sounds of practical importance.

The new determination of the loudness relations was extended to include measurements of the threshold of hearing. A tone which is only just audible may be said to have just-zero loudness, and it would be expected that the curve of the hearing threshold as a function of frequency would itself constitute a member of the set of equal-loudness contours and form a natural zero for the set. The procedures for determining the hearing threshold of a tone and the loudness equality of pairs of tones are quite different, of course, but it turns out that the threshold values could have been predicted with considerable precision merely by extrapolating the equal-loudness relations.

We have not attempted to delineate the upper boundary of the auditory diagram. The onset of physiological effects with increasing intensity has formed the basis of a number of other studies. It appears that various phases may be distinguished (temporary loss of hearing, permanent damage, pain, and so on) which occur at levels covering a rather wide range of intensity. The thresholds of the phenomena are not determinable with the precision of the threshold of audibility and they are subject to extraneous factors, notably the duration of exposure. Our loudness experiments ranged up to sound pressure levels of 130 db above 0.0002 dyn/cm^2 in the low-frequency region, using tones of comparatively short duration (of the order of one second) in testing sessions lasting a few minutes, and our observers did not encounter appreciable physical discomfort or measurable fatigue.

In order to obtain sufficiently representative results, about 130 subjects of both sexes and ranging from 17 to 63 years of age were tested. These people were examined by an otologist to ensure that they would be classed from a clinical point of view as persons with unimpaired hearing. In the population at large there is naturally a proportion with hearing defects of every degree of severity. We regard this as a separate question and consider that a standard determination of the primary characteristics of hearing must be based on a group with unimpaired hearing.

A full description of the test procedures has been given[3] and will not be repeated here. We will only mention that the basis of our loudness tests was the so-called "method of constant stimuli." In psychological circles much is made of the contingency of the results on the test procedure. We believe that the method just mentioned eliminates difficulties of this kind. In outline, the listener hears pairs of tones and makes snap judgments of which member of the pair is the louder. By varying the intensity of one (or both) tones in a random manner between successive judgments, the point of *equality* of loudness emerges as the level at which a reversal of the *inequality* judgments occurs. Considerable precision is obtained in this way and the observer can gain no assistance from extraneous clues. The price to be paid for these advantages is the length of time required to complete a single observation.

Reference Conditions and Units of Measurements

From a theoretical standpoint the pure-tone equal-loudness relations may be considered as a surface in three dimensions representing respectively the frequency and sound pressure level of the tone, and the loudness. Thus, given any two of these quantities the third is determinate. Certain reservations are to be borne in mind here. The loudness of a pure tone is not determined wholly by the other two parameters but also depends on the listening conditions, and for this reason a set of reference conditions must be specified. Moreover, it is not a simple matter to attach numerical

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[3] D. W. Robinson and R. S. Dadson, "A redetermination of the equal-loudness relation for pure tones," *Brit. J Appl. Phys.*, vol. 7, pp. 166–181; May, 1956.

scale values to the loudness axis, though as a result of some recent work this step may now be taken with reasonable accuracy. We shall consider these two points separately.

Reference Conditions

The listening conditions adopted by Fletcher and Munson, Churcher and King, and in the present case, consist of listening with both ears to a source of plane waves (or approximately plane waves) situated directly ahead of the listener. In the case where the tone whose intensity is varied has a frequency of 1000 cps, these conditions amount to a determination of the loudness level of the other tone in phons, the value in phons being numerically equal to the sound pressure level (in decibels relative to 0.0002 dyn/cm^2) of the 1000-cps tone judged equal in loudness to the test tone in the opinion of a group of normal listeners. The concept of loudness level proves very convenient for the estimation of the loudness of all types of continuous sound, including of course pure tones, and many of the results in the present investigation were obtained by comparison with the 1000-cps tone in this way. In the particular case of pure-tone comparisons, however, there is no particular significance in according a special place to the 1000-cps tone, and a number of experiments were carried out with entirely consistent results by comparing pairs of tones of various frequencies.

Nevertheless, we follow the convention in presenting the results as though they had all been determined in terms of the 1000-cps reference tone, that is to say, as cross sections of a three-dimensional surface at equal intervals of the loudness level—the usual "equal-loudness contours."

The reference conditions outlined owe their origin to their freedom from ambiguity of definition and to their (comparative) ease of realization in anechoic conditions. This makes a satisfactory basis for the primary data but subsidiary experiments are required to relate the results to hearing under other conditions. For example, some determinations that are now nearly completed at the National Physical Laboratory give the relations between loudness under the reference conditions and for different directions of arrival of sound and for diffuse sound fields.

These results will be published separately in due course but they can be anticipated qualitatively here. The effect of expressing the primary equal-loudness contours in terms of the free field sound pressure in a normally-incident progressive wave is to introduce features in the contours specifically associated with the geometry of the human head. In a diffuse sound field these features tend to be less marked.

Scaling the Loudness Axis

In many applications it is enough to regard the contours as relations of equality, for example, as in treating the contours as frequency response curves of the ear for the purpose of "correction" by inverse weighting networks. It then is only necessary to label the relevant loudnesses by an arbitrary numbering scheme such as the phon scale; but, it must be remembered that the latter is a purely physical scale (proportional to the logarithm of a sound pressure) and takes no account of the phenomena of hearing. Some confusion has occurred over the nature of the phon scale because of its logarithmic character erroneously being identified with a supposed logarithmic action of the ear. So far as the sensation of loudness is concerned, the ear is decidedly not logarithmic in operation; it approaches more to a power law. But a determination of the exact relationship is necessarily a matter for subjective experiment and presents a number of difficulties. Many experimenters have worked on this problem including the author[4] and surveys of the data have been given recently in separate papers by Stevens[5] and the author.[6] The scale of relative loudness (sones) is most conveniently expressed by its relation to the phon scale because this is in principle an invariant transformation. Direct relations between the loudness and the physical intensity would vary from one sound to another according to the character of the sound.

The subjective experiments referred to are mainly of the type in which observers find the increment or decrement in the loudness level of a sound which doubles or halves its apparent loudness. Other numerical factors have been used with consistent results. An assessment of the various data[6] leads to the result shown in Fig. 1, from which can be deduced the natural scale for the loudness axis in a three-dimensional representation of loudness contours.

At a recent international meeting (ISO), it was provisionally agreed to adopt a simpler form for the sone/phon transformation; according to this proposal a two-fold loudness change is identified with a 10-phon change in the loudness level and the unit (1 sone) is fixed at 40 phons. This is recognized as an approximation, but it is attractive for practical purposes on account of its simplicity.

REDETERMINATION OF THE EQUAL-LOUDNESS RELATIONS

Results of the redetermination of the equal-loudness contours are seen in Fig. 2; the curves were arrived at by smoothing the results of 141 measurements. Twenty-one of these were devoted to the threshold of hearing. In about 30 of the tests, a full team of over 120 persons took part, and the others represent results for a group of some 30 observers typical of the larger group. From

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[4] D. W. Robinson, "The relation between the sone and phon scales of loudness," *Acustica*, vol. 3, no. 5, pp. 344–358; 1953.

[5] S. S. Stevens, "The measurement of loudness," *J. Acoust. Soc. Amer.*, vol. 27, pp. 815–829; September, 1955.

[6] D. W. Robinson, "The subjective loudness scale," *Acustica*, vol. 7, no. 4, pp. 217–233; 1957.

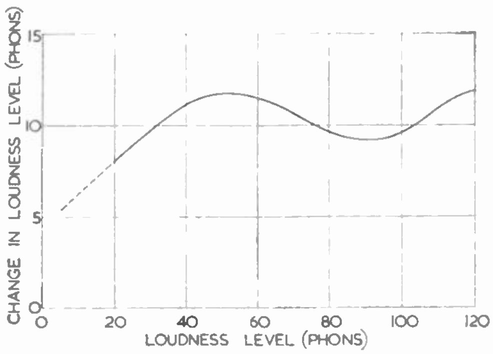

Fig. 1—Change in loudness level for twofold loudness change.

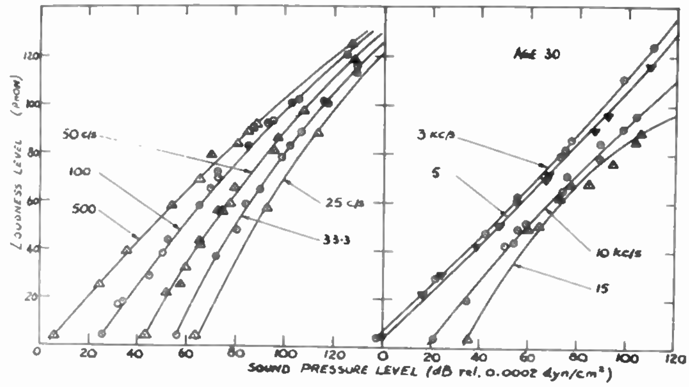

Fig. 3—Equal-loudness relations for typical frequencies.

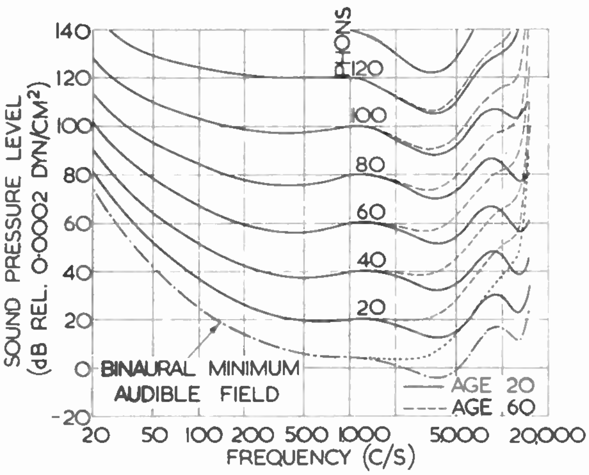

Fig. 2—Equal-loudness contours (Robinson and Dadson).

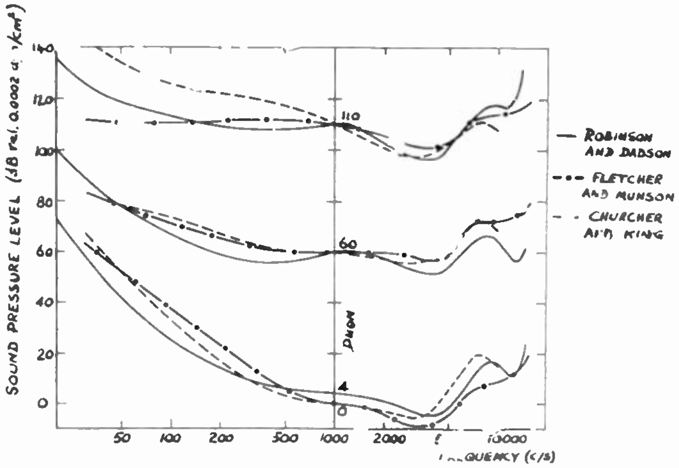

Fig. 4—Comparison of equal-loudness contours.

1000 cps up, the age of the listener is a significant factor and comes to dominate the result at 15,000 cps. Above this frequency the differences between observers even of the same age group would deprive a single value for the group of much meaning, and the experiments were terminated accordingly.

The loss of hearing with age (presbycusis) is discussed in another section, and in Fig. 2 we show only the results for ages 20 and 60 to avoid complicating the diagram.

The relations between loudness level and sound pressure level turned out to be very simple in form for frequencies over the whole audio range, which has enabled us to predict with some confidence the course of the relations slightly beyond the range of the measurements. A selection of the equal-loudness relations is shown in Fig. 3. They can be represented within the accuracy of the data points by equations of the second degree in the sound pressure level, thus enabling the complete results to be presented in short tabular form as a set of coefficients varying smoothly with the frequency. The appropriate tables are given in the original reference[3] and may be found convenient by some workers, especially in connection with loudness calculation in which it may be difficult to read from the graphical presentation with the required precision.

Over the greater part of the auditory diagram, including the threshold contour, the estimated accuracy of the smoothed data is 1 phon or better. Some reservation should be made regarding the values for 15,000 cps (because of the large individual variations), and the extrapolation from 25 to 20 cps.

COMPARISON WITH EARLIER RESULTS

General Features

Comparison of the general shape of the contours with the work of Fletcher and Munson and of Churcher and King is shown in Fig. 4 in which for clarity only a few contours have been shown.

The depression in the new curves centered on 400 cps was investigated closely by measurements under several different conditions and it was invariably confirmed. The new contours are less crowded in the bottom left-hand section of the auditory diagram than formerly, which is a reflection of the fact that lower threshold values have been obtained. In the upper left-hand section the results are intermediate between the earlier contours, and it should be noted that the new results are supported by experiment up to 130 db whereas the earlier data relied heavily on extrapolation in this region. The trends of the various sets of contours towards the high frequencies are in some respects similar, and the magnitude of the discrepancies suggests that age effects alone might account for the greater part.

Threshold of Hearing

A significant feature of the new results is the fact that the normal threshold of hearing corresponds to a loudness level of 4 phons and not 0 phons as had been conventionally shown in the earlier work. A tone of loudness level 0 phons is audible to only about one person in eight and even less for high tones. For this reason we prefer not to show a contour through the zero of the loudness level scale.

In comparing the new threshold contour with the other data (Fig. 4), it should be noted first that the 0-phon contours shown by Fletcher and Munson and also by Churcher and King do not correspond exactly to their own measurements of the hearing threshold.

An example occurs in Table 3 of Churcher and King's paper in which sound pressure levels of 38.5 and 27 db are given for the thresholds of audibility at 54 and 120 cps, respectively. Corresponding values from the present investigation are 39.5 and 25 db (39.5 being an interpolated value) which are in much better agreement than would be suggested by inspection of the equal-loudness contours. It is also of interest that the threshold sound pressure level for the 1000-cps tone obtained by Fletcher and Munson was 4 db, in exact agreement with the present work and also with the classic work of Sivian and White[7] which will be referred to again shortly. It is curious that Fletcher and Munson, in deducing their set of smoothed contours, should have drawn their 0-phon contour sloping more steeply towards the low-frequency end than a curve through their own threshold values would run. This factor goes some way towards accounting for the apparent difference between their work and the new results.

Another interesting comparison can be made with the threshold values of Sivian and White. In this connection, there are two related sets of data which can be taken into account. Sivian and White found a difference, which remains unexplained, between the minimum values of sound pressure required to excite the sensation of hearing according to whether the sound is heard through an earphone or from a loudspeaker. Allowing for the fact that one set of data is for monaural and the other for binaural listening and also taking into account the distribution of interaural sensitivity differences (these two factors at most account for about 3 db), the free-field threshold pressure remains some 6 or 7 db below the threshold for earphone listening. Munson and Wiener[8] christened the effect the "missing 6 db" and its reality becomes apparent in various practical ways, for example, in the assessment of ear-defender performance.[9]

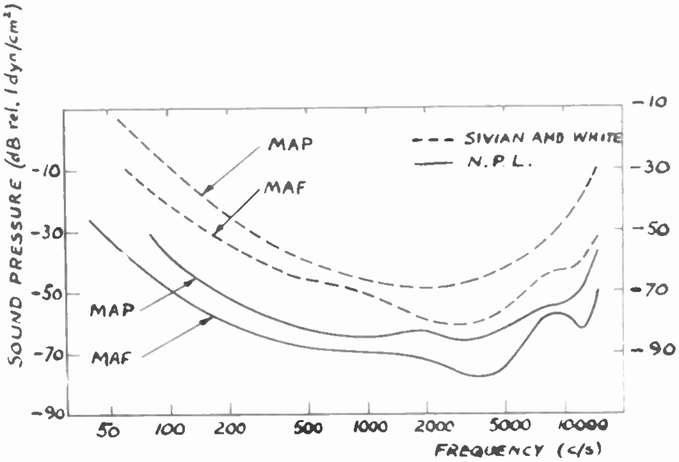

Fig. 5—Comparison of "minimum audible pressure" and "minimum audible field" curves.
Left-hand scale: NPL values. Right-hand scale: Sivian and White's values.

Taking the recent free-field threshold determination in conjunction with another investigation carried out at the National Physical Laboratory by Dadson and King[10] on the threshold by earphone listening, a striking confirmation of Sivian and White's effect is apparent. The corresponding pairs of "minimum audible field" and "minimum audible pressure" curves are illustrated in Fig. 5. In order to simplify the diagram, the curves of Sivian and White have been shifted upwards by 20 db.

At the lower frequencies the absolute values of threshold sound pressure are somewhat higher in the American work as compared with the recent British determinations; a factor which may be relevant is that the latter work was carried out in exceptionally silent conditions while Sivian and White and Fletcher and Munson made use of an open "sound stage."

Shape of the Equal-Loudness Relations

A feature of the loudness contours of Fletcher and Munson was the bunching of the intermediate contours at the low-frequency end. A typical equal-loudness relation taken from their paper is shown in Fig. 6(a). The bunching of the contours corresponds to the inflection in the figure. This trend is not supported by the new results, the corresponding relation (interpolated for 60 cps) being shown for comparison.

Towards the higher frequencies another change has occurred. Fletcher and Munson's curves indicate a progressive increase in the rate of growth of loudness level with the sound pressure level though this is not strongly supported by their experimental values. The present results conform to this trend from 1000 to 6500 cps but thereafter reverse. The difference becomes marked at 15,000 cps, at which the new results show a kind of saturation in the process of loudness growth [Fig. 6(b)].

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[7] L. J. Sivian and S. D. White, "On minimum audible sound fields," *J. Acoust. Soc. Amer.*, vol. 4, pp. 288–321; April, 1953.

[8] W. A. Munson and F. M. Wiener, "In search of the missing 6 db," *J. Acoust. Soc. Amer.*, vol. 24, pp. 498–501; September, 1952.

[9] See for example, J. Hershkowitz, and L. M. Levine, "Attenuation of ear protectors by loudness balance and threshold methods," *J. Acoust. Soc. Amer.*, vol. 29, pp. 889–894; August, 1957.

[10] R. S. Dadson and J. H. King, "A determination of the normal threshold of hearing and its relation to the standardization of audiometers," *J. Laryngol. and Otol.*, vol. 46, pp. 366–378; August, 1952.

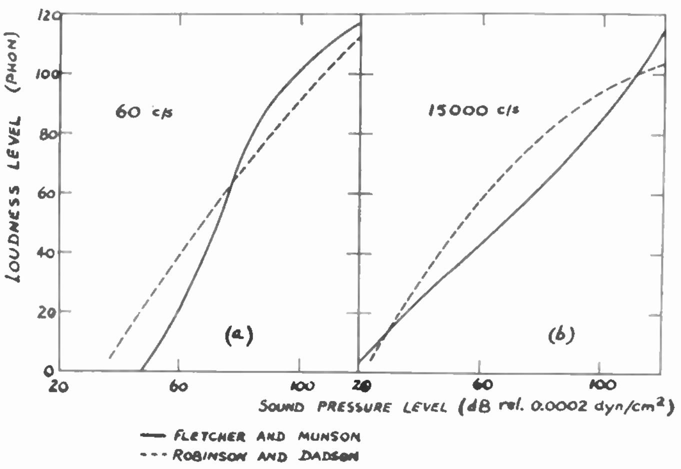

Fig. 6—Comparison of equal-loudness relations for 60 and 15,000 cps.

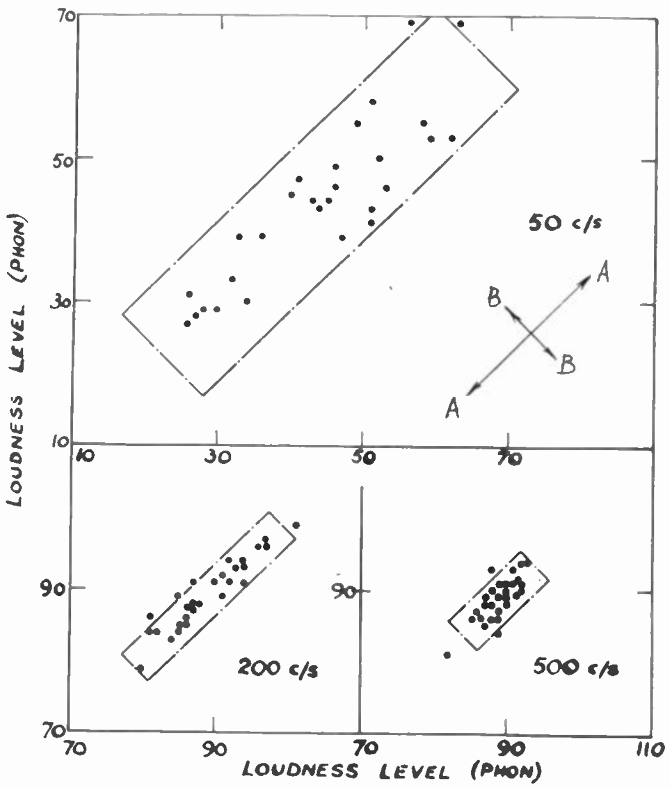

Fig. 7—Repeatability of measurements of loudness level of three pure tones by a group of 28 listeners.

ACCURACY OF LOUDNESS MEASUREMENTS

When an observer is listening to a sound for the purpose of judging its loudness, it must be remembered that he is making an abstraction from the total perceived sensation, and it is a matter for experimental verification whether the quality abstracted is influenced by the character of the other sound with which the first is being compared. If this were the case, the importance of loudness as a measurable attribute would be gravely impaired, of course. During the course of the recent equal-loudness determinations a number of triangular comparisons were included, in which tones of three different frequencies were compared in pairs. Averaged over a group of some 30 observers the closure of these triangles was in each case accurate to the order of 1 or 2 db which is comparable with the standard error of the comparisons, and thus disposes of doubt as to the validity of the measurements.

The accuracy of laboratory loudness measurements is illustrated in Fig. 7 by way of correlograms. In each section of Fig. 7 the horizontal and vertical axes represent the loudness levels of a tone of given frequency and sound pressure level, as judged against the 1000-cps reference tone on two separate occasions separated by an interval of about three weeks. The coordinates of each data point are the respective values obtained by one observer, and the results shown are for a group of 28. The dispersion between the judgments of different observers is measured by the spread along the *A* direction, and limit lines are shown at ±2 standard deviations about the mean. The accuracy of the individual measurements is measured by the spread in the *B* direction; limit lines corresponding to twice the error standard deviation are shown.

The point to notice is that the variability between observers is considerably the larger factor in each case. As would be expected, both components of the dispersion increase with the difficulty of the comparison, and in fact, are roughly proportional to the separation of the comparison tones in octaves.

The conclusion from these observations is that for a given expenditure of time a loudness determination preferably is carried out by a large number of observers making a single observation rather than by a smaller group making repeated measurements. And, as a corollary to this, once a loudness determination has been made by a group, little is to be gained by repeating it.

Similar conclusions can be drawn with regard to determinations of the hearing threshold. Fig. 8 shows correlograms for four repeated determinations by a group of about 100 observers, the interval between the tests being about 11 months in this case.

THE EFFECT OF AGE UPON LOUDNESS

The separation of the loudness contours for widely separated age groups has been shown in Fig. 2 and it is convenient to discuss these results from two aspects: the raising of the threshold of hearing and the effect upon the loudness of supraliminal tones.

We are conscious, in presenting these results, of the comparatively small numbers of listeners in each age group but the consistency of several trends which we can distinguish gives some confidence that they are fairly representative.

With regard to the loudness of tones above the hearing threshold, the results at each frequency tested from 2000 to 15,000 cps showed that the loss of hearing, over a given span of years, diminishes appreciably as the intensity is raised. In the clinical literature this phenomenon is described as recruitment and is regarded as diag-

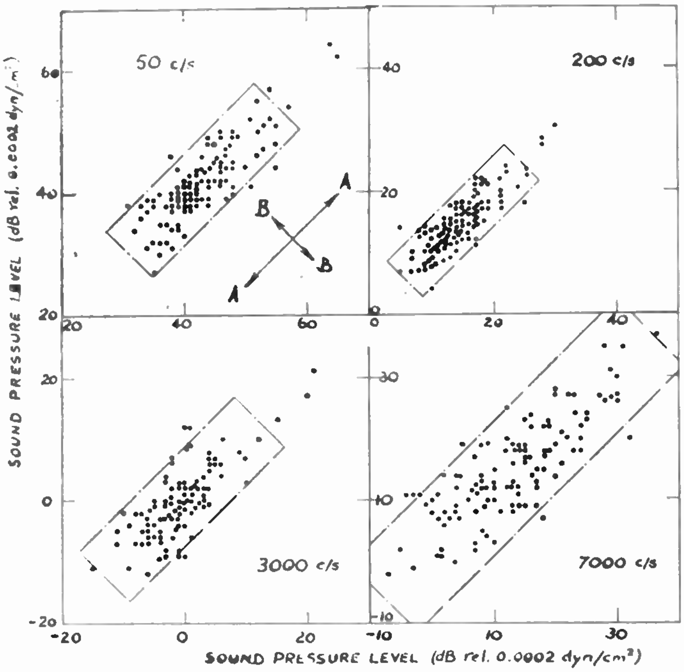

Fig. 8—Repeatability of threshold determinations at four frequencies by a group of about 100 listeners.

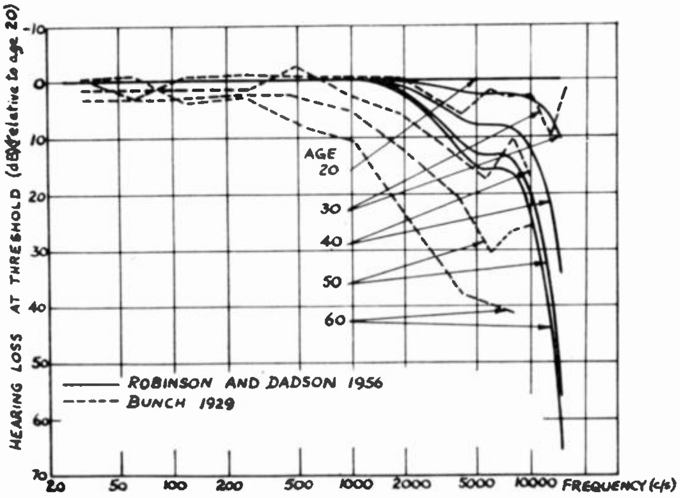

Fig. 9—Loss of hearing with age at threshold level.

nostic of certain types of nerve deafness. The present results refer, of course, to persons with ostensibly unimpaired hearing, and the degree of recruitment suggested by the data is in any case rather attenuated. Nevertheless it seems necessary to conclude that a mild degree of recruitment to high tones is a normal occurrence among older listeners. Moreover, it must be of binaural occurrence, otherwise the effect would be obscured by normal functioning of the better ear.

The rate of aging and the frequency dependence are illustrated best by reference to the raising of the threshold level. We found that the rise could be represented rather closely by the product of two factors, one depending only upon the age and the other only upon the frequency.

The variation with age seems to be steepest around 35 years and thereafter grows at a slower rate. The variation with frequency is negligible up to 1000 cps, and thereafter increases; the rate is greatly accelerated towards the upper frequency limit of the measurements. There is, however, a marked break in the upward trend around 5000 cps. This suggests a connection with the so-called "C^5-dip" well known in audiometric circles. On the place theory of hearing it is supposed that tones in this frequency region stimulate maximum excursion of the basilar membrane at a section which is peculiarly susceptible to overload damage.

The results are shown in Fig. 9 in the form of audiograms relative to normal hearing at age 20, and are combined with presbycusis curves based on the well-known work by Bunch.[11] The latter data apply to a very much larger group of subjects; on the other hand the subjects were hospital patients not necessarily in good health, which can account for the poor agreement with our data in absolute magnitude. There is a general similarity with regard to the frequency dependence in both sets of results.

Comparison of Results for Male and Female Listeners

The classification of the results of the loudness and threshold determinations by sex showed only small differences between group averages. Below 1000 cps they were negligible or unsystematic, but for the higher frequencies a consistent trend was apparent, as indicated by the open circles on Fig. 10.[12] The magnitude of the difference remains comparatively small, however, and in presenting the equal-loudness contours we have not considered it necessary to make a distinction.

On the other hand, an inquiry into the origin of the observed systematic differences at higher frequencies leads to interesting conclusions. In their paper on the threshold of hearing by earphone listening, Dadson and King[10] remark that systematic differences were not apparent at any frequency between the results of male and female subjects. This suggests that the results in Fig. 10 may be attributable to unequal diffraction by male and female heads in the reference sound field, and this turns out to be well supported by direct experimental evidence.

In connection with another study we have measured the "obstacle effect" of some 46 heads (24 male and 22 female) in the reference sound field over a wide frequency range. For this purpose a probe tube microphone was employed, and the results are expressed in terms of the ratio of the sound pressure at the entrance

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[11] C. C. Bunch, "Age variation in auditory acuity," *Arch. Otolaryngol.*, vol. 9, pp. 625–636; 1929.

[12] The data points shown are averaged over the threshold test and loudness tests at various intensity levels at the frequency shown. The values, though small, must be considered systematic, bearing in mind the large number of observations compressed into each point in Fig. 10.

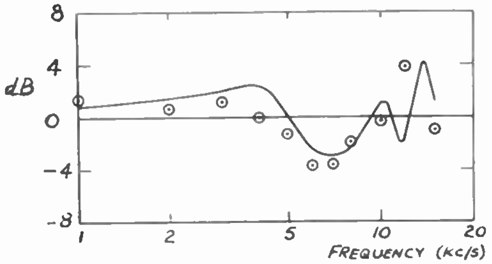

Fig. 10—Average loudness level difference for male and female listeners as a function of frequency.
⊙ Average values from loudness and threshold determinations.
— Difference between diffraction effects of male and female heads.

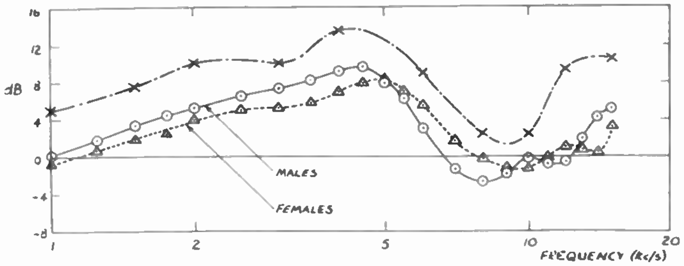

Fig. 11—Effect on reference sound field due to presence of listener's head.
⊙ Mean experimental results on 24 male heads.
△ Mean experimental results on 22 female heads.
× Difference between pressure and free field thresholds.

to the right external auditory meatus to the free field sound pressure in the progressive plane wave. Average results for the male and female groups are shown in Fig. 11. Each curve exhibits two maxima and two minima; moreover, the corresponding critical frequencies are in almost a constant ratio (about 1.15 to 1) which would be entirely consistent with an average difference in linear dimensions of male and female heads of this amount. It is interesting to remark here that measurements of the intramastoidal distance of 100 heads (which were made in another connection) gave average results of 13.6 cm and 12.4 cm for male and female heads respectively, which supports the previous argument.

That these geometrical considerations are probably sufficient explanation of the observed differences between the mean loudness judgments of male and female listeners is shown by the continuous curve in Fig. 10 which is merely a plot of the difference between the two lower curves in Fig. 11. We conclude there are no inherent differences in the hearing processes of men and women.

Finally it is interesting to consider the frequency dependence of the "missing 6 db." As has been seen, the "minimum audible field" curve is affected by head diffraction while the "minimum audible pressure" is not, of course. The difference between these curves thus would be expected to show the features characteristic of the "obstacle effect," and this is demonstrated clearly by the upper curve in Fig. 11 which is a plot of the difference between the lower curves of Fig. 5. The undulations of the "missing 6 db" are thus well accounted for, and we appear to be left with a residue which is more or less independent of the frequency.

ACKNOWLEDGMENT

The author wishes to acknowledge the cooperation of the members of the Laboratory staff who took part in the various phases of the investigations described, and the collaboration of R. S. Dadson with whom the greater part of the work was first published jointly.

Room Dimensions for Optimum Listening and the Half-Room Principle*

PAUL W. KLIPSCH†

Summary—**This paper discusses the relation of room dimensions and speaker placement to the quality of low-frequency sound reproduction. Dimensional ratios for home music rooms are suggested.**

APPARENTLY, based on experience, the diagonal D of Fig. 1 represents about the maximum wavelength which can be propagated into a room. Thus, with a speaker system known to exhibit good remaining efficiency down to 30 cycles, the playback of a live pipe organ recording (original tape) gives full response in a room with a 32-foot diagonal.[1] If the room is smaller, the lower part of the bottom octave is weakened. The difference in performance in a room 16×16 feet and one 16×25 feet was evident immediately. The 16×16 diagonal is not quite 23 feet; the 16×25 diagonal is nearly 30 feet. Some slight difference requiring the Figs. 1 and 2 listening test may be considered as marginal, but the difference in the two rooms was well above any liminal level. The rooms had the same treatment, mastic tile on concrete floor with celotex walls and ceiling, and 12-foot ceiling height in each case.

Several conclusions are to be drawn.

1) In designing a new house, the music room should be planned with a 32-foot diagonal, or as nearly that minimum as expedient. It is suggested that the ancient "golden mean ratio" apply with, for example, a length of 27 feet, width of 17 feet, and height of 10 feet, or some reasonable and feasible approach to those figures as in Fig. 3. This "room" is based on ratios of 0.618:1.00; the golden mean ratio is the limit of the ratio of adjacent terms in the Fibonacci series. The application for either single speaker or stereophonic would be good in a room of this size and shape.

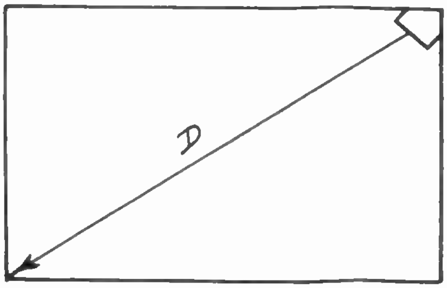

Fig. 1.

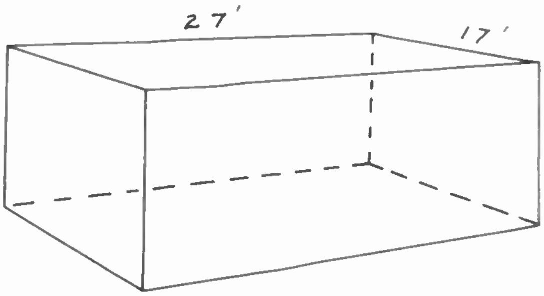

Fig. 2.

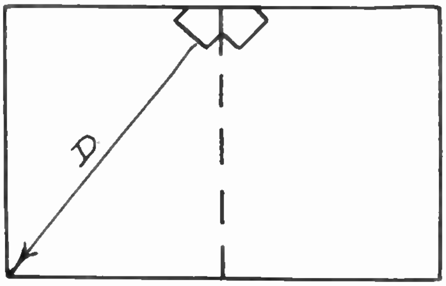

Fig. 3.

2) This brings up an interesting idea about noncorner speakers. Suppose a noncorner speaker is constructed by placing two corner-type speakers back to back against a wall in "free space," as in Fig. 2. This would be equivalent to a single corner unit in a corner, a fact which becomes obvious if one studies the mirror image principle. But in a room of a given size, the wall placement of a pair of corner speakers bisects the room; a wall along the dotted line would create a mirror image dispensing with the need of the second speaker, but the room would be half as large. Based on the 32-foot minimum diagonal thesis, the bass response for the two speakers as in Fig. 2 would be less than for the single speaker in Fig. 1.

Such is actually the case, based on experiment. In fact, the idea was extended to four corner speakers clustered in the center of a room, and the sound was not as satisfactory as for a single speaker system in the natural corner.

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† Klipsch and Associates, Hope, Ark.

[1] Some large pipe organs have 32- and even 64-foot "stops" representing pipes speaking at fundamental pitches of 16 and 8 cycles per second. Analyses of sound from these pipes show that the radiation is all in the partials or overtones. Ability of a speaker to reproduce uniformly down to 32.7 cycles will suffice to reproduce any pipe organ we have ever recorded.

This shows first that the wall speaker, even if intrinsically full range, is not as good as it would be if placed in a corner, and second, that it takes twice as much speaker for wall use as for corner use, and the response is less in spite of the doubled cost.

The immediate, simple, obvious, and conclusive inference is that any type speaker other than a corner type, and any placement other than in a natural corner, is a costly sacrifice.

Therefore, the design of new homes should be based on provision of corners for speakers, and the application of existing rooms for wide-range sound reproduction should be based on the use of corners even at the expense of remodeling if necessary.

3) The proposed minimum room dimensions and idealized proportions need not interfere with planning relative to nonparallel surfaces, Boner polycylindric treatment of walls, and other factors involving echo breakup and reverberation time. In fact, the liveness is a factor to be considered separately.

4) For the growing interest in stereophonic sound reproduction, it may be said the same principles apply. Experience shows that for the ideal 10×17×27-foot room [see 1)], the speakers for a two-channel stereophonic array should be placed at the opposite corners on the 27-foot wall.[2] Some lay remarks to the contrary notwithstanding, it has been found that systems designed for narrow spacing and wall placement were always improved by spacing the speakers to the corners, and further improved by substitution of speakers designed for corner application. Adding a third channel in the middle of the wall by mixing the two sound tracks has been found to provide a further improvement in stereo playback,[3] especially when used with corner speaker placement against the *long* wall of the room.

5) Acceptability for homes of Boner polycylindrical surfaces[4] may not be universal, but where good sound is a major consideration, such surfaces are recommended. One room 10×15×26 feet, built as a studio, was helped considerably by including 300 square feet of such surfaces to aid liveness while using rugs and drapes to offset slap from parallel surfaces.

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[2] P. W. Klipsch, "Experiences in stereophony," *Audio*, vol. 39, pp. 16–17, 41; July, 1955.

——, "Making stereophonic tapes," *Music at Home*, vol. 2, pp. 54–56, 68, 72; November–December, 1955.

[3] P. W. Klipsch, "Two track 3-channel stereo," *Audiocraft*, vol. 2, pp. 26–27, 45–48; November, 1957, and vol. 3, p. 37; January, 1958. Also see, "Stereophonic sound with two tracks, three channels by means of a phantom circuit," *J. Audio Eng. Soc.*; April, 1958.

[4] C. P. Boner, "Performance of broadcast studios designed with convex surfaces of plywood," *J. Acoust. Soc. Amer.*, vol. 13, pp. 244–247; January, 1942.

Permanent Magnets in Audio Devices*

R. J. PARKER†

Summary—**The permanent magnet is considered as a component for changing the form of energy. A brief review of the basic physics of the permanent magnet is included with emphasis on the nature of the magnetization process and how the permanent magnet functions in establishing external magnetic field energy.**

Presently available characteristics of permanent magnets and future possibilities for improving the efficiency of the permanent magnet are discussed as well as the relationships between audio device performance and the unit properties of permanent magnets.

In using the permanent magnet the choice of unit properties, volume, geometry, and magnetic circuit arrangement greatly influence the end performance and efficiency of audio devices. As an aid in exploiting the optimum combination of these variables, an electrical analog system using lumped constants is introduced. Data on leakage permeance are presented for the more widely used permanent magnet arrangements in audio work. The analog technique is of general interest from the viewpoint of understanding the energy relationships involved in the efficient application of the permanent magnet and as an aid in predicting permanent magnet performance on a firm engineering basis.

INTRODUCTION

PERMANENT magnets find wide application in audio devices in which a magnetic field serves as the medium of energy transformation in the transformation of electrical energy to mechanical energy and also in changing mechanical energy to electrical energy. As a key component in these devices the permanent magnet influences the efficiency, physical size, and cost. The purpose of this paper is to describe the permanent magnet as a basic system for establishing field energy and to show how permanent magnet properties influence audio device performance. Presently available permanent magnet materials and future possibilities are

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discussed as well as an electrical analog approach to permanent magnet design problems.

BASIC PHYSICS OF THE PERMANENT MAGNET

The permanent magnet can be conveniently thought of as a grouping of elementary magnetic volumes or domains. A domain is the smallest region in which the atoms have their magnetic moments held parallel and thus act as a single elementary magnet which may be controlled by man-made external fields. In a ferromagnetic material the size and orientation of the domains are influenced by three potential energies.

1) Potential energy due to the interaction existing between neighboring atoms.
2) Potential energy associated with the directional dependence of magnetization commonly called anisotropy energy.
3) Magnetostatic energy or the external field energy associated with the domain.

The size, shape, and orientation of the system of elementary magnet volumes in a given condition are in a state of balance such that minimum total potential energy is involved. In a demagnetized condition the domains shift so that closed paths for the flux exist and the magnetostatic energy is a minimum.

Any field which man can produce serves only as a control in changing the magnetostatic energy and thus the balance of the total influence on the domains. Magnetization curves and hysteresis loops show the change in induction due to domain boundaries shifting and due to the rotation of the magnetization vectors as the external field is increased. The shapes of the curves result from the fact that some domains are more favorably oriented with respect to the applied field direction than others. In many materials, attempts are made to order the system and increase the percentage of domains having this preferred axis aligned with the direction of ultimative magnetization and use.

In general, the principal action in low coercive force magnet materials is a shifting of the domain boundaries. In the early steel magnets coercive force is generally explained on the basis of producing strain in the crystal lattice which impeded the movement of domain boundaries. In the Alnico family the action is one of domain wall movement with low values of applied field and as the field is increased the magnetization vectors of the domains are actually rotated against the forces of anisotropy. In other words, if the domains have a preferred direction of magnetization with respect to the crystal lattice or with respect to their shape, external energy is necessary to rotate the magnetization vector into the direction of the applied fields.

Permanent magnets have been made from particles of single domain size. In such a system there are no domain walls since from the viewpoint of the potential energy associated with the domain there is a critical size below which domain boundaries cannot exist. In such a magnet the external field directly opposes the forces of anisotropy.

Recent advances make it possible to control the shape of these single domain volumes and when properly aligned and spaced in a composite magnet, volume properties as good as those of the Alnico family can be obtained with promise of vastly superior permanent magnets as this new technology is developed.

Fundamentally, the properties of permanent magnets appeared to be governed by the following.

1) Saturation induction of the domain (chemical composition).
2) Shape of the domains.
3) Spacing of the domains.
4) Orientation or ordering of the domain system.

Ability to control and change the unit building blocks and their arrangement offers tremendous possibilities in the designing of permanent magnet devices.

The mechanism of using the permanent magnet to establish external field energy is shown pictorially in Fig. 1. In Fig. 1(a) the external observation is of a demagnetized volume because the domains, although each is fully magnetized, satisfy the minimum energy requirements by taking position to form closed magnetic circuits within the material. In Fig. 1(b), under the influence of a high external field, the domains are rotated against the forces of anisotropy into the direction of the field. In terms of the hysteresis loop area $OABs$ represents the work done or energy extracted from the magnetizing source for a unit volume. In Fig. 1(c), as the field is reduced to zero, a residual flux remains representing a new minimum energy balance point. As the size and orientation of the domains has shifted, a new balance among the three potential energies occurs after the external field influence is removed. Area $OABr$ represents the energy returned from the magnet to the electrical circuit. In Fig. 1(d) a gap is introduced at each end of the magnet and the domains near the ends change their orientation due to the unbalance created by the gap and take up a position essentially 180° from the original direction in Fig. 1(c). It is this influence that gives rise to the negative magnetomotive force OH. Area ODT is proportional to potential energy in the external gap on a unit volume basis. In order to move the operating point from Br to D, additional energy input is required. In this case, the mechanical energy was necessary to introduce the gaps in the system. Area $ODBr$ is proportional to the total potential energy increase of the magnet and its external field. Area ODT is proportional to the potential energy stored in the external field and area $BrDT$ represents the potential stored energy within the magnet itself. With reference to Fig. 1(e), suppose the poles are allowed to contact the magnet faces reducing the gap to zero. Mechanical work will have been done and the operating point will move from D to S. The domains near the poles will revert back to nearly their same orientation.

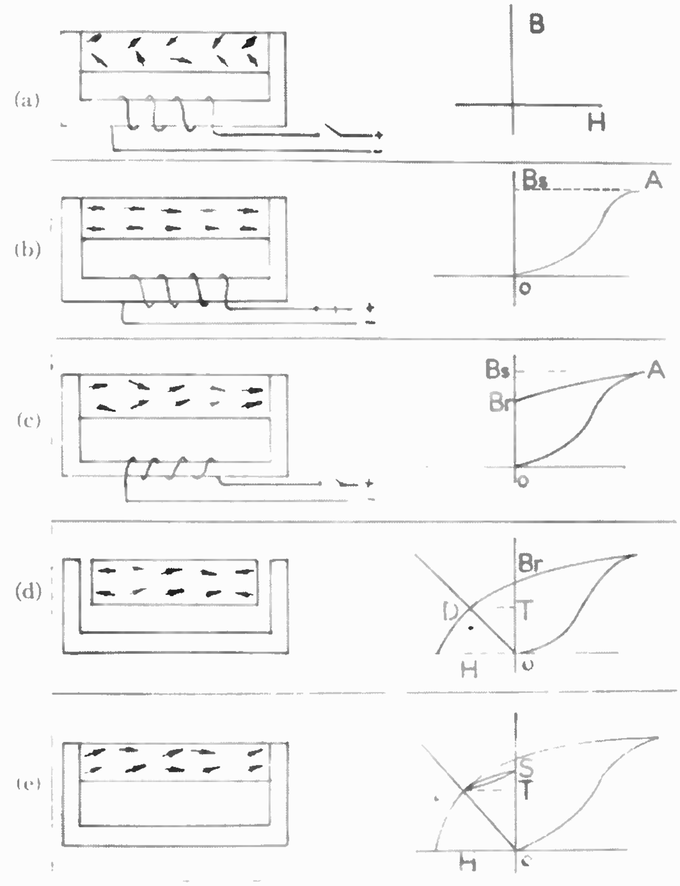


Fig. 1—Pictorial description of basic physics of the permanent magnet.

The potential energy in the external field and in the internal magnet system will be reduced and mechanical work will have been done. As the magnet cycles back and forth a minor hysteresis loop will be traced. In this service the magnet and its external field act as a system for alternately storing and releasing energy as the demagnetizing influence of the poles is changed.

Selecting the Permanent Magnet Material

Fig. 2 shows demagnetization and external energy product contours for widely used permanent magnets. Generally speaking, in audio considerations the energy product is the most significant criterion of a permanent magnet. In order to improve the fullness of the demagnetization curve ordering of the elementary magnet volumes has been used in many of the present-day magnets. Fig. 3 is a photograph of the crystal structure of Alnico 5 directional grain material. In this instance, by controlling the flow of heat during casting the crystal structure is oriented. Crystal edges are parallel over a large per cent of the magnet volume. During heat treatment an external field applied in the same direction as the parallel crystal edges is influential in aligning the domains in the same axis. The demagnetization curve of a highly ordered system of domains is essentially rectangular and with reference to Fig. 1(d) area *ODT* is a high per cent of the area *ODBr*, which means that as the self-demagnetization influence of the poles is encountered nearly all of the increase in potential energy of the system exists in the external field. This results in maximum volumetric efficiency for fixed gap devices.

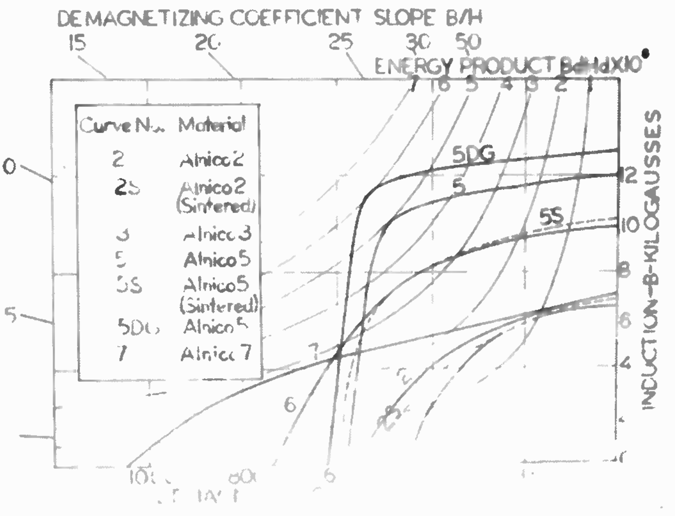


Fig. 2—Demagnetization and energy product curves.

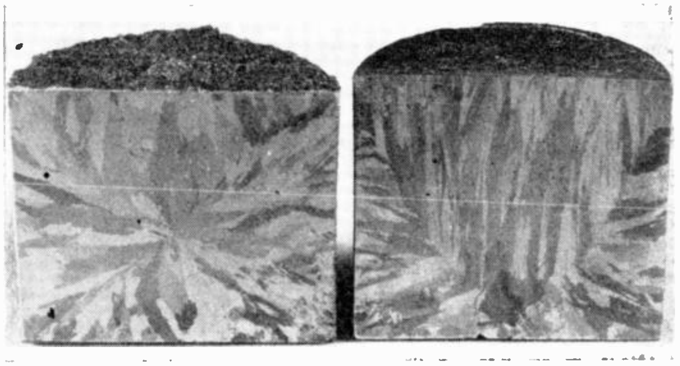


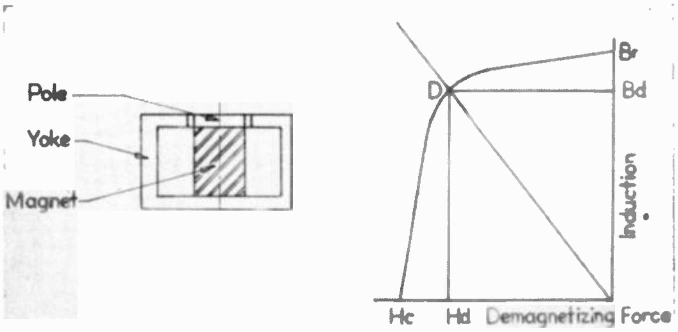
Fig. 3—Oriented crystal structure of Alnico 5 directional grain.

In applications involving the storing and releasing of potential field energy over an operating cycle (variable gap or external demagnetizing influence), linear demagnetization curves in which area *ODBr* of Fig. 1(d) is large in respect to area *ODT* offer the most efficient arrangement. In such a system the external energy product is not necessarily a significant criterion of permanent magnet performance.

Relating Permanent Magnet Properties to Audio Device Performance

Moving Coil Dynamic Systems

Moving coil dynamic systems constitute the largest category of usage of the permanent magnet in audio devices. The dynamic speaker is the largest volume application of permanent magnets in this country and essentially all loudspeakers use a permanent magnet. The characteristics of no power consumption, reduced hum, and lower installation costs are widely recognized advantages of the permanent magnet over electromagnetic excitation in speakers. Consider Fig. 4(a), the arrange-



(a) (b)

Fig. 4—The magnetic structure of the dynamic speaker.

ment of a typical permanent magnet and return path used in the loudspeaker, and Fig. 4(b), the demagnetizing curve of the permanent magnet material. In order to relate speaker performance to the magnet properties, consider the fundamental design equations of the permanent magnet in which the rise of magnetic potential is equated to the drop across the gap and the total flux in the magnet is equated to the flux in external space.

$$LmHd = LgHg \qquad (1)$$

where

Lm = magnet length (cm),
Lg = gap length (cm),
Hg = gap potential/cm,
Hd = magnet potential/cm.

$$AmBd = AgBgF \qquad (2)$$

where

Am = magnet area square centimeter,
Bd = magnet flux density,
Ag = gap area,
Bg = gap density,
F = leakage factor = total permeance/useful permeance,
$Bg = Hg$ (numerically in air gap).

Multiplying (1) and (2), we have $LmAmBdHd = LgAgBg^2F$ or

$$VmBdHd = VgBg^2F \qquad (3)$$

where Vm (magnet volume) $= LmAm$, Vg (gap volume) $= LgAg$, and

$$Bg = \sqrt{VmBdHd/FVg}. \qquad (4)$$

The sound pressure output of a speaker is proportional to Bg and in comparing sound pressure differences the decibel is commonly used. For a given configuration the change in sound pressure is related to gap density, magnet volume, and energy product by

$$\begin{aligned} \text{decibel (db)} &= 20 \log_{10} Bg_1/Bg_2 \\ &= 10 \log_{10} (BdHd)_1/(BdHd)_2 \\ &= 10 \log_{10} V_1/V_2. \qquad (5) \end{aligned}$$

From (3) the gap energy is proportional to the volume of the magnet and its external energy product and inversely proportional to F. The design problem in speakers is primarily one of arranging the magnetic circuit so that maximum total available energy is established for a given volume, and then arranging the exposed surfaces and circuit configuration to keep F to a minimum so that a high percentage of the total external energy exists in the gap. Each permanent magnet material has an optimum ratio of Bd/Hd (demagnetization coefficient). The selection of this ratio can be made from an inspection of Fig. 2. A line through the origin having a slope such that it intersects the demagnetization curve of a given material at the point of maximum BH product as indicated by the energy contour lines will represent the optimum Bd/Hd.

High gap densities are desirable in the speaker since the conversion efficiency of the speaker is a direct function of gap density. With the extreme case of zero gap density all the power input would be dissipated as heat in the voice coil and no sound power output would result. With a high value of gap density the voice coil moves as current flows in it and a counter electromotive force is established limiting the energy loss in the voice coil and allowing mechanical or acoustic output. Present-day magnetic materials limit the gap density to about 15,000 gauss. Table I lists performance data on commonly used magnet configurations for speakers. Magnet weight, gap density, gap energy expressed in ergs, magnetic efficiency, and gap ergs per ounce of magnet are listed for each standard voice coil group.

Four basic arrangements are used.

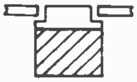
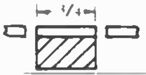
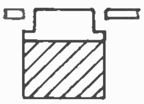
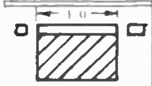
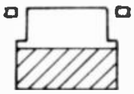
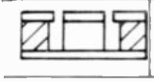
1) Pole stem permanent magnet material extending into top plate.
2) Standard RETMA magnets with stepped pole piece.
3) High efficiency cylindrical pole piece arrangement.
4) Ring magnets.

The design arrangement chosen depends primarily on the magnitude of gap density required. Pole stem and high efficiency arrangements allow limited concentration of the flux near the gap and the present operating densities of commercially available magnets yield gap densities of the order of 5000–7000 gauss.

The standard magnet series while laid out to cover a range gap density 6000–10,000 gauss finds widest application in the higher gap density requirements. The ring structure allows the magnet area to be independent of the voice coil diameter and allows considerable flux concentration in the top plate and gap densities of the order of 15,000 gauss are obtainable. The circuit efficiency is lowest in the ring arrangement due to the placement of the magnet with respect to the gap.

Magnet weight is to a large extent widely accepted as a criterion of speaker performance. As new permanent magnet materials and arrangements appear, the necessity of having a more realistic measure of performance

TABLE I
LOUDSPEAKER MAGNETIC STRUCTURE DATA

Structure	Gap Volume cm³	Gap Energy Ergs	Type	Magnet Weight Ounce	Gap Density Gauss	Efficiency
	0.134	0.11×10⁶	Pole Stem	0.5	4500	35%
	0.134	0.23×10⁶	RETMA 1	0.68	6600	50%
		0.30×10⁶	RETMA 2	1.00	7700	50%
		0.40×10⁶	RETMA 3	1.47	9100	50%
	0.240	0.40×10⁶	High Efficiency	1.0	6500	65%
	0.240	0.52×10⁶	RETMA 4	1.47	7400	50%
		0.68×10⁶	RETMA 5	2.15	8400	50%
		0.95×10⁶	RETMA 6	3.16	10300	50%
	4.98	0.94×10⁶	High Efficiency	2.5	7600	65%
	4.98	1.10×10⁶	RETMA 7	3.16	7600	50%
		1.60×10⁶	RETMA 8	4.60	8900	50%
		2.30×10⁶	RETMA 9	6.80	10800	50%
	4.98	[illegible].80×10⁶	Ring	14.0	12000	35%

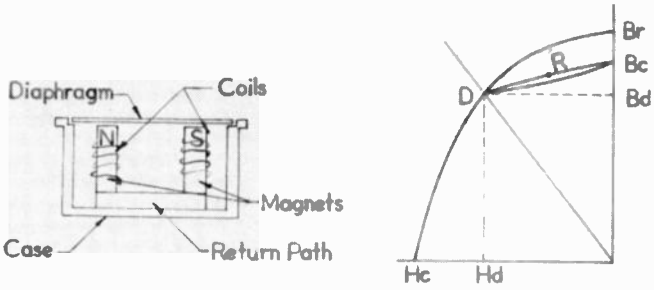
▨ Permanent Magnet Material ▭ Soft steel

is felt. The gap energy values are a more fundamental index of performance and undoubtedly will be accepted in specifying the magnetic structure of a speaker.

Moving Armature Systems

Fig. 5(a) illustrates the usage of the permanent magnet in moving armature systems, another broad category of audio devices employing the permanent magnet. In this arrangement a thin ferromagnetic diaphragm is placed over the poles of the magnet. On the poles are coils. The diaphragm is supported a few thousandths of an inch from the magnet and experiences an attractive force. When current flows through the coils in such a direction as to add to the magnet flux the diaphragm moves closer to the poles. When the current is reversed the pull is reduced. When an alternating current of audio frequency is applied to the coils the diaphragm motion results in sound power output.

To link the permanent magnet properties with device performance, reference is made to Fig. 5(b). The demagnetization curve and its air gap characteristic line are shown. With no signal applied, the magnet configuration and gap between poles and diaphragm result in magnet operation at point *D*. If the current allows the magnetomotive force contributed by the magnet to decrease then the flux density in the magnet will increase from *D* to *R*. The location of *R* depends on the product of current and turns involved, and the slope of the minor hysteresis loop. The force on the diaphragm will be proportional to the sum of the flux density originally contributed by the permanent magnet and the increase due to the current squared. Mathematically, the deflection change may be expressed as



(a) (b)

Fig. 5—The moving armature system.

$$\text{(d) deflection} = K(Bd + Ci)^2 = KBd^2 \qquad (6)$$

where

K = a constant,
d = deflection of diaphragm,
c = slope of minor hysteresis loop,
i = current.

Rewriting the above expression for deflection,

$$d = KB_dCi + KC^2i^2 = KCi(Bd + Ci). \qquad (7)$$

Since B_d is large compared with Ci, the approximate deflection charge may be written $d = KCB_di$.

The contribution of the permanent magnet in terms of deflection is apparent since without it the deflection would be only due to Ci. In selecting a permanent magnet for this usage magnets with high values of residual (Br) are popular. Since due to the nature of the permanent magnet high values of C are somewhat in conflict with high Br the best criterion is perhaps the product of Br and C. Another aspect of this problem is that to operate the magnet at high induction usually requires appreciable length of permanent magnet, and for a given amount of ampere turns the change in magnet magnetomotive force as plotted on the demagnetization curve will vary inversely with the magnet length.

THE ELECTRICAL ANALOG OF THE PERMANENT MAGNET

Permanent magnet circuit analysis by its very nature is cut and try and considerable time and effort is involved in optimizing a permanent magnet configuration. As an aid in exploiting new permanent magnet materials and circuit arrangements to utilize them most effectively, an electrical analog approach has been developed. Fig. 6 shows the basic electrical analogy of the permanent magnet.

In the interest of simplicity a linear demagnetization curve for a single cubic centimeter of permanent magnet material is shown in Fig. 6(a) with the assumption that

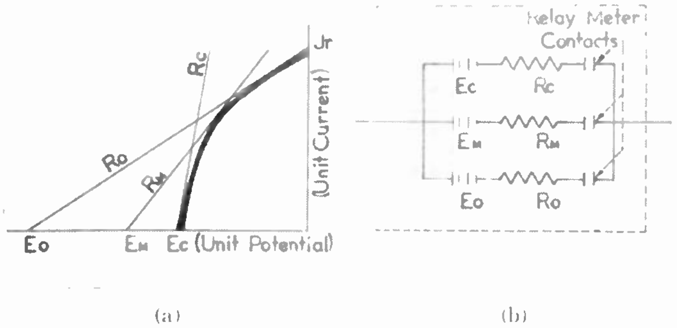
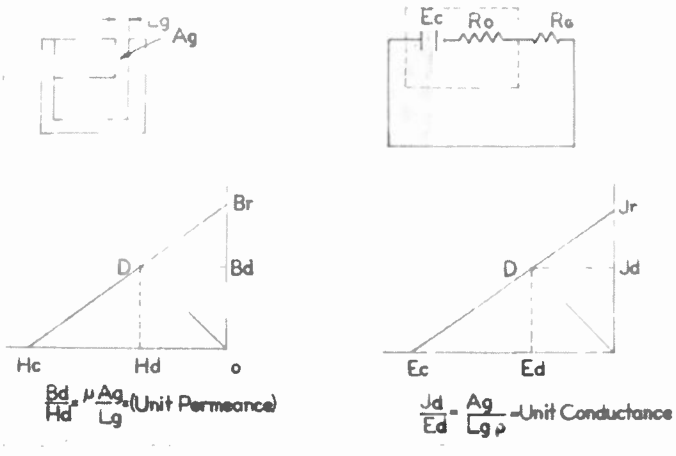


Fig. 6—The basic electrical analog of the permanent magnet.



$\frac{Bd}{Hd} = \mu \frac{Ag}{Lg}$ = (Unit Permeance)

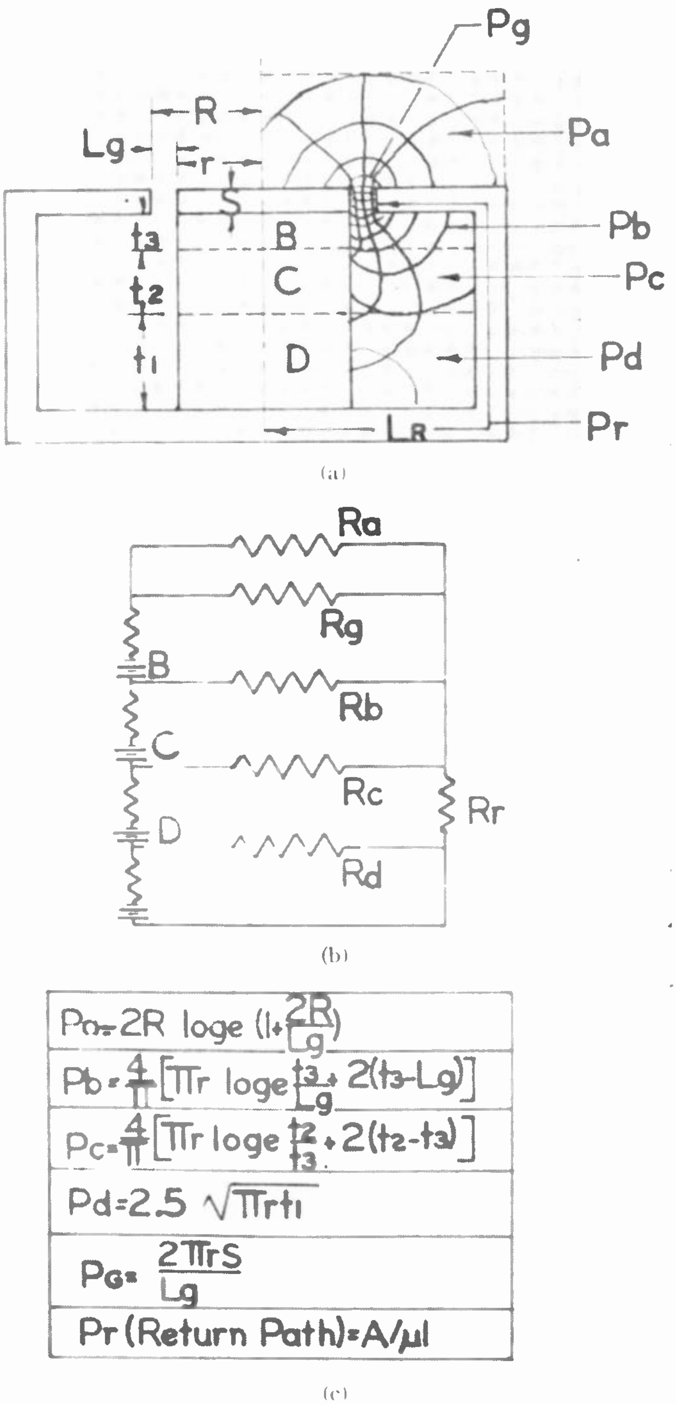
$\frac{Jd}{Ed} = \frac{Ag}{Lg\rho}$ = Unit Conductance

Fig. 7—The electrical analog of the demagnetization curve.

all the circuit permeance is in the air gap. Fig. 6(b) shows the electrical network representing this arrangement.

Since the demagnetization characteristic was assumed to be a straight line it may be represented by a linear resistance $R_0 = Ec/J_r$. In this case Ec represents the coercive force and J_r the residual flux density. The electrical analog of permeance is conductance (G) and is expressed as $A/L\rho$ where ρ is the resistivity. As convenient quantities 1 volt may represent 1000 oersteds and 1 amp 10^6 lines of flux. So that the resistivity of space becomes 1000 ohm/cm³ and permeance values may be converted into values of resistance, the reciprocal of conductance by the following relationship, $R = 1/G = 1/P \times 1000$.

In order to have a useful analog system one must be able to set up nonlinear B-H relationships and Fig. 7 shows how three constant voltage sources and linear resistances are used with predetermined switching to allow the simulation of any permanent magnet material. R_0 is tangent to the curve at Br and Rm is tangent at the maximum energy point with Rc tangent at the coercive force point. Contact making relays switch from one element to the next as controlled by the current in the network. Fig. 8(a) and 8(b) shows how a speaker magnet structure is zoned and the leakage permeance lumped to simulate magnet operation. Meters calibrated in terms of B and H allow the metering of gap density, leakage flux for each zone, and the flux density at each zone inside the magnet. Easily changed electrical components permit rapid change of unit properties and geometry. The zoning of the magnet and its leakage field allows considerable accuracy in that the effective magnetomotive force is associated with each zone and an ac-



$P_a = 2R \log_e \left(1 + \frac{2R}{Lg}\right)$

$P_b = \frac{4}{\pi}\left[\pi r \log_e \frac{t_3}{Lg} + 2(t_3 - Lg)\right]$

$P_c = \frac{4}{\pi}\left[\pi r \log_e \frac{t_2}{t_3} + 2(t_2 - t_3)\right]$

$P_d = 2.5\sqrt{\pi r t_1}$

$P_G = \frac{2\pi r S}{Lg}$

P_r (Return Path) $= A/\mu l$

Fig. 8—Equivalent electrical network of the dynamic speaker structure.

curate integration of magnetomotive force around the circuit results. Fig. 8(c) shows the mathematical expressions for permeance for the zones involved. For commonly encountered dimensions the leakage permeance or equivalent resistance can be plotted as a function of geometry. Once the network representing a particular permanent magnet and its external field is set up, the influence of external fields and interior loop operation can be conveniently studied by applying a voltage representing the magnitude of the influence.

Perhaps the greatest value of this analog approach is that it represents an orderly system of organizing performance data calculated or measured as a result of experience. These data are broken into increments which can be assembled in various ways to predict the performance of new permanent magnet systems.

CONCLUSION

The permanent magnet and its external field represent a unique system for changing the state of energy. Specific relationships between the external field and the induction for a given application service are desirable. Ability to isolate and control the nature of the elementary building block of the permanent magnet promises to make available superior permanent magnets with unlimited design possibilities. As an aid in understanding and predicting the performance of a given permanent magnet in a magnetic circuit, the use of electrical analogs offers great convenience and flexibility.

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Correspondence

Push-Pull Audio Amplifier Theory*

I have read Melehy's article[1] with interest, but I would like to point out that optimum match conditions may be approached from other points of view.

Thus, for example, the minimum value of load is limited by the condition that plate dissipation shall never exceed its allowed maximum. For class *B* stages this calculation leads to the commonplace equation

$$R = \frac{1}{\pi^2}\frac{E_{bb}}{N_d}$$

with R as load resistance for a single tube and N_d as plate dissipation. In the more general case of *AB* stages, however, an expansion of the analysis is neeeded.

I carried this through and published the results several years ago.[2] According to this calculation quiescent plate currents corresponding to the maximum allowable dissipation are assumed. If the current amplitude I_{max} exceeds the double amount of the quiescent current I_0, the total plate input power amounts to

$$N_i = 2E_{bb}I_0\left[1 + \frac{2}{\pi}(tg\,\phi - \phi)\right]$$

with

$$\phi = \text{arc cos}\,\frac{2I_0}{I_{max}}\cdot$$

The total output power amounts to

$$N_0 = \frac{I^2_{max}R}{2}$$

with R as load resistance for a single tube.

It can be shown by simple differentiation that the condition

$$(N_i - N_0)_{max} = 2E_{bb}I_0 = 2N_d$$

leads to the load value

$$R = 0.116\,\frac{E_{bb}^2}{N_d}$$

and to a maximum theoretical efficiency of 76 per cent with a maximum output of 4.3 N_d.

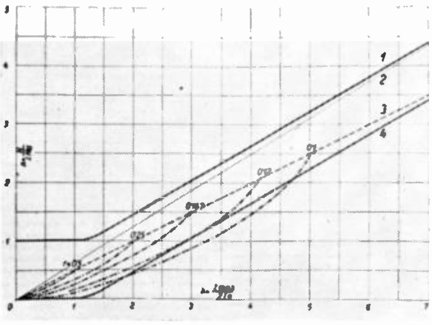

Fig. 1.

A summary of the analysis is displayed in Fig. 1 and shows power relations in dimensionless coordinates.

Curve 1 corresponds to plate input power with maximum quiescent current [*AB*].

Curve 2 corresponds to plate input power with pure *B* conditions. Output powers with different loads are shown as parabolas with the parameter

$$r = \frac{E_{bb}^2}{N_d}\cdot$$

Curve 3 is the geometrical locus for maximum outputs with different loads, and curve 4 is

$$\frac{N_i - 2N_d}{N_d}\cdot$$

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* Received by the PGA February 5, 1958.

[1] M. A. Melehy, IRE TRANS. ON AUDIO, vol. AU-5, pp. 86–89; July–August, 1957.

[2] I. P. Valkó, *Magyar Hiradástech.*, pp. 16–22, December, 1950.

A Wide Angle Loudspeaker of a New Type*

The paper by Pockman and Spragins[1] presents an attack on one of the few remaining distortion problems in sound reproduction. It is remindful of the Bell Laboratories' acoustic perspective equipment used for Walt Disney's "Fantasia."

Even if every other link in the chain of vibration translation and transmitting devices is distortion free, from microphone to

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* Received by the PGA, January 13, 1958.

[1] L. Pockman and J. Spragins, 1957 IRE WESCON CONVENTION RECORD, pt. 7, pp. 45–48.

a perfect loudspeaker cone motion, the directional characteristic of the speaker remains. Its angular radiation varies with frequency, so that nowhere in the sound field is there an accurate presentation of the energies of all the involved sound frequencies.

There appears to be but one type of radiator which will answer this problem, namely, a pulsating sphere.

I too have attacked this problem. My answer, though not quite the theoretically perfect one, will appear soon in a recently allowed patent. In this a dual-cone, electrodynamic speaker is used, concave sides facing one another, with a double-ended polarized magnet pot between. The voice coils are so phased that the cones move in opposite directions. Their convex, outer surfaces form, roughly, a sphere. The inwardly directed radiation of the concave surfaces is absorbed by intervening damping material, with air-breathing precautions.

Tests on such a speaker some years ago revealed almost uniform radiation at all except the very highest frequencies; these fell off somewhat in the general plane of the rim of the two cones. Of course, no baffle of any kind was used, nor is one required for such a radiator.

Since near spherical radiation is involved, the "efficiency" must be lower than that of conventional speakers, but it is believed that this can be tolerated where directional-characteristic distortions in the sound field are almost completely eliminated.

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Paul W. Klipsch (A'34–M'44–SM'45) was born in Elkhart, Ind., on March 9, 1904. He received the degrees of B.S. in E.E. in 1926 from the New Mexico College of Agriculture and Mechanic Arts, State College, N. M., and Engineer in E.E. in 1934 from Stanford University, Stanford, Calif.

From 1926 to 1928, he was affiliated with General Electric Company. He worked in the field of exploration geophysics from 1934 to 1941, when he began a four-year tour of active military duty. He is a lieutenant colonel in the Ordnance Reserves.

Since 1940, he has been engaged in the development of loudspeaker systems, and in 1946, he began their manufacture. He is the owner of Klipsch and Associates, Hope, Ark., and the KLIPSCHORN and SHORTHORN trademarks. He has been listed in "Who's Who in Engineering" since 1937.

Mr. Klipsch, a Fellow of the Audio Engineering Society, is a member of the American Institute of Electrical Engineers, Acoustical Society of America, Tau Beta Pi, and Sigma Xi.

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R. J. Parker

R. J. Parker was born in 1920, in Essex, Vt. He was graduated from the University of Vermont, Burlington, Vt., with the B.S. degree in electrical engineering in 1942.

From 1942 to 1945, he was a member of the General Electric Company Engineering Test Program. Since 1945, he has been associated with magnetic materials and their application at General Electric, and is presently an engineering specialist in the Magnetic Materials Section, Edmore, Mich.

Mr. Parker is an associate member of AIEE and a registered Professional Engineer.

D. W. Robinson

D. W. Robinson was born in London, Eng., on May 22, 1920. He was educated at the Imperial College of Science and Technology and received the Bachelor of Science degree in electrical engineering from the University of London in 1940.

From 1941 to 1946 Mr. Robinson served in the Royal Air Force. After the war he joined Standard Telephones and Cables where he was engaged in research and development work connected with the performance rating of telephone transmission systems.

Since 1950 he has been a member of the staff of the National Physical Laboratory, Teddington, England, where he has been primarily concerned with research in the field of psychoacoustics.

Mr. Robinson is an associate member of the Institution of Electrical Engineers, London.

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