Transactions of the I·R·E

Professional Group on Audio

A Group of Members of the I. R. E. devoted to the Advancement of Audio Technology

November - December, 1953

Published Bi-Monthly

Volume AU-1 **Number 6**

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The Institute of Radio Engineers

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 prescribed assessments.

Annual Assessment: $2.00

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TRANSACTIONS of the I • R • E®
Professional Group on Audio

Published by the Institute of Radio Engineers, Inc., for the Professional Group on Audio at 1 East 79th Street, New York 21, New York. Responsibility for the contents rests upon the authors, and not upon the Institute, the Group, or its members. Individual copies available for sale to IRE-PGA members at $0.90; to IRE members at $1.35; and to nonmembers at $2.70.

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World Radio History

IRE - PGA QUESTIONNAIRE DATA

R. E. Troxel, Chairman
IRE - PGA Committee on Chapters

The IRE-PGA obtained very informative results in its survey of the membership by the questionnaire postal card. Slightly over 600 cards have been returned at this writing, which represents approximately 28% of the total membership.

The summary of the "main interest" column is tabulated below.

	Number of Votes		
	1st Choice	2nd Choice	3rd Choice
High Fidelity	105	89	87
Design	98	70	53
Amplifiers	68	104	70
Hobbyist	59	26	48
Magnetic Recording	56	64	70
Broadcasting	47	18	20
Acoustics	44	53	40
Phonograph Reproduction	39	54	57
Loud Speakers	39	49	64
Microphones	11	32	21

Nearly all of the PGA Chapters were represented in the survey. A tabulation of members reporting from the the various chapters is shown below.

Albuquerque, New Mexico	1
Boston, Massachusetts	24
Chicago, Illinois	23
Cincinnati, Ohio	8
Houston, Texas	7
Kansas City, Missouri	3
Los Angeles, California	12
Milwaukee, Wisconsin	7
Philadelphia, Pennsylvania	30
San Diego, California	8
Seattle, Washington	7

Also, of those returning the cards, 87 were members of the Audio Engineering Society, 58 were members of the Acoustical Society of America, 42 were members of the Society of Motion Picture and Television Engineers, and 9 were members of the Chicago Acoustical and Audio Group.

Of special interest to the PGA Chapters Committee was the significant number of members desiring to become affiliated with a local chapter if one were organized and promoted. Cities showing special interest in this respect are New York City; Washington, D.C.; Toronto, Canada; Baltimore, Md.; Dayton, Ohio; Columbus, Ohio; and Memphis, Tennessee. At this date, some of these Sections are already contemplating organization of PGA Chapters.

All of the above cities have sufficient PGA Members to support local Chapters. The IRE-PGA Chapters Committee will cooperate readily and supply organizational information to any Section or person desiring to promote a new PGA Chapter. Please write to Robert E. Troxel, Chairman, Committee on Chapters, 225 West Huron Street, Chicago 10, Illinois.

REPORT ON STUDY OF CONCURRENT MEMBERSHIP

A. M. Wiggins, Chairman
IRE - PGA Committee on Membership

Recently a comparison has been made of membership lists of the several American societies interested primarily in audio and acoustics. The purpose of the study was to determine whether the membership of the three organizations was largely the same or independent. The results of the study were intended to influence the IRE-PGA policies on publication and other matters. The study reveals the following approximate data:

Total IRE-PGA membership	2000
IRE-PGA members also in Acoustical Society (5.4%)	108
IRE-PGA members also in Audio Engineering (3.4%)	68

All of these figures are subject to continuous revision. In fact the data from the recent IRE-PGA questionnaire do not yield exactly the same indication as the data here. In either case, however, it is clear that the current membership of IRE-PGA is chiefly independent of the two neighboring societies and, consequently, that there is not a substantial overlapping of activities.

Membership in the Professional Group on Audio is a concomitant of membership in the Institute of Radio Engineers. Each Professional Group has a field of interest approved by the Institute Committee on Professional Groups. According to the Constitution for the Professional Group on Audio, Article III, Section I, "The Field of Interest of the Group shall be the technology of communication at audio frequencies and of the audio-frequency portion of radio-frequency systems including the acoustic terminations and room acoustics of such systems and the recording and reproduction from recordings at audio frequencies, and shall include scientific, technical, industrial or other activities which contribute to this field, subject, as the art develops, to additions, subtractions, or other modifications directed or approved by the Institute Committee on Professional Groups."

A clear understanding by the membership of the purpose and organizational plan of the professional group system, data on the relative independence of the membership of IRE-PGA from neighbor societies, and the above definition of the field of interest of IRE-PGA, should assist the membership of IRE-PGA, not only in our own activities and operations but also in friendly cooperation and exchange of technical information with neighbor societies.

ANALYSIS OF READER INTEREST IN TRANSACTIONS

Daniel W. Martin, Chairman
IRE - PGA Editorial Committee

Ten percent of the PGA questionnaire cards returned contained comments and suggestions concerning TRANSACTIONS of the IRE-PGA. These specific, helpful responses from our readers are sincerely appreciated. Together with the larger body of general information contained in the "main interest" data (tabulated elsewhere in this issue), they will influence the policies, plans, and actions of the Editorial Committee.

The most frequent general suggestion was for further expansion of the technical papers section of TRANSACTIONS of the IRE-PGA. The Editorial Committee concurs, and has been working diligently toward that end. The rather slender appearance of the September-October issue was not indicative of our future outlook, and can be attributed to a combination of the following factors:

1. Publication of recent IRE-PGA papers in the CONVENTION RECORD.
2. A new, more compact format.
3. Seasonal reduction.
3. Postponed publication of manuscripts at hand pending necessary approvals.

During the current rapid commercial expansion of the audio field it is increasingly difficult for many of our most experienced authors in audio to find time for the preparation of technical papers. There is greater pressure for "commercial" papers than before and, in addition, they are probably easier to prepare. Your Editorial Committee is trying to meet this problem by more systematic solicitation from known potential authors (which we hope will not lose us friends). At the same time we want to encourage the newer people in the audio field to take advantage of the possibilities of publication of technical papers in TRANSACTIONS of the IRE-PGA. Don't wait to be asked to submit a paper!

Reader comments were much more complimentary than derogatory. If this does not express your viewpoint, "say it where it counts" – to us.

Several have asked why some of the papers from the 1953 Convention have not been published. In three sessions eleven papers were given. All of these were solicited for publication in the CONVENTION RECORD, and five made the deadline. Two more have since been published in TRANSACTIONS. Three authors declined to publish tutorial material which they had presented only by request, and which they had borrowed almost entirely from information published in their own textbooks and handbooks.

Requests were received for abstracts of papers published elsewhere. Your attention is called to the first section of the Abstracts and References department of PROCEEDINGS of the IRE, which, although incomplete, is very helpful along these lines. An attempt is already being made to obtain translations of some foreign audio papers of merit and interest for republication in TRANSACTIONS. Additional suggestions, and especially translations, are welcome. As a matter of information for engineers interested in patents as a source of technical information, many audio patents are reviewed regularly in the JOURNAL of the ACOUSTICAL SOCIETY.

A request was received for a cumulative index for TRANSACTIONS of the IRE-PGA. We are pleased to include such an index in this issue, covering all IRE-PGA material to date. A request for information on audio standards has perhaps been answered already by the current summary in the September-October issue.

With regard to style of technical papers, suggestions for higher standards for articles accepted for publication were matched by requests to "keep it down to earth." These two requirements are not necessarily contradictory.

Suggestions on subjects for future papers were varied. Many were helpful and will be followed up. For obvious reasons we should not attempt to answer the requests for articles on customer guidance, in the purchase of specific brands of equipment. However, the submission of papers similar in approach to the Technical Editorial "Selecting a Loudspeaker," written by Dr. H. F. Olson, is welcomed.

A brief analysis has been made of the types of technical papers and editorials published to date by IRE-PGA, including the present issue. A correlation of the analysis data with the main interest data from the postcard survey follows.

Totaling the first, second, and third place votes for each of the ten categories used for "main interest" yields the second column below. This gives a somewhat different order than is obtained from first choice votes alone, and is justified on the basis that a majority of the readers have a diversified interest in audio which a single choice cannot properly identify.

Each of the technical papers and editorials was classified in the same categories. The results are in column three. In some cases two categories applied. Eight audio papers did not fit into any of the categories listed. Three of these were on electronic music and the others were on audio measurements and measuring equipment.

Main Interest	Total 1st, 2nd, 3rd choice votes	Number of Technical Papers
High Fidelity	281	3
Amplifiers	242	5
Design	221	7
Magnetic Recording	190	8
Loudspeakers	152	16
Phonograph Reproduction	150	7
Acoustics	137	6
Hobbyist	133	1
Broadcasting	85	3
Microphones	64	7

It is interesting to note that all categories are at least represented. The strongest categories of interest are all matched by a reasonable number of papers with the exception of the first one, High Fidelity. Admittedly this is a difficult topic because it is so general. It is subject to various interpretations, and hard to discuss without being proprietary. However technical papers on this subject have been requested recently from two of the most active engineers in the field of high-fidelity system manufacture. If they respond, their papers will receive prompt publication. A comprehensive paper on power amplifiers, and two papers on low-level amplifier design problems are scheduled for publication in forthcoming issues.

In conclusion, a quotation from an editorial in the May-June 1953 issue:

"It is the pleasant responsibility of individual IRE-PGA members to be active in these matters, as well as interested. When some new principle or device or concept has been discovered, or when something well known has been re-examined to new advantage, the membership of IRE-PGA will certainly appreciate first chance to hear about it through TRANSACTIONS of the IRE-PGA."

PGA BRIEFS

A meeting of the IRE-PGA Administrative Committee was held in the Ruby Room of the Hotel Sherman in Chicago on September 28. Among the items discussed were the following:

1. Methods of nomination.
2. Report of the nominating committee (publication postponed until acceptances are received).
3. Liaison between Professional Groups and Technical Committees working in the same general area.
4. Annual assessment.
5. Postcard Survey of Membership (reported elsewhere in this issue).
6. Survey of Overlapping Membership (reported elsewhere in this issue).

A Papers Procurement Committee has been formed which has the following membership:

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Cambridge 39, Massachusetts

Melvin Chun
Southwest Research Institute
San Antonio, Texas

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RCA Victor Division
Camden, New Jersey

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Portland, Oregon

V. Salmon
Stanford Research Institute
Stanford, California

W. R. Thurston
General Radio Company
New York, New York

The new Chairman of the IRE-PGA Program Committee is Dr. Winston E. Kock, Director of Acoustics Research at Bell Telephone Laboratories. This committee is in charge of the PGA session at the IRE Convention in March, 1954.

The theme of the IRE-PGA program for the 1954 IRE Convention in March will be "High-Fidelity." Day-time sessions and a panel discussion in the evening are being planned. Papers already lined up for the program are in the following fields of PGA interests: microphones, power amplifier, loud speakers, reproduction of music, psycho-acoustics.

The Société des Radioélectriciens, 10 Avenue Pierre Larousse, Malakoff (Seine), in cooperation with other French technical societies, is planning to hold a Congrès International, de L'Enregistrement Sonore (International Meeting on Sound Recording), April 5-10, 1954. Any PGA members planning to attend will please so advise the president of IRE, Mr. J. W. MacRae.

The new address of the Chairman of the IRE-PGA Tapescripts Committee is

Mr. Andrew B. Jacobsen
1802 N. 47th Pl.
Phoenix, Arizona

Mr. Jacobsen is now associated with the Phoenix Research Laboratory of Motorola, Inc.

The new Publicity Chairman for the Chicago Chapter IRE-PGA,

Mr. Wallace H. Coulter
3023 West Fulton St.
Chicago, Illinois

has given a list of meetings, including those recently held, and those scheduled for the near future, as follows:

October 16	"Stereophonic Sound," William B. Snow, Consultant in Acoustics, Los Angeles, California
November 20	"An All Transistor Hearing Aid," Stanley K. Webster, Beltone Hearing Aid Co., Chicago
December 16	"Recent Advances in Compact Loudspeaker Housing," Daniel Plach, Jensen Mfg. Co., Chicago
January 15, 1954	"Audio Problems Peculiar to Television," George Ives, WBKB, Chicago (Demonstration Trip).

The Dayton, Ohio, IRE Section is engaged in organizing an IRE-PGA Chapter under the guidance of Mr. A. B. Henderson, Vice-Chairman, Dayton Section.

HOUSTON CHAPTER IRE-PGA

L. A. Geddes, Chairman
Baylor University College of Medicine
Houston, Texas

In response to the current enthusiasm for high fidelity sound, the executive committee of the Houston Section of the IRE sponsored two audio meetings. The purpose of the meetings was to examine the interest of the membership with a view to ultimately setting up a chapter of the Professional Group on Audio in Houston.

The first meeting held in November 1952 was unusually well attended. The program consisted of explanations and demonstrations of high fidelity reproducing equipment belonging to various local enthusiasts and members.

Following the demonstrations, the meeting adjourned with an informal get-together. Various members of the audience participated in tests permuting and combining the various pieces of apparatus and evaluating the results.

The success of the first meeting stimulated the executive committee to petition the IRE for permission to form a local chapter of the Professional Group on Audio. However, prior to the formal recognition of the Houston chapter, another meeting was sponsored with a program similar in nature to that of the first.

The second meeting held on May 19th included an election of officers. It was the aim to fully activate the chapter after formal recognition by IRE headquarters.

The program of the second meeting included first a detailed description of folded horn enclosures by D. P. Carlton of Humble Oil Company. Following the descriptions, demonstrations were given of various models of the horns described.

The second part of the program consisted of a PGA tapescript entitled "A Single-Ended Push-Pull Amplifier" by Peterson and Sinclair of General Radio. The tapescript was accompanied by the projection of slides pertinent to the explanation of the operation of the amplifier.

Following the tapescript, Mr. Roy Brougher, IRE Meetings Chairman, demonstrated a modified version of the Single-Ended Push-Pull Amplifier. The demonstration was well received, and much interest was shown in the circuit details.

A message repeater was then demonstrated by Jim Hallenberg, IRE Section Secretary. The message repeater consisted of a miniature tape recorder which repeated any dictated message of less than one-hundred seconds duration.

The Houston chapter of the Professional Group on Audio received recognition from National headquarters July 7th, and plans to hold regular meetings on Audio and allied subjects.

A MINIATURE MICROPHONE FOR TRANSISTORIZED AMPLIFIERS*

B. B. Bauer
Shure Brothers, Inc.
Chicago, Illinois

SUMMARY – A new magnetic microphone has been developed for use in hearing aids and communication and similar equipment which requires a small, light, medium-impedance microphone. The new microphone has a diameter of 1 inch and a thickness of 3/8 inch, and it weighs 9 grams. The sensitivity is high enough to override the relatively high noise level of transistors in the frequency range most useful for voice transmission.

The recent trend toward miniaturization and the use of transistors has created a demand for a microphone suitable for use in portable transmitters, mobile equipment, hearing aids, and the like, with the following combination of characteristics:

1. Small size and weight
2. High output
3. Frequency range suitable for intelligible transmission of speech
4. Satisfactory match to a load in the vicinity of 1000 ohms.
5. Ruggednes and reliability

In appraising these characteristics against the available methods of transduction, it was decided that they would be best fulfilled by a magnetically balanced moving armature structure.

A modified moving armature structure previously used in several military and civilian applications was adapted for this purpose. This structure has had a long production history, but it has not been previously described outside of its U.S. Patent.[1]

The principal structural differences between a conventional moving armature transducer and the new modified form are shown in Fig. 1. The conventional transducer, at the left, has a voice coil which is contained within the pole piece structure. The to-and-fro motions of the armature set up a differential flux through the armature and pole pieces as shown by the dash arrows. This conventional structure is beset by two handicaps: first, the ac flux component travels a relatively long path through the pole pieces which are highly biased by the dc flux component. Secondly, the relatively large volume of the coil surrounded by the pole pieces results in a substantial amount of leakage flux which, in turn, requires the use of heavy cross-section of iron and a large magnet, whereby the size and weight of the structure are adversely affected.

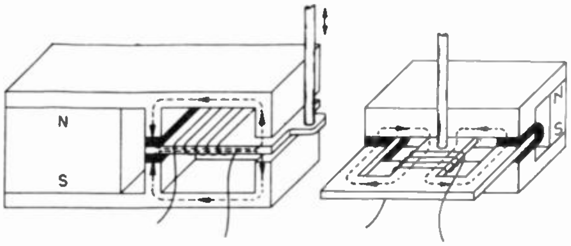

Fig. 1 – Comparison of conventional moving armature structure (left) with the new structure.

In the new unit, at the right, the coil is moved outside the magnetic structure. Therefore, the volume embraced by the pole pieces can be decreased, resulting in less leakage and allowing for a smaller magnet and thinner pole pieces. Additionally, the ac flux path in the pole pieces is shortened considerably.

The magnetic circuit of the new structure is shown schematically in Fig. 2. Stationary gaps at the two side legs taken jointly have a reluctance R_o which is the same as the steady state reluctance R_o of the gap at the moveable center leg. Assuming, for the sake of simplicity, that all the reluctance resides in the air gaps, the equivalent electrical circuit of the magnetic structure is shown at the right hand side. R_o's form the arms of a bridge. ϕ_t represents the total flux due to the magneto-motive force F. ϕ_1 is the flux through the center leg, which in actual practice is surrounded by the voice coil. It is evident, that ϕ_1 is O in the "at rest" position of the armature when the reluctances of the air gaps are equal. When the center leg of the armature moves a distance x to the right, and defining $k = x/d$, the reluctance of the left gap becomes $R_o(1 + k)$ and that of the right gap becomes $R_o(1 - k)$. ϕ_1 can be calculated by the following equations:

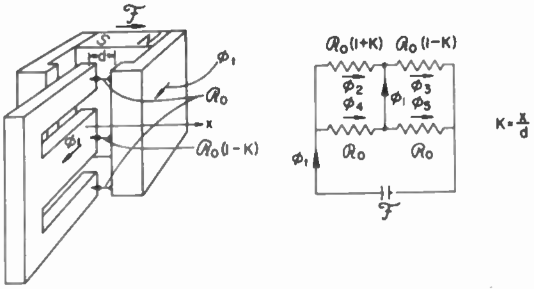

Fig. 2 – Approximate equivalent electric circuit of magnetic structure.

$$\phi_2 = \frac{F\,(2 - k)}{2R_o\,(2 - k^2)} \qquad (k = x/d) \tag{1}$$

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*Manuscript received June 17, 1953. Also published in Journ. Acoust. Soc. Amer., vol. 25, p. 867; September, 1953.

[1] B. B. Bauer, U.S. Patent 2,454,425, November, 1948.

$$\phi_3 = \frac{F\ (2 + k)}{2R_o\ (2 - k^2)} \qquad (2)$$

$$\phi_1 = \phi_3\ \phi_2 = \frac{F}{R_o} \cdot \frac{k}{(2 - k^2)} \approx \frac{F}{2R_o}\ k = \frac{F}{2R_o}\ \frac{x}{d}$$

$$(x << d) \qquad (3)$$

From (3), it is seen that for small motions of the armature, ϕ_1 is directly proportional to the armature displacement. The voltage induced in the coil equals:

$$e = n \frac{d\ \phi_1}{dt}\ x\ 10^{-8} = n\ \frac{F\ 10^{-8}}{2R_o d}\ \frac{dx}{dt}\ \text{volts} \qquad (4)$$

From (4), one might assume that the sensitivity of the structure can be increased indefinitely by increasing the polarizing flux, or decreasing the air gap distance d. It is well-known, however, that this is not the case because of mechanical instability which develops above a given level of polarization. Let us analyze approximately the nature of this instability. The forces F_2 and F_3 at the left and right air gaps of the center leg may be calculated from the equation

$$F_n = \phi_n^2 / 8\pi A$$

Substituting ϕ_2 and ϕ_3 into this expression, the following is obtained:

$$F_2 = \frac{\phi_2^2}{8\pi A} = \frac{F^2\ (2 - k)^2}{32\pi A R_o^2\ (2 - k^2)^2}\ \text{dynes} \qquad (5)$$

$$F_3 = \frac{\phi 3^2}{8\pi A} = \frac{F^2\ (2 + k)^2}{32\pi A R_o^2 (2 - k^2)^2}\ \text{dynes} \qquad (6)$$

and

$$F_1 = -(F_3 - F_2) = -\frac{F^2 x}{16\pi A d R_o^2 \left(1 - \dfrac{x^2}{2d^2}\right)^2}\ \text{dynes} \qquad (7)$$

The net force F_1 is negative because it is opposed to the direction of armature displacement. This gives rise to a negative stiffness S_1 which can be obtained by differentiating F_1 with respect to x. With the armature centrally disposed, the following result is obtained:

$$S_1 = \frac{dF_1}{dx} = -\frac{F^2}{16\pi A d R_o^2}\ \text{dynes/cm.} \qquad (8)$$

Whenever the negative magnetic force F_1 exceeds the mechanical restoring force of the armature, or the negative stiffness S_1 exceeds the positive stiffness of the armature, a condition of instability will result. It is found that the negative stiffness S_1 is related to the voltage generated e by a factor of proportionality which includes the polarizing flux ϕ_t. Therefore, sensitivity and instability go hand-in-hand, and hence, all the factors of the magnetic transducer must be carefully balanced in a manner which must be left to the judgment and the skill of the designer.

The component parts of the microphone are shown in Fig. 3. At the upper left is the E-shaped armature which is made of high permeability material. The two non-magnetic spacers and the Y-shaped drive unit are attached

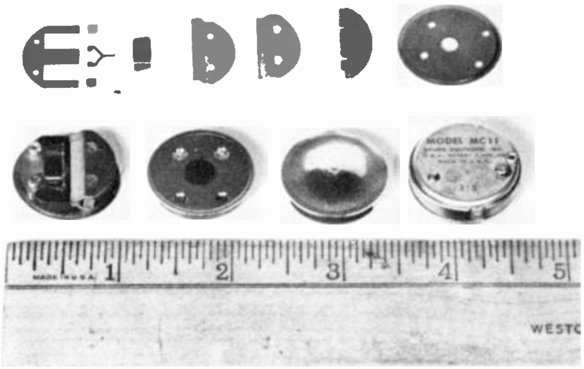

Fig. 3 – Component parts and assembly of magnetic microphone.

to the end of the armature legs after installation of the bobbin. Thereupon, the armature, the two pole pieces, and the magnet are assembled to the circular base plate. At the lower left is the completed motor. Turning it over, we see attached a piece of damping fabric and the drive unit protruding through a hole in the fabric. Lastly, the diaphragm is attached and cemented to the drive unit, and the motor assembly is placed in an aluminum case. The complete structure is 1" diameter, ⅜" thick, and it weighs approximately 10 grams.

The cross section of the microphone is shown at left in Fig. 4 and at right is the equivalent circuit. The sound pressure P_1 enters the front chamber through a

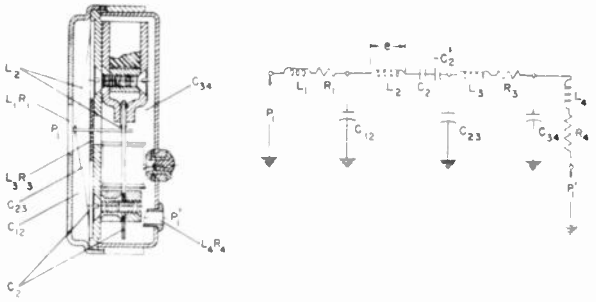

Fig. 4 – Equivalent electrical circuit of the acoustical structure of the new microphone (classical or impedance analogy).

hole in the front cover which defines a resistance R_1 and an inductance L_1. The chamber has an acoustic compliance C_{12}. The diaphragm and the armature have a joint acoustic mass L_2 and acoustic compliance C_2. To this, we must add the acoustic compliance due to the negative magnetic pull $-C_2' = A^2/S_1$, where A is the diaphragm area. The motion of the diaphragm compresses the air in the chamber between the diaphragm and the mounting plate which defines the compliance C_{23}. This causes a flow of fluid through the fabric in the center hole defining an inductance L_3 and a resistance R_3 into the back volume which has a compliance C_{34}. A Thuras type resonator tube defining L_4 and R_4 is used to couple this latter compliance with the outside pressure P_1', and it serves to improve the low frequency response.

The particular unit here described was designed to meet a specification which requires a rise of response at about 3 kc, low frequency response to 400 cps, combined with a minimum volume. Speaking in general terms, the mesh $L_1R_1C_{12}$ provides a resonant rise at 3 kc. The mesh $R_4L_4C_{34}$ provides a rise at around 400 cps, and the central portion of the network provides a slight hump at 1500 cps. The response frequency characteristic typical of production units is shown in Fig. 5. Because the impedance of the voice coil is inductive, the open circuit response has been adjusted to provide a generally rising characteristic so that when the unit is connected to a 1000 ohm load, a slightly rising over-all characteristic is obtained. The output into 1000 ohms is approximately 70 db re 1 volt/microbar which is equivalent to 10^{-10} watts for a 1 microbar signal. This is as much sensitivity as is obtained from many conventional microphones several times the size of this particular unit.

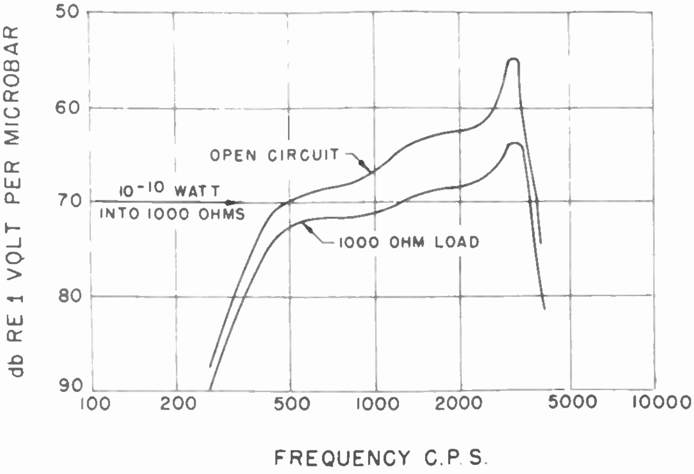

Fig. 5 – Response-frequency characteristic of the new microphone.

CONCLUSION

By suitable proportioning of the magnetic circuit, and by taking advantage of resonant effects in acoustic meshes, it is possible to construct a magnetic microphone which is small, light, stable, and with excellent sensitivity in the frequency range most important for voice transmission.

ACKNOWLEDGMENT

The new miniature magnetic microphone was developed with the participation of Mr. E. V. Carlson and Mr. R. Carr.

A MINIATURE PIEZOELECTRIC MICROPHONE*

John Medill
Shure Brothers, Inc.
Chicago, Illinois

SUMMARY – A new Rochelle salt microphone has been developed for use as a secondary standard in production testing, sound level measurements, high quality transmission of sound, and similar applications. The diameter of the new microphone (1¼ inch) is half the diameter of similar units in current use. Frequency response, directional characteristics, and moisture protection have been improved without a significant loss in sensitivity.

The practical study of acoustics requires that measurements be made. Whether the specific problem at hand involves frequency-response determinations, production testing, ambient noise-levels, reverberation measurements, or any of a host of other possibilities, some type of microphone is required. Some measurements, of course, require a degree of precision which can be obtained only by the use of a primary standard microphone. But such microphones are expensive, and must be very carefully handled and maintained, if their calibrations are to remain accurate.

However, for many applications, a secondary standard microphone is quite adequate. Among the desirable attributes of such a microphone are: (1) uniform frequency response; (2) high sensitivity; (3) high acoustic impedance; (4) small size; and (5) freedom from electrostatic and electromagnetic induction. Other important characteristics are portability, and relative low cost. For many years these requirements have been met by the Shure 98-98 microphone, which has been an accepted secondary standard, and has proved a valuable tool in this field. The purpose of this paper, though, is to introduce the type 98-99 microphone, which embodies many improvements over the 98-98.

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*Manuscript received June, 19, 1953. Also published in Journ. Acoust. Soc. Amer., vol. 25, p. 864; September, 1953.

In Fig. 1 can be seen a photographic comparison of the two microphones, with the newer 98-99 on the right. The smaller size and lighter weight of the new model make it easier to handle and use, in addition to the advantage of its reduced diffraction effects. Model 98-99 also has an improved frequency-response and greater protection against the effects of humidity, which make this model even more useful than was its predecessor.

Fig. 1 – Comparison of 98-98 and 98-99 microphones.

Construction of the 98-99 "cartridge" is shown in Fig. 2. At the extreme left the foil-wrapped crystal, in its mounting bracket, can be seen inside the "cartridge" case, with the drive-arm extending upward from the unsupported corner of the crystal. This crystal is a Rochelle-salt torsion bimorph, and is supported on three corners by its mounting bracket. The second view shows the diaphragm in position, with the drive-arm projecting through its center. Around the outer edge of the diaphragm is a spacer, which provides clearance between diaphragm and damping plate. This damping plate, with damping cloth in place, is shown in the third view, while, at the extreme right, a completed "cartridge", with grille, is shown.

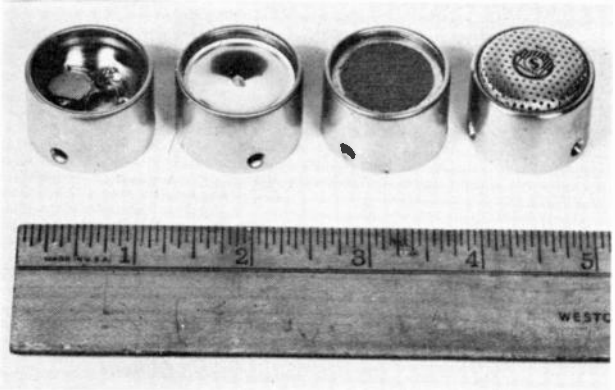
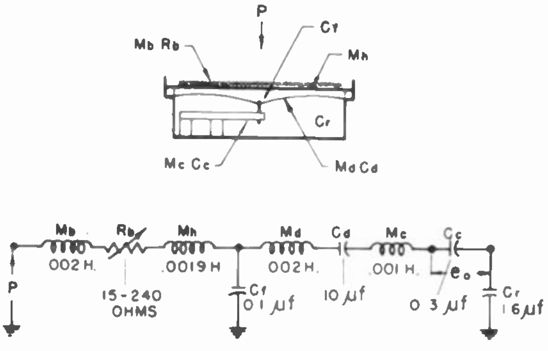


Fig. 2 – Construction of 98-99 microphone.

It should be noted that the design of this microphone is considerably different from the usual crystal microphone, intended for public address and home use. The "cartridge" is a heavy die-casting and the damping plate is of heavy gauge metal, especially intended to eliminate resonances within the frequency range of the instrument.

Without the damping plate, the resonant frequency of the system is about 5 kc. Since a "flat" response is desired, the damping plate is provided with an appropriate resistance, coupled into the diaphragm by the small volume between diaphragm and damping plate. Mechanical constants of the crystal, diaphragm, damping cloth, and the volume between damping plate and diaphragm, are the principal factors which determine the frequency-response of the microphone.

A diagrammatic cross-section and an equivalent circuit of the 98-99 "cartridge," in terms of acoustical constants, is shown in Fig. 3. The diaphragm mass and compliance are respectively M_d and C_d, while those of the crystal are signified by M_c and C_c. The volume of air at the rear of the diaphragm has a compliance C_r. The stress developed in the crystal is represented by the voltage drop E_o across the condenser C_c. If this system were not damped in some manner, it would exhibit a sharp peak at 5 kc. To flatten this peak, the damping plate is installed, providing a damping impedance, and the sound pressure P acts upon the diaphragm through this damping plate. The symbols M_b and R_b refer to the acoustic mass and resistance of the damping cloth. M_h is the mass of air in the damping plate holes, together with end effects. C_f represents the acoustic compliance of the air in front of the diaphragm. By altering R_b, any degree of damping may be obtained.



EQUIVALENT CIRCUIT

Fig. 3 – Equivalent circuit of 98-99 microphone.

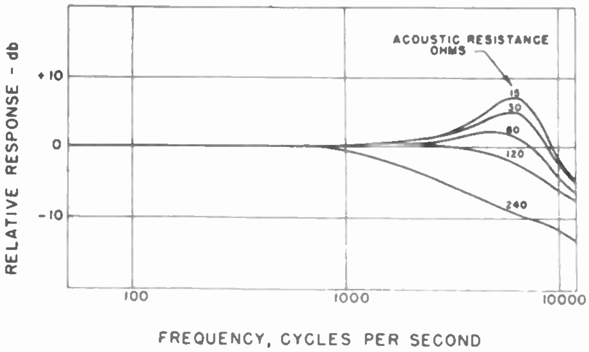


Fig. 4 – Effect of damping-resistance, R_b.

A family of transmission curves, run on an electrical analog of this microphone, is shown in Fig. 4. The numbers 15 through 240 refer to the equivalent damping resistance in acoustical ohms. From the curves can be seen the effect on frequency-response of the various damping resistances used. For instance, with only 15 ohms of damping resistance, the resonant peak is about 8 db high, while a resistance of 60 to 120 ohms provides a substantially flat curve. Actually, the 98-99 model uses damping of 120 ohms; however, the response curve is flatter than that shown in Fig. 4 because of the effects of diffraction, which are best determined by experimenting with the model.

In Fig. 5 is shown the actual frequency-response of the 98-99 microphone, for different angles of sound incidence.

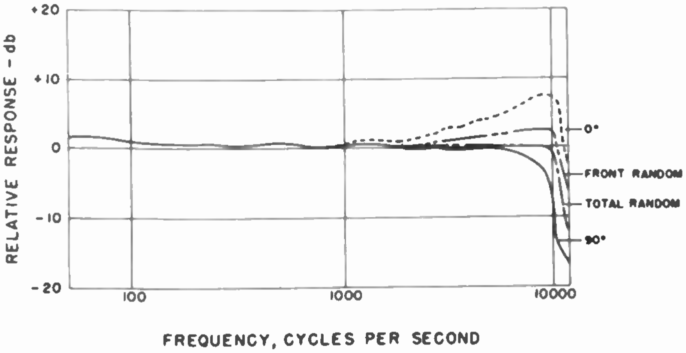


Fig. 5 – Typical response-frequency characteristic of 98-99 microphone.

The dotted line represents the axial response of the unit and exhibits the typical rise at higher frequencies due to diffraction and reflection, while the solid line indicates response at 90° incidence. Also shown, however, are curves of front random incidence response, and of total random incidence response. The front random efficiency is as defined by American Standard Z24.3-1944, Sound Level Meters, etc., and integrates over only the front hemisphere. This response is indicated by the next-to-highest curve. On the other hand, the curve representing total random efficiency is integrated over both the front and rear hemispheres, and hence gives a more accurate indication in a random sound field.

Protection of Rochelle salt crystals from effects of extremes of himidity has always been a problem. In the older Model 98-98, protection of the crystal is accomplished by the use of a special wasing process, which, though complicated, does provide a satisfactory life, even under conditions of high humidity. More complete humidity protection is supplied in the new 98-99 microphone, since it uses a further improvement, a foil-wrapped crystal. A summary of extensive moisture-proofing tests is shown in Fig. 6. In these tests, the crystals, with various types of treatments, were exposed to a constant humidity of 93%, at a temperature of 100° Fahrenheit. This relative humidity was obtained in sealed chambers containing a saturated solution of ammonium dihydrogen phosphate, with an excess of the salt in solid phase. This is a very rigorous method, and it represents a greatly accelerated life test. The wax-protected crystals averaged about 30 hours before reaching a leakage resistance of 1 megohm. The foil-wrapped crystals, after 100 hours exposure, still had leakage resistance in the order of 35 megohms.

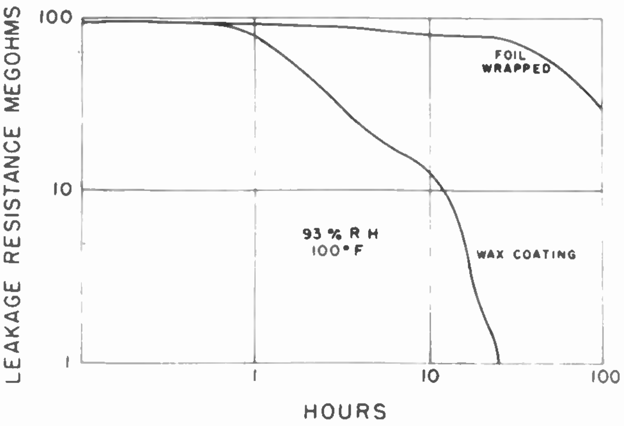


Fig. 6 – Comparison of moisture-protection methods.

Measurements of high sound intensities require that the microphone output be linear with respect to the sound level. Fig. 7 shows the linearity of the type 98-99 microphone, carried out to 10,000 microbars, or 154 db above 0.0002 dynes per square centimeter. It will be noted that the departure from linearity is 1/2 db, which approaches the limit of accuracy of our measurements.

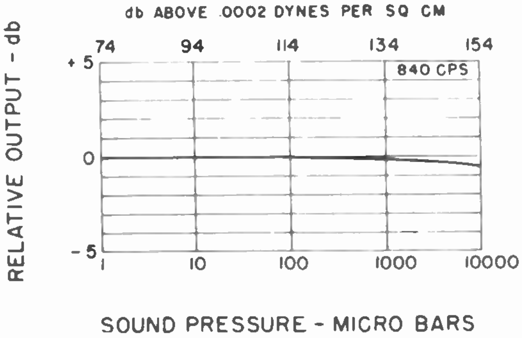


Fig. 7 – Linearity of 98-99 microphone.

An interesting variation of the 98-99 is the general purpose type 777 microphone shown in Fig. 8. As can be seen in the photographs, a somewhat longer handle has been provided, plus several accessories which adapt it for use on a stand. There are some other differences which are desirable from the standpoints of the fields of application of a general purpose microphone. These differences are in such things as diaphragm thickness, damping, and frequency-response. To give a slight "lift" to

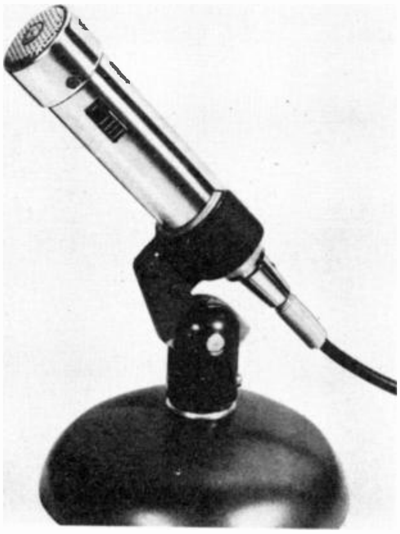


Fig. 8 – Model 777 "Slim-X" microphone, with swivel-type stand.

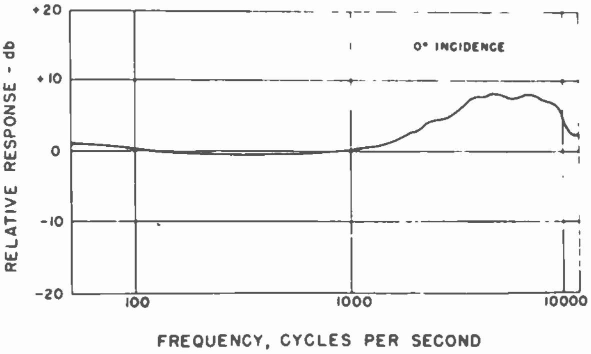


Fig. 9 – Typical response-frequency characteristic of 777 microphone.

the high frequencies, the damping resistance has been reduced to 70 ohms. This results in a rise at high frequencies which has been found of value in public address and communications uses. This is shown in Fig. 9, which is a typical axial response curve of the Model 777 microphone.

ACKNOWLEDGMENT

The author wishes to express his appreciation to B. B. Bauer for his many helpful suggestions in the preparation of this paper.

A LOW-FREQUENCY SELECTIVE AMPLIFIER*

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SUMMARY – A selective feedback amplifier which is useful at sub-audio frequencies is described. It is shown that it has the same characteristic as a simple resonant circuit and that the selectivity is improved by an increase in gain. The measurements on an actual amplifier are presented; they show close agreement with the theory.

INTRODUCTION

At audio and sub-audio frequencies it is highly impractical if not impossible to construct a frequency selective amplifier using inductances. The methods actually used at present utilize either a null network (Wien bridge, parallel T, bridged T, etc.)[1,2] in a negative feedback circuit or a regenerative amplifier[3,4,5] on the verge of oscillation. The first requires inconveniently large components for very low frequencies and the second is extremely sensitive to normal variations in amplifier gain. This paper described a selective amplifier which uses components of reasonable size and which is considerably more stable than a regenerative amplifier.

THEORY

Consider the familiar parallel resonant circuit of Fig. 1. Its driving point impedance is

$$Z = \frac{pL}{p^2 LC + pL/R + 1} \tag{1}$$

---

* Manuscript received August 24, 1953.

** Now with the Ralph M. Parsons Company, Pasadena, California.

[1] G. E. Valley and H. Wallman, "Vacuum Tube Amplifiers," McGraw Hill Book Co., Inc., New York, N.Y., pp. 384-408; 1948.

[2] E. A. G. Shaw, "A Tunable Audio Frequency Amplifier of variable Selectivity," *Journ. Sci. Instr.*, vol. 27, pp. 295-298; November, 1950.

[3] C. C. Shumard, "Design of high-pass, low-pass, and band-pass filters using RC networks and direct current amplifiers with feedback," *RCA Rev.*, vol. 11, pp. 534-564; December, 1950.

[4] O.G. Villard, Jr.; "Independent control of selectivity and bandwidth," *Electronics*, vol. 24, pp. 121-123; April, 1951.

[5] C. H. Miller, "RC amplifier filters," *Wireless Eng.*, vol. 27, pp. 26-29; January, 1950.

Substituting $w^2_o = 1/LC$ and $Q_o = R/w_oL = Rw_oC$ then (1) becomes

$$Z = \frac{pL}{p^2/w^2_o + p/w_oQ_o + 1} \qquad (2)$$

where $p = jw$, w_o is the resonant (angular) frequency and Q_o is the resonant Q.

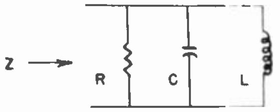

Fig. 1 – Parellel resonant circuit.

Now consider the voltage gain of the circuit in Fig. 2.

$$K = E_o/E_i = \frac{-A_1A_2T_1p}{(1 + A_1A_2)T_1T_2p^2 + (T_1 + T_2)p + 1} \qquad (3)$$

where $T_1 = R_1C_1$ and $T_2 = R_2C_2$. Also, either A_1 or A_2 (not both) can have the negative sign associated with it.

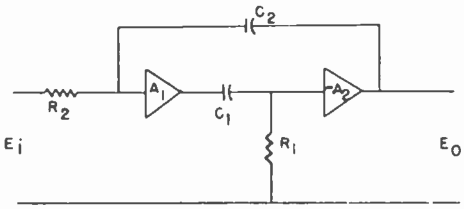

Fig. 2 – Block diagram of selective amplifier.

Notice that (3) has exactly the same form as (2). This means that the gain of the circuit in Fig. 2 has exactly the same frequency characteristic as the impedance of the circuit in Fig. 1. That is, K exhibits the same resonance curve as Z.

By direct analogy to (2), we set

$$w^2_o = \frac{1}{(1 + A_1A_2)T_1T_2} \qquad (4)$$

and

$$Q_o = \frac{\sqrt{T_1T_2(1 + A_1A_2)}}{T_1 + T_2} \qquad (5)$$

If Q_o is differentiated with respect to T_1 (or T_2) and the derivative is set equal to zero, it is found that Q_o has a maximum when $T_1 = T_2$. Setting $T_1 = T_2$ in (5) we get

$$Q_{o\,\max} = \frac{\sqrt{1 + A_1A_2}}{2} \qquad (6)$$

Thus, the selectivity of the amplifier is determined by its gain. To obtain high selectivity, one uses a high gain amplifier and the only practical limits on obtainable selectivity are the practical limits on gain of dc amplifiers.

For maximum selectivity and also convenience, we take $R_1 = R_2 = R$ and $C_1 = C_2 = C$. Also, let $A_1A_2 = A$. Then (3) becomes

$$K = \frac{-ARCp}{(1 + A)R^2C^2p^2 + 2RCp + 1} \qquad (7)$$

and (4) becomes

$$w_o = \frac{1}{RC\sqrt{1 + A}} \qquad (8)$$

Equation 6 becomes

$$Q_{o\,\max} = \frac{\sqrt{1 + A}}{2} \qquad (9)$$

and the gain at resonance

$$K_o = -A/2 \qquad (10)$$

It can be seen from (8) that resonant frequency is dependent upon gain. Because of this, it is possible to get low resonant frequencies merely by making the gain large. On the other hand, the frequency will change as the tubes age – this could be highly unsatisfactory in any application requiring high frequency stability. However, frequency varies as a function of the square root of gain which means that the percentage change in frequency will be less than half of the percentage change in gain. This seems to assure adequate stability for many practical purposes.

DESIGN CONSIDERATIONS

The output impedances of the two amplifiers, A_1 and A_2, must be small compared to R. (Equation 3 is written with the assumption that the output impedance is zero.) This situation is identical to that encountered in ordinary RC coupling: if the grid resistor is too small, the gain of the amplifier is reduced. In the selective amplifier, unnecessary loss of gain should be avoided because of the dependence of all characteristics upon gain.

As with all feedback amplifiers, the possibility of high frequency oscillations must be taken into account. If there are only one or two stages in the amplifier, then oscillations are unlikely. However, if there are three or more stages, oscillation is almost certain and some sort of corrective network is required.

PRACTICAL RESULTS

Fig. 3 shows the schematic of a selective amplifier built according to these principles and Fig. 4 shows the resulting frequency response. The A_1 Amplifier is a cathode follower and thus has a gain of about unity. The A_2 amplifier has a gain of about -650 and has essentially

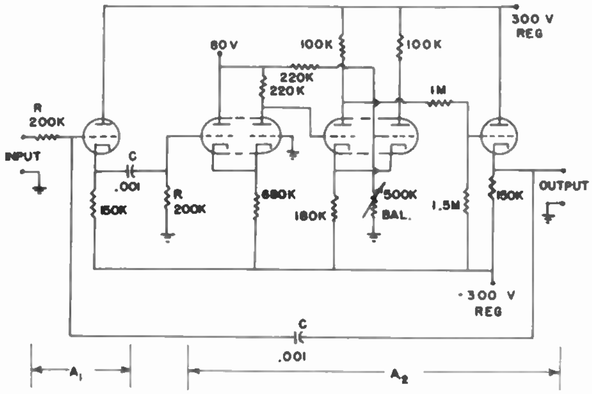

Fig. 3 – Schematic of selective amplifier
(All tubes are 12AX7's).

two stages so that there is no oscillation problem. Cathode followers are used to keep output impedances low.

The values of R and C are 200,000 ohms and 0.001 mf respectively. Since the overall gain is 650, one would expect a Q of 12.5, a resonant gain of 325, and a resonant frequency of 31 cps. The measured Q is 10.5, the measured gain is 303 and the resonant frequency is 29.5 cps. Although these values are close enough to the theory for most practical purposes, the discrepancies are not readily explained.

CONCLUSIONS

A simpler amplifier could certainly be devised. If, for example, amplifier A_1 were to have high gain and A_2 were a cathode follower, most of the difficulties of a dc amplifier (drift, output voltage level, etc.) would be blocked out by the condenser. However, the amplifier shown was readily available so it was used.

The resonant frequency may easily be lowered considerably by using larger values of R and C. For example, if C is increased to 0.01 mf, the resonant frequency would be about 3 cps. Thirty cps was chosen only because measurements are fairly simple to make at that frequency.

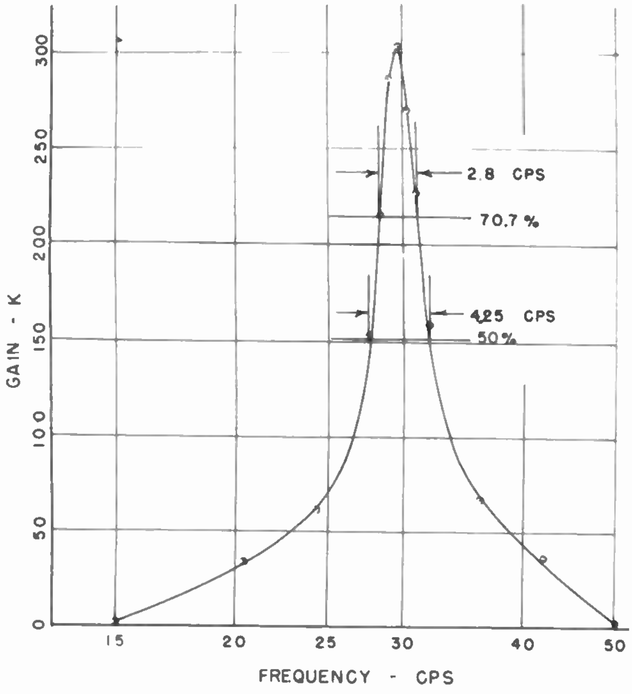

Fig. 4 – Frequency response of selective amplifier.

To obtain higher selectivity, it would seem to be advisable to cascade several networks of moderate Q rather than to construct a dc amplifier of extremely high gain. This is partly due to the great difficulties encountered with high gain dc amplifiers but also, since the selectivity is only proportional to the square root of gain, one rapidly reaches the point of diminishing returns when increasing gain.

ACKNOWLEDGMENT

The author wishes to take this opportunity to acknowledge the advice and assistance of Dr. G. H. Fett of the University of Illinois in the preparation of this paper.

* * *

STEREOPHONIC RECORDING EQUIPMENT*

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SUMMARY – The normal individual has no more than two ears (unfortunately, sometimes only one, putting him at a stereophonic disadvantage), and so it was at first erroneously believed that only two channels need be used for stereophonic reproduction. Earphone listening, binaurally, has certain deficiencies, except for certain subjective listening studies. Loudspeaker reproduction reaches more people at a given time, and corrects some of the deficiencies of listening through earphones. However, room acoustics problems, not present when earphones are used, enter here. An optimum minimum of three channels for loudspeaker listening has been established by comparative listening tests. Electrical phasing, time phasing, and balanced loudness between channels are necessary for the maximum realization of the benefits of a stereophonic system. Minimum harmonic and intermodulation distortion obviously aids any system. Transmitted band width has an effect on realism also.

It has been stated that the distinguishing characteristic of man is his ability to communicate his thoughts to another. Man has progressed through the successive stages of communicating over distances from whispering, talking, yelling, wig-wagging, heliographing, telegraphing, telephoning, wirelessing and aural-broadcasting to televising. It is inevitable that now, since he has transmitted instantaneous pictures, he should go back a bit to do something more than merely transmit intelligence. We come, then, to the refinements. The Session on Binaural Broadcasting concerns itself with a means of reproducing sound more faithfully than before.

The title of the session uses the adjective "binaural." This paper uses the adjective "stereophonic." For a clearer understanding of the question perhaps some lexicography is in order. "Binaural" is defined by Websters' Unabridged Dictionary as "Having or relating to two ears; involving the use of both ears." This, then, is purely a subjective term relating to one's innerself. "Stereophonic" is defined as "Giving a three-dimensional effect of auditory perspective; of sound reproduced." This word, then, is an objective term, relating to something perceived externally to one's self, like perhaps a stereoscopic picture. "Binaural" is from the Latin, meaning "two-eared." "Stereophonic" is from the Greek, meaning "solid sound." Perhaps we should say that we use our *binaural* sense to perceive sound *stereophonically*, or in auditory perspective.

In fact, this very term, *auditory perspective*, was used throughout the six papers,[1] written by members of the Bell Telephone Laboratories, reporting their research preparatory to transmitting the sound of the Philadelphia Symphony in auditory perspective from Philadelphia to Washington, D.C. in 1933. The orchestra performed in Philadelphia, and the sound was picked up by three microphones, transmitted over three separate channels, and reproduced over three separate loudspeaker systems on the stage of Constitution Hall. This transmission was the demonstration of the results of their research into this fascinating business of increased realism in reproduction.

Just now are we becoming publically aware of the possibilities of stereophonic reproduction. This time lag is probably due to several factors. 1933 was a depression year. Such demonstrations cost money. Constitution Hall, though packed for the occasion, could accommodate only a fraction of the total population who might be interested. Only since World War II have we had the means at hand of easily, cheaply, and simply recording more than one channel at a time, by the use of tape recording. It should be pointed out that multi-channel tape recordings of music pre-dated the recent interest in multi-channel broadcasting. Some of the first of these recordings were made at the Summer Music Camp at Interlochen, Michigan in 1951. Subsequently, two-channel broadcasts were made in Chicago and New York. More recently Standard Oil of California sponsored a series of two-channel delayed broadcasts at San Francisco. Currently NBC has a weekly two-channel program at Chicago billed as stereophonic. Several other AM-FM broadcasts have been made in various parts of the country.

The tape recordings at Interlochen were made with two closely-spaced microphones (about 8 inches apart) on two separate channels and were to be listened to by means of earphones. A switch was provided to feed one of the two channels to both earphones, ignoring the other channel, to simulate monaural conditions for comparison purposes. When the switch was thrown to give the two-channel effect, it was startling, to say the least. One seemed to be in the midst of the orchestra. And it recalled to mind the two-eared, hydrophone listening used aboard submarines in World War I, and the Bell Laboratories Oscar exhibit at the World's Fair in Chicago in 1933.

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*Manuscript received September 14, 1953. Simultaneous publication with AIEE, with permission. Presented at AIEE meeting, Atlantic City, June 16, 1953.

[1] *Elect. Eng.*, vol. 53, no. 1; January, 1934.

This exhibit is now housed at Chicago's Museum of Science and Industry. To refresh your memory, Oscar was a life-sized dummy with two microphones hidden in his head at the normal ear locations. He was enclosed in a glass-walled room, so that all could see the lecturer walk around Oscar. Several pairs of earphones were available to observers outside the room. They wore these and could both see and hear where the lecturer walked with respect to Oscar. The various auditors seemed acoustically to be where Oscar stood. But the curious point was that Oscar had his back to the audience. This, the lecturer explained, was because, as he walked behind Oscar while talking, he appeared aurally to be walking behind the auditor. And when he walked in front of Oscar, he still appeared to be walking *behind* Oscar! This was a paradox. The eyes said "yes," but the ears said an emphatic "*no.*"

Now this condition was again evident when one listened by means of earphones to an orchestral recording. The sound which should have been in front of the listener was perceived to be all around him, or behind him. Thus we came to the inescapable conclusion that we should reproduce the sound by means of a multiple loudspeaker system, which would definitely help the auditor to localize the sound in front of himself where it logically should be. Here was this subjective "binaural" listening, as contrasted to the objective "stereophonic" reproduction.

Recalling the earlier experimental work back of the Philadelphia-to-Washington transmission, we found that the researchers had explored many of the parameters involved. Using separate transmitting and listening rooms, they had tried listening tests using two, three, four and more separate channels. They also tried dividing the output of two microphones to three loudspeakers, and of three microphones to two loudspeakers. Phasing and loudness tests were made. The following conclusions were reached:

1. One channel gave no lateral information, but *did* yield some depth information, due to loudness changes and increased reverberation as microphone-to-source distance increased.
2. Two channels gave fair lateral judgment, but poor depth determination.
3. Three channels gave good depth information and good lateral information by filling in at the center.
4. Four or more channels gave but little more information than the three-channel system, laterally or depthwise. Therefore they concluded that the three-channel system was the optimum minimum number of channels to be used for best results.
5. Borrowing from another channel (i.e. three microphones to two loudspeakers, or two microphones to three loudspeakers) was only a little better than the two-channel system and not nearly so good as the three-channel system.
6. Proper phasing of all channels was a necessity to avoid cancellation effects.
7. Varying the relative loudness between channels made the source appear to move toward the louder reproducing point.
8. Microphone placement must be in relation to loudspeaker placement.

Ampex began the commercial production of multitrack tape recorders about three or four years ago for those interested in recording telemetered information from guided missiles and the like. These equipments provide any number of simultaneous channels up to fourteen. It was a simple step, therefore, to make stereophonic tape recorders with two or more channels. In reviewing the literature, and our prospective customers' needs, we have built both two-track and three-track machines. The two-track units have been used primarily in the industrial field, where one is definitely planning to use the equipment for the purely investigative purposes of localizing and subjectively analyzing sound sources, or making sounds subjectively appear more realistic. This is accomplished primarily by means of two earphones, and only rarely by means of two loudspeakers. One track is often also used for quantitative measurement, while the other is used for running commentary. The three-track units have been used primarily where sound is to be reproduced by means of a loudspeaker system. Obviously, one may use only two tracks if he wishes to use earphones. When using loudspeakers, the problem of listening-room acoustics is all important, and must be taken into consideration, but this is beyond the scope of this paper.[2]

In recording multi-channel sound for later reproduction, we have not only verified all of the findings of the Bell Labs. experiments of twenty years ago, but we have also run into one other problem. Since the Bell Labs. experiments were all concerned with instantaneous transmission of the original sound, time lag effects between channels were not factors. A recorder, basically, is a time storage device. In delaying time we find that we must delay all of the channels by the same amount. Because they are recorded side by side on the same tape, one expects that they must all be reproduced at the same time. However, we have found that any deviation of spacing, longitudinally with respect to the direction of tape motion, introduces small constant time differences between channels. This has the effect in reproduction of making the apparent location of a given source deviate from its actual original position. The angle of deviation increases as the time differential increases, and can be calculated. Therefore, all of the heads must have the smallest possible error in parallel alignment. Some manufacturers both record and reproduce using the same heads for the two functions. Here, obviously, there is no time error. But should such a recording be played on another machine, the head spacing can not be different from the first without running afoul of this time-phase shift.

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[2] R. J. Tinkham, "Binaural or stereophonics," *Audio Eng.*, January, 1953.

Ampex uses two separate sets of heads and amplifiers, one set for recording, and one for playing back the same record an instant after it has been made. This method has obvious monitoring advantages during the recording of a program. It also has the problem for the manufacturer, not the user, of making it necessary to build high accuracy into the head spacing. This problem and the one of inductive cross-talk between adjacent channels (40 db) have been worked out.

DESCRIPTION OF EQUIPMENT

The two- and three-track Ampex systems are housed in three luggage cases. One case contains the mechanical equipment involved in tape motion, the second contains the requisite number of combined record/playback amplifiers, each with separate controls and meter. The third case contains the power supplies for the amplifiers. All parts, optionally, may be mounted in a standard 19" relay rack.

The new series 350 Ampex mechanical assembly is mounted on a 15¾ x 19" panel. Each reel turntable is driven by its own torque motor, and each motor is equipped with a solenoid actuated brack, self-energizing in the proper direction.

All ball-bearing mounted flywheel, driven by the passage of the tape around a drum mounted on the same shaft and above the panel, stabilizes the tape motion as it approaches the head assembly. The head assembly holds, from left to right, the full-track erase head, the two- or three-track playback head. The heads are suitably shielded in mu-metal cans, with covers which fall into place as the hinged portion of the assembly is lowered into place after tape threading. The tape is accurately guided on and off the heads by means of pyrex glass guides spaced as far apart as the width of the tape at the entrance and exit of the assembly. The tape is pulled over the heads by means of a pinch drive which consists of a capstan and a rubber capstan idler roller. The capstan is the accurately ground shaft of a dual-speed hysteresis motor, and is capable of driving the tape at either seven and one-half inches or fifteen inches per second, with a timing accuracy of ± 3.6 seconds in thirty minutes of recording time. The capstan motor is also equipped with a flywheel. Motor speed is changed by a toggle switch. All mechanical functions – fast forward, fast rewind, stop, and playing speed forward – are controlled by means of momentary contact push-buttons. Electrical memory is furnished by dc actuated relays. Therefore the entire system may be remotely controlled from a separate push-button station. Ampex Speed Lock equipment may also be plugged into the mechanism to make possible the synchronizing of the equipment with motion picture camera and projector equipment to within one/one-thousandth of a second accuracy. This is an electrical arrangement and requires no additional heads or mechanical modification to the equipment.

Each separate amplifier channel has both a recording and reproducing amplifier, with appropriate switching, so that either the incoming signal on that channel, or the signal just recorded on the tape for that channel, may be monitored. Each standard four-inch VU meter may also be switched between the recording amplifier and the playback amplifier. Erase and bias voltages for each channel may also be read on this meter through appropriate switching. The recording amplifier has a choice of three inputs: low-impedance microphone, balanced, and unbalanced bridge input. The playback amplifier delivers + 8 VU across a balanced or unbalanced 600 ohm line output. An internal 600 ohm load resistor may be cut in or out by means of a switch. Suitable gain controls are provided for each input and output. Erase and bias current is obtained from a push-pull oscillator using a toroidally wound coil, and is tuned to approximately 100 kilocycles. This oscillator is mounted integrally on one of the amplifiers. Its output is also fed to separate buffer amplifiers associated with each of the other channels. This eliminates the possibility of beats which would exist if each channel had its own oscillator.

The power supplies are straightforward. They are mounted separately in order to reduce hum pickup and to divide the weight into convenient packages.

On the three-track system, the tracks are each 0.040 inches wide, and are separated by blank tape space of about 0.050 inches. All three tracks lie side by side on standard tape of one-quarter inch width. With such narrow tracks, some signal-to-noise ratio is sacrificed. A restricted bandwidth would give less background noise. While it has been stated that we can tolerate a more restricted bandwidth when using multi-track reproduction to get same subjective feeling of presence as compared to a mon-aural system, it is also true that the full auditory band width will given even more realism to the sound.

USE OF THE INDICES

Daniel W. Martin, Chairman
Editorial Committee IRE - PGA

The cumulative indices which follow are of three types. The first type is simply a compilation of Tables of Contents of TRANSACTIONS of the IRE-PGA, preceded by a list of the newsletters and other publications which came before the publication of TRANSACTIONS. Next is an Author Index. The third type is an Analytic Subject Index.

From the standpoint of indexing it is unfortunate that a consistent numbering system for volumes and pages could not have been adopted at the start. Absence of such a system has pointed up the necessity for these cumulative indices. It is planned that future volumes will adopt the conventional consecutive page-numbering system, which will simplify both indexing and the reference use of the publication.

The earliest technical papers circulated among the membership of the IRE Professional Group on Audio, and the separate NEWSLETTERS carried no identifying numbers other than dates. Late in 1951 several technical papers were issued as separate TRANSACTIONS of the IRE-PGA, and these were assigned PGA numbers PGA-1, PGA-2, etc. Early in 1952 the NEWSLETTER was absorbed into TRANSACTIONS, and the latter became a regular bimonthly publication, continuing to use the same numbering system through PGA-10, the final issue of 1952. Because most of the previously unnumbered publications predate this numbering system, a series of *Roman* numerals has been assigned to them in the Tables of Contents which follow. Thus PGA-I is the first paper circulated by IRE-PGA to its membership back in 1950, and PGA-1 is the first paper published as an official TRANSACTIONS, and made available also outside the membership of IRE-PGA.

The volume system of indexing began with the first issue of 1953. Volume AU-1, issues 1, 2, ... 6, contain all IRE-PGA publications for the year except Section 3 of the CONVENTION RECORD. In the Tables of Contents this section has been assigned a number CR-1-3, and inserted chronologically between issues AU-1-3 and AU-1-4 of the TRANSACTIONS of the IRE-PGA.

In both the Author Index and the Analytic Subject Index references are made to publications by the Roman or Arabic numbers of the PGA series, or by the issue number in volume AU-1, plus the page number in the issue. In the future this can be simplified to the volume number and the page number in the volume (e.g., AU-2,56).

The Analytic Subject Index lists titles under the appropriate classifications in the series shown below. In many cases valuable material is published under titles which cannot be fully descriptive of all the material which the paper covers. It is for this reason that some titles are listed under various classifications, some of which may seem inappropriate to the title itself. It is hoped that this will increase the probability of finding quickly most of the information available under a particular classification.

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   1.1 General
   1.2 Constitution and By-Laws
   1.3 National and Regional Meetings
   1.4 Chapters
   1.5 Membership
   1.6 TRANSACTIONS
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2. Bibliographies, Reviews, Standards, Tapescripts

   2.1 Bibliographies
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3. Sound Systems

   3.1 General

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   4.2 Condenser
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5. Amplifiers

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6. Loudspeakers
    - 6.1 General
    - 6.2 Direct – Radiator Units
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7. Disc Recording and Reproduction
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    - 8.2 Tape and Wire
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PGA-II The Application of Damping to Phonograph Reproducer Arms . . . . William S. Bachman (Presented at IRE Convention, March 22, 1951, and distributed to PGA in mimeographed sheets.)

PGA-III A Single-Ended Push-Pull Audio Amplifier . . . . . Arnold Peterson and Donald B. Sinclair (Presented at IRE Convention, March 22, 1951 and distributed to PGA in mimeographed sheets.)

PGA-IV Informal Newsletters 1-6, issued mimeographed to PGA members prior to adoption of standard format and cover.

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———Chairman's Final Report 1951-52. PGA-6, 3, March, 1952.

———The New Republication Procedure of the IRE-PGA, 6, March, 1952.

———Results of Survey of PGA Interest, PGA-6, 14, March, 1952.

———Members Joining in Mid Year, PGA-7, 4, May, 1952.

———Microphone Directivity, PGA-8, 10, July, 1952.

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———Measuring the Stability of Sonic Recorders, PGA-6, 20, May, 1952.

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———Comparison of Recording Processes, Part II, PGA-7, 5, May, 1952.

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Military Research and Development in Acoustics and Audio, Paul J. Weber, AU-1-3- 4, May-June, 1953.

Applications of High Intensity Microphones, John K. Hilliard, CR-1-3, 44, June, 1953.

9.2 Room Acoustics

Why Studio Acoustics, R. H. Bolt, PGA-6, 7, March, 1952.

Direct Measurement of the Efficiency of Loudspeakers by use of a Reverberation Room, H. C. Hardy, H. H. Hall and L. G. Ramer, PGA-10, 14, November-December, 1952

Sound System for Plenary Hall of United Nations General Assembly Building, C. W. Goyder and L. L. Beranek, CR-1-3, 26, June, 1953.

Room Acoustics, Hale J. Sabine, AU-1-4; 4, July-August, 1953.

9.5 Music

Imitation of Natural Sounds, Daniel W. Martin, PGA-VII, 7, November, 1951.

9.6 Hearing

Engineering Listening, R. D. Darrell, PGA-VIII, 8, January, 1952.

Do You Auralize?, Daniel W. Martin, PGA-8, 2, July, 1952.

A Practical Binaural Recording System, Otto C. Bixler, AU-1-1, 14, January-February, 1953.

Stereophonic Recording Equipment, Russell J. Tinkham, AU-1-6, 13, November-December, 1953.

10. Broadcast Audio

Why Studio Acoustics?, R. H. Bolt; PGA-6, 7, March, 1952.

Over-all Audio Performance of Commercial Radio Receivers, W. B. Clark, PGA-7, 11, May, 1952.

Do You Auralize?, Daniel W. Martin, PGA-8, 2, July, 1952.

Proper Care of Test Records, L. A. Wood and R. C. Moyer, PGA-8, 4, July, 1952.

A New Audio Control Console for Television and Radio, W. W. Dean, PGA-8, 28, July, 1952.

Increased Audio without Splatter, John L. Reinartz, PGA-9, 22, September-October, 1952.

A Practical Binaural Recording System, Otto C. Bixler, AU-1-1, 14, January-February, 1953.

Why Fight Grid Current in Class B Modulators, J. L. Hollis, AU-1-2, 26, March-April, 1953.

11. Audio Measuring Equipment and Techniques

An Instrument for Measuring the Time Displacement Error of Recorders, E. N. Dingley, Jr., PGA-6, 37, March, 1952.

Measuring the Stability of Sonic Recorders, E. N. Dingley, Jr., PGA-7, 20, May, 1952.

A Method for Measuring the Changes Introduced in Recorded Time Intervals by a Recorder-Reproducer, J. F. Sweeney, PGA-7, 24, May, 1952.

A Sound-Survey Meter, Arnold Peterson, PGA-7, 30, May, 1952.

Microphones for the Measurement of Sound Pressure Levels of High Intensity over Wide Frequency Range, J. K. Hilliard, PGA-7, 38, May, 1952.

A Phase and Gain Meter, Stephen F. Condon, PGA-8, 37, July, 1952.

A Ceramic Vibration Pickup, E. V. Carlson, PGA-10, 2, November-December, 1952.

Direct Measurement of the Efficiency of Loudspeakers by Use of a Reverberation Room, H. C. Hardy, H. H. Hall, and L. G. Ramer, PGA-10, 14, November-December, 1952.

Sensitivity of Microphones to Stray Magnetic Fields, L. J. Anderson, AU-1-1, 1, January-February, 1953.

Loudspeaker Impedance, Vincent Salmon, AU-1-4, 1, July-August, 1953.

Technical Committee Work on Audio-Frequency Measurements, Arnold Peterson, AU-1-5, 4, September-October, 1953.

Power Capacity of Loudspeakers, Paul S. Veneklasen, AU-1-5, 5, September-October, 1953.

12. Electronic Musical Instruments

An Electronic Music Box, Earle L. Kent, PGA-4, December, 1951.

Imitation of Natural Sounds, Daniel W. Martin, PGA-VII, 7, November, 1951.

Electronic Music – Past, Present, and Future, Earle L. Kent, AU-1-2, 1, March-April, 1953.

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THE ASTATIC CORPORATION, Harbor and Jackson Streets, Conneaut, Ohio
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THE BRUSH ELECTRONICS COMPANY, 3405 Perkins Avenue, Cleveland 14, Ohio
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THE DAVEN COMPANY, 191 Central Avenue, Newark 4, New Jersey
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ELECTRO-VOICE, INC., Buchanan, Michigan
Microphones, Pickups, Speakers, Television Boosters, Acoustic Devices

JENSEN MANUFACTURING COMPANY, 6601 South Laramie Avenue, Chicago 38, Illinois
Loudspeakers, Reproducer Systems, Enclosures

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