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CONTRIBUTIONS

CORRESPONDENCE

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Professional Group on Audio

IRE TECHNICAL PROFESSIONAL GROUP ON AUDIO

The Professional Technical 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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The Editor's Corner

Suggestions to College Professors

EDUCATORS are always revising the curriculum and you hear quite a bit nowadays about "the new mathematics," "aural-oral" and other short-cuts that will lay down a magic carpet on the royal road to learning, and perhaps will even provide a chariot ride for the lucky new generation.

Each new course is advertised as "designed to adapt one to working and living in our complex technological age." One might therefore expect that the educators were spending a good deal of time in industry, in research laboratories, and in government, finding out which gaps should be filled, and which courses could be replaced.

Maybe this is the case, but in twenty-five odd years of working at the trades of engineering and physics, we have never been asked for advice. It is really a shame to have all this practical experience lost forever (while they still teach descriptive geometry), so we are now suggesting a few courses of great utility to the engineer, but which will probably never be offered in any accredited university.

INTERPRETATION OF CATALOG DESCRIPTIONS

(*Poetry, 307*)

Selected phrases from leading radio-parts catalogs are analyzed in detail, showing their remote relationship to the product. Special regard is given to poetic license as applied to "house-brands," kits, and high-fi equipment.

TECHNICAL WRITING

(*Fiction, 409*)

The goal is to prepare a thirty page final report which says absolutely nothing. Starting with words that are somewhat ambiguous, indefinite sentences are constructed. These are grouped into inconclusive paragraphs and finally into incomprehensible, though plausible, sections. Examples are given of great literature of this type. Talented students are encouraged to do original work in this fascinating field.

NON-STANDARDIZATION

(*Creative Engineering, 524*)

Creating a design in which no part can be obtained from a competitive source calls for great ingenuity, but pays handsomely for successful companies. An expendible or consumable "non-standard" is the highest accomplishment, seldom achieved purely by chance. A scientific procedure is taught for consumable non-standardization including mechanical dimensions; speeds; electrical, mechanical, and chemical incompatibility; corrosion enhancement; embrittlement; acceleration of shrinking, warping, and peeling.

COMMITTEES

(*Political Science, 404*)

Committees are ideal for shifting responsibility, perpetuating programs, and giving directors the feeling that they are directing something. Meetings are also a pleasant way to spend a relaxing afternoon. Although one can feel at home without any training, the course gives fine points in the arts of procrastination, persuasion, looking intelligent, brain-storming, use of proper committee language, effective jokes, and how to adjourn nonchalantly.

ADAPTING TO THE CORPORATE ENVIRONMENT

(*Business, 574*)

This elusive subject, formerly a matter of instinct, was formulated into a science by Dale Carnegie and other unselfish pioneers. Guest speakers who are acknowledged masters will discuss their experiences in the art of appearing busy; reflecting confidence; inspiring enthusiasm; expanding one's department 1) in personnel, 2) in space allocations, 3) in fiscal allotments. Engineering an increased budget; methods for spectacular budget consumption; expense accounts; appearing wise in the presence of 1) engineers, 2) non-technical officers, 3) lower ranks. Getting by for the less ambitious. Suggestions for eating, drinking, selecting a proper car, home, wife, lawnmower.

MARVIN CAMRAS, *Editor*

PGTA News

CHAPTER NEWS

Boston

"Music Acoustics and Philharmonic Hall" was presented by Dr. Leo L. Beranek of Bolt Beranek, and Newman, Inc., at the PTGA meeting held October 4, 1962.

Chicago

At the first meeting of the fall season on September 11, 1962, PTGA sponsored two papers. The General IRE Section paper was "From Telegraphone to Tiros—The Past and Future of Magnetic Recording" by Marvin Camras of Armour Research Foundation. A résumé of the talk was reported in *Scanfax:*

> Although nearly 75 years of age, magnetic recording is still young, and a number of magnetic recording devices, now in the laboratory, may become important in the future. Among these are low-cost video recorders, improved tape cartridges, coil-less pickups using semiconductor elements, and cross field heads giving 15-kc response at $1\frac{7}{8}$ inches per second. These innovations were described, together with happenings that took place in the early days of magnetic recording. An experimental automatic stereo tape cartridge changer was demonstrated.
>
> Important factors responsible for the postwar growth of magnetic recording were the improvements brought about by high-frequency bias, better record media and better heads. These led to applications where magnetic recording proved indispensable: for broadcast audio and video, motion picture sound, computer memories, satellites, and home recording.
>
> In the future we may see magnetic tape in motion picture cameras that play back immediately on one's television screen, compact recorders storing more information at slower speeds than are now possible, and heads using semiconductor elements.

The second audio paper, entitled "Precision Testing of Phonograph Sound Reproduction Components and Systems," was presented by Jack Mowry of B and K Instruments, Inc. An abstract of his talk, as it appeared in *Scanfax* was:

> In the development and testing of phonograph sound reproduction components and complete systems, the use of precision test records is desirable. The records must be compatible with RIAA and IEC standards and the requirements for completely automatic measurement system operation.
>
> A complete measurement system using standard acoustic instrumentation was used to demonstrate frequency response, reproducer resonances, stylus wear check, cross-talk in stereophonic systems, harmonic analysis, and mechanically generated reproducer characteristics such as wow, rumble, or noise level. Reproducer pickups with various performance characteristics were used in the demonstrations.
>
> **Jack Mowry** is Assistant Sales Manager for B and K Instruments, Inc., Cleveland, Ohio. He has had six years' experience in the sale and application of Bruel and Kjaer precision instruments for sound and vibration measurements. He received the B.S.E.E. degree from Case Institute of Technology and is a member of the Acoustical Society of America.

"The Jensen SUB-1 Underwater Loudspeaker" was presented at a joint meeting with the Chicago Acoustical and Audio Group, on October 24, 1962, at the "Dolphin Room" of the Dolphin Motel and Restaurant in Niles, Ill. The speaker was Robert J. Larson of Jensen Manufacturing Company who discussed the design of this unique speaker and its application as a source for underwater entertainment and instruction. The device was demonstrated in the swimming pool after the talk. Members were invited to join in the swim for the demonstration, bringing their own suits and towels.

On December 14, John M. Eargle of RCA Recording Studios and Robert J. Larson of Jensen Manufacturing Company spoke on "Loudspeaker Testing in Reverberent Rooms." Their talk was summarized in the December issue of *Scanfax:*

In measuring the frequency response of loudspeakers, it has been customary to make use of an anechoic, or free space, chamber. This paper shows the advantages of the opposite approach: a reverberant chamber, for evaluating loudspeaker performance. The instrumentation procedures used in mean energy density (MED) testing will be described in detail, with particular emphasis on the facility at Jensen Manufacturing Co. The role of MED measurements in the evaluation of loudspeakers will be discussed. Tape recordings of reverberation time measurements and response curve slides will show typical results obtained with this method. Bob Larson gave the paper.

John Eargle received the Bachelor of Music degree from the Eastman School of Music, the Master of Music degree from the University of Michigan, and the Bachelor of Science degree in electrical engineering from the University of Texas.

He worked for the Defense Research Laboratory of the University of Texas and the Austin Recording Company; then for Klipsch and Associates, and next for the Jensen Manufacturing Company. While at Jensen he did development work in horn loudspeakers and in mean energy density measuring techniques. He is currently with RCA Recording Studios.

Mr. Eargle is an associate of the American Guild of Organists and a member of the IRE, Audio Engineering Society, Tau Beta Pi, and Eta Kappa Nu.

Bob Larson received the B.S. degree in electrical engineering from Northwestern University in 1951. While at Northwestern he was employed by Jensen Manufacturing under the cooperative work program. After serving in the Navy during the Korean conflict, he returned to Jensen, where he is now Senior Development Engineer.

Mr. Larson is a member of the IRE, the Acoustical Society of America, and the Chicago Acoustical and Audio Group, as well as Tau Beta Pi and Eta Kappa Nu. He is a past chairman of the Chicago PGA and is now on the Arrangements Committee of the Chicago Section.

Cleveland

"New Techniques in Stereophonic Recording for Multiplex" was presented by Kenneth R. Hamann of the Cleveland Recording Company at the meeting on May 24, 1962.

Dayton

The 1961–1962 PGA activities were summarized in the Dayton IRE *Wave Guide:*

The Dayton Chapter of the Professional Group on Audio featured four interesting and well-attended meetings during the past year.

The first meeting of the year was held on October 4, 1961. Edward Meagher, Amperex Electronic Corp., L. I., N. Y., discussed and demonstrated applications of vacuum tubes and semiconductors to high fidelity and general entertainment types of equipment. This included both professional and non-professional devices.

On December 6, 1961, PGA and PGANE in a joint session presented talks and a demonstration of "FM Stereo Multiplex Broadcasting" by Hans Bott of RCA and Maurice L. Myers, Technical Director of Radio Station WPFB, Middletown, Ohio. Mr. Bott is designer of the BTS-1A, RCA subcarrier generator used by the station.

On March 7, 1962, PGA presented W. S. Curtis, David Taylor Model Basin, Carderock, Md. Mr. Curtis spoke on "The Sounding Sea," and presented a series of very interesting recordings of sounds to be found at various depths in the oceans and seas of the world.

On April 4, 1962, PGA in its final meeting of the season, presented E. O. Valentine of the Communications and Control Branch, B-70 Engineering Office, Deputy for Engineering, ASD. Mr. Valentine presented an illustrated talk on "Tape Recorders—Luxury or Necessity." Professional recording equipment was displayed and demonstrated to a capacity audience.

The Dayton Section meeting for November featured Dr. Harry F. Olson of the RCA Laboratories. He spoke on the "Processing of Audio Information" at the 8:00 P.M. meeting on November 7 at the Engineers' Club. This interesting meeting was sponsored by PGA.


L. to R.: T. C. Rynda, Vice Chairman, Stan Weber, Retiring Chairman, Ray E. Kellogg, Secretary, and A. P. Parker, Chairman.

The most important systems for the communication of information today are the written and printed page, the photograph, the telegraph, the telephone, the phonograph, the radio, the sound motion picture and television. However, the list will not end with the communication systems that have just been enumerated. There is in the process of development today a new category of systems which involve the conversion, transmission and utilization of audio information. These various methods for the processing of audio information involve the analysis of audio information in various forms, the conversion to a code and the synthesis of information in various forms from a code. The development of audio information processing systems will provide many new facilities for the reproduction of speech and music, the conversion of speech and music to a code, the production of speech and music from a code, the conversion to speech from the printed page, the conversion of speech to the printed page, the control of machines by speech and the translation of speech from one language to another. The processing of audio information will increase the means for the production, reproduction and use of speech, music and the printed page in the communication of information between individuals and to and from machines.

The presentation included a general description of the systems for the processing of audio information. This was followed by a specific and detailed description of the Electronic Music Synthesizer, the Random Probability System for composing music, the Phonetic Typewriter and the Syllable Communication System. There were demonstrations of music produced by the Electronic Music Synthesizer, of music composed by the Random Probability System and of speech transmitted by the Syllable Communication System.

Harry F. Olson received the B.S., M.S., Ph.D., and E.E. degrees from the University of Iowa, and an Honorary D.Sc. degree from Iowa Wesleyan College. He has been affiliated with the Research Department of Radio Corporation of America, the Engineering Department of RCA Photophone, the Research Division of RCA Manufacturing Company, and RCA Laboratories. He is Director of the Acoustical and Electromechanical Research Laboratory of the RCA Laboratories.

Dr. Olson is a past president of the Audio Engineering Society, past president of the Acoustical Society of America, and past chairman of the Administrative Committee of the IRE Professional Group on Audio, and past Director of the IRE.

He holds more than 90 U. S. patents. He is the author of 85 papers and the books, "Elements of Acoustical Engineering," "Acoustical Engineering," "Dynamical Analogies," and "Musical Engineering."

Dr. Olson has received the following honors: The Modern Pioneer Award of the National Association of Manufacturers, the John H. Potts Medal of the Audio Engineering Society, the Samuel L. Warner Medal of the Society of Motion Picture and Television Engineers, the John Scott Medal of the City of Philadelphia, and the Achievement Award of the Professional Group on Audio of the Institute of Radio Engineers.

Dr. Olson is a member of Tau Beta Pi, Sigma Xi, and the National Academy of Sciences. He is a Fellow of the Society of Motion Picture and Television Engineers, the American Physical Society, the Institute of Radio Engineers, and the Acoustical Society of America, and an honorary member of the Audio Engineering Society.

The PGA featured Stanley M. Slawsky of Smith Kline Precision, at their 9:00 P.M. meeting at the Engineers' Club on December 5. Mr. Slawsky's interesting topic was "Ultrasonography in Medical Diagnosis." This lecture discussed research underway throughout the world on pulsed ultrasonic techniques in medical diagnosis. Typical design and clinical interpretation problems and findings were illustrated by examples drawn from the work of Dr. Gilbert Baum and the speaker in the field of ophthalmological diagnosis.

Stanley Slawsky has been with Smith Kline as Development Engineer since June 1962. Prior to that time he was with GPL as Manager of their Medical Electronic Program.

Mr. Slawsky is a native of Albany, N. Y. He graduated from Rensselaer Polytechnic Institute and did graduate work at M.I.T. and Virginia Polytech Institute.

Mr. Slawsky was employed at General Electric as Advanced Development Engineer from 1946 to 1948. He served as Research Fellow at Rensselaer from 1948 to 1951, returning to G.E. as Senior Systems Designer until 1959, when he joined GPL.

Philadelphia

At the Philadelphia PGA meeting held September 28, 1962, Robert Kerr of E. I. DuPont Company of Wilmington, Del., described "A System of Electrostatic Recording" in which the record is impressed as relatively permanent charges in a thin mylar ribbon.

San Diego

"FM Stereophonic Broadcasting" was the subject of the PGA meeting on September 5, 1962. John A. Mosley of Mosley Associates in Santa Barbara, Calif., was the speaker.

Obituary

Howard C. Hardy (M'46–SM'51–F'60) who was an authority in the field of acoustics, and headed his own consulting firm, Hardy and Associates, Chicago, Ill., died on December 20, 1962, near Wheeling, Ill.

Born on October 3, 1911, in Martinsburg, W. Va., he received the Ph.D. degree from Pennsylvania State University in 1941, and was associated with the Universities of New Hampshire, Harvard, and Pennsylvania where he worked and taught from 1941 to 1945. From 1945 to 1956 he was Head of the Acoustics Division of Armour Research Foundation, Chicago, Ill. He formed his own acoustical consulting firm in 1956. He was the author of fifty papers, and made contributions in the fields of noise control, prevention of hearing loss, acoustic design using scale models, and architectural acoustical treatment.

Dr. Hardy was a member of the Acoustical Society of America, the AAAS, and was President of the National Council of Acoustical Consultants. He was Chairman of the PTGA chapter in Chicago and Associate Editor of these TRANSACTIONS.

MINUTES OF THE IRE PROFESSIONAL TECHNICAL GROUP ON AUDIO ADMINISTRATIVE COMMITTEE MEETING

March 27, 1962—New York, N. Y.

Members Present

- C. M. Harris, Chairman
- H. E. Roys, Vice Chairman
- R. W. Benson
- A. B. Bereskin
- D. E. Brinkerhoff
- F. A. Comerci
- P. C. Goldmark
- H. S. Knowles
- J. R. Macdonald
- W. C. Wayne
- M. Copel, Secretary-Treasurer

Newly Elected Members Present

- R. W. Benson, Chairman 1962–1963
- F. A. Comerci, Vice Chairman 1962–1963
- E. E. David, Jr.
- D. F. Eldridge
- W. M. Ihde
- J. F. Novak

Guests Present

- B. B. Bauer
- M. Camras
- D. W. Martin

The meeting was held at the Waldorf-Astoria and was called to order at 8 P.M.

Upon motion duly seconded, a rising vote of thanks was given to B. B. Bauer for his faithful and long service to the Administrative Committee of PGA as its Secretary-Treasurer as well as for his active participation in the work of PGA in various capacities.

Upon motion duly seconded the minutes of the last meeting of the Administrative Committee held November 11, 1961, in Cincinnati, Ohio, were unanimously approved.

Chairman Harris announced the final results of the PGA election as transmitted by IRE Headquarters:

R. W. Benson, Chairman 1962–1963
F. A. Comerci, Vice Chairman 1962–1963
E. E. David, Jr., Member 1962–1965
D. F. Eldridge, Member 1962–1965
W. M. Ihde, Member 1962–1965
J. F. Novak, Member 1962–1965

Chairman Harris stated that he had received many requests from manufacturers for a listing of PGA membership, that he saw no objection to supplying such listing, and suggested that it be published in the TRANSACTIONS. Upon motion by A. Bereskin, seconded by R. Benson, it was decided that a "Directory" issue would be published, members to be listed alphabetically and in geographical groups. F. Comerci voted negatively on this motion. During the discussion it was pointed out that one full issue of the TRANSACTIONS would be required and that additions and deletions could be issued yearly in the TRANSACTIONS.

Report of Committee on Constitution and By-Laws

Report by Chairman Roys contained proposed changes to the Constitution and Bylaws in line with the instructions received at the November, 1961, meeting in Cincinnati. Upon motion by R. Benson, seconded by D. Brinkerhoff, the following was unanimously adopted:

1) Accept the report of Chairman Roys.
2) Submit changes to Constitution and Bylaws to proper authorities for their approval.
3) If approval is obtained, publish the changes in the TRANSACTIONS.
4) If approval is obtained, to adopt the amendments to the Constitution and Bylaws.

Report of Committee on Chapters and Memberships

Report by Chairman Ihde outlined the activities of the Committee and indicated that the program to get more Sections interested in organizing local Chapters of PGA has not been too successful. One new Chapter was approved for the Montreal Section.

The report was unanimously accepted. During a discussion it was pointed out that the problem in organizing local Chapters was mainly caused by the difficulty in recruiting leadership for same.

Report of Awards Committee

The Committee was chaired by J. Macdonald. However, since he was a leading candidate for an award, Chairman Harris asked him to resign and took over for him. The committee nominated J. Macdonald as recipient of the 1961 PGA Achievement Award.

The report was unanimously accepted.

Report of Program Committee

The report of Chairman Comerci covering the Audio Sessions for the 1962 National Convention was unanimously accepted.

Report of Ways and Means Committee

Report by Chairman Copel indicated that seven Institutional Listings were renewed and paid for, and that the books were in good order. The report was unanimously accepted.

Report of Editing Committee

Editor Camras reported that the machinery for reviewing and editing papers was running smoothly, but not enough papers were submitted. Suggestion for a Papers Committee was made. The report was unanimously accepted.

Treasurer's Report

Treasurer Bauer presented the 1962 estimated budget as restated by Headquarters. The change is due to a new subsidy formula for publications subject to subsidy. The report was unanimously accepted.

Other Business

1962 Fall Meeting—After discussion and upon motion of H. Knowles duly seconded, it was decided that the Administrative Committee would meet in New York during the week of October 15, and that there would be no technical sessions, but that plans should get under way in the fall for technical sessions for the fall meeting of 1963.

Communication from H. H. Scott—After discussion, the Administrative Committee decided to take no action at this time on this matter.

The meeting was adjourned at 10:05 P.M. and immediately reconvened by Chairman Benson.

Future technical programs to be sponsored by PGA were discussed. For the 1963 Fall Meeting D. Eldridge will investigate possible audio sessions at WESCON. Other possibilities for joint meetings mentioned were NEC, Radio Fall Meeting, Acoustical Society Meetings. Chairman Benson will look into a possible meeting at Wright Field. J. Novak will investigate NEC for the fall meeting of 1964. E. David suggested a National Meeting of PGA in Mexico City or New Orleans.

For the National Convention of IRE Spring 1963 Chairman Benson appointed E. David and J. Novak to organize the audio sessions.

Upon motion duly seconded the meeting was adjourned at 11 P.M.

MICHEL COPEL
Secretary-Treasurer

CHAPTER OFFICERS AND MEMBERSHIP STATISTICS

The IRE Professional Technical Group on Audio includes seventeen active chapters as listed below. There are approximately 4400 members as of November 30, 1962. Officers are listed from the latest information received by the IRE headquarters to December 20, 1962.

Chapter	Chairman	Vice Chairman	Secretary and/or Treasurer
Albuquerque-Los Alamos	John F. Dankworth 1133 S. Monroe St. Albuquerque, N. M.		Dwayne Fry Gen. Chenault, N.E. Albuquerque, N. M.
Baltimore	James H. Jackson Bendix Radio Towson 4, Md.	William J. Parrish Westinghouse Air Arm Baltimore 3, Md.	George Kroen WMAR-TV Baltimore, Md.
Boston	Charles I. Malme, Bolt, Beranek & Newman Inc. 50 Moulton St. Cambridge 38, Mass.	Richard L. Kaye WCRB Boston, Mass.	Marcello J. Carrabes Northeastern Univ. 360 Huntington Ave. Boston 15, Mass.
Chicago	Howard C. Hardy Howard C. Hardy Assocs. 53 W. Jackson Blvd. Chicago 4, Ill.	Lane Gorton General Radio 6605 W. North Ave. Oak Park, Ill.	James L. Laughlin Jensen Mfg. Co. 6601 S. Laramie Chicago 38, Ill.
Cincinnati	John Brean Baldwin Piano Co. 1801 Gilbert Ave. Cincinnati 12, Ohio		
Cleveland	Kenneth Hamann 1515 Euclid Ave. Cleveland 15, Ohio	Adolph Friedman Ind. Comm. Corp. 12217 Euclid Ave. Cleveland, Ohio	W. Zachman 4041 Rocky River Ave. Apt. 10 Cleveland 38, Ohio
Dayton	Albert P. Parker USAF, WADC Wright-Patterson AFB, Ohio	Theodore C. Rynda (same as Chairman)	Ray E. Kellogg (same as Chairman)
Houston	James H. Carter The Wrye Co. 2410 W. Alabama Houston, Tex.		
Milwaukee	Anton E. Horvath Wisconsin Electric Power Co. Milwaukee 3, Wisc.		
Montreal	Charles Sankey CNHQ Bldg., POB 8100 Montreal, Quebec, Canada		
Omaha-Lincoln	Al H. Smith 1418 W. 26th St. Sioux City, Iowa	Harry C. Snyder KHUB Fremont, Neb.	U. L. Lynch KMMJ Grand Island, Neb.
Philadelphia	Hanz Dietze, RCA Camden, N. J.	Carl H. Brummer, Jr. 5530 Wayne Ave. Pennsauken, N. J.	Bruce DiPalma Dynaco, Inc. Philadelphia, Pa.
San Antonio	Bill Case 122 W. White Ave. San Antonio, Tex.		
San Diego	Roswell W. Austin Scripps Institution of Oceanography San Diego 52, Calif.	Donald M. Lowe USN Electronics Lab. San Diego 52, Calif.	
San Francisco	Stanley K. Oleson Stanford Research Institute Menlo Park, Calif.	Ralph L. Brown Lenkurt Electric Co. 1105 County Road San Carlos, Calif.	Herbert U. Ragle, Jr. Ampex Corp. 935 Charter St. Redwood City, Calif.
Twin Cities	Richard F. Dubbe Minn. Mining & Mfg. Co. 900 Bush Ave. St. Paul 6, Minn.	Edward W. Harding Helmann Co. 1711 Hawthorne Ave. Minneapolis, Minn.	Lowell Brown Waters, Conley & Co. Rochester, Minn.
Washington	R. J. Carpenter 4425 Chestnut St. Bethesda, Md.	Glen Whipple Fed. Commun. Comm. Washington, D.C.	Richard Knodle Box 708 Adelphi, Md.

Applications and Limitations of the New Magnetic Recording Model[*]

C. D. MEE[†], SENIOR MEMBER, IRE

Summary—**The simple magnetic recording model which describes the basic phenomena in terms of the growth and decay of a cylindrical magnetization volume from one side of the tape coating is reviewed. The relevance of practical tape hysteresis loops is considered and a model hysteresis loop developed and applied to the description of the recording process. Areas of applicability for the recording model are described including distortion in ac-bias recording.**

RECORDING MODEL

A READILY UNDERSTANDABLE model for the magnetic recording process has been proposed recently.[1] Using the simplifying assumptions of an active recording field equivalent to the longitudinal component of the fringe field from a recording head with an infinitesimal gap, recording is pictured as the growth into the tape of a cylindrical zone of saturation magnetization whose extent is proportional to the recording signal. Fig. 1 depicts this action for a sinusoidal signal superimposed on a dc-bias signal. The instantaneous recording zone near the gap is a cylinder of length equal to the track width and radius r_c given by

$$r_c = 2ni/H_c \tag{1}$$

where

n = number of turns on recording-head winding
i = signal current
H_c = particle switching field.

If the separation between the tape and the recording head pole pieces can be considered negligible, compared to the maximum cylinder diameter, the model then predicts that the recorded magnetization is proportional to the recording head current and distortionless recording takes place without bias. Although in practice this is not strictly true when recording with narrow gaps, there is a considerable linearization of the remanent magnetization characteristic compared to that obtained with uniform magnetization by a solenoid field. One purpose of this paper is to study further the distortion associated with this partially linearized remanent magnetization curve when using ac-bias recording techniques. Limitations of the model will also be discussed with regard to the magnetization mechanism occurring during the recording process.

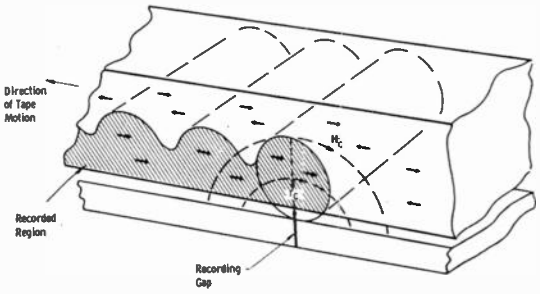


Fig. 1—Magnetic recording model; sinusoidal signal.

AC-BIAS RECORDING

Using the recording model, the ac-bias recording process consists of laying down successive overlapping cylindrical magnetization volumes of opposite polarity. In the absence of a signal field the ac-bias field creates equal maximum cylindrical volumes, leaving equal volume magnetization shells in the tape after it has passed the recording head. This condition is shown on the left-hand side of Fig. 2. On adding a signal field, low in frequency with respect to the bias field, the overlapping of adjacent cylinders is no longer symmetrical and the resultant area of tape magnetized in the signal field direction increases. Provided the remote side of the tape is not reached during the recording process, the increase of magnetization area in the signal field direction is proportional to the field magnitude. Penetration of the remote side of the magnetic coating by the recording field leads to distortion.

In an analogous fashion the tape magnetization, for a given signal, depends on the magnitude of the ac bias and increases with bias amplitude until the remote side of the tape is reached. When the recording cylinder diameter exceeds the coating thickness, however, a geometrical calculation shows that the area of tape magnetized in the signal field direction decreases rapidly with increase of bias amplitude. This can be seen qualitatively by studying the magnetization pattern for signal and bias applied simultaneously, as shown on the right-hand side of Fig. 2. Here, magnetization due to the signal starts at the upper side of the coating which is the remote side of the tape from the head. Increasing the bias amplitude will push this area beyond the coating, resulting in loss of signal field magnetization. In this way, the familiar maximum in the recording sensitivity curve shown in Fig. 3 is explained.

---

[*] Received August 20, 1962. This paper was presented at the convention of the Audio Engineering Society, New York, N. Y.; October 12, 1961.

[†] IBM Research Center, Yorktown Heights, N. Y. Formerly with CBS Laboratories, Stamford, Conn.

[1] B. B. Bauer and C. D. Mee, "A new model for magnetic recording," 1961 IRE NATIONAL CONVENTION RECORD, pt. 2, pp. 61–68.

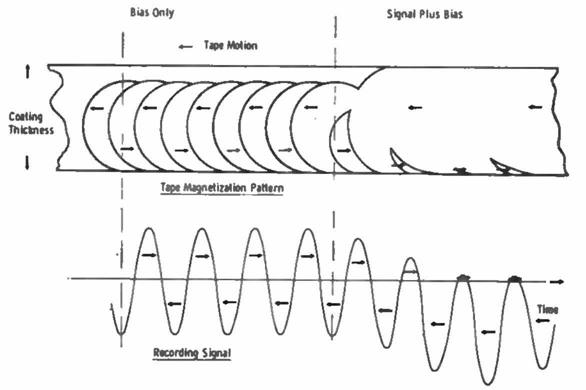


Fig. 2—AC recording signal and tape magnetization pattern.

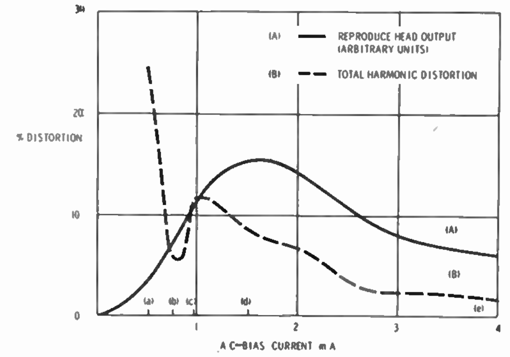


Fig. 3—Output and distortion vs bias for long wavelength recording.

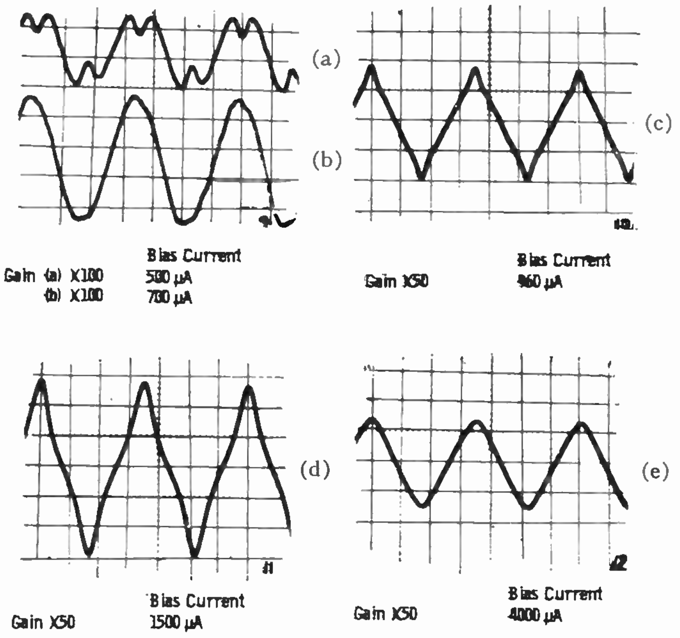


Fig. 4—Distortions occurring in ac-bias recording.

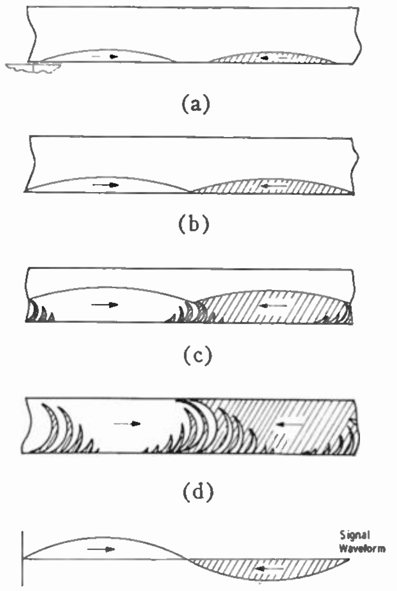


Fig. 5—Long wavelength recording for different bias levels.

Distortion in AC-Bias Recording

The proposed model may be extended to explain the dependence of harmonic distortion content on the strength of the ac bias, in terms of the boundary conditions set by the front and back surfaces of the tape, as the magnetization cylinder grows into and beyond the tape coating. The total harmonic distortion is plotted in Fig. 3 as a function of ac-bias level using a narrow gap recording head and a long recorded wavelength compared to the coating thickness. The distorted waveforms obtained at the replay head for various bias levels are shown in Fig. 4(a)–4(e) and the corresponding bias currents are noted on Fig. 3. The distortions are those due to a signal level large enough to approach tape saturation when the bias level is adjusted for maximum output. For smaller signal levels a similar set of replay waveforms is obtained, except that the saturation distortion at the higher bias levels is absent.

All of the distortions observed may be qualitatively explained by considering the magnetization pattern in terms of the proposed model. The patterns corresponding to the distortion waveforms of Fig. 4 are shown in Fig. 5. The magnetization pattern with 500-μa bias [Fig. 5(a)] is a variable depth magnetization, following the signal amplitude, due to the growth of the cylindrical magnetization volume into the coating. This is similar to a zero-bias recording since the bias component of the magnetization cylinder is not sufficient to penetrate the tape. However, on increasing the bias amplitude [Figs. 4(b), 5(b)], a point is reached where the bias is just sufficient to magnetize the surface layer. At this point the signal recording is pushed into the tape far enough to avoid the distortion at the low signal part of the waveform and a distortionless recording results. Distortion rapidly rises again, however, on further increase of bias amplitude [Figs. 4(c), 5(c)]. It can be seen from Fig. 5(c) that this is due to the sinusoidal magnetization being carried further into the tape coating by the bias giving larger maximum flux, even though the tape magnetization returns to zero each time the signal passes through zero. The rate of change of recorded flux is, thus, greater at zero signal than that corresponding to a sinusoidal curve, leading to the sharply peaked replay-head output waveform shown in Fig. 5(c). When the magnetization due to the bias extends through the whole coating thickness, depth recording by the superimposed signal ceases and the overall tape magnetization change is due to varying degrees of overlap of the bias cylinders, as shown in Fig. 5(d) (and on the right-hand side of Fig. 2). In Fig. 5(d) the maximum of the signal is large enough to produce complete tape saturation, thus giving the distorted waveform of Fig. 4(d). Finally, if the bias is substantially increased this distortion disappears due to the relatively smaller change of magnetization cylinder diameter with signal amplitude, resulting in nonsaturation of the tape.

APPLICATION OF PRACTICAL MAGNETIZATION LOOPS

The simple model of a magnetization cylinder growing into and beyond the magnetic layer of the tape is capable of satisfactory qualitative description of those recording characteristics primarily dependent on the boundary conditions imposed by the tape geometry. However, recording characteristics which depend primarily on the magnetizing power of the recording head field, when the magnetization cylinders have constant maximum amplitude, are not adequately explained. For instance, the relatively low recording sensitivity, when using ac bias, is controlled by the distribution of effective particle switching fields due to interaction fields between particles as well as by the relative volumes of successive cylindrical magnetization zones.

Quantitative analysis of the ac-bias recording process has been achieved by assuming a Gaussian distribution of interaction fields.[2] This could be extended by making correction for the different maximum fields experienced by tape elements at different distances from the recording gap. Although the simple recording model does not take interaction effects into account, it is possible to discuss the model in terms of a practical hysteresis loop involving interaction effects and thereby illustrate the relationship between various approaches to analysis of the recording process.

A typical magnetic tape hysteresis loop with a family of minor loops about saturation is shown in Fig. 6 for oriented acicular particles of γFe_2O_3. It is clearly shown that the portions of the minor loops from $-H_{max}$ to zero field, representing reversible magnetization changes, have equal differential susceptibilities, whatever the value of $-H_{max}$. On the other hand, for positive fields above $H \approx 0.2\ H_{max}$ the differential susceptibility suddenly increases for all the minor loops due to the onset of irreversible changes and its magnitude increases with the size of the minor loop. This leads to asymmetrical minor loops which are a feature of interaction fields between particles due to the resulting inequality between the positive and negative effective particle switching fields.

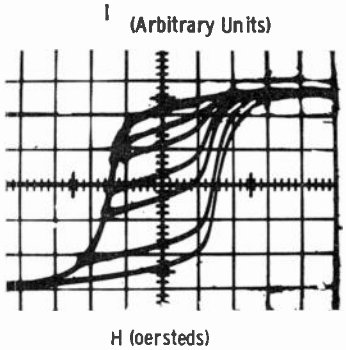
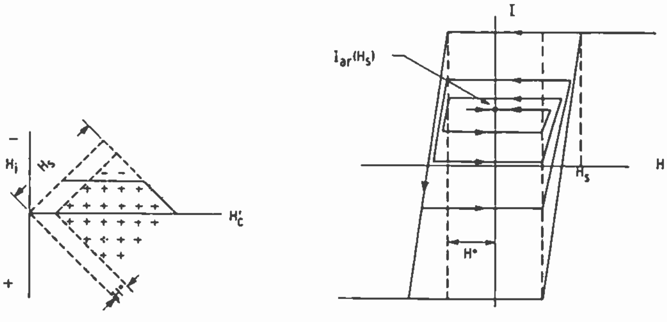


Fig. 6—Minor hysteresis loops for oriented acicular particles of γFe_2O_3; field applied along orientation direction; $H_{max} = 1000$ oe.



(a) (b)

Fig. 7—(a) Preisach diagram. (b) Anhysteretic magnetization loops computed from Preisach diagram.

Formal assumption of asymmetrical particle switching fields is made in the Preisach diagram[3–5] shown in Fig. 7(a). Here, the particle coercivity is plotted as abscissa (H_c') and the local internal field (H_i) as ordinate. Assuming that the particles in the tape may be described by a uniform distribution on the Preisach plane above some critical field H^*, the minor hysteresis loops traversed during the anhysteretic magnetization process will be as shown in Fig. 7(b). The resultant remanent magnetization $[I_{cr}(H_s)]$ is that due to the part of the distribution marked with plus signs above the abscissa [Fig. 7(a)]. Here, the reversible magnetization component is ignored since the final magnetization is achieved by irreversible processes alone. It is seen that the differential susceptibility for irreversible magnetization in the minor loops increases with increasing loop size in good agreement with the experimental loops. Similar minor loops would be traversed if the anhysteretic magnetization process is modified to the condition of constant ratio of ac to dc signals, as occurs in ac-bias recording. In both cases it is demonstrated that finite initial anhysteretic susceptibility occurs, thus explaining the finite recording sensitivity.

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[2] D. F. Eldridge, "The mechanism of ac biased magnetic recording," 1961 IRE NATIONAL CONVENTION RECORD, pt. 2, pp. 69–73.

[3] E. D. Daniel and I. Levine, "Experimental and theoretical investigation of the magnetic properties of iron oxide recording tape," *J. Acoust. Soc. Am.*, vol. 32, pp. 1–15; January, 1960.

[4] J. G. Woodward and E. Della Torre, "Particle interaction in magnetic recording tapes," *J. Appl. Phys.*, vol. 31, pp. 56–62, January, 1960; vol. 32, pp. 126–127, January, 1961.

[5] G. Schwantke, "The magnetic tape recording process in terms of the Preisach representation," *J. Audio Engrg. Soc.*, vol. 9, pp. 37–47; January, 1961.

By comparison, the simple noninteracting particle system initially assumed for the recording model would be represented by a point on the abscissa of the Preisach diagram, yielding infinite anhysteretic susceptibility. If allowance is made for a distribution of particle switching fields, as would be represented by a line distribution along the abscissa of the Preisach diagram, the magnetization cylinder of the model for a given recording field would have a range of diameters corresponding to the range of switching fields. From Fig. 6 it may be estimated for the major loop that the bulk of the irreversible magnetization takes place in a field range approximately equal to the field required to commence such magnetization changes. In the model loop of Fig. 7(b), $H_s \approx 2H^*$ and the corresponding magnetization cylinder radius would occur with equal probability over a 2:1 range. Coherent recording of the bias would not occur in this case although the principle of the simple model is still effective. In other words, since adjacent particles may have different intrinsic switching fields (H_c'), their corresponding magnetization cylinders will have different radii. Consequently, it is possible for the recording field to have opposite polarities at the times that the two particles reach the boundary of their magnetization cylinders, and the particles then become oppositely magnetized. In the absence of a recording signal equal numbers of particles will be magnetized in the two directions of the applied field due to the ac bias. However, if the bias wavelength is very small, all particles would be magnetized in the direction of a small signal field superimposed on the bias unless account is also taken of the interaction fields. From the point of view of the recording model, the interaction field acting on a particle can be looked upon as a constant field opposing or aiding the signal field. When the two fields are opposing, a finite recording field, equal to the interaction field, is required to produce bias magnetization cylinders of equal size (as shown on the left-hand side of Fig. 2). Thus, the recording sensitivity is reduced and is controlled by the magnitude of the internal field.

CONCLUSIONS

By taking into account the practical conditions of switching field distribution and interaction fields, it is possible to obtain better agreement between the recording model and experimental recording characteristics such as variation of recording sensitivity with bias frequency and amplitude and, also, to account qualitatively for the relatively low recording sensitivity. The relationship of this recording model to the anhysteretic magnetization and Preisach diagram concepts have been discussed to illustrate their relative abilities to explain the recording mechanism.

Loudspeaker Structures with Strontium-Ferrite Magnets*

A. COCHARDT†

Summary—**A new, inexpensive permanent magnet material is now available which has a higher magnetic energy than any other ceramic magnet material previously known. It is a modified strontium ferrite. One of its most important applications is in moving coil loudspeakers. Sixteen widely used gap configurations, including the nine Electronic Industries Association standards, with gap energies between 0.1 and 20 mega-ergs are described for which strontium-ferrite rings are used. The leakage permeances, the flux densities inside the magnet, and the permeance of the return circuit are estimated. The process of successive approximations is used to calculate the dimensions of the strontium-ferrite rings. It is found that systems with strontium ferrite are smaller, simpler, and lighter in most cases than equivalent systems with Alnico-5 magnets. This is mainly due to the much lower permeability of strontium ferrite as compared to that of Alnico-5. The low permeability makes limb leakage negligibly small in compact strontium-ferrite structures. Strontium-ferrite speaker systems are particularly suitable for low-cost applications and whenever high gap energies and high gap densities are needed.**

NOMENCLATURE

THE FOLLOWING nomenclature is used in the paper:

L = magnet length, in.
G = radial gap length, in.
E_g = gap energy, mega-ergs.
A_m = magnet area, sq in.
A_g = gap area, sq in.
A_{cp} = area of center pole, sq in.
B_1 = effective magnet flux density, gauss, for minimum-magnet weight and for −10°F minimum-safe operating temperature.
B_g = gap density, gauss.
B_{cp} = flux density at base of center pole, gauss.
f = reluctance factor = ratio of mmf supplied by magnet to mmf required by gap.
σ = leakage factor = ratio of total magnet flux to flux in gap.
H_1 = field corresponding to B_1, oe.

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* Received September 14, 1962.

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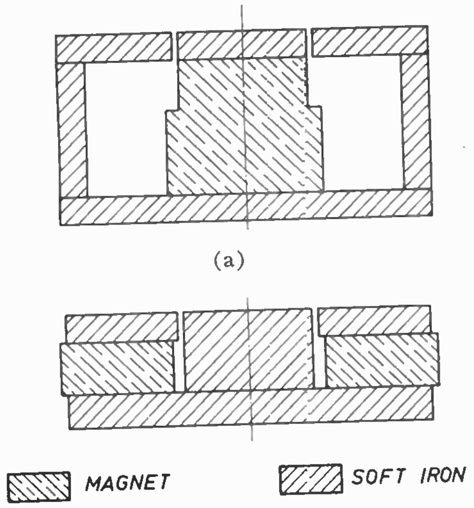

(a)

(b)

Fig. 1—Comparison of equivalent systems. (a) Alnico-5 system. (b) Strontium-ferrite system.

H_{cp} = field corresponding to B_{cp}, oe.
p = permeance coefficient = slope of load line.
r = radius of point inside magnet, in.
z = distance from magnet bottom surface, in.
δ = lumped residual air gap = 0.004 in.
$\mu = B_{cp}/H_{cp}$.
D = diameter of voice coil, in.
D_1 = diameter of center pole, in.
D_2 = ID of pole plate, in.
D_3 = ID of magnet, in.
D_4 = OD of pole plate, in.
D_5 = OD of magnet, in.
T_1 = thickness of upper plate, in.
T_2 = thickness of lower plate, in.

INTRODUCTION

Almost all loudspeakers now are of the dynamic moving-coil type with permanent magnetic field excitation. No power consumption, reduced hum, and lower cost are the main advantages of permanent magnetic over electromagnetic field excitation. The permanent magnet decisively influences the performance, size, and cost of a loudspeaker. Many different designs of the speaker magnet have been used in the past.[1,2]

One of the latest advances is the structure with a dual-diameter Alnico-5 magnet seen in Fig. 1(a). The magnet is in the center of the structure surrounded by an iron yoke or pot. The iron pole cap on top of the magnet concentrates the flux into an annular gap in which the voice coil moves (not shown). Such a system has a higher efficiency than any other Alnico-5 system.[3]

Fig. 1(b) shows the equivalent system with a new permanent magnet material, a modified strontium ferrite. The gap configuration and the gap density are the same in both cases. It is noted that the strontium-ferrite system is smaller than the Alnico-5 system. In some cases, the strontium-ferrite system may be sheathed with a layer of polystyrene.[1] It would then be slightly larger than shown in Fig. 1. It is the purpose of the present paper to show the advantages and limitations of strontium ferrite as the material for the speaker magnet.

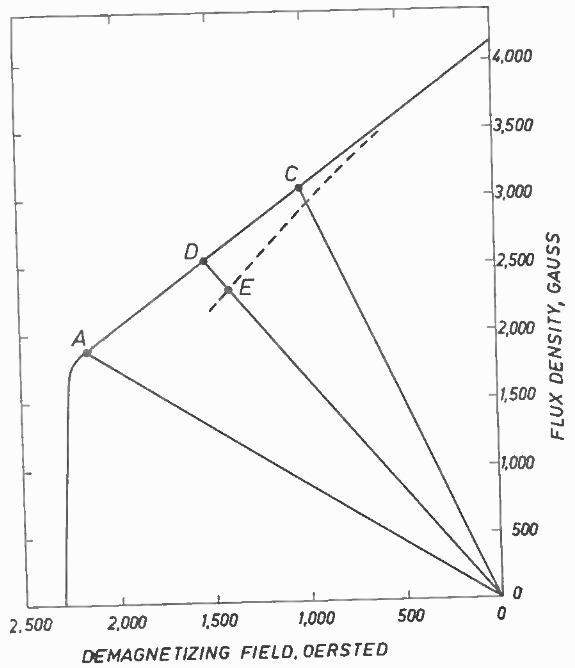

Fig. 2—Magnet flux density vs internal demagnetizing field.

STRONTIUM-FERRITE MAGNETS

The process of making strontium ferrite is similar to the barium-ferrite process which has been known for several years.[4] Both ferrites are magnetoplumbites with a hexagonal crystal structure. Strontium ferrite has a somewhat higher energy and lower density than barium ferrite. In addition, it is easier to manufacture than barium ferrite.

Fig. 2 shows a demagnetization curve (solid line) of a grade of strontium ferrite which is suitable as a low-cost loudspeaker magnet material for a minimum safe operating temperature of −10°F. The remanence is approximately 4150 gauss, the coercive force 2300 oe, the maximum energy product 4.0 mega-gauss ×oersted, and the specific gravity 4.9. Magnets with better properties can be prepared under more careful conditions.[5] Occasionally, speaker performance is improved if the remanence of the ferrite is increased at the expense of coercive force. This can be done by sintering the ferrite at a higher temperature.

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[1] H. L. Johnson, "Designing loudspeaker magnets with Indox V," *Appl. Magnetics*, vol. 9, pp. 1–5; First Quarter, 1961.

[2] R. J. Parker, "Permanent magnets in audio devices," IRE TRANS. ON COMPONENT PARTS, vol. CP-5, pp. 32–37; March, 1958.

[3] R. J. Parker and R. J. Studders, "Permanent Magnets and Their Application," John Wiley and Sons, Inc., New York, N. Y., pp. 256–261, 195, 165; 1962.

[4] D. Hadfield, "Permanent Magnets and Magnetism," Iliffe Books Ltd., London, England, pp. 389–392; 1962.

[5] A. Cochardt, "Modified strontium ferrite, a new permanent magnet material," *J. Appl. Phys.* (to be published).

TABLE I
SOME WIDELY USED GAP CONFIGURATIONS

System No.	D (in)	T_1 (in)	G (in)	B_g gauss	E_g mega-ergs	Alnico 5	
						structure	magnet weight (oz)
I	0.562	0.156	0.032	4500	0.12	pole stem	0.55
II	0.750	0.187	0.032	6600	0.40	pole cap	1.0
III	1.000	0.250	0.035	7600	1.04	pole cap	2.5
IV	0.562	0.156	0.032	6600	0.25	EIA Standard 1	0.68
V	0.562	0.156	0.032	7700	0.34	EIA Standard 2	1.0
VI	0.562	0.156	0.032	9100	0.47	EIA Standard 3	1.47
VII	0.750	0.187	0.032	7000	0.45	EIA Standard 4	1.47
VIII	0.750	0.187	0.032	8400	0.65	EIA Standard 5	2.15
IX	0.750	0.187	0.032	10,000	0.92	EIA Standard 6	3.16
X	1.000	0.250	0.035	7400	0.99	EIA Standard 7	3.16
XI	1.000	0.250	0.035	9200	1.52	EIA Standard 8	4.64
XII	1.000	0.250	0.035	10,800	2.10	EIA Standard 9	6.8
XIII	1.250	0.250	0.038	11,000	2.9	ring	14
XIV	1.500	0.312	0.038	11,000	4.4	ring	22
XV	2.000	0.400	0.052	11,500	11.3	ring	52
XVI	2.500	0.500	0.056	12,000	20.7	ring	120

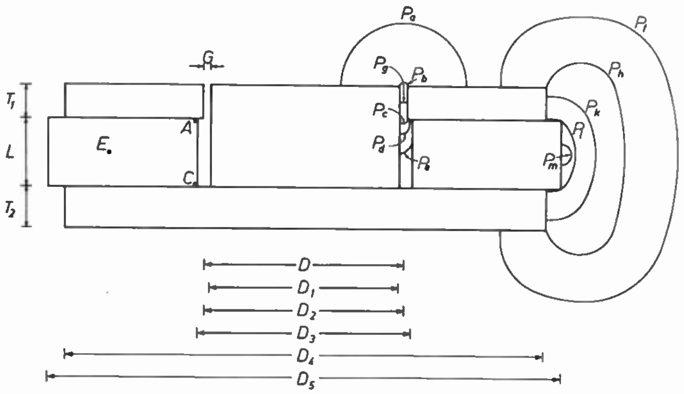

Fig. 3—Strontium-ferrite structure with leakage paths.

STANDARD GAP CONFIGURATIONS

The sound-power output of a loudspeaker is proportional to B_g^2 and to the volume of conducting material in the gap.[3] A high gap density has other beneficial effects on speaker operation. It is therefore highly desirable to make the gap density as high as possible. However, the cost of the speaker generally increases with gap density and gap volume. A compromise has to be made for a particular application between gap density, gap volume, the cost of the system, and other factors.

Table I lists sixteen widely used gap configurations. D, T_1, and G are identified in Fig. 3. The systems are numbered with Roman numerals from I to XVI. It is seen that the gap density varies between 4500 and 12,000 gauss and the gap energy between 0.12 and 20.7 mega-ergs. The last two columns in Table I indicate the Alnico-5 magnet structure and weight that is currently used for the respective systems.[3] Nine of the sixteen systems are the standards of the Electronics Industries Association (EIA). For a given structure type, the Alnico-5 magnet weight is roughly proportional to the gap energy.

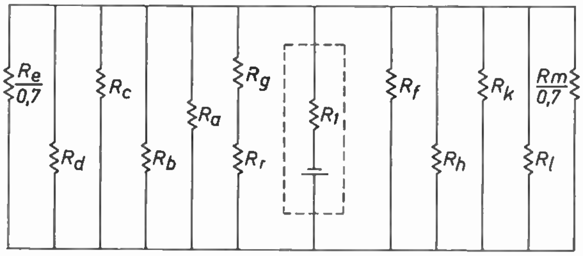

Fig. 4—Simplified electrical analog of speaker magnet circuit.

MAGNET CIRCUIT AND ELECTRICAL ANALOG

The dimensions of the magnet structure will be calculated for the case that the Alnico-5 magnet is replaced by a strontium-ferrite ring for each of the sixteen standard gap configurations of Table I. Fig. 3 shows such a structure with the ten most likely leakage paths designated by the symbols P_a through P_m—except for P_g which designates the useful flux lines. Fig. 4 shows the simplified, electrical analog of the magnet circuit that is used in the calculations below. The subscripts in Fig. 4 correspond to those in Fig. 3. R_1 corresponds to the internal reluctance and R_r represents the reluctance of the return circuit.

The actual electrical analog of the magnet circuit of Fig. 3 is much more complicated than the one shown in Fig. 4. Instead of only one resistance R_r, there are really many more such resistances, representing the reluctances of the upper pole plate, the center pole, the lower plate, the two small residual gaps between magnet and plates, and the residual gap between center pole and lower plate. In the actual electrical analog, some of these resistances are in series with some of the leakage path resistances. For example, there should be part of R_r in series with R_a because the corresponding leakage flux goes through the center pole and the lower plate. But a reonably good approximation is obtained if the reluctance of the return circuit is lumped into

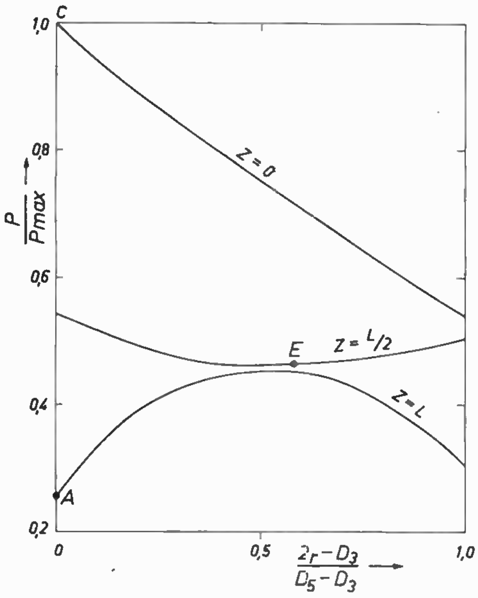

Fig. 5—Permeance coefficient in fraction of maximum permeance coefficient in radial direction.

TABLE II

PERMEANCES OF FLUX PATHS

$P_g = \dfrac{\pi D T_1}{G}$	$P_f = \dfrac{\pi^{3/2}(D_4{}^2 - D_2{}^2)}{4s^{1/2}}$
$P_a = D \log_e \dfrac{D_2}{G}$	$P_h = P = \dfrac{\pi D_4}{4}$
$P_b = P_c = \dfrac{\pi D_2}{4}$	$P_k = \dfrac{\pi^{3/2} T_1 D_4}{s^{1/2}}$
$\overline{P}_e = \dfrac{2\pi L}{\log_e \dfrac{D_3 + 0.4(D_5 - D_3)}{D_1}}$	$P_m = \dfrac{\pi^{3/2} L D_5}{s^{1/2}}$
$P_d = 2D_1 \log_e \dfrac{D_3 - D_1}{2G} + \dfrac{4}{\pi}(D_3 - D_2)$	
$s = \pi D_5 L/2 + T_1 \pi D_4 + \pi(D_4{}^2 - D_2{}^2)/4 + T_1 \pi D_2 + \pi D_2 L/2$	

only one reluctance and if this reluctance is placed in series with the reluctance of the annular gap as was suggested before.[6]

Fig. 4 shows a further simplification. The resistances R_e and R_m are divided by 0.7. This is done because only part of the full mmf is acting on the two leakage paths e and m as is seen from Fig. 3. To compensate for this, the permeances of these two flux paths are multiplied with 0.7 as is usually done in such a case.

In addition to R_1 and the one voltage in Fig. 4, several more internal resistances and voltages would have to be considered in the actual electrical analog. Different points of the magnet operate at different load lines or at different values of p. This is seen from Fig. 5 which shows the ratio $p/p_{\max}$ as a function of the distance from the inside magnet surface in fraction of the difference between outside and inside radius of the magnet ring. Point C in Fig. 5 (with coordinates $z=0$ and $r=D_3/2$) operates at the maximum permeance coefficient $p_{\max}$ as is indicated also in Figs. 2 and 3. Point A with $z=L$ and $r=D_3/2$ has the lowest p. This was already pointed out by Schwabe[7] for a barium-ferrite speaker structure. It is assumed in the following calculation that the entire magnet operates at $p=B_1/H_1$ given by point E in Figs. 3 and 5 which is the magnet volume center point. Its coordinates are $z=L/2$ and $r=0.353\ (D_5{}^2-D_3{}^2)^{1/2}$. The leakage flux from the magnet surface is treated as if originated from the pole plates as shown in Fig. 4. This is a satisfactory approximation for the purpose of this paper. A step-by-step calculation used in designing Alnico-5 speaker magnets[3] is far more difficult for strontium-ferrite magnets than for Alnico magnets because of the large variations of p in cross sections parallel to the pole plates (see Fig. 5).

PERMEANCES OF FLUX PATHS

Table II lists the expressions for the permeances of the eleven flux paths shown in Fig. 3. P_a and P_d were derived by Spreadbury.[8] P_b, P_c, P_h, and P_l are from Rotors.[9] P_f, P_k, and P_m were derived by using the free pole formula[3] for the magnet ring and the plates and by assuming that the ratio of the permeance of each surface element to the total permeance of the "pole" is equal to the ratio of the area of the surface element to the total area of the "pole."

$\overline{P}_e$ requires particular mention because it shows why strontium ferrite outperforms Alnico 5 in some static applications although its maximum energy product is lower than that of Alnico 5. P_e is the permeance between two concentric cylinders and is usually given[9] by

$$P_e = \frac{2\pi L}{\log_e D_3/D_1}. \tag{1}$$

Eq. (1) is derived from electrostatic potential theory under the assumption that the two cylinders have a high conductivity. It holds for the magnetostatic analog if the permeability of the cylinders is large compared to that of air, as is generally the case for metallic permanent magnet materials such as Alnico 5. But strontium ferrite has essentially the same permeability

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[6] H. Krieger, "Design of loudspeaker systems with barium ferrite magnets," *Radio Mentor*, vol. 24, pp. 837–839; December, 1958.

[7] E. Schwabe, "Temperature dependence of magnetic properties of barium ferrite," *Z. angew. Phys.*, vol. 9, pp. 183–187; April, 1957.

[8] F. G. Spreadbury, "Permanent Magnets," Sir Isaac Pitman and Sons, Ltd., London, England, p. 101; 1949.

[9] H. C. Rotors, "Electromagnetic Devices," John Wiley and Sons, Inc., New York, N. Y., p. 120; 1941.

as air. Therefore, (1) would give much too high a value for the leakage flux between the strontium-ferrite cylinder and the iron center pole.

The low permeability of strontium ferrite is, to a large extent, the reason for the surprisingly small and simple speaker magnet structure and for its remarkable performance. Unlike Alnico 5, the strontium-ferrite magnet ring has negligibly small limb leakage, even if its inside surface touches the center pole.[10] Because of its much higher permeability, an Alnico-5 structure must have a rather large ratio of D_3/D_1. That is why Alnico speaker structures are relatively large. In addition to P_e, other permeances, such as P_f, P_h, P_k, etc., become large if the ratio D_3/D_1 is increased. This is the reason why an Alnico-5 ring magnet structure is considerably less efficient than a strontium-ferrite ring magnet structure as will be shown below.

Instead of (1), a weighted, average permeance has to be used for a strontium-ferrite ring or for a ring from any other material with a permeability of essentially 1. This average $\overline{P}_e$ can be expressed as

$$\overline{P}_e = \frac{8}{D_5^2 - D_3^2} \int_{D_3/2}^{D_5/2} P_e r dr. \tag{2}$$

The leakage path P_e is thought to originate not from the inside magnet surface only, as is the case for a ring of a material with a high permeability, but from the entire magnet cross section. Eq. (2) is approximated for the following calculations by the expression for $\overline{P}_e$ given in Table II.

DESIGN EQUATIONS

The basic two equations of permanent magnet design are

$$L = \frac{B_g G f}{H_1}$$

and

$$A_m = \frac{B_g A_g \sigma}{B_1}.$$

The reluctance factor f is given by the mmf loss in the plates and in the center pole, and by the mmf loss of the two joints between magnet ring and plates and the joint between center pole and lower plate. The mmf loss in the plates can be neglected because the flux density is relatively small in the top and bottom plate. Most of the mmf loss occurs at the bottom of the center pole where the flux density is highest. The mmf loss of the circuit joints depends on the flatness of the contact surfaces, particularly on those between the center pole and the bottom plate. It is found that the reluctance factor can be approximated by the expression

$$f = 1 + \frac{0.7\, B_{cp}\delta + H_{cp}L}{B_g G}$$

where

$$B_{cp} = \frac{B_1 A_m}{A_{cp}} \frac{P_g' + P_a + P_b + P_c + P_d + 0.7\, \overline{P}_e}{P_t},$$

with

$$P_g' = \frac{P_g \cdot P_r}{P_g + P_r}$$

and

$$P_t = P_g' + P_a + P_b + P_c + P_d + 0.7\, \overline{P}_e + P_f + P_h + P_k + P_l + 0.7\, P_m.$$

The permeance of the return path P_r depends primarily on the permeance at the bottom of the center pole and the permeance of the residual air gap between center pole and bottom plate. P_r can be written as

$$P_r = \frac{A_{cp}}{L/\mu + \delta}.$$

The μ of annealed, cold-rolled steel is used in the calculations. The thickness T_2 of the bottom plate is given by

$$T_2 = \frac{B_{cp} \cdot D_1}{60{,}000},$$

if the maximum flux density in the bottom plate is taken as 15,000 gauss. According to Fig. 4, the leakage factor can be expressed by

$$\sigma = \frac{P_t}{P_g}.$$

RESULTS OF THE CALCULATION

The process of successive approximations was used to determine the dimensions of the magnet structures. A certain σ, f, D_3, and B_{cp} was first assumed, and values for D_4, D_5, and L were calculated. The eleven permeances were then determined, and σ, f, etc., were calculated. New values for σ, f, etc., were assumed, and the calculation was repeated.

B_1 and H_1 were taken as 2320 gauss and 1400 oersted, respectively. These are the values of point E in Fig. 2. After an exposure to −10°F, point D moves down to point E. The volume portion near point A in Fig. 3 operates below the knee of the demagnetization curve at −10°F. Thus the magnet suffers a small, irreversible loss after being cooled to that temperature. From then on, the magnet works reversibly down to −10°F. Strontium ferrite behaves like barium ferrite as far as the temperature effects are concerned.[7]

Table III gives the results of the calculations for the sixteen systems of Table I. It is seen that σ varies between 1.8 and 2.6, and f varies between 1.14 and 1.50. The reluctance factor f can have lower values in stron-

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[10] A. T. van Urk and A. Rademakers, "Permanent magnet circuit," German Patent No. 975, 665; April 19, 1962.

TABLE III

RESULTS OF CALCULATION FOR MINIMUM MAGNET WEIGHT

System No.	σ	f	L (in)	D_3 (in)	D_4 (in)	D_5 (in)	T_2 (in)	Magnet weight (oz)
I	2.2	1.19	0.122	0.688	1.35	1.41	0.08	0.41
II	2.0	1.16	0.174	0.875	1.90	1.99	0.14	1.2
III	1.9	1.16	0.211	1.188	2.71	2.82	0.21	3.1
IV	2.3	1.19	0.180	0.688	1.57	1.66	0.12	0.91
V	2.3	1.17	0.205	0.688	1.74	1.74	0.14	1.2
VI	2.6	1.48	0.308	0.688	1.84	1.99	0.17	2.4
VII	2.0	1.17	0.188	0.875	1.94	2.03	0.15	1.4
VIII	2.1	1.19	0.230	0.875	2.08	2.20	0.17	2.1
IX	2.2	1.35	0.309	0.875	2.32	2.48	0.20	3.4
X	1.9	1.15	0.213	1.188	2.68	2.79	0.20	3.0
XI	2.0	1.22	0.281	1.188	2.92	3.06	0.23	5.0
XII	2.1	1.50	0.405	1.188	3.07	3.28	0.28	8.4
XIII	2.0	1.15	0.345	1.438	3.56	3.73	0.30	8.9
XIV	1.8	1.18	0.354	1.750	4.38	4.56	0.37	13.9
XV	1.9	1.14	0.493	2.313	5.82	6.07	0.50	34.9
XVI	1.8	1.16	0.558	2.875	7.42	7.72	0.66	64.0

tium-ferrite structures than are obtainable in Alnico structures. This is due to the lower mmf loss between strontium ferrite and iron than between Alnico and iron. Generally, the efficiency of a system increases with its size. The reason for this is that the gap permeance is usually larger for the larger systems. The least efficient systems are the three systems VI, IX, and XII (EIA standards 3, 6, and 9) because the mmf loss in the center pole is relatively large in these cases.

The inside diameter of the magnet ring D_3 should be as small as possible because P_d, P_f, P_h, P_k, P_l, and P_m decrease with decreasing D_3. Only $\overline{P}_e$ increases with decreasing D_3. However, as was pointed out above, $\overline{P}_e$ is relatively small due to the low permeability of strontium ferrite. D_3 was taken in multiples of 1/16 in and was made as small as appears agreeable with manufacturing tolerances.

D_4 should be smaller than D_5, as was already mentioned for barium-ferrite systems.[1,6] P_f, P_h, P_k, and P_l become smaller with smaller D_4. But the total flux entering the top plate also becomes smaller when D_4 is decreased. The efficiency has a maximum when $2\ (D_5 - D_4)$ is approximately equal to L.

When the weights of the strontium-ferrite magnets (Table III) are compared with the weights of the Alnico-5 magnets (Table I), it is noted that in eight out of the sixteen systems the strontium-ferrite system requires less magnet weight. But magnet weight is only one of several important factors in speaker magnet design. Actually, the strontium-ferrite systems look much better than is apparent from a comparison of magnet weights. Even if the magnet weight is appreciably larger, the strontium-ferrite system may cost less, be smaller, and weigh less than the equivalent Alnico-5 system.

It is further seen from Table III that the magnet length L is only 0.122 to 0.558 in. It may be more convenient to manufacture thicker magnets. In fact, a less efficient system (more magnet weight per given gap energy) with a thicker magnet may have a smaller size and weigh and cost less than a more efficient system with a thin magnet. As the L/A_m ratio of the magnet is increased, D_4 and D_5 become smaller for a given gap configuration. Less iron is needed. The leakage flux becomes somewhat smaller because the decrease in P_f, P_h, P_k, P_l, and P_m more than makes up for the increase in $\overline{P}_e$. The system suffers less loss after an exposure to a low temperature because the entire magnet operates higher up on the demagnetization curve. Grinding costs are less because of the smaller A_m and because only the end faces need to be ground. The manufacturing process is simplified because warpage of the ceramic magnet rings can be eliminated. The increase in magnet weight has relatively little influence on the cost of the magnet because the raw material cost of strontium ferrite is a small portion of the total cost.

For all these reasons, the above calculations were repeated for thicker magnet rings. Systems VI, IX, and XII were not considered because these systems already have relatively thick magnets due to the large mmf loss in the center pole. Also, these systems are less suited for a simple design with strontium ferrite. For the other systems, the same σ values and f values were used as for the thinner magnets since the decrease in σ and the increase in f are relatively small when the thickness of the magnet is increased for a given gap configuration.

Table IV gives the results of the calculation. The new values are designated herein by an asterisk to differentiate them from those in Table III. D_3 and T_2 are unchanged. $B_1{}^*$ and $H_1{}^*$ were taken from the dashed curve in Fig. 2 which gives the effective magnet flux density after an exposure to $-10°$F as a function of the effective demagnetizing field. $D_4{}^*$ and $D_5{}^*$ are smaller than D_4 and D_5, but more magnet weight is needed than before as a comparison between Tables III and IV shows. The weight savings in iron are several times larger than the increase of magnet weight. For example, 1.6 oz less iron and 0.4 oz more magnet are needed for system VIII and 6.2 oz less iron and 1.1 oz more magnet for system XIII. The L^*-values were arbitrarily chosen. A magnet length

TABLE IV

RESULTS OF CALCULATION FOR THICKER MAGNETS

System No.	L^* (in)	B_1^* gauss	H_1^* oe	D_4^* (in)	D_5^* (in)	Magnet weight (oz)
I	0.250	3380	685	1.11	1.23	0.53
II	0.312	3250	770	1.58	1.74	1.5
III	0.375	3220	790	2.13	2.32	4.0
IV	0.312	3200	800	1.30	1.46	1.1
V	0.312	3040	920	1.40	1.56	1.4
VII	0.375	3340	700	1.57	1.76	1.9
VIII	0.375	3120	860	1.76	1.95	2.5
X	0.375	3200	800	2.69	2.68	3.6
XI	0.437	3100	900	2.67	2.89	5.8
XIII	0.500	2980	960	3.12	3.37	10.0
XIV	0.500	2940	990	3.87	4.12	15.5
XV	0.750	3040	920	5.04	5.41	40
XVI	0.750	2850	1050	6.69	7.06	69

between L and L^* may be most suitable in a given situation.

DISCUSSION OF THE RESULTS AND CONCLUSIONS

Strontium ferrite is made from inexpensive raw materials which cost four to six times less than the Alnico-5 raw materials. It lends itself better to processes of mass production than Alnico 5 which has to be melted and cast, and which undergoes complicated heat treatments. Therefore, strontium ferrite should be used whenever the cost of the magnet material is of prime importance.

Magnet structures with strontium ferrite are generally smaller than those with Alnico 5, and they are considerably shorter. Less steel is generally needed for a strontium-ferrite structure than for the equivalent Alnico-5 structure. Thus, strontium ferrite should be used whenever the size, length, and weight of a speaker structure is of great importance.

When very large gap densities are required a ring-type magnet structure is superior to a structure with a center-core magnet. One reason for this is that flux flowing from the outside to the inside of the pole plate can be concentrated to a considerable degree. In this way, the pole plate acts like a conventional pole piece. This is not possible with a simple pole plate, when the magnet is in the center because then the flux has to flow from the inside to the outside. Ring-type Alnico-5 structures are much less efficient than ring-type strontium-ferrite structures. Therefore, strontium-ferrite structures should be used whenever a speaker with a very high gap density is needed, such as in high-fidelity applications.

It is difficult to provide large amounts of gap energy from a magnet located in the center of a structure. To obtain sufficient flux for a high energy gap, large magnet cross sections are required. But the cross section of the voice coil cannot be increased in the same proportion. Thus, there is a limit as to the amount of flux that a center magnet can provide for certain voice coils. There is no such limitation in a ring-type structure. For this reason, strontium-ferrite ring-type structures should be used whenever large gap energies are required, such as in theater loudspeakers and the like.

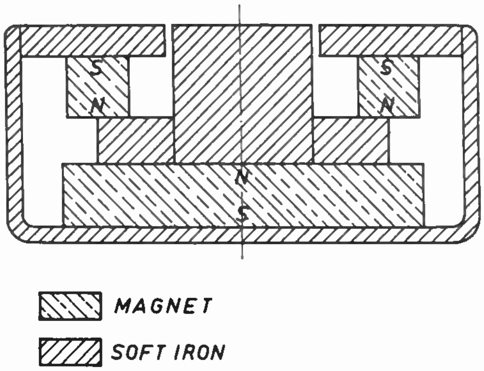

Fig. 6—Strontium-ferrite speaker magnet design with low external stray flux.

There is less mmf loss in a well-designed strontium-ferrite system than in the equivalent Alnico system. This is explained by the low flux density in the circuit joints between strontium ferrite and iron. In the equivalent Alnico system, the flux density in these residual gaps (and, as a consequence, the mmf loss) is higher.

Of the nine gap configurations of the EIA standards, the standards 3, 6, and 9 are less suited for strontium ferrite. There is an appreciable mmf loss in the center pole in these three systems when the simple strontium-ferrite design of Fig. 3 is used.

In some speaker applications, the relatively large stray flux inherent in a ring-type structure may be a disadvantage. A speaker magnet design can then be used similar to the design that is now used for most of the German barium-ferrite television speakers.[11] Fig. 6 shows such a magnet structure. Two permanent magnets, one a disk and the other a ring, are connected in parallel. They are inside a pot. External stray flux is greatly reduced, even more so than in a system with an Alnico center magnet.[11]

It is a widespread misconception that it is only the maximum energy product that determines how much magnet weight is needed for a given type of structure. However, the permeability and the coercive force of the magnet material are also of great importance. When the permeability is essentially that of air, such as with strontium ferrite, magnet and iron can be brought close together. Flux leakage from the pole plate is greatly reduced, and the efficiency of the system is considerably increased. When the coercive force is high, at the same level of energy product, the performance of the magnet structure is improved because volume portions of the magnet near the inside and outside upper edges will have less tendency to operate below the knee of the demagnetizing curve.

In all, it can be safely concluded that strontium ferrite will find wide use in speaker applications.

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[11] E. Schwabe, "Loudspeaker systems with barium ferrite magnets," *Radio Mentor*, vol. 24, pp. 24–36; January, 1958.

A New Automatic Level Control for Monophonic and Stereophonic Broadcasting*

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Summary—The need for conserving technical manpower in broadcasting operations has spurred interest in automatic level controlling systems to achieve optimum modulation. A set of operating standards can be established so that any system of level control, manual or automatic, can be appraised. These standards temper technical and aesthetic considerations. An examination of the prior art in the field discloses the shortcomings of systems using the conventional approach and the large degree of compromise that must be accepted by their use.

A completely new system, the Audimax, employing simple switching logic has been devised which satisfies the requirements of the operating standards with negligible compromise. This system is described in detail.

In order to satisfy the level control problems for stereophonic broadcasting, an adapter is provided for use with two Audimax units which makes the system responsive to the sum of the left and right signals. In this way, the stereophonic perspective is maintained and maximum modulation ensured.

Operational experience with the Audimax is described briefly.

IT IS A WELL-KNOWN fact that radio listeners tend to favor a station which comes in "loud and clear." This trend has become especially important because of the large number of portable and automotive receivers which operate in noisy surroundings. Since the AVC of radio receivers tends to equalize the carrier strength prior to detection, high modulation level is required to attract the listener. This paper describes a new automatic level control amplifier, called the Audimax, which maximizes the level of modulation in accordance with accepted broadcast studio control practices, but which is not subject to the limitations of human reflexes and span of attention. This is especially important as programming complications have tended to augment the number of tasks performed by studio engineers.

FM multiplex stereophonic broadcasting imposes additional problems since two channels of audio are now involved and a specific relationship must be preserved between them. This is further complicated by the fact that modulation levels are determined by the instantaneous *sum* of these two channels.

GENERAL REQUIREMENTS FOR AUDIO LEVEL CONTROL

Using an accepted volume indicator and his hearing, a conscientious technician is required to:

1. Prevent excess levels from overdriving the audio system by a rapid reduction of gain.
2. Offset a reduction in the average audio level by an increase of gain at a modest but steady rate.
3. Recognize that pauses in the audio of several seconds' duration require no alteration of gain.
4. Recognize that occasional excessive audible peaks that are out of context with the mean level will be handled by the peak limiter feeding the transmitter or recording amplifier and require no manual change of gain.

THE PRIOR ART

Since variable gain program-level amplifiers have been available for several decades, the question may be asked, how well do they fulfill the objectives listed above? Let us consider, therefore, a conventional variable gain amplifier which reduces gain above a critical signal input with a speed of a few milliseconds, and upon cessation of the input recovers its gain in a manner which may be adjusted at will. As a typical example, let us assume that gain reduction takes place in 15 msec and 63 per cent of gain recovery in about 2 sec. To provide an adequate range of gain control the amplifier is adjusted so that normal input level produces 10 db of gain reduction.

With regard to the first requirement indicated for audio level control, conventional devices provide adequate performance because of their "attack" speed. However, with a recovery speed as indicated, considerable gain increase accompanies the "valleys" associated with speech or singing. This gives rise to the phenomenon known as "pumping" where the level of background sounds or accompaniment rises and falls with variations in level between syllables or groups of syllables. By employing a recovery time of 10 sec or longer, this effect is alleviated but another problem arises, later to be described.

Referring to the second requirement, conventional devices can provide adequate gain increases to accommodate reduced levels *provided* the recovery time is sufficiently *short*. Otherwise a low level caused by switching program sources might produce an extended period of inadequate gain. This requirement, therefore, conflicts with the necessity for eliminating "pumping."

The third requirement must be examined from two aspects: first, brief lapses of audio of about 2-sec duration caused by pauses in speech to punctuate sentences or paragraphs or to take a breath, and second, pauses of greater duration for dramatic purposes. In the first case, conventional variable gain amplifiers with short recovery time tend to exaggerate the sound of breath intake immediately preceding the resumption of speech in addition to raising the level of background quite notice-

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* Received July 18, 1962. Presented at the 1962 IRE International Convention, New York, N. Y.

† CBS Laboratories, Stamford, Conn.

ably. In the second case, the full gain of the system would be restored with possible exaggeration of background; for example, motion picture sound tracks. If a long recovery is substituted, the system then will *not* accommodate a drop in level adequately.

A studio technician will generally have little difficulty in meeting the fourth requirement since his speed of response is inadequate to effect a quick gain reduction. However, conventional variable gain amplifiers operating with long recovery times will cause the program to suffer prolonged gain reduction on occasional short "bursts" of sound. The classic case is that of a pistol shot. Audio immediately following is attenuated for several seconds.

By way of summary, a so-called "conflict of interests" exists with reference to the recovery characteristics of conventional variable gain devices. If too short, we experience "pumping" and the degradation of dynamic fidelity caused by an alteration of the peak-to-valley ratio. If too long, the system will not restore the gain required for a drop in level with adequate speed and it becomes vulnerable to having "holes" in the audio caused by high level short bursts.

This situation has been partially resolved by the inclusion of so-called "dual time-constants." In effect, this is a compromise solution. The use of expander modes to prevent an increase of background level during prolonged pauses is not an altogether satisfactory solution to the problem since it introduces a severe discontinuity in the input-output function, and where the signal level is just beyond the "verge of limiting" the severe gain reduction is as apparent as a gain increase would be without it.

Finally, the listener experiences a feeling of instability caused by the tendency of the gain to follow the contour of the signal continuously in contrast to the solidarity experienced with manual control.

The Audimax System

Fig. 1 shows a block diagram of the Audimax system. The main signal channel consists of a high-quality program level amplifier with V3 as a variable gain stage to which the control voltage is applied and V4 as the output stage. The output of detector 1 is stored in a memory from which the comparator extracts information regarding the program content for the preceding 10 sec. A decision is then made by the comparator based upon the memory content and the output of detector 2 as to whether a gain change is required. If so, this will be effected within 1 to 2 sec if the gain is to be increased and in less than 15 msec if decreased. Detectors 1 and 2 are differently "weighted." Each responds to those properties of the program signal with which it is concerned for the purpose of enabling the comparator to make a proper decision.

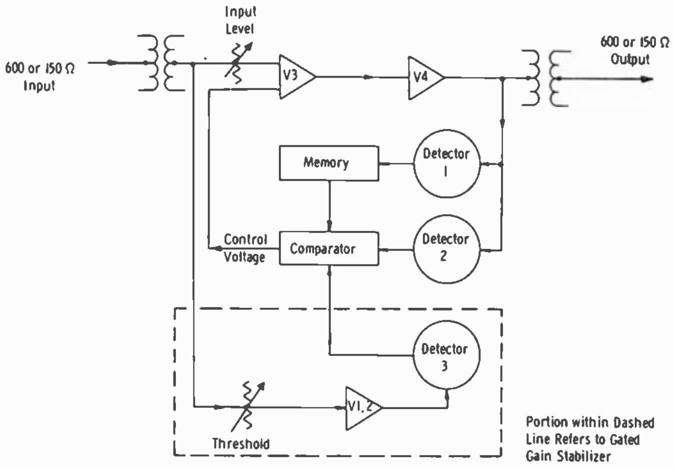

Fig. 1—System block diagram.

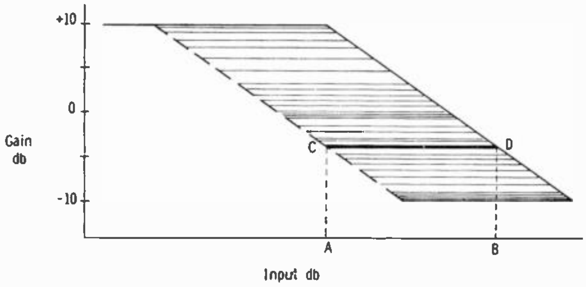

Fig. 2—Audimax performance.

Audimax functions in a four-dimensional domain whose coordinates are input level, output level, memory and time. Fig. 2 is a two-dimensional representation of the system gain vs input level. This diagram illustrates the operation of the memory device. The gain at any time is dependent on both the weighted input level and the program content during the preceding 10 sec. For example, for a range of input levels from A to B, the gain of Audimax remains on a stable "platform" C–D as determined by the comparator. If the range of input levels shifts to a new region, the gain "platform" is quickly readjusted to the new value required to yield the desired output. If operation were on gain platform C–D and an audible short duration signal occurred well above the level of B, the gain would immediately be reduced but would quickly return to C–D since the *average* value of the audio had not changed.

Referring once again to Fig. 1, detector 3 follows amplifier V1,2 which is fed from the input. If the audio level drops below a threshold as set by the control so-labeled, detector 3 supplies gated information to the comparator and a change of control voltage is inhibited until detector 3 indicates the resumption of audio above threshold. This feature is referred to as Gated Gain Stabilizer.

In its earliest embodiment, the gain of Audimax was held constant indefinitely as long as operation remained on a given platform. As a result of operational experience, this has been modified to permit a steady gain recovery at the rate of 63 per cent per 12 sec. This in no way alters the interplay of the various elements described above but rather enhances the operation of the system. It has been observed that speech level of announcers tends to drop during a sentence as lung air pressure decreases. The slow recovery tends to offset this drop.

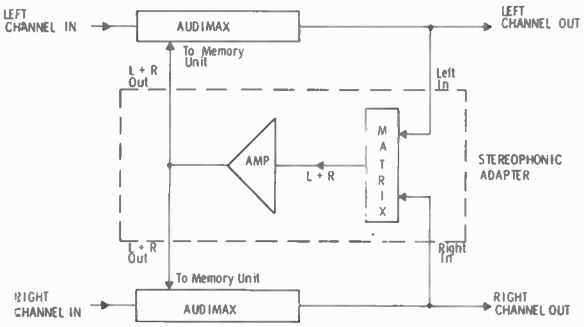

Fig. 3—Audimax stereophonic control.

In reviewing the four requirements cited above for artistically acceptable level control, it becomes apparent that Audimax satisfies the first requirement by virtue of its fast gain reduction capability. The second requirement is satisfied by the fact that *maintained* changes of gain are effected by the *average* value of the audio. The third requirement is met in two ways; for short pauses by the finite time required for the establishment of a new average, and consequent "platform," and for long pauses by the Gated Gain Stabilization described above. Finally the fourth requirement is met by providing for a return to the earlier platform following a gain reduction caused by a short audible peak. The "limiting" action for such peaks is then divided between Audimax and the transmitter peak-limiter with quick recovery on both.

STEREOPHONIC OPERATION

Fig. 3 is a block diagram showing the manner in which two Audimax units controlling left and right signals respectively are interconnected with the Audimax Stereophonic Adapter. The output of each Audimax is bridged and fed to a summing matrix from which a left plus right signal is derived. This is suitably amplified and applied to each of the Audimax memory units. In the manner the gain of both channels is identical and responsive to the L+R output, thus preserving the stereophonic separation and perspective. Inasmuch as the modulation amplitude in FM multiplex stereophonic broadcasting is a function of the L+R signal, by ensuring the maximum amplitude of L+R we realize the optimum modulation from the system.

OPERATIONAL EXPERIENCE

Fig. 4 is a photograph of the Audimax. It accommodates standard 19 inch rack mounting, is $5\frac{1}{4}$ inches high, $12\frac{3}{8}$ inches deep and weighs 27 lbs. Output level is +16 vu; −10 is minimum input for normal operation. It is recommended for use ahead of the line to the transmitter peak limiter.

Early in 1961, an Audimax was installed at WCBS-AM in New York City and shortly thereafter on two of the network lines. Subsequently, an Audimax was placed in continuous service on WCBS-TV. During the spring of 1961, Audimax units were given field tests at four AM stations along the East Coast. Audimax units are now in full-time operation at all CBS owned radio stations and at key points of the CBS television network as well as at almost one hundred independent stations across the country. In every case, a marked improvement in average modulation levels was noted without sacrifice to signal quality. Fig. 5 shows two one-hour segments of WCBS-TV programming recorded on a graphic volume indicator. The lower was recorded *without* Audimax employing normal manual control at the originating studio. The upper chart shows similar programming with Audimax in use. The average level with Audimax exhibits a 4–6 db increase.

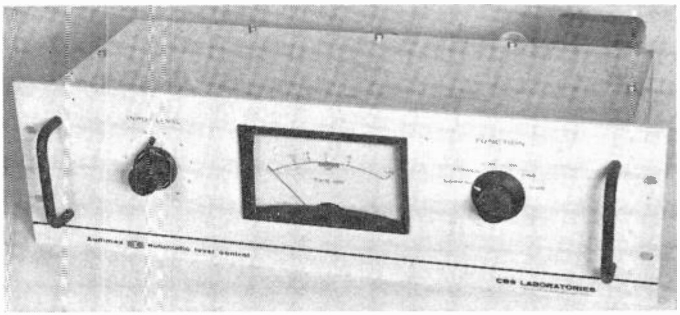

Fig. 4.

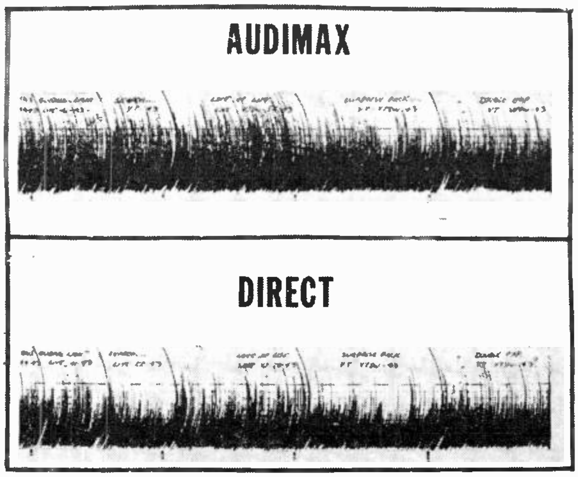

Fig. 5—Operating experience.

CONCLUSION

In attempting to solve the problem of artistically acceptable automatic level control, the authors have approached their task by creating a device which can simulate both the thought processes and reactions of a highly competent studio technician without many of the limitations of human control. Endorsement of the Audimax by those who are using it and the objective evidence as to its capabilities for improving average modulation have affirmed the validity of this approach.

ACKNOWLEDGMENT

The authors wish to acknowledge their indebtedness to Dr. P. C. Goldmark, President of CBS Laboratories, for his enthusiastic support and to Vorhes, Peck and Korkes of CBS Radio and to O'Brien, Monroe and Palmquist of CBS Television for their invaluable collaboration.

Stereo Geometry Tests*

PAUL W. KLIPSCH†, SENIOR MEMBER, IRE

Summary—Since judgement of distance to a sound source is vague, whereas lateral localization is about 2°, stereo tests were conducted with a single row of sound sources.

Live sounds were observed and recorded outdoors; reproduction indoors utilized speakers on a 25-foot array. To express the results a criterion of error was computed which ranged from 0.042 for live listening to 0.60 for 2-loudspeaker stereo without toe-in. Three-loudspeaker arrays with toe-in exhibited criterion-of-error values of 0.11 to 0.14 with no significant difference between 2 and 3 electrical channels.

INTRODUCTION

EARLY WORKERS in the art of stereo[1,2] achieved realism in spatial relations in the same way that some have found tonal accuracy in "high fidelity" sound reproduction. Others appear to have felt that the illusion of spaciousness suffices to purvey the essence of stereo. The viewpoint taken previously[3] by this writer, and again in this paper, is that stereophonic sound reproduction aims to reproduce the original spatial relations, or the spatial relations such as one experiences at a concert. An observer's ability to locate sounds in relation to each other is regarded as superior to either a mere right-left sensation or the sensation of ambiency.

Previous experiments by the writer[4,5] have shown that the stereo effect becomes marginal at a distance about 1.5 times the spacing of the flanking speakers, which is the prime purpose for wide speaker spacing.

Earlier stereo geometry tests[1–3] utilized 2 or 3 rows of points at which sounds were generated, thus requiring judgements of distance as well as angle. Snow[2] points out that depth perception is vague whereas angular perception is acute.

CURRENT EXPERIMENTS

To eliminate the errors due to judgement of distance, a single row of sound sources is employed. Fig. 1 shows the plan view of an outdoor (anechoic) array of microphone and listener stations and a single row of sound sources.

Playback was conducted indoors with a 25-foot loudspeaker array. Where 3 electrical channels were used a center microphone location was employed (not shown in Fig. 1) and the center loudspeaker was connected to the center microphone via an electrically independent third channel. For 2 channel conditions, the center loudspeaker (if used) was bridged across the 2 stereo channels. Except as indicated, flanking loudspeakers were "toed-in" approximately 45 degrees.

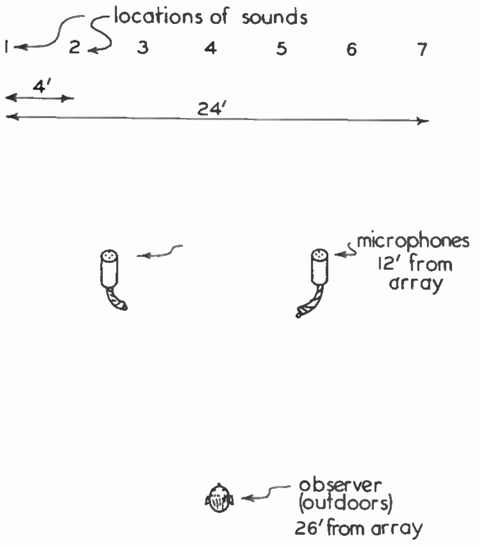

Fig. 1—Outdoor plan of sound sources, microphone locations and listener station.

Live Tests

For the live tests, an observer closes his eyes and attempts to point to a caller who moves to a location and then makes a short recitation. The observer opens his eyes and both he and the caller estimate the angle.

The point at which the finger aims can easily be estimated to within a fraction of the distance between the crests of the ilia—aims from 20 feet rarely fall outside the abdominal area and never at the caller's mouth. This fact seems to confirm previous expressions that lateral localization is considerably more acute than vertical localization.

The caller backsights the observer's point to confirm the localization. Experiments with a pistol-like aiming device did not seem to improve scores and were not exploited since the results attained with the pointed finger reduced errors to less than one-third of previous errors.

The outdoor stations are 4 feet apart and the observing locations are 26 feet away, so one space is about 8 degrees. Fig. 2 shows a "live" plot in which the vertical lines represent true locations and the numbers represent the calls. Vertical displacement in the figure is not sig-

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[1] J. C. Steinberg and W. B. Snow, "Physical factors," *Symp. on Auditory Perspective, Elec. Engrg.*, vol. 53, pp. 9–32, 216–219; January, 1934.

[2] W. B. Snow, "Basic principles of stereophonic sound," *J. SMPTE*, vol. 61, pp. 567–589; November, 1953.

[3] P. W. Klipsch, "Wide stage stereo," IRE TRANS. ON AUDIO, vol. AU-7, pp. 93–96; July-August, 1959.

[4] P. W. Klipsch, "Corner speaker placement," *J. Audio Engr. Soc.*, vol. 7, pp. 106–109, 114; July, 1959.

[5] P. W. Klipsch, "Experiments and experiences in stereo," IRE TRANS. ON AUDIO, vol. AU-8, pp. 91–94; May-June, 1960.

nificant, being used merely to be able to write the numbers. The results seem to be more consistent with other observed facts than the errors of the previous experiments. The angular data for the new direct observations yield a standard error of 2.1°, which agrees (at least in order of magnitude) with Snow[1] who observed that " . . . differences as small as 1° to 2° can be perceived."

The arithmetic mean error was 1.2°. The probable error of the mean was 0.2°.[6] One might write the standard error as 2.1 ±0.2 which seems to justify retaining the 2 significant figures. Several other samplings yielded 1.6 to 2.4° rms error.

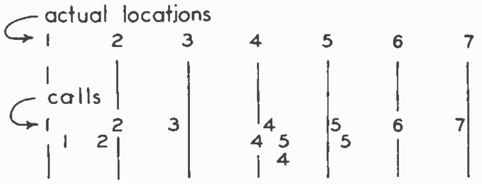

Fig. 2—Plot of listening calls for one of the "live" tests. Upper row designates actual lateral location of sound sources, lower figures represent observer estimates of lateral locations. (Vertical displacement is not significant, being merely to provide space for writing.)

Tests Using Recorded Material

Following the live tests, a series of recordings were made at the outdoor location. A caller recited a series of words ending with an encoded position. At least 2 calls were made from each position with extra calls from the 3 central positions.

The recordings are played back indoors where the flanking speakers are approximately 25 feet apart and the sound stage is marked by 7 cards, approximately 4 feet apart.

The recordings were done with 2 spaced microphones and with the stereo microphone.

The recording playbacks were heard by observers who pointed to the virtual sound source, and wrote down the apparent location with the encoded position number on a plot similar to Fig. 2. These data were then decoded, the errors determined and the rms error computed. At least 2 observers were employed, with several other listeners engaging in part of the recorded listening tests. Hundreds of people have engaged in the "live" tests.

Test Using 3 Channels

The 3 channel observations involved a caller at the outdoor location, observers at the indoor location, 3 electrically independent channels, but no recorder. The caller encoded his locations and the observer plotted the virtual sound sources which were then decoded and the rms error determined.

Criterion of Error

Earlier experiments with narrow stage widths gave small stereo geometry errors—the narrower the stage the smaller the absolute error, and of course the smaller the stereo effect. The error takes on significance if expressed as a fraction of stage width, so the rms error was divided by the stage width to yield the single number called criterion of error.

The rms error or "standard deviation" is

$$\sigma = [(e_1^2 + e_2^2 + \cdots + e_n^2)/n]^{1/2}$$

where e_1, etc., are individual errors and n is the number of observations. The criterion of error is the rms error divided by the stage width in similar units so the resulting number is a dimensionless fraction or "per cent" error.

THE DATA

In Table I (next page), "live" indicates direct listening without intervening electro-acoustic devices:

2 2 2	means 2 microphones, 2 tracks, 2 loudspeakers.
3 3 3	means 3 microphones, 3 electrically independent sound tracks, 3 loudspeakers.
2 2 3	means 2 microphones, 2 tracks with bridged center loudspeaker.
SD 2 3	means stereo (directional) microphone, 2 tracks, bridged center loudspeaker.

The first lines in Table I represent the errors and criteria of error derived from the writer's earlier paper.[2]

The rest of the data is from the current experiments.

INTERPRETATION

The small differences between the figures 0.11, 0.14 and 0.12 indicate negligible preference. If measurements can be further refined it may develop that there is no statistically significant difference. The sensation that there is slightly less vagueness in the 3 3 3 system than in the 2 2 3 system should show up as a numerically significant difference. But there is no statistically significant difference between the 2 2 3, 3 3 3 and SD 2 3 systems. The previous finding that the 3 3 3 system contains substantially the same signal mutuality as the 2 channel with bridged center[7] would seem to be checked by the present results.

A single sound source seems to be less definitely localized than a source in combination with other sounds.

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[6] The probable error of the mean is derived from the same data as the mean itself. This may seem to be lifting oneself by one's own bootstraps and this philosophy may have prompted H. Poincaré to remark, "Everybody firmly believes in it (the law of errors), because mathematicians imagine it is a fact of observation, and observers, that it is a theorem of mathematics." (J. W. Mellor, "Mathematics for Students of Chemistry, and Physics," Longmans, Green and Co., Ltd., New York, N. Y., p. 515; 1926.) The second statistic is at least of value in testing the first.

[7] P. W. Klipsch, "Signal mutuality in stereo systems," IRE TRANS. ON AUDIO, vol. AU-8, pp. 168–173; September-October, 1960.

TABLE I

Note	rms Error	Criterion of Error
Data from "Wide Stage Stereo"[3]		
Live	15°	0.20
2 2 3*	17°	0.21
2 2 2*	20°	0.27
New data		
Live	2.1°	0.042
SD 2 3†,‡	9.0°	0.11
2 2 3*	11.2°	0.14
3 3 3*	10.0°	0.12
2 2 2*	27.0°	0.30
Observer 8 feet off axis		
2 2 3		0.16
2 2 2‖		0.60

* Altec M-20 microphones, 21-D heads.

† Telefunken SM-2 "Stereo" microphone.

‡ Center output lowered 3 db. With the center speaker off, results were the same as for the 2 2 2 system.

‖ Center speaker off, flanking speakers not toed-in, but parallel; observer hears only one speaker. This value can be regarded as a "worst possible value" for the configuration. This has to be based on an equal number of calls at each station. Other data sets were "weighted" by using more calls in the central locations.

Eargle[8] showed that sounds reproduced from a recording of a 4 piece band retain their relative locations even when the virtual source of the group is shifted laterally due to shift of the location of the observer. It follows that individual sounds within a group are localized relative to each other in spite of a group shift, whereas single sounds are simply shifted with respect to fixed space. The one represents a closer approach to realism than the other.

In the 3-loudspeaker playbacks, localization of a soloist with respect to an accompanying group is good. A soprano 4 feet to the left of the podium in front of a symphony orchestra was heard in proper spatial relation to the orchestra, even for observer locations at the extreme flanks of the listening area.

On the other hand the blend of a violin section precludes localizing individual instruments, but the section is definitely located in the proper region. Reproduction of a musical group of any size on a normal stage is reproduced in proportional size on the playback stage.

CONCLUSION

The difference in accuracy of localization between a stereo system using 3 independent channels and one using 2 channels with a bridged center loudspeaker output is small. Qualitatively there is a certain vagueness in both, varying with the ability of a listener to achieve "fusion" of sounds between loudspeakers. The small difference between systems is in agreement with the idea that there is common signal content or "signal mutuality" in the various channels, even in the absence of electrical crosstalk.[7]

Requirements for good stereo reproduction for accurate localization may be listed:

1) Three widely spaced loudspeakers,
2) Flanking units rotated or toed-in at about 45 degrees, and
3) Either 3 electrically independent channels or 2 channels with a center loudspeaker bridged across the 2 channels.

The comparison has been between 2 channels with a bridged center loudspeaker and with 3 electrically independent channels which are shown to be quantitatively similar in accuracy of localization.

Likewise, recordings with separated microphones and a "stereo microphone" have been compared and found substantially similar. In the stereo microphone example it was found that the strong monophonic component necessitated about 6-db extra attenuation of the center microphone. The presence of the center microphone does not, however, obviate the necessity for the center loudspeaker. No matter how much "center fill" is provided with the center microphone, the center loudspeaker is still required to reproduce it, and the "stereo seat" is eliminated only by the use of the center loudspeaker either bridged or fed independently.

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[8] J. M. Eargle, "Stereophonic localization: an analysis of listener reaction to current techniques," IRE TRANS. ON AUDIO, vol. AU-8, pp. 174–178; September-October, 1960.

Correspondence

Comments on "A Network Transfer Theorem"*

G. F. Montgomery[1] in a recent letter pointed out a network transfer theorem which seems to have gone unnoticed, and stated that no text reference of the theorem could be found. In a text by Mason and Zimmerman,[2] the theorem is proved and discussed for the general case of a multiterminal network. Specifically, it is stated that "For reciprocal networks (those which obey reciprocity) . . . the open circuit voltage transfer ratio from one node to another is equal to the negative of the short circuit current transfer ratio in the opposite direction between these two nodes." It is seen that Hurtig's theorem is thus a special case of the more general theorem.

EUGENE J. MCMANUS
Army Missile Command
Huntsville, Ala.

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* Received October 9, 1962.

[1] G. F. Montgomery, "A network transfer theorem," IRE TRANS. ON AUDIO, vol. AU-10, p. 88; May–June, 1962.

[2] S. J. Mason and H. J. Zimmerman, "Electronic Circuits, Signals, and Systems," John Wiley and Sons, Inc., New York, N. Y., ch. 2, sec. 2.8.; 1960.

Author's Reply[3]

I am pleased to know that the theorem in question has found its way into a standard text, accompanied by a useful discussion. McManus infers that the textbook statement of the theorem, because it deals with a multiterminal network, is more general than Hurtig's statement. But the theorem involves only two ports, and since a multiterminal network can be considered a collection of two-port networks in the sense of the theorem, the two statements are equally general.

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[3] Received October 24, 1962.

Contributors

Benjamin B. Bauer (S'37–A'39–SM'44–F'53), for a photograph and biography please see page 153 of the September–October, 1962, issue of these TRANSACTIONS.

❖

A. Cochardt biography and photograph not available at time of publication.

❖

Arthur Kaiser (A'52–M'53) was born in Brooklyn, N. Y., on July 8, 1921. He received the B.S. degree in physics from The College of the City of New York, in 1942. He did graduate work at Harvard University, Cambridge, Mass., Massachusetts Institute of Technology, Cambridge, and Polytechnic Institute of Brooklyn, N. Y.

A World War II U. S. Air Force Electronic Officer, he was a rated Aircraft Observer specializing in radio and radar countermeasures. From 1953 to 1955 he was Senior Electronic Designer with Sperry Products, Danbury, Conn., developing video display and measuring equipment. Prior to that he was a Group Leader with the General Electric Company, for development of microwave equipment for commercial and governmental requirements. During the years 1955 to 1958 he served as Assistant Department Manager at Remington Rand Univac, Components Development Department. He has been responsible for important aspects of such equipment as the AN/APR-12 Receiving System, Sperry UW Reflectoscope, and Univac Gemmac Computer.

Mr. Kaiser came to CBS Laboratories, Stamford, Conn., in 1958. At present he is Section Head, Audio Circuitry Research, Acoustics and Magnetics Department. His activities at CBS include investigation and developments in transmission systems, transistor circuit technology, and audio gain control techniques.

❖

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

He was employed in the testing department of General Electric Co. from 1926 to 1928; the Anglo-Chilean Consolidated Nitrate Corp., Tocopilla, Chile, from 1928 to 1931; the Independent Exploration Co., Houston, Tex., from 1934 to 1936; the Subterrex Co., Houston, Tex., from 1937 to 1941; and the U. S. Army Ordnance Department from 1941 to 1945 (Major, 1943; Lt. Col., 1953). At present, he is the president of Klipsch and Associates, Inc., Hope, Ark., manufacturer of loudspeakers. His specialization since 1939 has been heavily concentrated in acoustics and those phases of engineering related to it. Testing means developed have included devices for measuring distortion, voice-coil impedance, frequency response, a logarithmic converter to produce a dc output response in decibels of the largest output of a plurality of microphones and other specialized research and development tools in the field of audio.

Mr. Klipsch is a Fellow of the Audio Engineering Society, and a member of the AIEE, the Acoustical Society of America, Tau Beta Pi and Sigma Xi. He is a Licensed Professional Engineer in the States of Texas and Arkansas.

❖

Charles D. Mee (SM'58) was born in Loughborough, England, on December 28, 1927. He received the B.Sc. degree in in physics from London University, England, in 1948 and the Ph.D. degree from Nottingham University, England, in 1951.

From 1951 to 1954 he was employed by the Magnetics Laboratory of the Steel Company of Wales, England, where he specialized in research on soft magnetic materials. Then he became associated with the MSS Recording Company, Colnbrook, England, where he was in charge of a research program on the development of data-recording magnetic tape. In 1957 he joined CBS Laboratories, Stamford, Conn., where he was Technical Director of the Magnetics Research Department. At CBS he has directed research programs on short wavelength magnetic recording problems, video recording and new magnetic materials for tape. Recently he joined the IBM Research Center, Yorktown Heights, N. Y.

Dr. Mee is a member of the Institute of Physics.

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