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Professional Group on Audio

IRE PROFESSIONAL GROUP ON AUDIO

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

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IRE TRANSACTIONS on AUDIO

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World Radio History

Why Engineers Should Write Technical Papers*

At a recent meeting of the national Administrative Committee of the IRE Professional Group on Circuit Theory we were trying to think of people to nominate for membership on this Committee. One of the members of the Professional Group had taken the trouble to write to the Editor and tell him what was wrong with one issue of the TRANSACTIONS. In accord with the usual attitude of such organizations, that anyone who has a good idea is chairman of the committee, he is now being considered for a nomination. This bit of writing brought him to the attention of officers looking for help, and he may soon achieve national recognition.

Record Your Accomplishments

Technical reports and papers are about the only sure way the younger engineers in a large company have of bringing their work to the attention of top engineering management. It may take many years of work in the laboratory before one is in charge of an experimental project big enough to attract equal attention. When the company is looking for someone to promote to a position of great responsibility they are sure to think of those people who have regularly demonstrated, with a continuous stream of reports, technical papers, and well-written letters that they are able to think clearly and write clearly. If someone has shown that he can reduce complex problems to a simple explanation, he will inspire confidence in his ability. It is necessary to present a record of accomplishment that is seen regularly before someone opens the door that starts you up the road to your goal.

Technical Papers Help You and Society

In many companies most engineers can build the kind of a future they want. It should never be necessary to keep a man on a job he doesn't like, over a long period of time. If you would like to become an internationally-known engineer or scientist you are limited only by your own ability. However, many engineers feel that personal publicity is not necessary and that the world will soon discover their real ability. Sometimes it does not work out this way. The man who writes up the scientific knowledge is the one who often gets credit for having created it, even though he may have done no more than edit the copy. This may seem to be unfair, but actually it is not. By making the knowledge available to the public in a published paper he may have provided a far greater service to society than the engineer who created the knowledge but did not write it up for others. Be sure you get the proper credit for your work by finishing the job.

Neglect Leads to Waste

I have known some very good engineers who have done much valuable research and development work but who never write reports about their discoveries. In a short time the company has a big pile of obsolete equipment, with circuits partly unknown, and all of the information in the mind of one man. This is a very dangerous situation. If the man dies, retires, leaves the company, or is transferred to other work, the great investment in the experiment is lost.

You Acquire Broader Perspective

It is often said that the best way to learn is to teach. The first time a new course is given the teacher will learn far more than the students. When an engineer writes a technical paper which describes his work he may find loose ends that need further study. If the paper is to appear in a leading journal, and stand the test of time, it is important that it be written as clearly as possible. The review and careful study that leads to the finished paper always gives the author a much better understanding and perspective.

Talk to Associates

The amount of knowledge written is only a very small part of that available. To get at the unwritten part it is necessary to sit down with other workers in the same field and talk things over. Often it is possible to learn more in an hour this way than you could work out for yourself in weeks. The life of experts in science is often a lonely one, and you will be welcomed when you ask to talk to them, if you have shown by your writing that you are thoroughly competent and will not waste their time.

Help Is Available

The PGA officers want to improve the number and quality of the technical papers written. They will do everything possible to help you. The first paper is the hard one to write. How long should it be? Who will make the drawings? What is the approved form for typing the manuscript? Once you have done one paper, these questions are easy.

The responsibility for your development and advancement is entirely yours. Why not start now?

—M. S. CORRINGTON, *Vice-Chairman*

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* Reprinted from *RCA Engineer*, vol. 1, p. 2; June–July, 1955.

PGA News

IRE-PGA ADMINISTRATIVE COMMITTEE

In order to better acquaint the membership of the IRE-PGA with the background and appearance of the members of its 1955–56 Administrative Committee we are publishing pictures and biographies of these committee members. Pictures and biographies were not available for W. D. Goodale and J. Kessler at the time this issue went to press.

W. E. KOCK

M. S. CORRINGTON

Winston E. Kock is Director of Acoustics Research at Bell Telephone Laboratories.

Dr. Kock received his E.E. and M.S. degrees at the University of Cincinnati in 1932 and 1933, and his Ph.D. degree from the University of Berlin in 1934. He continued his graduate study at the Institute for Advanced Study at Princeton and at the Indian Institute of Science in Bangalore, India. Following several years as Director of Electronic Research at the Baldwin Piano Co., he joined the Radio Research Department of Bell Telephone Laboratories in 1942, where he engaged in microwave radar antenna research that resulted in the microwave lens antenna. In 1952 he was appointed Director of Acoustics Research and in that capacity supervised the development of Audrey, the automatic digit recognizer.

Dr. Kock is a Fellow of the American Physical Society, the Institute of Radio Engineers, and the Acoustical Society, and is a member of Tau Beta Pi, Eta Kappa Nu, and Sigma Xi. In 1952 he was awarded the honorary Doctor of Science degree by the University of Cincinnati.

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Murlan S. Corrington was born on May 26, 1913 in Bristol, S. Dak. He received the B.S. degree in Electrical Engineering in 1934 from the South Dakota School of Mines and Technology, and the M.Sc. degree in 1936 from Ohio State University. From 1935 to 1937, he was a graduate assistant in the Physics Department of Ohio State University. In 1937 he joined the Rochester Institute of Technology, where he taught mathematics, mechanics, and related subjects.

Since 1942 Mr. Corrington has been engaged in Mathematical Engineering in the Advanced Development Section of the RCA Victor Television Division, Radio Corporation of America, at Camden, N. J. He is manager of Audio, Acoustics, and Antennas for the Section.

Mr. Corrington is a member of Sigma Pi Sigma, the Acoustical Society of America, the Society of Industrial and Applied Mathematics, and a Fellow of the Institute of Radio Engineers. In the IRE he is Vice-Chairman of the Sound Recording and Reproducing Committee, Chairman of the Basic Measurements Subcommittee of the Radio Frequency Interference Committee, Vice-Chairman of the national Professional Group on Audio, a member of the national Administrative Committee of the Professional Group on Circuit Theory, and Vice-Chairman of the Philadelphia Section.

He has written many technical papers on frequency modulation, circuit theory, transients and cone motion in loudspeakers, distortion in phonograph records, etc., and is the author of two textbooks.

D. W. MARTIN

Biographical material appears in Nominating Committee Report.

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A. B. JACOBSEN

Biographical material appears in Nominating Committee Report.

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F. H. SLAYMAKER

Frank H. Slaymaker was born in Lincoln, Nebraska. He obtained the B.S. degree in Electrical Engineering from the University of Nebraska, Lincoln, Nebraska, in 1941, and the E.E. degree in 1946 from the University of Nebraska.

He started with the Stromberg-Carlson Company in 1941, in the Research Department at the main plant, where he worked on development of noise reducing microphones, electronic carillons, ultrasonic devices, loudspeakers, etc., and joined the Sound Equipment Division, Engineering Department, in the fall of 1950, where he has worked on electronic carillons, and acoustical problems associated with the loudspeakers and sound distributing systems in large arenas.

Mr. Slaymaker is a Fellow of the Acoustical Society of America and a member of the Institute of Radio Engineers. He is a licensed professional engineer in the State of New York.

He is the author of numerous papers published in the Journal of the Acoustical Society of America, Electronics, and Audio Engineering; and has taken out patents on acoustical transducers and circuits for ultrasonic blind-guidance devices, for noise reducing microphones. He has several patents in process on electronic carillons.

He is Chairman of the RETMA Committee on High Fidelity Systems, SE-8, is a member of the Administrative Committee of the IRE Professional Group on Audio, and is a member of the Committee on Audio Techniques of IRE.

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FRANK LENNERT

Frank G. Lennert was born in Oakland, Calif., on January 24, 1924. He received the B.S. degree in Electrical Engineering from the University of California in 1947, and joined Trilon Manufacturing Co. in Oakland where he set up studio installation and was responsible for all recording activities.

Mr. Lennert became affiliated with Ampex Corp. in Redwood City, Calif. as Development Engineer in 1948. He established all Ampex audio record and reproducing characteristics for tape recording at 30, 15, 7½, and 3¾ inches per second, and was responsible for the development of electronics on Ampex Models 300 and 400, and all development on the Ampex Model 350 recorder.

In 1952, Mr. Lennert set up and managed production engineering facilities for purposes of stressing low manufacturing cost, and minimizing inventory through parts standardization. He became manager of the Manufacturing Division of Ampex in 1954 and presently serves in this capacity.

Mr. Lennert is a senior member of the IRE and Vice-Chairman of the San Francisco Section of the PGA. He is also Chairman of the San Francisco Section of the Professional Group on Production Techniques and a member of the Audio Engineering Society, the Board of the Manufacturer's Association of San Mateo County, and Preparatory Committee 2 of C.C.I.R.

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ARNOLD PETERSON

Arnold Peterson was born in De Kalb, Ill., in 1914. He was awarded the B.E. degree by the University of Toledo and the Master and Doctor of Science degrees by the Massachusetts Institute of Technology.

From 1936 to 1940 Mr. Peterson was a research assistant at M.I.T. working on ultra-high-frequency oscillators and measurements. In 1940 he joined the General Radio Co. as an Engineer and since 1947 has been with the company as Engineer in charge of acoustical and audio-frequency instrumentation.

He is a member of Sigma Xi, the Acoustical Society of America, the American Physical Society, the American Association for the Advancement of Science, the American Institute of Electrical Engineers, and the American Geophysical Union.

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B. B. BAUER

Benjamin B. Bauer graduated in Industrial Electrical Engineering from Pratt Institute in 1932, and received the E.E. degree from the University of Cincinnati in 1937.

He joined Shure Brothers, Inc. in 1936, became Chief Engineer in 1940, Director of Engineering in 1944, and Vice-President in 1948.

Mr. Bauer is a Fellow of the Institute of Radio Engineers, former National Chairman and Editor-in-Chief of the TRANSACTIONS OF THE IRE ON AUDIO, and is presently Secretary-Treasurer of the IRE Professional Group on Audio. He is also a Fellow of the Acoustical Society of America, Fellow of the Audio Engineering Society, and an Associate Editor of the *Journal of the Acoustical Society of America*. He is a member of Eta Kappa Nu, Tau Beta Pi, and Sigma Xi.

REPORT OF THE IRE-PGA NOMINATING COMMITTEE

Each year three members are elected to replace those on our Administrative Committee whose term expires. Six candidates have been selected by the Nominating Committee and approved by the Administrative Committee in accordance with our constitution and bylaws:

For member of the PGA-Administrative Committee for three years beginning April 1, 1956 (three to be elected):

Semi J. Begun studied electrical engineering at the Institute of Technology in Berlin where he obtained his master's degree in 1929 and his doctor's degree in 1933. He worked in various fields of telecommunication in Germany until 1935 when he came to this country.

After having been associated with Guided Radio and Acoustic Consultants from 1935 to 1938, Dr. Begun joined the Brush Development Co., which merged with the Cleveland Graphite Bronze Co. about three years ago. He served as a Vice-President and Director of Advance Development at the Clevite Research Center until recently. He is now Director of Marketing for the Clevite Corp.

For many years Dr. Begun has been interested in various aspects of sound recording. He has published papers on mechanical and magnetic recording, and is author of a book entitled, "Magnetic Recording." He also holds more than 40 issued U. S. patents, mostly in the field of magnetic recording and related circuitry.

Dr. Begun is a Fellow of the Institute of Radio Engineers, Fellow of the Acoustical Society of America, and has received the Presidential Certificate of Merit for scientific work during World War II.

Alexander B. Bereskin received the degree of electrical Engineer in 1935 and the M.Sc. degree in Engineering in 1941, both from the University of Cincinnati. He had been employed by the Commonwealth Manufacturing Corp. and the Cincinnati Gas and Electric Co. before joining the faculty of the University of Cincinnati, where he now holds the rank of Professor of Electrical Engineering. In 1944–45 he worked for the Western Electric Co., on leave of absence from the University of Cincinnati. He is also a consulting engineer and a registered professional engineer in the State of Ohio.

Mr. Bereskin has published work on audio power amplifiers, video amplifiers, regulated power supplies, and power factor meters. A paper on a 3,000 watt audio power amplifier is scheduled for early publication and for presentation at the 1956 IRE National Convention. Mr. Bereskin has also done work in the fields of special RC oscillators, frequency selective amplifiers, low jitter multivibrators, special stabilized power supplies, and transistor audio power amplifiers.

He is a member of the American Institute of Electrical Engineers, Sigma Xi, and Eta Kappa Nu.

In the IRE Mr. Bereskin is a senior member, a member of the Education Committee, Chairman of the Region IV Subcommittee of the Education Committee, and Institute Representative at the University of Cincinnati. He is Past Chairman, Vice-Chairman, and Treasurer of the Cincinnati Section and is at present Editor of the IRE Transactions on Audio.

Michel Copel was born in Paris, France, in 1916. He received the B.S. degree in 1935 from the University of Paris and the E.E. degree in 1937 from the Conservatoire National des Arts et Métiers in Paris. Mr. Copel also attended New York University.

From 1942 to 1946 he was engaged in the design and development of military loudspeaker equipment as chief design engineer of University Laboratories. He was senior engineer at Dictograph Products, Inc., from 1946 to 1948.

Since 1948 he has been engaged in investigations, developments, and evaluations of audio communication systems at the Naval Material Laboratory in Brooklyn, N. Y. where he holds the position of supervising electronics scientist (electro-acoustic).

Mr. Copel is a member of the Acoustical Society of America and the Institute of Radio Engineers. He is presently serving on the IRE Electro-Acoustic Committee and the American Standard Association Committee Z24 W22 on Loudspeaker Measurements. In addition, Mr. Copel is Chairman of the IRE-PGA Ways and Means Committee and East Coast Regional Program Committee. He organized the Audio Sessions of the 1955 and 1956 IRE National Conventions.

Irving Levine received his technical education at Stevens Institute of Technology where he received the M.E. degree in 1941 and the M.S. degree in 1944.

He taught in the mathematics department of Stevens Institute from 1941 to 1944 and was an electronic technician with the U. S. Navy from 1944 to 1946. He was engaged in graduate work at Harvard University from 1946 to 1947.

Mr. Levine was senior electronic engineer at Melpar, Inc., in Alexandria, Va. from 1947 to 1949 and since that time has been with the National Bureau of Standards as an electronic scientist.

In the IRE, Mr. Levine is Chairman of the Washington Section of the Professional Group on Audio. He is also President of the Washington Audio Society.

Harry F. Olson attended the University of Iowa where he received the B.E. degree in 1924, the M.S. degree in 1925, the Ph.D. degree in 1928, and the professional degree of E.E. in 1932.

Dr. Olson joined RCA Laboratories in Princeton, N. J. in 1928 and is now Director of the Acoustical and Electromechanical Laboratory. He holds more than 60 patents on devices and systems in the acoustical field and is the author of more than 70 professional papers as well as several books including "Dynamical Analogies," "Elements of Acoustical Engineering," and "Musical Engineering."

He is a Fellow of the Society of Motion Picture and Television Engineers, the American Physical Society, the Institute of Radio Engineers, the Acoustical Society of America, and the Audio Engineering Society of America.

For his contributions in the audio field, Dr. Olson received the John H. Potts Medal of the Audio Engineering Society in 1952 and the Samuel L. Warner Medal of the Society of Motion Picture and Television Engineers in 1955.

Philip B. Williams was born in Ancon, Canal Zone, in 1916. His interest in electronics began with amateur radio work in 1931, and extended to physics and mathematics studies at Southeast Missouri State College. After receiving the A.B. degree in 1937, he joined the staff of Station KBTM, Jonesboro, Ark., subsequently studying at RCA Institutes and Illinois Institute of Technology, Chicago.

He was employed by Zenith Radio Corp. in equipment engineering and broadcast work. Later, Mr. Williams joined Jensen Manufacturing Co., Chicago where he was engaged in audio and acoustics work. He became development engineer in 1948, senior engineer in 1950, and chief engineer in 1952. He has been responsible for advanced development of military and commercial transducers.

Mr. Williams is a member of C.A.A.G., the American Engineering Society, and IRE, and is active in the Chicago Section of the IRE and the national Professional Group on Audio, in which he is currently chairman of the Program Committee. He has presented papers on transducers before professional groups and has authored or co-authored papers published in various professional and trade journals.

For Chairman of the Administrative Committee (one to be elected):

Andrew B. Jacobsen was born November 4, 1915 in Seattle, Wash. He received the B.S. degree in electrical engineering in 1941 from the University of Washington and worked there as a graduate assistant in electrical engineering from 1941 to 1942.

As a staff member of the Radiation Laboratory of M.I.T. from 1942 to 1945, he was engaged in the development and design of radar range circuits, computers, and data transmission systems. Several patents have been granted to him on this work. He is co-author of the section on voltage and current regulators in the Electronics Instruments volume of the Radiation Laboratory Series published by McGraw-Hill.

Mr. Jacobsen was a senior engineer on FM communications and TV receiver development with the Galvin Manufacturing Corp. from 1945 to 1946. From 1946 to 1953, he was on the staff of the University of Washington Engineering College, Seattle, as an instructor in electrical engineering and research engineer supervising a project on electronic instrumentation for research.

Since July, 1953, Mr. Jacobsen has been with the Phoenix Research Laboratory of Motorola, Inc., as a project leader on transistor applications, and as transistor circuit section head in the newly-formed semiconductor department of Motorola, Inc.

Mr. Jacobsen is a registered professional electrical engineer in the state of Washington. He is a member of the American Institute of Electrical Engineers, senior member of IRE, served as Chairman of the Seattle Section for two years, and has been Chairman of the PGA Tapescripts Committee since its inception in 1951. At present he is a member of the National Administrative Committee of PGA. His research and development work in communications, electronics, and instrumentation has resulted in the publication of several technical papers.

Daniel W. Martin received the Ph.D. degree in physics from the University of Illinois. Since 1949 he has been with The Baldwin Piano Co. as head of the Acoustical Research Section which engages in physical and psychoacoustic research on musical tone and tone-producing means, research and development of electronic organ tone cabinets, and government acoustical and audio research and development.

During World War II, he was acoustical development engineer for RCA, specializing in government audio communication systems, sound-powered telephone, microphones, earphones, electropiano development, and theater and studio acoustics.

Dr. Martin, a senior member of the IRE, is a former Editor of the IRE TRANSACTIONS ON AUDIO. He is now a member of the PGA Administrative Committee, Chairman of the PGA Awards Committee, and Chairman of the Cincinnati Section. He is also a Fellow of the Acoustical Society of America, and a member of its Committee on Music, and Committee on Membership; Chairman of the ASA Standards Committees on Musical Acoustics Terminology, and Electronic Carillons. Dr. Martin is patent reviewer for the *Journal of the Acoustical Society* and has made frequent contributions to that publication and to the IRE Transactions on Audio.

The following members of the Administrative Committee continue in office:

To March 31, 1958	*To March 31, 1957*
M. S. Corrington	W. Goodale
A. B. Jacobsen	D. W. Martin
W. E. Kock	F. H. Slaymaker

It is expected that ballots for the coming election will be mailed shortly to all members.

MARVIN CAMRAS, *Chairman*
PGA Nominating Committee

A. PREISMAN—MEMBER OF NOMINATING COMMITTEE

In publishing the list of committee members of the Nominating Committee of the IRE-PGA in the July–August 1955 issue of the IRE TRANSACTIONS ON AUDIO, the name of A. Preisman has been inadvertently omitted. Mr. Preisman is a Fellow of the IRE and has been for many years active in the IRE and PGA, holding membership on several committees. He has been especially helpful with the work of the Nominating Committee for the past two years. He is Vice-President in Charge of Engineering at the Capital Radio Institute of Washington, D. C.

HARRY F. OLSON RECEIVES SMPTE WARNER AWARD

The Society of Motion Picture and Television Engineers selected Dr. Harry F. Olson of the Radio Corporation of America as the recipient of its Samuel L. Warner Memorial Award for 1955. A gold medal and citation were presented to Dr. Olson on Tuesday evening, October 4, during the Society's 78th semiannual convention at the Lake Placid Club, Essex County, New York.

The Warner Award is given to "a candidate who has done outstanding work in the field of sound motion-picture engineering and in the development of new and improved methods or apparatus designed for sound motion pictures." Dr. Olson was selected for the results of his productive career in audio engineering.

Dr. Olson attended the University of Iowa where he received his B.E. degree in 1924, his M.S. degree in 1925 and his Ph.D. degree in 1928 and the professional degree of E.E. in 1932.

Dr. Olson, who is today Director of the RCA Acoustical and Electromechanical Research Laboratory, Princeton, New Jersey, joined that Company in 1928. He holds more than 60 patents on devices and systems in the acoustical field and is also the author of more than seventy articles and papers in professional journals, as well as several books including *Dynamical Analogies*, *Elements of Acoustical Engineering*, and *Musical Engineering*.

For his contributions to the field of audio engineering, Dr. Olson received the John H. Potts Medal of the Audio Engineering Society in 1952. He is a past president of the Acoustical Society.

IRE-PGA CHAPTER ACTIVITIES

Cincinnati, Ohio

On October 18, J. F. Jordan, Director of Engineering and Research at the Baldwin Piano Company of Cincinnati, Ohio, gave a talk on "Electronic Musical Tone Colors." The next meeting is planned for January 17, 1956, at which time R. J. Larson of the Jensen Manufacturing Company will present a paper on "The Electrostatic Loudspeaker, An Objective Evaluation."

Cleveland, Ohio

O. Kornei of the Clevite Research Center gave a talk on "A Recent Development in Magnetic Playback Heads" on October 20. This talk covered the characteristics of a flux-responsive head which is capable of reading the flux density in a magnetic tape or other magnetic material regardless of tape speed. A demonstration was held of the new Ampex Stereo-tape player in accord with the new policy of the Cleveland Chapter of holding meetings with "dual" features. The dual feature consists in having a technical paper followed by either a demonstration of some audio equipment or a timely movie covering some subject of interest to the members.

The following programs have been planned for future meetings: Recording and Reproducing Techniques, Loudspeakers and Enclosures, and The Use of Transistors in Audio Circuits.

The advertising program of the Cleveland Chapter has been greatly stepped up, as follows: The meetings are first announced in the Section News and in the College Student Publication. They are next announced over a local radio station during one of their stereo broadcasts. Finally posters are sent to the leading industrial firms and laboratories in the Greater Cleveland area, as well as to members.

E. R. Wagenhals feels that a good deal of the success of the Cleveland Chapter is due to the following questionnaire which was sent to all Audio Group Members.

Professional Group on Audio

Questionnaire

Please mark five subjects of interest to you in the order of their importance.

( ) Amplifiers and Preamps
( ) Physics of Music and Hearing
( ) Recording and Reproducing Techniques
( ) Stereophonic Sound
( ) Transducers—Phono Pick Up
    —Magnetic Heads
    —Loudspeakers and Enclosures
    —Microphones
( )
( ) (Specify Others)

Name ______________________________

Address ____________________________

Check One ( ) You are *now* a member of the Professional Audio Group.
( ) You are prepared to *become* a member of the Professional Audio Group.

Dayton, Ohio

The first meeting of the newly organized Dayton Chapter of the PGA was held on October 6. Dr. Martin of the Baldwin Piano Company of Cincinnati, Ohio spoke on "Electronic Musical Tone Colors." E. Lazur of the Communication and Navigation Laboratory of the Wright Air Development Center presided at the excellently attended meeting.

Philadelphia, Pa.

M. E. Swift, chairman of the Philadelphia Chapter reports that they now have over 200 members. On October 18, 1955, Mr. Mitchell Cotter of Consumers' Union presented a paper on "Playback Phonodynamics." On November 2, 1955, Dr. Harry Olson and Herbert Belar of RCA Laboratories spoke on their "Electronic Music Synthesizer" at a special Ladies Night session. On February 15, 1956 Homer Dudley of Bell Laboratories will address a joint meeting with the Acoustical Society of America on "Speech Synthesis."

San Francisco, Calif.

The following officers have been elected for the 1955–56 season:

R. A. Long, *Chairman*
Stanford Research Institute
Menlo Park, California

Frank Lennert, *Vice-Chairman*
Ampex Corporation
934 Charter St.
Redwood City, California

D. L. Broderick, *Secretary-Treasurer*
Hewlett-Packard Company
275 Page Mill Road
Palo Alto, California

Syracuse, N. Y.

The first meeting of the season was held October 6. At this time Dr. W. E. Kock, Director of Acoustics Research at Bell Laboratories, and chairman of the IRE Professional Group on Audio, gave a paper on "Speech, Music, and Hearing." On November 15 Dr. D. E. Wiegand of the Armour Research Foundation spoke on "The Modulator Type Magnetic Playback Head." On December 1, Peter Goldmark, Director of the CBS Laboratories Division, spoke on "Highway Hi-Fi." The January meeting has been lined up with F. H. Slaymaker, Chief Engineer of Stromberg-Carlson Sound Equipment Division, scheduled to make a talk on "Bells, Electronic Carillons, and Chimes" while Messrs. Roy Dally and A. Petrie of the General Electric Company are scheduled to speak on "Phonograph Pickup Cartridge Design" at the February meeting. Mr. Dean of the Syracuse Chapter reports excellent cooperation and interest between the Syracuse Section and the professional group chapter with several joint sessions scheduled.

Washington, D. C.

On November 22 F. V. Hunt of Harvard University gave a talk on "Electro-Acoustics in the East Building Lecture Room of the National Bureau of Standards." The Washington Chapter reports that there has been a growing interest in its activities and a substantial increase in its membership.

WITH OTHER ACOUSTICAL AND AUDIO SOCIETIES

The September, 1955, issue of the *Journal of the Acoustical Society of America* contains 25 papers on various phases of theoretical and applied acoustics.

In the "Measurement of Loudness," page 815, S. S. Stevens of Harvard University, Cambridge, Mass., reviews the relationship between the intensity of sound and the sensation of loudness which it produces. In the words of the author, the purpose of the paper is "to examine the available data on the measurement of subjective loudness. It is hoped that by assembling the relevant information in one place we may be able to reach a reasonable conclusion concerning the relation between loudness and intensity. The various results obtained by workers in this field make it plain that the scale relating loudness to intensity is not something that can be determined with high precision, but these efforts also make it plain that people are able to make quantitative estimates of loudness and that it is not unreasonable to try to determine a loudness scale that will be representative of the typical listener." This purpose Dr. Stevens achieves in an eminently successful manner. A pair of 1,000 cycle tones that differ in intensity by 10 db produce sensations of loudness in a ratio of 2:1, he concludes. In terms of sones, where 1 sone is the loudness produced by a tone at 40 db above the standard reference level, the equation for loudness L as a function of the number of decibels N becomes: $\log L=0.03N-1.2$. The suggestion is made that for all levels greater than 50 db the loudness of continuous noises may be calculated from the equation: $\log L=0.03N+S$, where S is a spectrum parameter to be determined empirically.

On page 939 appears a paper by Romuald I. Scibor-Marchocki of the Hoffman Laboratories, Los Angeles, California; "Analysis of Hypex Horns." In this comprehensive theoretical paper impedance transformations of the "Hypex" horns are derived for all cases of mismatch for both increasing and decreasing characteristic impedance. The author constructs a Smith chart which assists in the graphical determination of the performance conditions of the horn under various conditions of mismatch.

In a Letter to the Editor, "Synchronization of Music on Dual Tapes" A. G. Pikler, U. S. Navy Electronics Laboratory, San Diego, Calif., proposes a method for synchronization of musical context (as exemplified by adding new accompaniment to an old solo recording) which eliminates the difficulties associated with cueing, acoustical feedback, allowance bearings and fidelity loss encountered with currently used methods.

The September issue of the *Journal* contains its usual extensive references to contemporary papers on acoustics, by R. T. Beyer; and review of acoustical patents by R. W. Young.

The April, 1955, issue of the *Journal of the Audio Engineering Society* recently received contains ten papers principally originating from the Sixth Annual Convention in New York, October 14–16, 1955.

A paper by A. M. Max of RCA Victor Division, Indianapolis, Ind., reviews some of the previously published data dealing with stylus pressure, and shows the importance of giving consideration to visco-elastic properties of plastics in the investigations of the phenomena associated with deformation of groove wall by the stylus.

A paper by W. B. Snow, Consulting Engineer, Santa Monica, Calif., reviews the effects of acoustic feedback upon the over-all frequency response of a public address system.

R. M. Carrell and L. M. Wigington of RCA, Camden, N. J., describe a piece of test gear constructed in the form of a pendulum to which microphones may be attached. The swinging of the pendulum provides a calculable wind velocity which is used to measure the sensitivity of microphones to wind noises.

B. B. BAUER

PGA-SPONSORED SESSIONS AT NATIONAL CONVENTION

SESSION 13

Tuesday, March 20
10:00 A.M.–12:30 P.M.
Sert Room, Waldorf-Astoria

AUDIO TECHNIQUES

Chairman: HUGH S. KNOWLES, *Knowles Electronics, Inc. Franklin Park, Ill.*

13.1 "A Simplified Procedure for the Design of Transistor Audio Amplifiers," W. W. Wells and A. E. Hayes, Jr., North American Aviation, Downey, Calif.

13.2 "An Audio Flutter Weighting Network," F. A. Comerci, 63 Carlton Terrace, Nutley, N. J.

13.3 "A Flutter Meter Incorporating Subjective Weightings," M. A. Cotter, Consumers Union of the U. S., Inc., Mount Vernon, N. Y.

13.4 "Performance Measurements of Magnetic Tape Recorders," J. B. Hull, Audio Division, Ampex Corp., Redwood City, Calif.

13.5 "A 3,000 Watt Audio Power Amplifier," A. B. Bereskin, Professor of Electrical Engineering, University of Cincinnati, Cincinnati, Ohio.

SESSION 21

Tuesday, March 20
2:30–5:00 P.M.
Sert Room, Waldorf-Astoria

HIGH QUALITY SOUND REPRODUCTION

Chairman: DANIEL W. MARTIN, *The Baldwin Piano Co., Cincinnati, Ohio*

21.1 "Equalization Considerations in the Design of High Quality Tape Recorders," R. H. Snyder, Ampex Corp., Redwood City, Calif.

21.2 "Design of a High Fidelity 10-Watt Transistor Audio Amplifier," R. P. Crow and R. D. Mohler, Motorola, Inc., Chicago, Ill.

21.3 "Performance of the 'Distributed Port' Loudspeaker Enclosure," A. F. Petrie, Radio and Television Dept., General Electric Co., Syracuse, N. Y.

21.4 "A Phonograph System for the Automobile," P. C. Goldmark, President, CBS Laboratories, New York, N. Y.

21.5 "The Recent History of High Quality Magnetic Phonograph Pickups," N. C. Pickering, Pickering and Co., Inc., Oceanside, N. Y.

SESSION 25

Tuesday, March 20
8:00–10:30 P.M.
Marconi Hall, Kingsbridge Armory

COLOR TELEVISION TAPE RECORDING

Chairman: W. W. WETZEL, *Minnesota Mining & Manufacturing Co., St. Paul, Minn.*

25.1 "A Magnetic Tape System for Recording and Reproducing Standard FCC Color Television Signals—General Considerations," H. F. Olson, RCA Laboratories, Princeton, N. J.

25.2 "Electronic System," W. D. Houghton, RCA Laboratories, Princeton, N. J.

25.3 "The Magnetic Head," J. A. Zenel, RCA Laboratories, Princeton, N. J.

25.4 "The Tape Transport Mechanism," A. R. Morgan and M. Artzt, RCA Laboratories, Princeton, N. J.

25.5 "Audio Systems," J. G. Woodward, RCA Laboratories, Princeton, N. J.

This session is jointly sponsored by PGA and PGBTS (Broadcast Transmission Systems).

* * *

Miniaturized Audio Transformer Design for Transistor Applications*

H. H. KAJIHARA†

Summary—**The electrical and physical parameters which are of concern in audio transformer design and their relationships to the problems of miniaturization are discussed. A detailed design of two typical audio transformers for transistor application is presented to illustrate the application of the design information obtained in the SCEL investigation on the subject. Several methods of sealing these miniature units and the effect on the ultimate size are reviewed. General information pertinent to the design of miniaturized audio transformers is assembled in the appendix.**

INTRODUCTION

THE INTRODUCTION of the transistor into the electronic art has generated extensive governmental and industrial development of new families of compatible components suited in both electrical ratings and physical size to the low voltage, low power transistor circuits. Resistors, capacitors, switches, connectors, and sockets have been developed with various degrees of success for these applications; in like fashion, a variety of subminiature audio transformers have been produced, emphasizing diminutive size as a prime accomplishment.

The achievement of a substantial size reduction in an audio transformer, however, is generally attended by some performance compromises. It is essential that the circuit designer recognize the performance limitations inherent in such subminiature designs; it is important too, if the ultimate in size reduction is desired, that he recognize some of the important factors under his control that have a direct influence on the size of the unit which the transformer designer can produce without excessive degradation in performance.

To the end of serving both the transistor circuit designer and the transformer engineer, this paper presents the electrical design approaches, materials, and construction features, and reviews the sensitive circuit parameters that determine ultimate practical size of such transformers.

DISCUSSION

The prime sacrifices in electrical performance necessitated by the reduction in the physical size of audio transformers are the degradation of frequency response and the reduction in electrical efficiency. Concurrently, a size reduction decreases the power level of operation and reduces the unbalanced direct current carrying capacity of the windings. These effects are reviewed individually in the following paragraphs.

Frequency Response

The high frequency response of an audio transformer is dependent on the magnitude of the leakage inductance and distributed capacitance of the windings. These parameters decrease with transformer size, hence good high frequency response and size reduction are complementary. In miniature audio transformers good response up to frequencies as high as thirty kilocycles per second are obtainable with the simplest of coil configurations. In audio applications, the uppermost frequency of interest is far below thirty kilocycles per second, hence, in general, no design problems are encountered for the high frequency portion of the response in miniature audio transformers.

The low frequency response is dependent on the primary inductance (OCL) which is given by:

$$L_n = \frac{3.19 N^2 A_c \times 10^{-8}}{lg + \dfrac{l_c}{\mu_{ac}}} \text{ henrys,} \qquad (1)$$

where:

L_n = primary open-circuit inductance (henrys),
N = turns,
A_c = core area (square inch),
lg = effective air gap length (inch),
l_c = magnetic core length (inch),
μ_{ac} = incremental permeability.

For N turns on a particular size core, the inductance is maximum when the core assembly has minimum air gap. When unbalanced direct current flows in the N turns, the core is subjected to a dc magnetizing force,

$$H_c = \frac{1}{\mu_{dc}}\left(\frac{0.5 N I_{dc}}{l_g + \dfrac{l_c}{\mu_{dc}}}\right) \text{ oersted} \qquad (2)$$

H_c = dc magnetizing force (oersted)
I_{dc} = unbalanced direct current (amperes)
μ_{dc} = dc permeability.

This dc mmf reduces the incremental permeability of the core material, thus lowering the inductance. To remedy this situation an air gap is inserted in the core assembly. However, the amount of air gap that can be practically incorporated is limited because of its lowering effect on the inductance. To illustrate the effect of air gaps on the OCL, data obtained on an experimental transformer are shown in Table I. From the tabulated data, it is noted that the inductance obtainable on a given size lamination is reduced appreciably with the presence of very small air gaps. The effect of such a lowered inductance is reflected in a poorer low frequency

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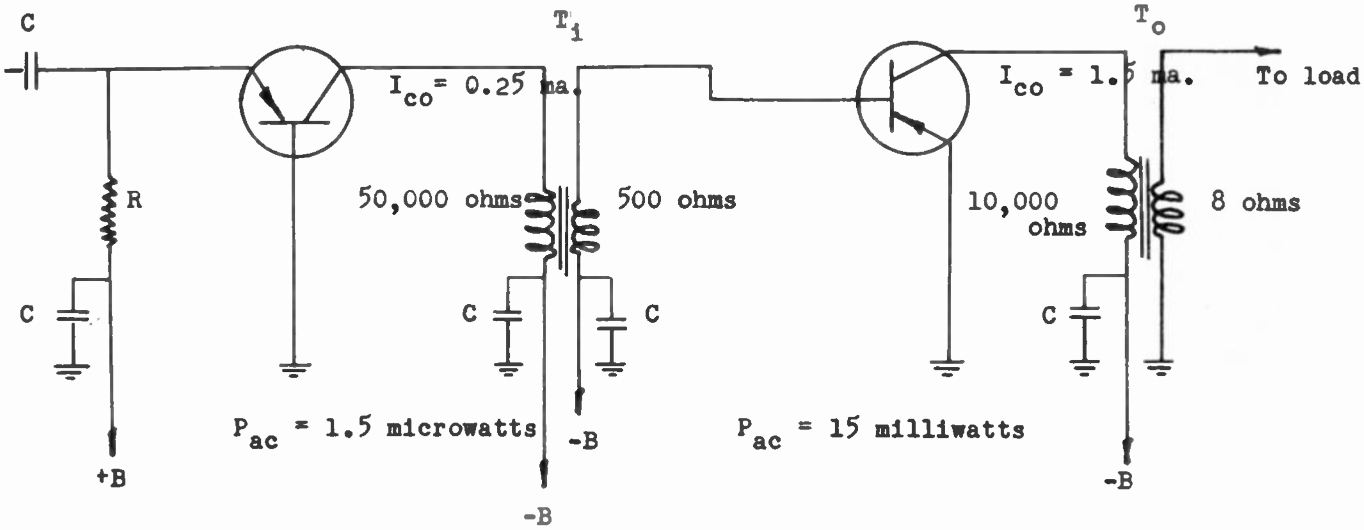


Fig. 1—Transistor amplifier.

TABLE I

EFFECTS OF AIR GAPS ON INDUCTANCE

Lamination Assembly	Primary OCL (henrys)
1. Interlace 3×3	120
2. Butt joint	
a no gap	32
b 0.001 inch inserted	20
c 0.002 inch inserted	12

Note: Data of test transformer: Lamination size and material—EE 24–25; Alloy 4750; Number of turns—4000 turns; Core area—1/16 square inch.

response and a lowering of the input impedance of the transformer at higher frequencies in the low frequency response range.

Unbalanced Direct Current Carrying Capacity

The primary OCL is proportional to the product of the square of the turns and the core area and inversely proportional to the air gap in the core assembly (1). As the transformer size is progressively reduced, both the core area and the number of turns which can be accommodated in the coil space are reduced. Consequently, the air gap must also be reduced to obtain the magnitude of inductance as determined by the low frequency response requirement. The reduced air gap, however, will allow less unbalanced direct current to flow in the transformer winding because of dc core saturation. Consequently, as a transformer size is progressively reduced, the unbalanced direct current carrying capacity is reduced.

Efficiency

The limited coil space necessitates use of fine wire, resulting in high winding resistance. If all of the losses may be attributed to the winding loss, the electrical efficiency is given by:

$$\text{Efficiency } (\%) = \frac{1}{1 + \dfrac{R_{\text{pri}} + n^2 R_{\text{sec}}}{n^2 R_L}} \times 100, \qquad (3)$$

where:

R_{pri} = primary winding resistance,
R_{sec} = secondary winding resistance,
R_L = load impedance (resistive),
n = primary to secondary turns ratio.

This formula must be modified to account for the core loss. Miniaturized audio transformers carrying unbalanced direct current operate at high flux density and the core loss becomes appreciable. For approximating the efficiency in cases where appropriate core loss data are unavailable the following modified equation may be used. The modified equation is:

$$\text{Eff } (\%) = \frac{1}{1 + 1.5\,\dfrac{R_{\text{pri}} + n^2 R_{\text{sec}}}{n^2 R_L}} \times 100. \qquad (4)$$

This equation gives a sufficiently close approximation of the efficiency of very small audio units carrying unbalanced direct current.

Voltage Level of Operation

The operation of transformers must be kept below the saturation flux density of the core material. The ac flux density is directly proportional to voltage and inversely proportional to core area and turns. Consequently, to avoid core saturation, the voltage level of operation must be lowered as core size is reduced. Existence of a dc magnetizing force reduces the operating voltage further because magnetic saturation is dependent on the sum of the ac and dc flux density.

DESIGN OF TRANSFORMERS

The application of specific design information pertinent to transistor audio transformers is perhaps best illustrated by presenting step-by-step designs of two typical units. A transistor amplifier utilizing an interstage transformer T_i and an output transformer T_0 is shown in Fig. 1. Curves and data used in the design of these miniature units are assembled in the appendix.

Design of Transformer T_i

A) Electrical Specification:

1. Power level—1.5 microwatts.
2. Frequency response—xxxxxx.
3. Primary impedance—50,000 ohms.
4. Secondary impedance—500 ohms.
5. Unbalanced dc in:
   a) primary—0.25 milliampere,
   b) secondary—negligible.
6. Input impedance—not to fall below 0.7 of impedance at mid-band frequency (1,000 cps) through 300 cps to 15,000 cps.

B) Comments: Transformer T_i illustrates a very low power, high impedance, low unbalanced direct current carrying audio unit. The primary impedance level is the predominant factor in limiting the extent of miniaturization.

C) Design Procedure and Considerations: 1. The ac voltage (E) impressed on the primary is equal to the square root of the product of power and reflected load resistance. Hence, the voltage equals:

$$E = \sqrt{PR_2} = \sqrt{(1.5 \times 10^{-6} \text{ watt})(50{,}000 \text{ ohms})}$$
$$= 0.27 \text{ volt.}$$

2. The turns ratio of the primary to the secondary (n_1/n_2) is equal to the square root of the primary impedance (Z_1) divided by the secondary impedance (Z_2). Hence, the turns ratio equals:

$$\frac{n_1}{n_2} = \sqrt{\frac{Z_1}{Z_2}} = \sqrt{\frac{50{,}000}{500}} = 10.$$

3. From the variation of input impedance of transformers at low frequency curve in Fig. 2 (minimum of 0.7 input impedance of the midband frequency of 1,000 cps), the ratio of the shunting inductive impedance to the reflected load resistance (X_n/R_2) must equal 1.0. Therefore, the minimum primary inductance (L_n) at frequency of 300 cps is obtained by solving the above relationship for L_n:

$$L_n = \frac{1.0R_2}{2\pi f} = \frac{1.0 \times 50{,}000}{2\pi \times 300} = 26.6 \text{ henrys.}$$

The leakage inductance and distributed capacitance, which affects the input impedance at high frequency is small in miniature transformers and at a frequency of 15,000 cps the effects are negligible.

4. It was stated in an earlier paragraph that the magnitude of air gaps must be kept small in miniature audio transformers to obtain the primary inductance required. The maximum air gaps inserted in the core assembly in the design of transistor transformers on the lamination, shown in Table II opposite, were of the order of 0.002 inch on EE 24–25, and less for the smaller laminations. A good starting point in the design of T_i is to assume a "$l_g+(l_c/\mu_{ac})$" value of 0.001 inch in (1).

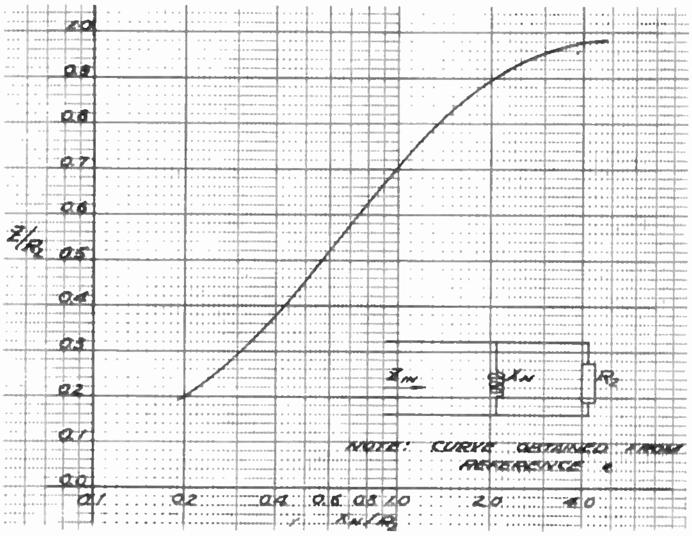


Fig. 2—Variation of input impedance with transformer characteristics at low frequencies.

The initial trial selection for the core will be a square stack (the buildup of the laminations equal to the width of the center leg) of F-14. With a stacking factor of 90 per cent for 0.006 inch thickness lamination, the core area (A_c) is 0.032 square inch. Rearranging (1) and solving for the turns:

$$N = \sqrt{\frac{L_n\left(l_g + \dfrac{l_c}{\mu_{ac}}\right)}{3.19A_c \times 10^{-8}}} = \sqrt{\frac{26.6 \times 0.001}{3.19 \times 0.032 \times 10^{-8}}}$$
$$= 5100 \text{ turns.}$$

5. The ac flux swing is determined from the relation:

$$B_{ac} = \frac{3.49E \times 10^6}{fA_cN} = \frac{3.49 \times 0.27 \times 10^6}{300 \times 0.032 \times 5100} = 19.2 \text{ gauss.}$$

The ac flux swing is low as might have been expected by the low power level specification. Mumetal will be used for the core material because it has high incremental permeability at low ac flux density.

6. To prevent core saturation, the maximum flux density is limited to 4,000 gauss. Therefore, since ac flux swing is negligible, operation at B_{dc} of 4,000 gauss is permissible.

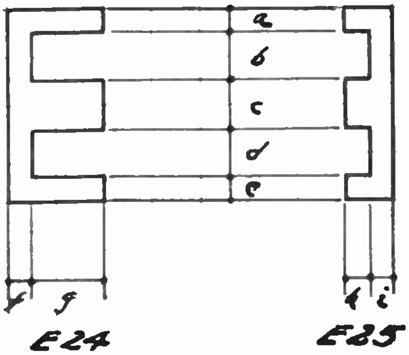
7. The air gap required is obtained by rearranging (2), substituting $H_c = B_{dc}/\mu_{dc}$ and from Fig. 3 (p. 14):

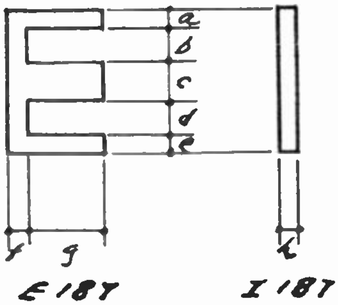
$$l_g = \frac{0.5NI_{dc}}{B_{dc}} - \frac{l_c}{\mu_{dc}} = \frac{0.5 \times 5100 \times 0.00025}{4000} - \frac{1.25}{60{,}000}$$
$$= 0.00016 - 0.00021 = 0.00014 \text{ inch.}$$

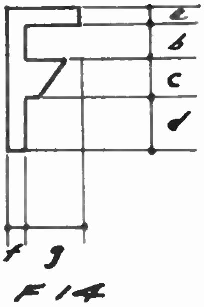
The laminations will be interlaced 3×3 to obtain an air gap of 0.00015 inch (See Table III, p. 14). From Fig. 4 (p. 15), μ_{ac} is 5,000 for B_{ac} of 20 gauss, B_{dc} of 3,700 gauss, and frequency of 300 cps, μ_{ac} is 5,000. The "l_g+l_c/μ_{ac}" is $0.00015+1.25/5000=0.0004$. Step 4 is repeated with the new value of "l_g+l_c/μ_{ac}." The turns required to obtain 26.6 henrys are 3,200.

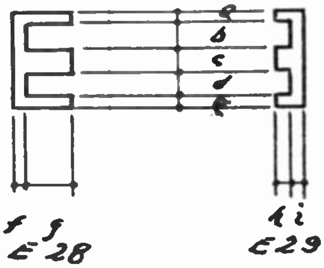
TABLE II

TRANSFORMER LAMINATIONS









	A_c	A_w	l_c
EE 24–25	0.0625	0.125	2.0
EZ 187	0.035	0.082	1.72
F 14	0.035	0.046	1.25
EE 28–29	0.0156	0.039	1.125

Symbols:

A_c = core area (in.^{2})
square stack (stacking factor not included)
A_w = window area (in.^{2})
l_c = magnetic path length (in.)

	EE 24–25	EZ-187	F-14	EE 28–29
a	$\frac{1}{8}$	$\frac{3}{32}$	0.1	$\frac{1}{16}$
b	$\frac{1}{4}$	$\frac{3}{16}$	0.188	$\frac{1}{8}$
c	$\frac{1}{4}$	$\frac{3}{16}$	0.188	$\frac{1}{8}$
d	$\frac{1}{4}$	$\frac{3}{16}$	0.283	$\frac{1}{8}$
e	$\frac{1}{8}$	$\frac{3}{32}$	—	$\frac{1}{8}$
f	$\frac{1}{8}$	$\frac{3}{32}$	0.1	$\frac{1}{16}$
g	$\frac{3}{8}$	$\frac{7}{16}$	0.25	$\frac{1}{4}$
h	$\frac{1}{8}$	$\frac{3}{32}$	—	$\frac{1}{16}$
i	$\frac{1}{8}$	—	—	$\frac{1}{16}$

Dimensions in inch

8. B_{ac} and B_{dc} are recalculated with the new value of turns and found to be 30 gauss and 2,400 gauss, respectively. μ_{ac} is 8,000. The primary inductance equals:

$$L = \frac{3.19 N^2 A_c \times 10^{-8}}{l_a + \dfrac{l_c}{\mu_{ac}}} = \frac{3.19 \times 3200^2 \times 0.032 \times 10^{-8}}{0.00015 + \dfrac{1.25}{8000}}$$

$$= 32 \text{ henrys.}$$

Either the turns or the core area may be decreased since 26.6 henrys is the inductance required. Considering the coil space available and the number of turns, the ratio of the winding resistance to the terminating impedance should be relatively low. The efficiency will be high. Thus, the latter alternative is selected. Core area is reduced by 26.6/32.

9. The coil is fitted into the coil space. 3,200 turns of No. 48 SF wire and 320 turns of No. 36 SF wire can be accommodated by the coil space. If the primary is wound first, and then the secondary, the respective winding resistance is, approximately, 2,500 and 22 ohms.

10. The approximate efficiency is computed from (4):

$$\text{Eff }(\%) = \frac{1}{1 + 1.5\dfrac{R_{\text{pri}} + n^2 R_{\text{sec}}}{n^2 R_L}} \times 100$$

$$= \frac{1}{1 + 1.5\dfrac{2500 + 10^2 \times 22}{10^2 \times 500}} = 87.6\%.$$

Design of Transformer T_0

A) *Electrical Specification:*

1. Power level—15 milliwatts.
2. Frequency response—minus 1.5 db, 300 cps through 15,000 cps.
3. Primary impedance—10,000 ohms.
4. Secondary impedance—8 ohms.
5. Unbalanced dc in: primary—1.5 milliamperes, secondary—none.
6. Input impedance—xxxx.

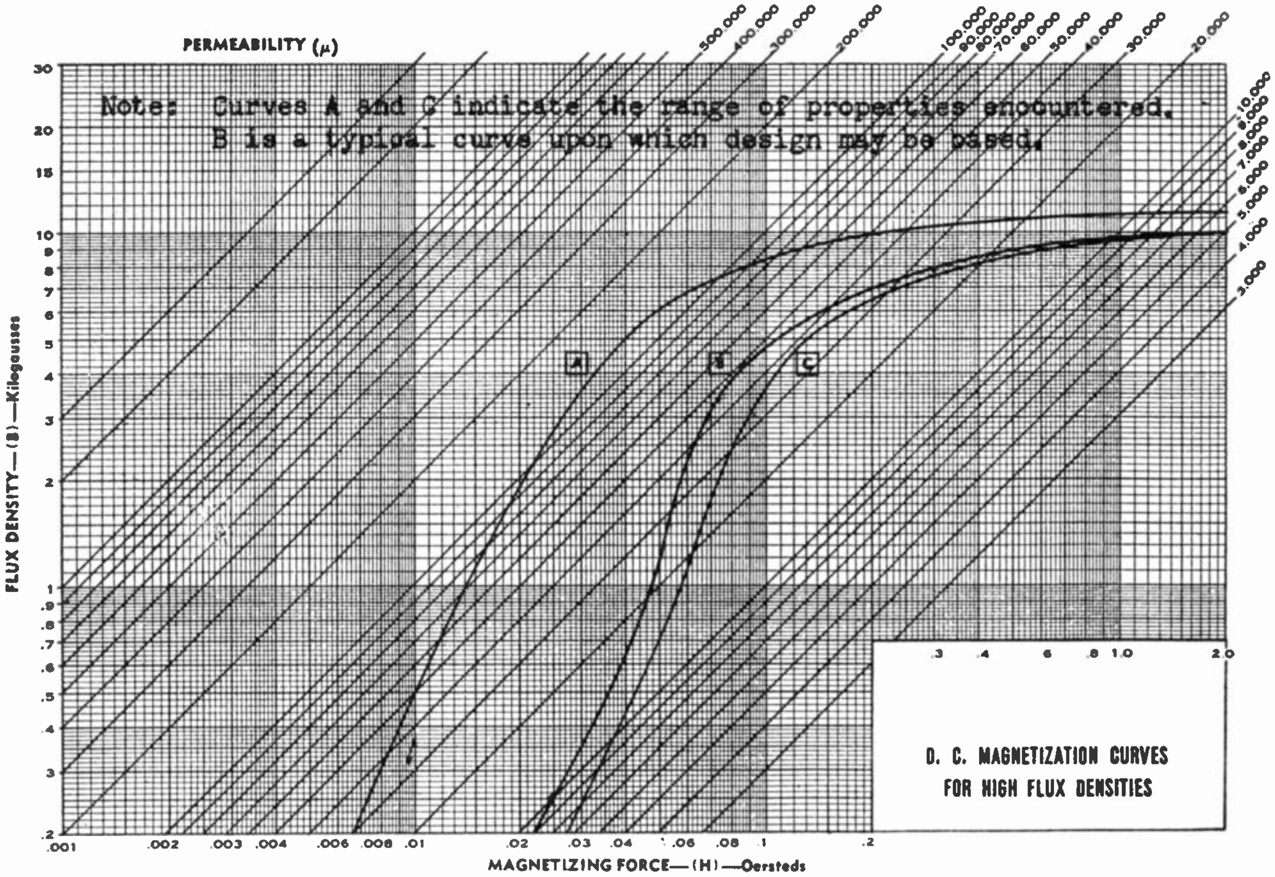


Fig. 3—DC magnetization curve of Mumetal.

TABLE III
EQUIVALENT AIR GAPS IN SMALL LAMINATIONS

0.006 inch Laminations Core Assembly	Nominal Effective Air Gaps in Inches
Interlace 1×1	0.00005
Interlace 3×3	0.00015
Butt joint with zero gap	0.0006
Butt joint with 0.001 inch gap inserted	0.0012
Butt joint with 0.002 inch gap inserted	0.0022

Note: Tabulated data are for laminations having a length of magnetic path of two inches or less.

B) *Comments:* Transformer T_0 illustrates a relatively high power, medium impedance, high unbalanced direct current carrying audio unit. The last item is the predominant factor in limiting extent of miniaturization.

C) *Design Procedure and Considerations:* The procedure outlined in the previous design will be followed. The solution to the simpler steps will be obtained without detailed explanation.

1. The ac voltage impressed on the primary equals:

$$E = \sqrt{PR_2} = \sqrt{(15 \times 10^{-3}\,\text{watts})(10 \times 10^{3}\,\text{ohms})}$$
$$= 12.4 \text{ volts.}$$

2. The turns ratio equals:

$$\frac{n_1}{n_2} = \sqrt{\frac{Z_1}{Z_2}} = \sqrt{\frac{10{,}000}{8}} = 35.4.$$

3. From the transformer response curve in Fig. 5, the primary inductance required is determined. Looking back into the collector-emitter terminals of the transistor, the impedance is high, of the order of 100,000 ohms. Thus, the ratio of source impedance to reflected load resistance is about 10, and the "R_p/R_2 equals 10" curve in Fig. 5 is used to determine the required inductance. To satisfy the response requirement of −1.5 db, the ratio of shunting inductive impedance to the reflected load resistance (X_n/R_2) must equal 1.35. Hence, the minimum primary inductance (L_n) at 300 cps is obtained by rearranging the above relationship and solving for L_n:

$$L_n = \frac{1.35R_2}{2\pi f} = \frac{1.35 \times 10{,}000}{2\pi \times 300} = 7.15 \text{ henrys.}$$

As stated in the discussion on frequency response, the leakage inductance and distributed capacitance, which affect the high frequency response, are small in miniature transformers and at a frequency of 15,000 cps their effects are negligible.

4. The initial trial selection for the core will be a square stack of EE 28–29. The core area is 0.014 square inch. A value of 0.001 inch will be assumed for the "$l_g+(l_c/\mu_{ac})$" term. The turns required to obtain 7.15 henrys on this lamination is found by rearranging (1):

$$N = \sqrt{\frac{L_n\left(l_g + \frac{l_g}{\mu_{ac}}\right)}{3.19A_c \times 10^{-8}}} = \sqrt{\frac{7.15 \times 0.001}{3.19 \times 0.014 \times 10^{-8}}}$$
$$= 4{,}000 \text{ turns.}$$

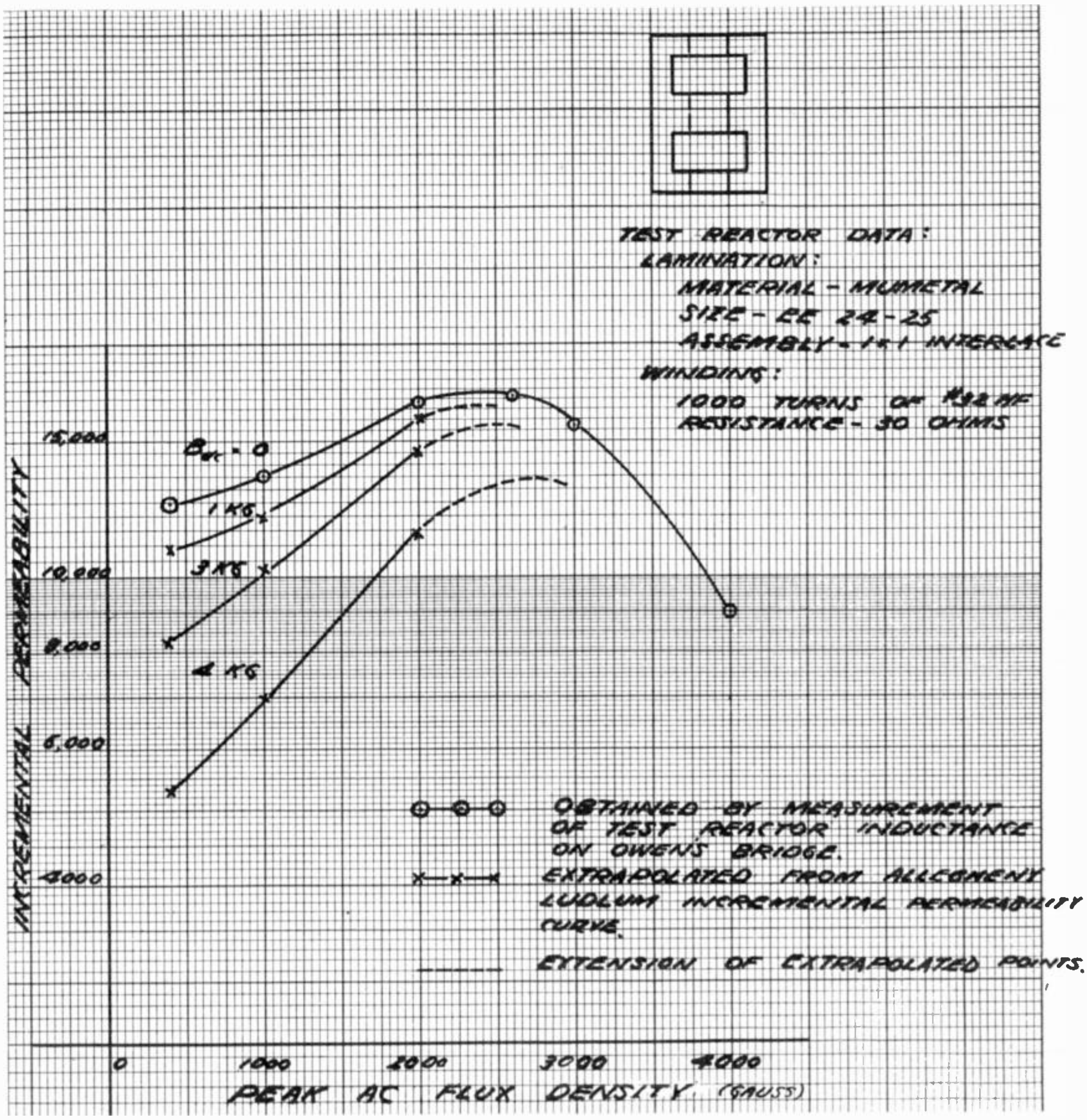


Fig. 4—300-cycle incremental permeability characteristics .006 inch Mumetal.

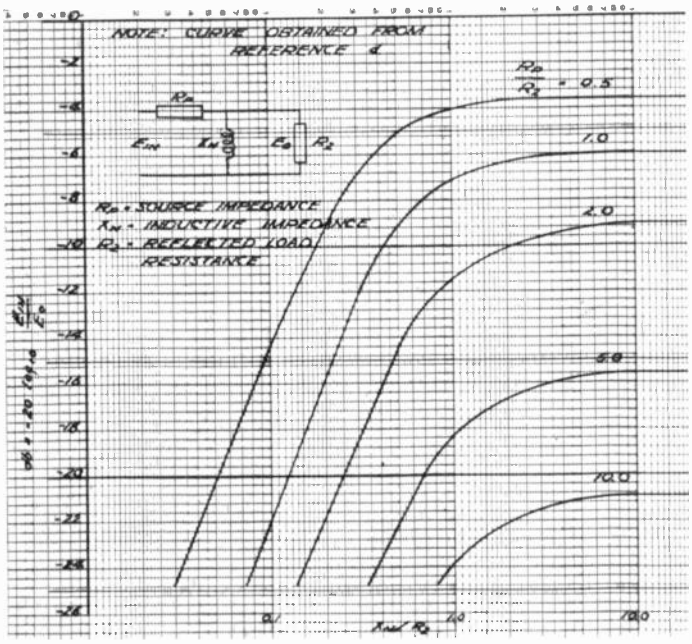


Fig. 5—Transformer output voltage at low frequencies.

5. The peak ac flux swing is determined from:

$$B_{ac} = \frac{3.49E \times 10^6}{f A_c N} = \frac{3.49 \times 12.4 \times 10^6}{300 \times 0.014 \times 4{,}000}$$
$$= 2{,}560 \text{ gauss.}$$

Since the ac flux swing is appreciable and the dc flux density is anticipated to be high from the unbalanced direct current specification, a core material having high saturation flux density is preferable. Consequently, Alloy 4750 is selected for the core material.

6. To prevent core saturation, the maximum flux density is limited to 6,000 gauss. Hence, the dc flux is 6,000 minus 2,560, which is approximately, 3,400 gauss.

7. The air gap required is determined from Fig. 6 and equation:

$$l_g = \frac{0.5 N I_{dc}}{B_{dc}} - \frac{l_c}{\mu_{ac}} = \frac{0.5 \times 4{,}000 \times 0.0015}{3{,}400} - \frac{1.125}{45{,}000}$$
$$= 0.00088 - 0.000025 = 0.00086 \text{ inch.}$$

The 0.0009 inch air gap is obtained by inserting 0.0003 inch paper in the core assembly.

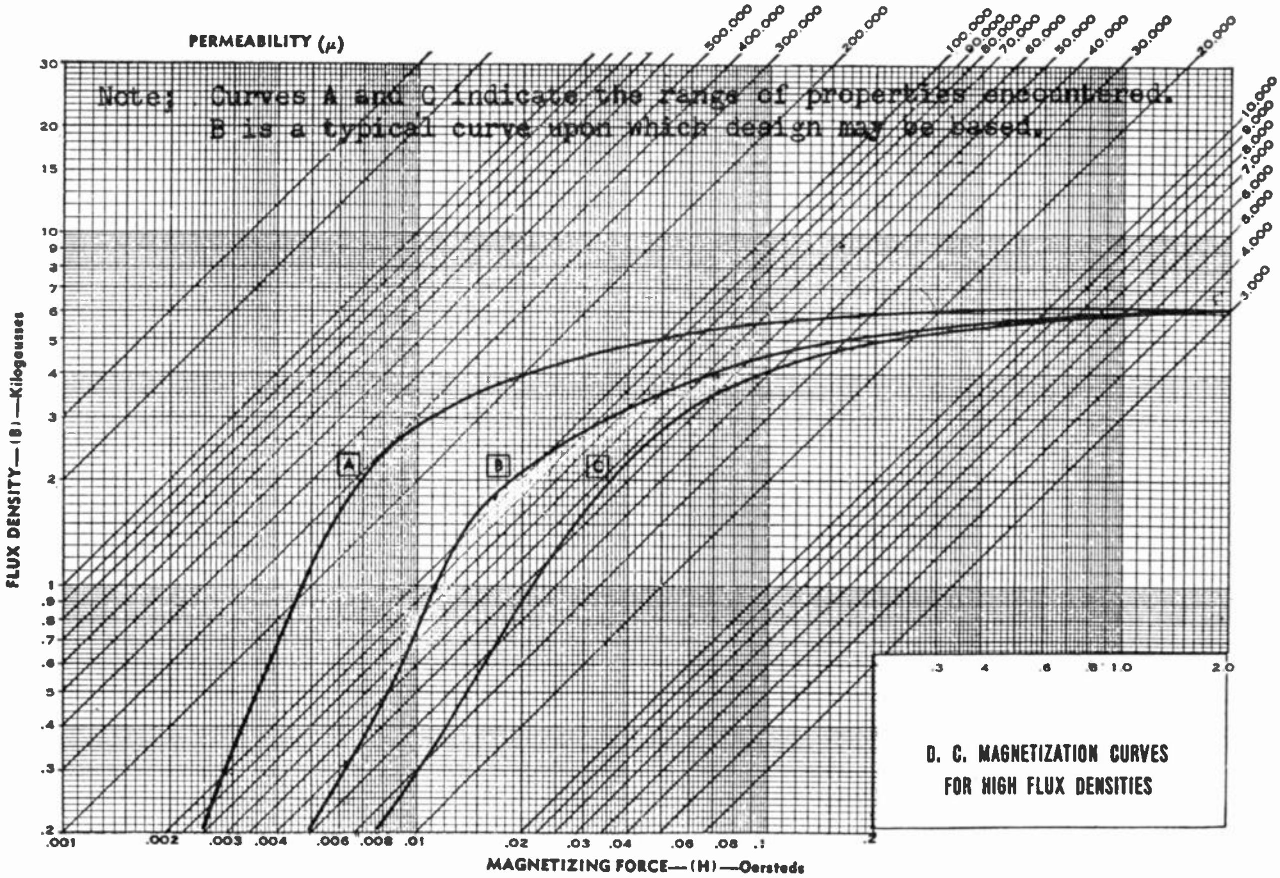


Fig. 6—DC magnetization curve of 4750.

8. The primary inductance is determined from (1) and Fig. 7. For B_{ac} of 2,560, B_{dc} of 3,300, and frequency of 300 cps, μ_{ac} is 5,000.

$$L_p = \frac{3.19 N^2 A_c \times 10^{-8}}{l_g + \frac{l_c}{\mu_{ac}}} = \frac{3.19 \times 4{,}000^2 \times 0.014 \times 10^{-8}}{0.0009 + \frac{1.125}{5{,}000}}$$

$$= 6.35 \text{ henrys.}$$

Either the turns or the core area must be increased to obtain the required inductance. Since the efficiency is anticipated to be fairly low utilizing a wire size to fit 4,000 turns in the coil space, the latter alternative is selected. The core area is increased by 7.15/6.35.

9. The coil is fitted into the coil space. 4,000 turns of No. 48 AWG wire and 113 turns of No. 32 AWG wire can be accommodated by the coil space. If the primary is wound first, then the secondary, the respective winding resistance is 2,000 ohms and 2 ohms.

10. The approximate efficiency is computed from (4):

$$\text{Eff } (\%) = \frac{1}{1 + 1.5\,\frac{P_{\text{pri}} + n^2 R_{\text{sec}}}{n^2 R_L}} \times 100$$

$$= 1 + 1.5\,\frac{2{,}000 + 35.4^2 \times 2}{35.4^2 \times 8}$$

$$= 60 \text{ per cent.}$$

To improve this phase of the transformer performance, it will be necessary to design on a large size lamination.

PERFORMANCE

Fabricated transformers, T_i and T_0, are in Fig. 8 (p. 18). The finished units are open core and coil with air dry varnish treatment. The coils are bobbin-wound.

The input impedance characteristics, the test circuit and a table of calculated and measured parameter values of transformer T_i are shown in Fig. 9 (p. 18). Primary OCL value was only two-thirds the value required to meet the input impedance requirement. This low inductance is due to the substitution of a lower permeability core material, Alloy 4750, for Mumetal. The latter material was not available.

Frequency response curve, and other test data of transformer T_0 are in Fig. 10 (p. 18). Correlation between calculated and measured performance of unit is good.

GENERAL INFORMATION

Transformer Cores

All of the miniature transformers designed at SCEL utilize stamped laminations (see Table II) in which air gaps can be incorporated in the core assembly. Several experimental transformers were designed on high permeability, continuous tape-wound cores. These units were found to saturate readily with the existence of unbalanced bias currents.

Core Materials

The miniature transformers designed at SCEL utilize nickel-iron alloys for the core material. Mumetal, an alloy of approximately 78 per cent nickel, 15 per cent

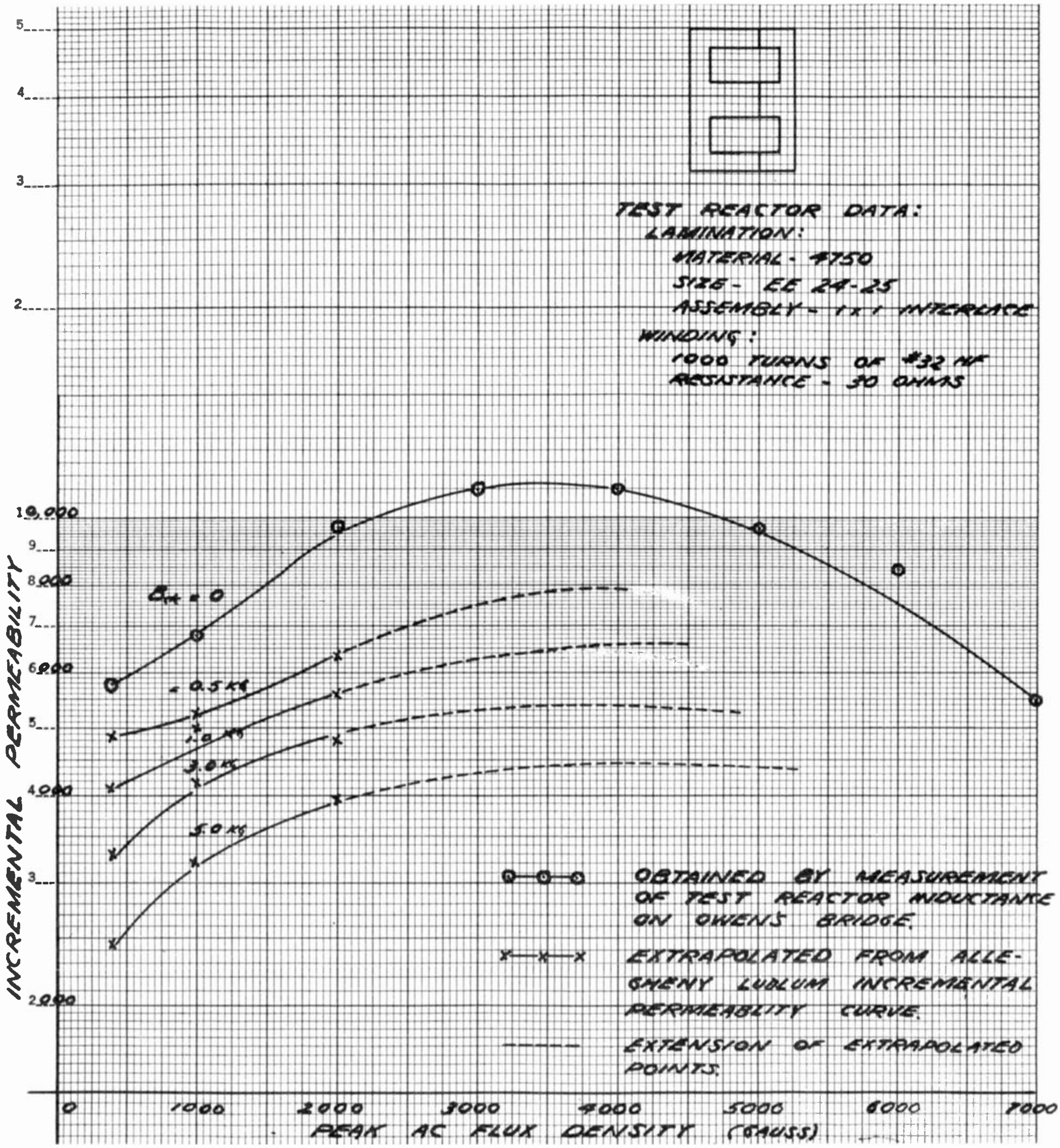


Fig. 7—300-cycle incremental permeability characteristics .006 inch 4750.

iron, and the balance copper and chromium, is particularly suitable for very low power, low unbalanced direct current carrying transformers, while alloy 4,750, containing approximately 48 per cent nickel, balance iron, is suitable for higher power levels and higher unbalanced direct current carrying transformers. For very high power levels and large unbalanced direct current it may be worthwhile to investigate the possible use of $3\frac{1}{2}$–$3\frac{3}{4}$ per cent silicon steel. This material has lower incremental permeability compared to nickel iron alloys. However, when air gaps of very small magnitude, one to two mils, are inserted in the core assembly of small laminations the high incremental permeability properties of nickel iron alloys are nullified. Silicon steel may be used to advantage since it has higher saturation flux density, its incremental permeability is less affected by dc mmf, and it is less expensive.

Effects of Sealing on Finished Size

To meet the Grade I (moisture-proof) requirements of MIL-T-27, it will be necessary to seal the transformers by one of the following methods:

1) Hermetic sealing in metal cases will result in transformers with the largest volume increase. The base

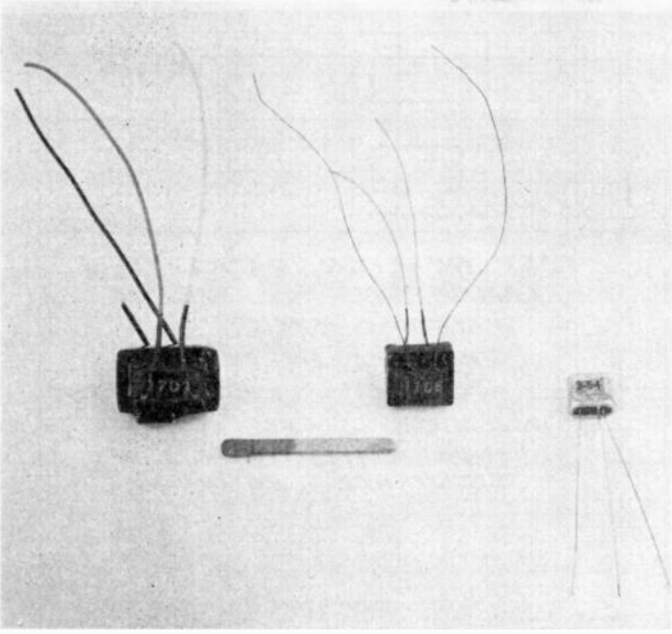


Fig. 8—Interstage transformer (T_i) and output transformer (T_0).

dimensions are increased by approximately 20 per cent per side with greater increase in the height dimension where the terminals are mounted. The percentage increase in size of cased to open core and coil is proportionately larger for progressively smaller size units since a minimum clearance of approximately ⅛ inch per side between transformer and the case wall is required in all encased units.

2) Sealing by encapsulating the miniature transformers in epoxy resins or potting in compounds results in smaller sized units relative to metal cased units. An open core and coil construction with an air dry varnish dip is acceptable if the subsequent transistorized system is totally enclosed in protective seal.

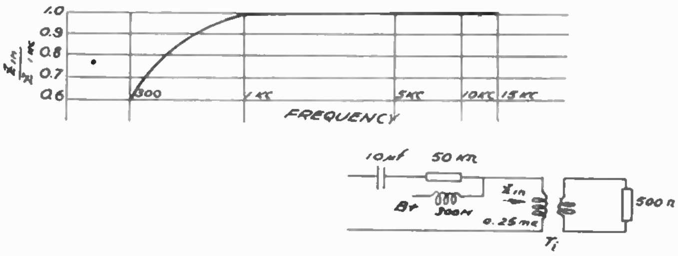
CONCLUSIONS

1) The electrical parameters which limit the extent of miniaturization are: (a) the unbalanced direct current to be carried by the transformer winding; (b) the impedance level; (c) the voltage or power level; and (d) the efficiency requirement.

2) Of the four parameters above, the transformer size is particularly sensitive to (a) and the circuit engineer has some control of this parameter in circuitry design.

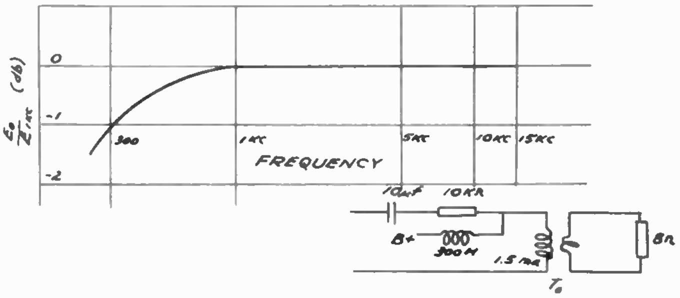
3) In miniature size audio transformers, appreciable air gaps cannot be incorporated in the core assembly due to its lowering effect on the shunting inductance. Large values of unbalanced direct current cannot be carried by the transformer windings. Unbalanced bias currents of one to two milliamperes to be carried by impedance winding of ten thousand ohms and higher are to be considered appreciable in transistor audio transformers.

4) As the size of the audio transformers is progressively reduced, the shunting inductance obtainable is lowered. This has two undesired effects: (a) low frequency response becomes poorer and (b) variation in transformer input impedance at the lower portion of the frequency response commences at higher frequencies.



Parameter	Calc.	Meas.
Pri Ocl (300 cps)	26.6	17*
Resistance Pri Sec	2500 22	2600 23
Eff.(1kc)	87.6%	82%

Fig. 9—Input impedance characteristics of interstage transformer (T_i). *Alloy 4750 used. Mumetal was not available.



Parameter	Calc.	Meas.
Pri. Ocl (300 cps)	7.15	7.2
Resistance Pri Sec	2000 2	1760 1.75
Eff.(1kc)	60%	62.5%

Fig. 10—Frequency response of output transformer (T_0).

5) The limited coil space necessitates the use of fine wire resulting in high winding resistance, hence low efficient units.

ACKNOWLEDGMENT

The invaluable service rendered by the Reactor and Transformer Shop, Evans Signal Laboratory, Mr. M. H. Ritter, foreman, in fabricating the numerous test transformers required in the investigation is acknowledged. Appreciation is expressed to the Performance Test Section, Components and Materials Branch, particularly to Mr. J. Cresser for his assistance on the subject pertaining to transformer sealing methods.

Thanks are also due to Mr. S. F. Danko for his helpful suggestions and comments in the preparation of this report.

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Efficiency and Power Rating of Loudspeakers*

R. W. BENSON†

Summary—**The specification of the performance of loudspeakers is a subject of international controversy at the present time. Several groups in this country are concerned with standardized methods of evaluating the performance of loudspeakers in order to have a basis for comparison. Several European countries are also concerned with similar problems.**

The measurement of the response-frequency characteristic and directional characteristics of loudspeakers is routinely performed by various laboratories. Sufficient agreement can be attained by the various laboratories to standardize this measure of performance. It is important to have a measure of the efficiency, that is sound power output vs electrical power input, and also a method of specifying the power handling capacity of a loudspeaker. Various methods are in use at the present time to indicate the characteristics of a loudspeaker concerning these two measures. The method of using a reverberation chamber to integrate acoustic power output and thus determine the efficiency will be discussed in comparison to the more tedious method of analytical integration of measurements performed in free space. Power handling capabilities of loudspeakers as determined by distortion measurements and mechanical or electrical failure will also be discussed. A summary of the various methods of specifying both efficiency and power handling capacity as used in various laboratories in both the United States and Europe will be included.

INTRODUCTION

THERE HAS BEEN much activity during the past few years on the standardization of measurements on the performance of loudspeakers. Groups in this country, under the sponsorship of the Acoustical Society of America, the Institute of Radio Engineers, and the Society of Motion Picture and Television Engineers have been given the task of preparing an American Standard on procedures for the measurement of loudspeaker performance. There is in existence at the present time a British standard and a German standard. In addition to these groups there is a committee of the international electro-technical commission which is assigned the task of preparing an international standard. None of these standards are directly concerned with what characterizes a good quality loudspeaker, but rather a method of evaluating the various measures of performance.

There are various measures of performance which manufacturers use to describe the properties of different loudspeakers. The most common measure quoted is the power rating of the loudspeaker. Other measures used include (a) nominal impedance, (b) response vs frequency characteristics, (c) directional properties, (d) efficiency, and (e) distortion. In general, these characteristics are given by descriptive terms rather than by actual measures of performance. For instance, frequency response characteristics are described by the terms "flat" or "range from 75 to 12,000 cps." The directional properties may be described by terms such as "broad coverage" or "120 degree distribution." Much more attention has been given to the specification of the electrical input to the loudspeaker than to actual measures of performance as an electroacoustic transducer.

In order to assess the importance of various measures of performance, it is necessary to know their relative value to the user. In the ordinary home installation, the major factor is the faithfulness of reproduction. Little energy is required to produce satisfactory listening levels, and directional characteristics are only a problem at the higher frequencies. Since the majority of loudspeakers are used in home reproducing sets, the majority of consumers are satisfied with obtaining information which describes the faithfulness of reproduction.

Only a few users are concerned with the efficiency of transduction, from either an economical or a size and weight viewpoint. Many large installations such as paging systems in factories are concerned with over-all system performance and cost rather than the actual efficiency of the loudspeaker. The quality of reproduction can be sacrificed, that is to say, the lower frequencies need not be reproduced and a smaller, more economical unit can be used. The two main characteristics needed are the directional properties and the levels produced as a function of distance and direction.

In commercial indoor installations of loudspeakers, such as motion picture theaters, quality is usually of the utmost importance. It is desirable, however, to know the efficiency of the loudspeaker if one is to predict the sound levels produced in the remote parts of the auditorium. In near proximity to the loudspeaker, the radiation pattern is of importance, but, in general, the seating area is sufficiently far from the loudspeaker that most of the sound is arriving after reflection from either walls or ceiling. Direct radiator loudspeakers are usually used which have sufficiently broad radiation patterns that directional properties are of little or no value.

EFFICIENCY

Although the measure of efficiency is used by a very small number of consumers, it is also desirable to the manufacturer to aid in the design and development of new models. There are several methods of determining efficiency of a loudspeaker which I should like to discuss. Each of these methods is described in one of the proposed standards. It is assumed that the electrical power input can be measured, so the determination of efficiency is essentially a method for measuring acoustical power output.

The first method may be called the method of integration. A measurement of the power output of a speaker may be obtained by placing the loudspeaker in free space (commonly referred to as "free-field") and measuring the sound pressure at a great number of points of a sphere, the center of which is occupied by

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the loudspeaker. If the radius of the sphere is large in relation to the wavelength, the sound pressure measured at each point is in phase with the particle velocity, and the total acoustic power P is then given by

$$P = \frac{1}{\rho c} \iint p^2 dS. \tag{1}$$

Integration over the entire surface of the sphere gives the total acoustic output.

This method is extremely rigorous if a sufficiently large number of points are measured and if the directional properties are describable by mathematical functions which can be accurately integrated. There are two reasons why this method is usually not acceptable: first, if sufficient measurements are made, the method is too time-consuming and if only a few measurements are made, the accuracy is poor; and second, a relatively large anechoic chamber is required for the measurement, which is usually not available to the manufacturer.

The second method is the least accurate and applies in general to those loudspeakers with extremely high efficiencies. This is the so-called "motional impedance method." One measurement is the input impedance of the loudspeaker when it functions normally and the other when the vibrating system is entirely blocked. The resistive components determined from the two measurements indicate the ratio of power which is absorbed by the loudspeaker when it is radiating acoustic energy, to the power absorbed when just supplying the electrical losses. The efficiency is then given by

$$\text{Efficiency} = \frac{R_1}{R} \times 100. \tag{2}$$

R is given directly by the first measurement, and R_1 is equal to $R-R'$, R' being given by the second measurement. When the efficiency is low, R and R' are essentially the same and the accuracy is extremely poor. If the diaphragm is entirely blocked, no mechanical losses are supplied to the system; however, it is extremely difficult to block the diaphragm for the higher frequencies. The method is extremely simple to use but ignores the mechanical losses of the loudspeaker in addition to being inaccurate for low efficiencies.

The third method is called the "reverberation chamber method" and utilizes a room to integrate the total acoustic output of the loudspeaker. If the total acoustic absorption of a room is known, and the sound pressure level produced in the room is measured, then the acoustic power can be calculated. This technique is based on the assumption that the sound pressure level will build up in a room until the sound energy absorbed is equal to that emitted by a source. The total power radiated by the source is given by the expression

$$P = \text{antliog}\,(L + 10 \log A - 136.2), \tag{3}$$

where L is the sound pressure level relative to 0.0002 microbar and A is the absorption of the room in sabins. The constant 136.2 corrects for the impedance of air as well as the units of measurement.

The reverberation chamber method lacks acceptance mainly due to lack of data verifying the measures against the precise determination by the numerical integration technique. Previous authors[1] have shown the equivalence of the two methods but have not shown either a sufficient reduction in time or a reduction in the facilities required for the measurement. A series of loudspeaker efficiencies were measured by the author to provide data on several horn-type loudspeakers. Methods were devised to employ automatic techniques for the evaluation of the efficiencies of several loudspeakers within a reasonable length of time. First, the absorption of the reverberation chamber, shown in Fig. 1, was determined by measuring the reverberation time of the chamber. The reverberation time is defined as the time for the sound to decay 60 db below its original value after the source is switched off. The absorption is related to the reverberation time by Sabine's formula[2]

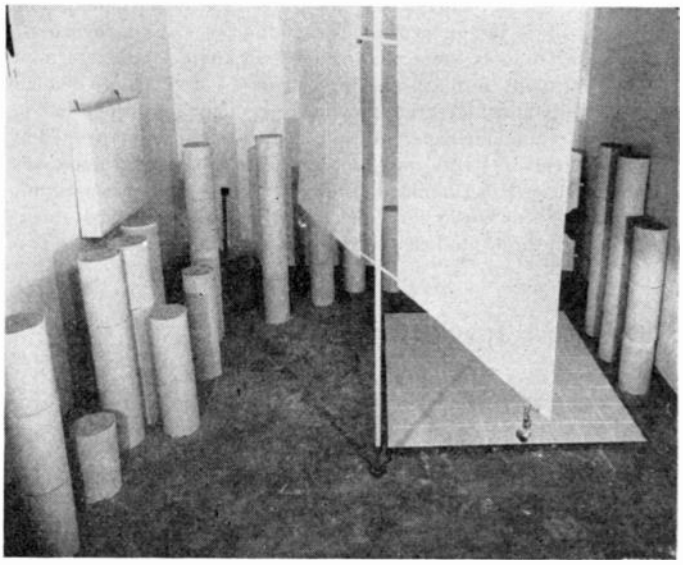

Fig. 1—Riverbank reverberation chamber.

$$A = \frac{0.49V}{T_{60}}, \tag{4}$$

which is sufficiently accurate for rectangular rooms having long reverberation times. Test signals were produced with bands of white noise, one-quarter octave wide, recorded and reproduced from magnetic tape. These signals were used for the determination of absorption as well as the actual measurements of sound pressure levels during the efficiency measurements. The absorption of the reverberation chamber is shown as a function of frequency in Table I.

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[1] H. C. Hardy, H. H. Hall, and L. G. Ramer, "Direct measurement of the efficiency of loudspeakers by use of a reverberation room," *Proc. NEC*, vol. 8, pp. 99–107; 1953.

[2] V. O. Knudsen, "Architectural Acoustics," John Wiley & Sons, Inc., New York, N. Y.

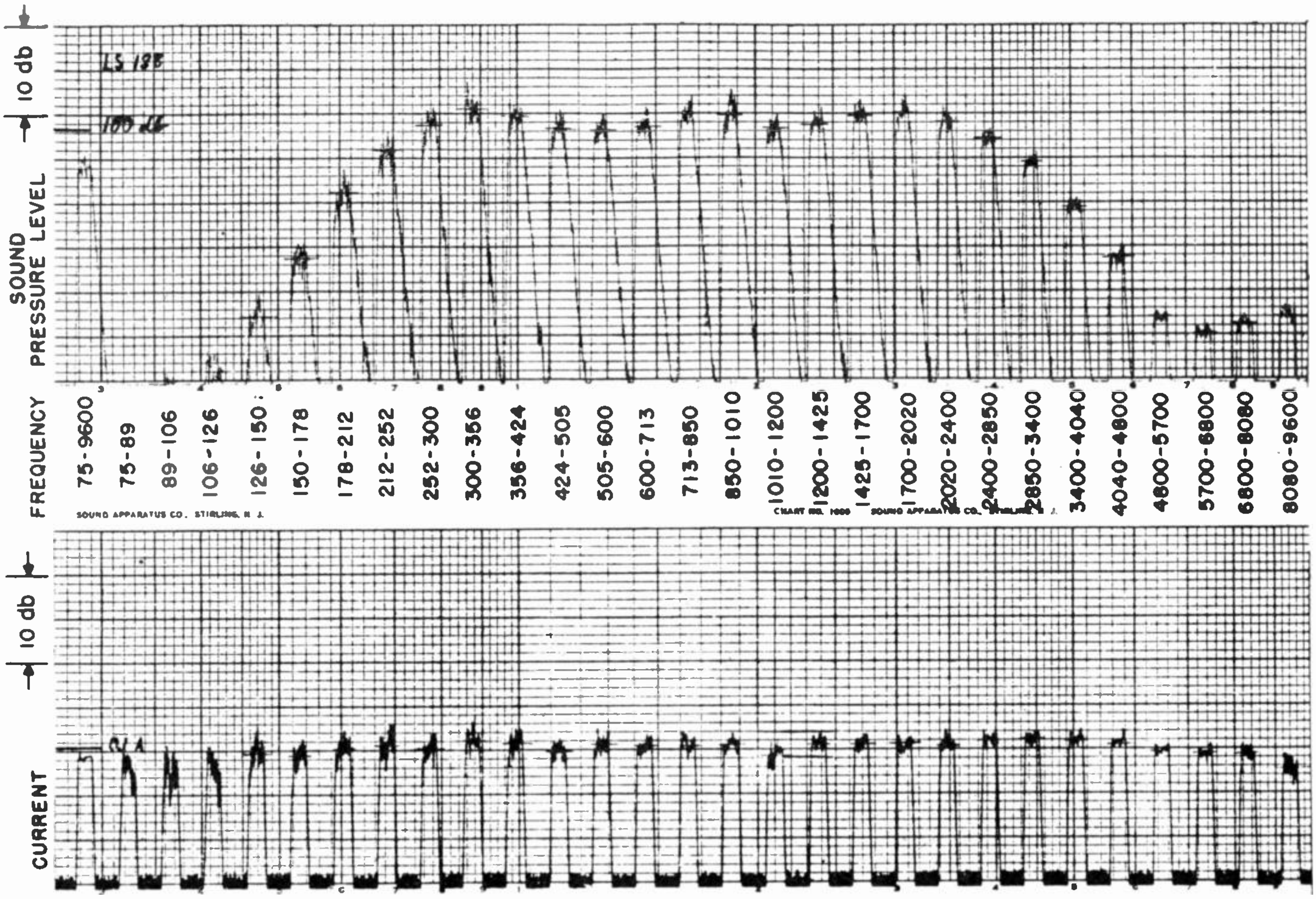

Fig. 2—Chart record of reverberation room measurement.

TABLE I

RIVERBANK REVERBERATION CHAMBER
ABSORPTION (SABINS)
QUARTER-OCTAVE BAND NOISE

Frequency	Absorption	Frequency	Absorption
75–89	105.3	850–1010	123.5
89–106	95.5	1010–1200	130
106–126	101	1200–1425	127
126–150	95.5	1425–1700	133.5
150–178	103	1700–2020	137.5
178–212	105	2020–2400	145.5
212–252	115	2400–2850	150
252–300	115	2850–3400	160
300–356	115	3400–4040	165
356–425	112	4040–4800	170
425–505	118	4800–5700	170
505–600	120.5	5700–6800	241
600–713	123.5	6800–8080	309
713–850	123.5	8080–9600	381

The tape consisted of twenty-eight quarter-octave bands of noise recorded successively for two seconds with three-second silent intervals between them. Sound pressure levels and power input to the speakers were determined simultaneously on a dual-channel level recorder, by the recording of sound pressure levels in the chamber and current through the voice coil of the loudspeaker. The power input to the loudspeaker was determined from the I^2R losses and the power output from the sound pressure level and the previously determined absorption of the chamber. A sample record of the actual measurements is shown in Fig. 2.

The actual efficiency of the speaker can be calculated from the above measures, but calculations can be simplified if the loss factor is determined in decibels. The loss factor is defined as the number of decibels by which the power is reduced due to transduction and may be calculated from the following expression:

$$D = -10 \log E = 10 \log \frac{I^2R}{P}$$

$$= L + 10 \log A - 20 \log I - 10 \log R - 136.2, \qquad (5)$$

where D is the loss factor in decibels; E is the efficiency; I is the current in amperes; P is the acoustic power output; L is the sound pressure level in db re 0.0002 microbar; A is the absorption of the room in sabins, and R is the real component of the input impedance.

The absorption and resistance must be transformed by logarithms; however, the sound pressure level and current level may be read directly from the automatic level recorder chart.

Fig. 3 shows the resistance and reactance of an LB 35 driver unit mounted on an SMH horn manufactured by the University Loudspeaker Company. These measure-

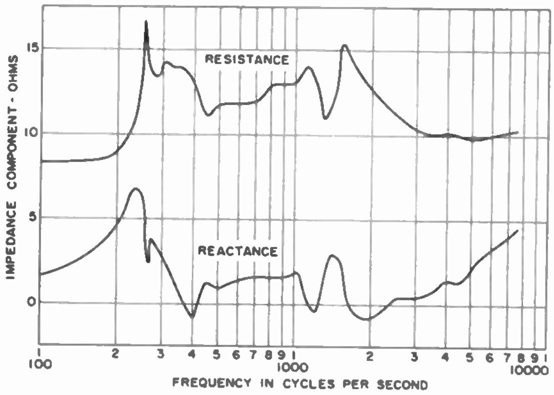

Fig. 3—Impedance components of an LB 35.

ments were made using a Technology Instruments Company's impedance bridge and are necessary to determine the power input to the loudspeaker independent of the technique of determining acoustic power output. Fig. 4 shows the acoustic power output, the electric losses, and other losses expressed as a percentage of the total power input. The output was obtained from measurements in the reverberation chamber, the electrical losses were calculated from the I^2R loss in the voice coil, and the other losses are the difference between power input and the total of output power plus electric losses. It can be seen that the other losses, consisting of mechanical losses and losses due to mismatch of the electro-mechano-acoustic system, reach a minimum of about two per cent at the major resonance in the system. The lower part of the figure illustrates the characteristic which would be obtained by the motional impedance method. The plot shows the ratio of the real part of the input impedance to the resistance of the voice coil. When the ratio is greater than unity, there is either acoustic power output or other losses. It is apparent from this figure that in this particular unit, efficiency could only be increased by reducing the electric losses in the voice coil and that maximum efficiency is obtained at the mechanical resonance of the system.

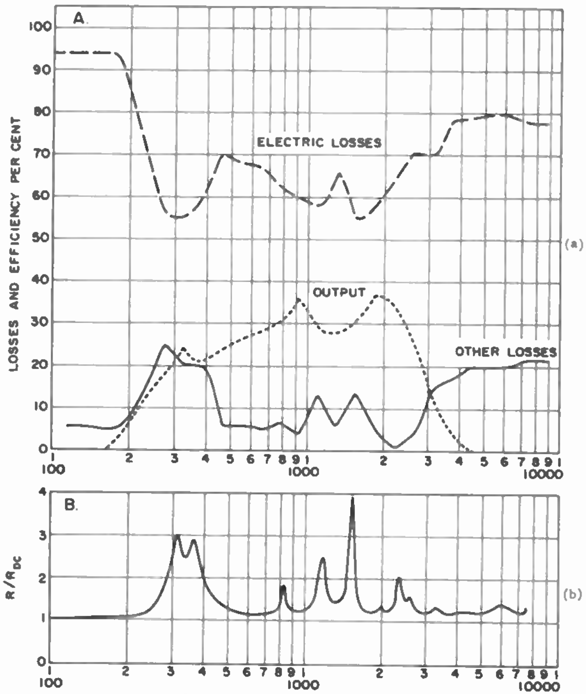

Fig. 4—(a) Loss and efficiency of LS 188 speaker. (b) Resistance of one LB 35 driver on LS 188 unit.

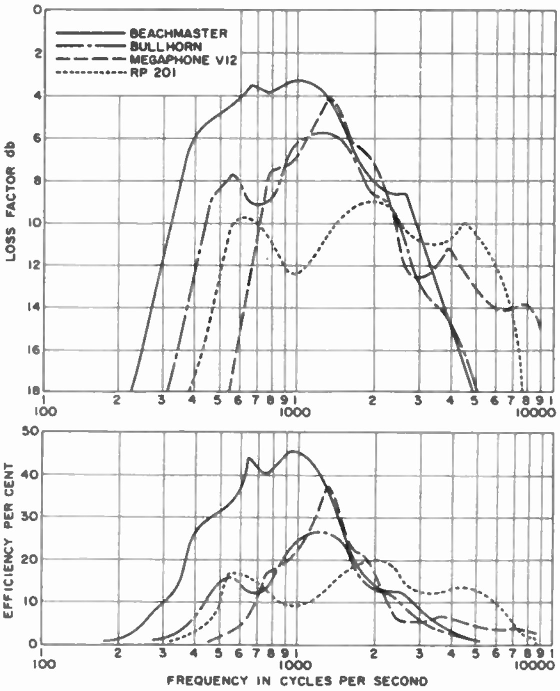

Fig. 5—Efficiency of several horn loudspeakers of widely-different power ratings (all made by Jensen).

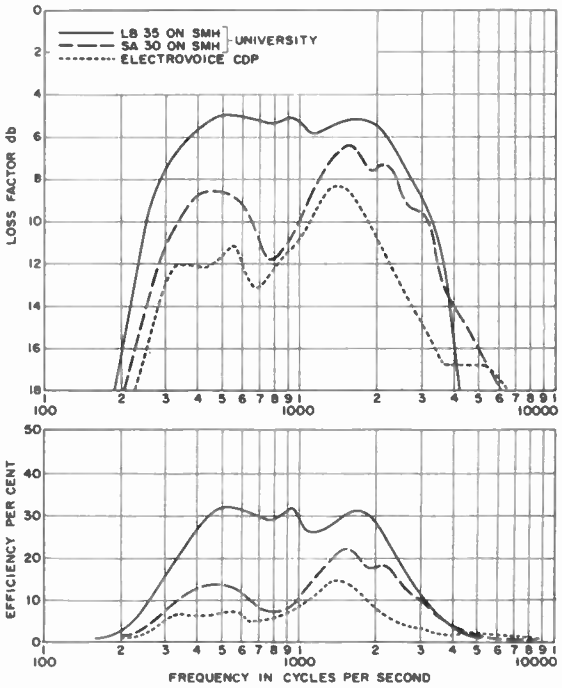

Fig. 6—Efficiency of three commercial 30 w PA system speakers.

Figs. 5 and 6 show a series of efficiencies obtained on seven different horn type loudspeakers. The maximum efficiency varies from 15 per cent to 45 per cent. Calculations of losses indicated that the major losses occurred in the voice coils. Mechanical losses account for part of the power at low and high frequencies, but have little effect in the medium frequency range. These statements apply only to the selection of horn type loudspeakers tested and direct radiator loudspeakers certainly would not be expected to have the same distribution of power and losses. It should be pointed out, however, that the accuracy of this method increases with lower efficiency units such as direct radiator loudspeakers.

Since most sound reinforcing systems are designed by calculating the relative power gain, it is advantageous to use the loss factor plotted in most of the graphs. The accuracy of the measurement then is independent of the loss factor since the measurement of sound level produced in the chamber and the current level is measured on a decibel scale. Sound pressure levels produced by a sound reinforcement system can be calculated if the sensitivity of the microphone, the power gain of the amplifying system, the loss factor of the loudspeaker, and the absorption of the room are known. If (5) is used, solving for L, the resulting level is that which will be produced in the remote parts of an auditorium where the sound level is the result of reflected acoustic energy. If the microphones are placed outside of the direct field of the loudspeakers, the maximum usable power gain may be calculated which will keep the system below feedback.

The use of the reverberation chamber method of measuring loudspeaker efficiencies has been shown to be a simple, useful technique. The resulting efficiencies are accurate on a decibel scale independent of the actual efficiency. Since the resulting information will be transformed to a decibel scale to determine sound pressure levels in an auditorium, the method is applicable to all loudspeakers. Furthermore, it is not necessary to have an extremely reverberant chamber as was used in these measurements. If the information can be used to predict levels in auditoria, then auditoria can be used to measure efficiency, providing measurements are made in the reverberant field. In any room for which the absorption can be determined as a function of frequency, and for which a sufficiently large volume of the room lies in the reverberant field, efficiency measures can be made. These conditions can be met by relatively large rooms of simple rectangular shape having no excessive acoustic treatment, except for the very low frequencies for which the dimensions of the room are comparable to the wavelength of sound. The use of bands of noise decreases standing wave patterns and allows the use of rooms over a wider frequency range.

POWER RATING

If one is to assess the relative merits of a loudspeaker on the basis of size and weight vs acoustical power output, it is necessary to know the power rating of the unit in addition to its efficiency. In some instances one would obtain as much acoustical power output with the same distortion for a loudspeaker rated at 25 watts as one would with a unit rated at 100 watts, both units operating at rated power. This is possible since the 25-watt unit may be four times as efficient as the 100-watt unit. In addition to this possible discrepancy, the rating of a unit at a given power level may be determined by either or both of two factors. The power rating may be an indication of the safe limit of continuous power input to the unit without failure or it may be the maximum input which produces less than a specified amount of distortion. If distortion is the criterion of acceptability to the user, the 100-watt unit may be able to dissipate more power electrically and yet produce as much distortion at 25 watts input as the 25-watt unit. Unless there is a common method of describing both ratings, that is, the level for a given distortion and the level for failure, the consumer is faced with the possibility of buying a larger unit which is only capable of absorbing more power.

It is extremely difficult to perform either test since harmonic or intermodulation distortion measurements must be performed by point by point analysis, and mechanical and electrical failure is only indicated by a destructive type test. In addition, the failure of a loudspeaker is usually dependent upon the type of signal that is applied, that is, whether it is pure tone, broad band noise, speech spectra, or modified noise spectra. Both methods are used to determine power ratings; however, distortion is usually the limiting factor in direct radiator-type loudspeakers, whereas mechanical or electrical failure is usually the limiting factor in horn-type loudspeakers. The problem of uniform specification of power handling capacity may be simplified by defining the spectrum which is to be used to determine the failure. The power rating must be a safe value for continuous use on speech or music, but not necessarily for pure tones over the entire audio range of frequencies. If the distortion is greater than a certain value, say one per cent, then the distortion should be given at rated power as a function of frequency. Most horn-type loudspeakers would be rated on the basis of failure, whereas the manufacturer would be allowed to rate his direct radiator speakers at a given distortion level if he so desires. The consumer would then be in a position to judge each unit on the basis of electroacoustic performance rather than comparing the electrical absorbing properties of the loudspeakers.

CONCLUSION

The user of loudspeakers is often faced with the problem of choosing a loudspeaker on the basis of electrical performance plus quality of reproduction as determined by a listening test. A measure of the efficiency and power handling capacity of a loudspeaker would aid the consumer in designing a sound reinforcing system and would allow a choice based upon merits of performance. The efficiency can be determined by the use of the reverberation chamber method in a relatively short time and with readily available equipment. Power ratings of loudspeakers should be uniformly determined and must include both measures of failure and distortion.

Bells, Electronic Carillons, and Chimes*

F. H. SLAYMAKER†

Summary—**Bells and chimes, unlike the more familiar string and wind instruments, produce tones in which the overtone structure cannot be expressed as a series of harmonics. The accuracy of tuning of the various overtones varies widely but the better cast bell carillons, electronic carillons, and tubular chimes do have very accurately tuned overtones. This paper describes the results of measurements on cast bells, electronic carillons, and tubular chimes. Data will be given on relative amplitude and decay rates of the various overtones. The reaction of "out-of-tuneness" will be discussed and explained. A new type of tone source for electronic carillons will be described. With this new tone source, a rod of carefully controlled rectangular cross section is used. This rod can give in a single unified structure essentially the same overtone array as that of an accurately tuned cast carillon bell.**

BACKGROUND

MOST PEOPLE will recognize the cup-shaped cast bronze bell as a bell when they see one, whether they are experts or laymen. Also they will recognize the polished brass tubes, such as used with pipe organs or in the percussion section of a symphony orchestra, as chimes. The so-called electronic carillon, however, is less familiar in its appearance although it is becoming more and more familiar as a sound. The most obvious external characteristic of an electronic carillon is the sound of bell-like tones coming from a set of loudspeakers in a church tower. In a little room tucked away in the church someplace there is likely to be a case containing a set of tuned rods. These rods, about an eighth of an inch in diameter and a foot or two in length are struck with little hammers. The vibrations of the rods are picked up with magnetic or electrostatic pickups, amplified, and radiated from loudspeakers. Once the sound is out in the air, however, the easy and certain choice of identifying names vanishes and the use of the words bell, chime, and carillon becomes confusingly intermixed. It might be presumed by most engineers and physicists that the actual tone can be described in quantitative terms as a fundamental and a series of harmonics; *i.e.*, a Fourier series. But even in the scientific analysis of the tone of a bell, chime, or electronic carillon, preconceived ideas about tone description must be forgotten. Fig. 1 shows the sound spectrum of the ideal cast carillon bell, the tubular chime, the simple minor-tuned clamped-end rod as used in electronic carillons and the more familiar harmonic series. More overtones, higher in frequency, are present than those shown in Fig. 1, but the higher overtones become less and less strong. The sequence of musical notes marking the position of each component in the complex sound spectrum of the bell, chime, and the clamped-end rod do not follow a Fourier series at all. By far the majority of electronic carillons made in this country have a tonal spectrum that can be expressed by the set of components given for the minor-tuned clamped-end rod or for the tubular chime. It is the attempt to identify the electronic carillon tone with the tone of a cast bell or tubular chime that causes so much confusion in the use of the words carillon, bell, and chime. To some people the tone is bell-like if it is deep and rich in contrast to the dainty etherealness of the tubular chime. To others, perhaps those who have heard poorly tuned bells, the word bell suggests something harsh and "clangy," while the word chime suggests something pleasant and sweet. The Guild of Carillonneurs defines a carillon, in part, as an instrument made up of twenty-three or more chromatically tuned cup-shaped bells, while an instrument having less than twenty-three bells would be called a chime. To other people it is the minor interval (the *E* flat in Fig. 1) that is characteristic of the true bell tone while the major interval (*E* natural in Fig. 1) is characteristic of chimes. And so it goes. For the purposes of this paper, a chime is a tubular chime; a bell is the cast campaniform bell; and a carillon is the traditional carillon as defined by the Guild of Carillonneurs. The electronic carillon is a new instrument, as yet undefined.

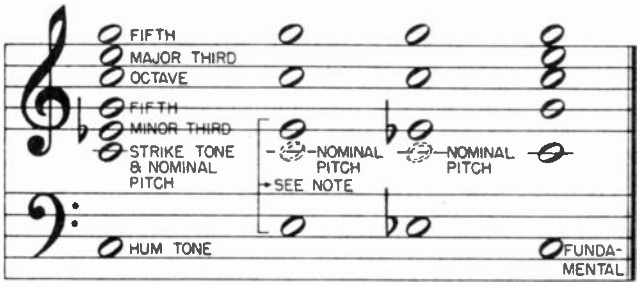

Fig. 1—Sound spectra of the ideal cast carillon bell tuned to middle "C"; the tubular chime tuned to a nominal middle "C"; the simple minor-tuned clamped-end rod tuned to a nominal middle "C"; and the harmonic series fundamental one octave below middle "C." (Note: Weak in the tubular chime.)

Sooner or later in any discussion of bells, chimes, and electronic carillons, the question comes up, "Why do they sound out of tune?"

The most obvious answer is that some of the instruments *are* out of tune. The better grades of bells, chimes, and electronic carillons, however, are so accurately in tune that the tuning discrepancies are too small to be noticeable. Even so, some notes do *sound* out of tune. Let us examine the spectrum in Fig. 1 to see what clues appear. All of the complex tones represented are supposed to sound like a *C* of some sort. Yet only in the harmonic series, such as approximated by a string or wind instrument, and in the spectrum for the cast carillon bell do we find the lower two components falling on a *C*. In the simple rod and the tubular chime the lower two components fall on some other note. From a look at the spectrum it is a little surprising that the rod and

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the tubular chime sound like *C* at all since we have two *E*'s or *E* flats and only one *C*. Also, no component is present physically at the nominal pitch; *i.e.*, there is no actual middle *C* present in the tone. I don't know a really good explanation for the apparent pitch but here are a couple of theories.

The *C* component an octave above middle *C* is likely to be the most prominent component in the entire spectrum. The pitch may sound an octave lower because the presence of the two lower frequency components influences the listener's judgment as to the octave. Another theory is that the *C* and *G* components, because they are separated by an amount equal to the frequency of middle *C*, combine in the ear to produce the impression of a pitch of middle *C*. Unfortunately the casual listener hasn't heard of these theories and he often hears an *E* or *E* flat or a *G* instead of a *C* and becomes very much confused. "Somebody sure hit a wrong note," he will say, or, "That thing sounds out of tune." The chances of such misunderstandings occurring with the string or cast bell tone are much more remote since in a space of two octaves there are three *C*'s, whereas for the rod and chime there is only one.

What can be done to alleviate the out-of-tuneness of the simple rod or chime? A compromise is necessary, a compromise between (a) a deep sounding tone in which the lower *E* or *E* flat components are very strong but which is likely to sound more like an *E* of some sort than a *C*, and (b) a thin light tone in which the lower *E*'s or *E* flats are suppressed to make the *C* more prominent. The light thin tone, of course, is suitable for use indoors with the support of an organ or a symphony orchestra but is not very appropriate for use in a bell tower. The outdoor tone needs the body and bigness.

The amplified vibration of the clamped-end rod are often compared to the cast bell tone because of the strength that it is possible to give to the lower components. The lower components in the tone of the tubular chime, however, are very weak. The tubular chime is too small physically to be a good acoustical radiator at the long wavelengths of the lower components. The tubular chime tone, then, is dainty and light but sounds better in tune than the deeper and more bell-like tone of the simple clamped-end rod.

Since tower music should sound rich and deep to be emotionally satisfying, how can one avoid the necessity of making a compromise between depth of tone and the impression of out-of-tuneness? To combine the feeling of bigness with accurate pitch, the lower two components in the tone must be *C*'s for a *C* bell. When this condition exists, it is possible to make the tone very deep, and still have the tune sound like *C*, by increasing the relative acoustical power in lower components. The lower components in the harmonic series, of course, meet this requirement as do the lower components in the spectrum of the ideal cast bell. The spectrum of the simple rod or the tubular chime does not fulfill this condition. A tone with a spectrum coinciding with the harmonic series, however, will sound like a harp, a banjo, or some string instrument rather than like a bell.

Although ideal for tower music, cast bells themselves are heavy, expensive, and unwieldy. The electronic carillon is much more feasible in this modern economy than the cast bell carillon, and it would be very desirable to have an electronic carillon in which the tone fulfilled the condition for both bigness of tone and accuracy of pitch. It would be possible, of course, to create tones synthetically by mixing the tones of several rods. With a careful selection of the rods a great variety of effects could be obtained. It is a problem to strike several rods at once, however, and maintain the effect of a single bell being struck. A single structure producing the desired spectrum as an inherent result of its shape would be an ideal tone source.

TECHNICAL SECTION

The final structure, surprisingly enough, turned out to be a rather simple one, even though it was the result of a rather lengthy research program. The answer is a rod of rectangular cross section in which the ratio of the sides is the same as the ratio of the frequencies in a minor third; *i.e.*, 1.2 to 1 in the just intonation, or 1.189 to 1 in the equally tempered scale. The allowed frequencies of a clamped-end bar are:[1]

$$f_n = \pi/2l^2\sqrt{Qk^2/p}B_n^2 \tag{1}$$

where

f = frequency, cycles per second

$n = 1, 2, 3, 4, \cdots$

l = length of bar in centimeters

Q = Young's modulus in dynes per square centimeter

p = density in grams per cubic centimeter

k = radius of gyration of the cross section in centimeters

$B_1 = 0.597$, $B_2 = 1.494$, $B_3 = 2.500$

$B_n = n - \frac{1}{2}$ for $n > 2$.

The ratio of successive allowed frequencies for a clamped-end rod are given in Table I. For a rectangle, the radius of gyration, about a center line perpendicular to h, the height of the rectangle, is $h/\sqrt{12}$.

TABLE I

RATIOS OF SUCCESSIVE ALLOWED FREQUENCIES FOR A CLAMPED-END ROD AND THE DEPARTURES FROM THE TUNING SHOWN IN FIG. 1

Allowed Frequencies for A Clamped-End Rod	Departure from the Spectrum of Fig. 1, Assuming f_5 is Tuned to *C*
(1) $f_1 =$ —	—
(2) $f_2 = 6.236\ f_1$	—
(3) $f_3 = 2.801\ f_2$	E^b+65 cents*
(4) $f_4 = 1.960\ f_3$	E^b+30 cents
(5) $f_5 = 1.653\ f_4$	*C* ± 0 cents
(6) $f_6 = 1.494\ f_5$	*G* − 5 cents

* A cent is 1/100 semi-tone, or the 1200th root of 2.

When the rectangle is turned through 90 degrees the other side becomes the "*h*" and a new value of the radius of gyration is obtained corresponding to a new set of

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[1] P. M. Morse, "Vibration and Sound," McGraw-Hill Book Company, Inc., New York, N. Y., 2nd ed., p. 158; 1948.

allowed frequencies of vibration. Striking the rod on the corner excites both sets of allowed frequencies.

The allowed frequencies of vibration for a simple clamped-end rod, however, do not fit very well into the musical scale as shown in Fig. 1. They come too close together (See Table I). If the *C* component in the rod spectrum of Fig. 1 is tuned accurately the *G* above will be flat and the *E* flat below will be sharp. The lowest *E* flat will be even sharper. If, on the other hand, we use a rod that is pivoted at one end[2] instead of being rigidly clamped, the allowed frequencies are too far apart. A flexible support consisting of a notch, or necked portion of the rod, at the clamped-end can be made to give the proper spread to the allowed frequencies. The components of the spectrum shown in Fig. 1 correspond to the third, fourth, fifth, and sixth allowed frequencies or normal modes of vibration. The first two allowed frequencies are so far apart that they are of little use and they usually are too low in frequency to be passed by the reproducing system.

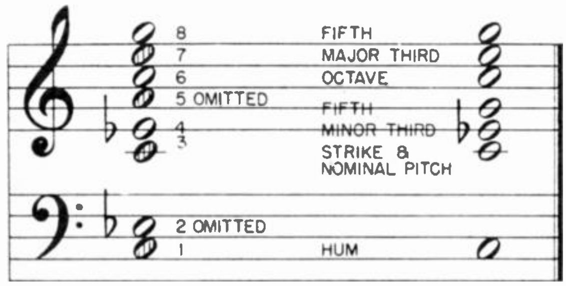

Fig. 2—The sound spectrum of the rectangular rod tuned to middle "C" compared with the spectrum of an ideal cast bell.

Fig. 2 shows two sets of components as obtained from the two directions of motion of a rectangular rod. The odd numbered set is obtained from the vibration of the rod perpendicular to its broad face and the even numbered set is obtained from the vibration perpendicular to the narrow face. Notice that the even numbered set corresponds exactly to the clamped rod spectrum in Fig. 1 for a tone that sounds like *C*. The odd numbered set, then, would sound like *A* if the *A* component (No. 5) were left in the reproduced tone. But the *A* can be removed by using two pickups as shown in Fig. 3. Pickup No. 2 is mounted opposite the broad face to pick up the odd numbered set of components. It is located at a point along the rod that is opposite a node for the normal mode corresponding to the *A* component. In the absence of the A component, there is no chance of the resulting tone sounding like both a *C* and an *A* sounding at once. The lower *E* flat in the even numbered set can be removed by suitable location of the pickup or by filtering it out of the electric circuit. The resultant tone contains a low *C* and one at middle *C* corresponding to the hum and strike tone of the bell, a minor third, an octave above the strike tone, a major third and a perfect fifth. Only one component is missing in the one to one correspondence between the components of a bell and the tone produced by the rectangular rod. It is the first perfect fifth. It is entirely a matter of coincidence that this particular component in a bell tone is weak and dies out rapidly,[3] so that the fact that it does not appear in tone of rectangular rod works out very well.

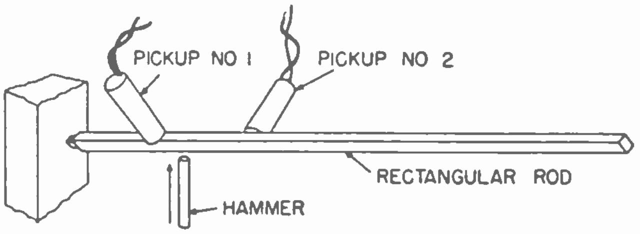

Fig. 3—Orientation of pickups and hammer used with rectangular rod.

As a preliminary to the research which resulted in this rectangular rod tone generator, we analyzed the tone of a large number of cast carillon bells.[3] Table II shows a comparison between the tuning of a well-tuned carillon bell and a well-tuned rectangular rod. The equally tempered scale is taken as the normal standard though in some instruments the overtone structure fits the just intonation better.

TABLE II

COMPARISON OF TUNING OF A WELL-TUNED RECTANGULAR ROD AND A WELL-TUNED CAST CARILLON BELL

	Rectangular Rod	Cast Carillon Bell
	Deviation from Equally-Tempered Scale	
Hum Tone	0 cents	+ 5 cents
Strike Tone	0 cents	0 cents
Minor Third	+ 2 cents	− 7 cents
Perfect Fifth	—	+18 cents
Octave	− 1 cent	− 1 cent
Major Third	+ 8 cents	− 8 cents
Perfect Fifth	+10 cents	−12 cents

The extremely high accuracy of the tuning of the octaves in the rectangular rod is due to a very great extent to extremely precise control of the cross sectional shape of the rectangular rod. The other components differ from the tempered scale frequencies by an amount so small that it is less than the difference between a third on the tempered scale and a third figured on the just intonation; *i.e.*, if the minor third were one derived from the harmonic series it would be about 16 cents sharp compared to the tempered scale, while a major third figured on the just intonation would be 14 cents flat compared to the tempered scale.

So, with a carefully designed rectangular rod as a tone source, an electronic carillon can be built in which the components in the tonal spectrum fulfill the requirements for accurate pitch and the production of a deep, rich, and satisfying bell tone.

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[2] L. Raleigh, "The Theory of Sound," Dover Publications, New York, N. Y., vol. 1, 2nd ed., p. 286; 1945.

[3] F. H. Slaymaker and W. F. Meeker, "Measurements of the tonal characteristics of carillon bells," *J. Acoust. Soc.*, vol. 26, pp. 515–522; July, 1954.

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H. H. Kajihara

H. H. Kajihara was born on March 12, 1928, in Shelton, Wash. He received the B.S. in electrical engineering from the University of California at Berkeley, Calif., in 1950. After graduation he worked for Shure Brothers Corp. until November, 1950 and since that time he has been associated with the Signal Corp Engineering Laboratory at Fort Monmouth, N. J. where he has specialized in the design of transformers and magnetic amplifiers.

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F. H. Slaymaker's photograph and biography appear on p. 3 of this issue.

Correction

Hiroshi Amemiya, author of the paper "Analyses of Drivers for Single-Ended Push-Pull Stage," which appeared on pages 162–167 of the September–October issue of Transactions of the PGA, has brought the following corrections to the attention of the editors.

1. Throughout the paper, the term E_{out} should read E_{OUT}.
2. Three lines below Eq. 2, the term V_{0i} should read V_{01}.
3. The denominator of Eq. 3 should be

$$(2A_0+\mu_1+2)R_L+(2A_0+1)R_{P1}.$$

4. In Eq. 8, the denominator should read

$$(A_0+1)\{R_{L2}+R_{P2}+(\mu_2+1)R_K\}R_{L1}-A_0(\mu_2+1)R_KR_{L2}.$$

5. The term $(A_0+1)R_K$ in the denominator of Eq. 8′ should be $(A_0+1)R_L$.
6. Three lines from the end of page 165, should read

   the grid voltage of V_2 is in the correct phase . . .

7. The term K_1 should be changed to K_I on page 166, five lines from the end, and on page 167, in the paragraph which begins

   At first sight it might seem that there are an infinite . . .

8. The second line of Eq. 12 should read

$$K_I=\frac{R_L + R_{P1} + (\mu_1 + 1)R_K}{\mu_1 R_1}.$$

9. The equal sign in the equation immediately preceding the Conclusion should be $\geqq$.

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