Transactions of the I·R·E

Professional Group on Audio

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

September-October, 1953

Published Bi-Monthly

Volume AU-1 **Number 5**

TABLE OF CONTENTS

The Institute of Radio Engineers

IRE PROFESSIONAL GROUP ON AUDIO

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

Annual Assessment: $2.00

TRANSACTIONS of the IRE®
Professional Group on Audio

Published by the Institute of Radio Engineers, Inc., for the Professional Group on Audio at 1 East 79th Street, New York 21, New York. Responsibility for the contents rests upon the authors, and not upon the Institute, the Group, or its members. Individual copies available for sale to IRE-PGA members at $0.50; to IRE members at $0.75; and to nonmembers at $1.50.

PHILADELPHIA CHAPTER CONDUCTS SYMPOSIUM ON AUDIO*

William G. Chaney
Bell Telephone Company of Pennsylvania
Philadelphia, Pennsylvania

With the Philadelphia Chapter of the P. G. A. struggling to gain a recognized place in local I. R. E. activities, the idea of a symposium seemed to be highly in order. First, it would stimulate interest in the Chapter and encourage membership. Second, it would bring prominent speakers to Philadelphia to present various phases of the subject in a cohesive fashion. There was ample proof that audio papers were in demand by the phenomenal attendance at scattered section meetings over the past few seasons.

It was found that the Communications Division of the New York Section A.I.E.E. was also planning to offer a series of six papers on audio. There seemed to be no reason why the two should not parallel each other and by working out a cooperative schedule it was possible to have three of the speakers present their papers in both places.

An offer of joint sponsorship was accepted by the Philadelphia Section of the A.I.E.E. This was done to promote better relations between the two organizations and to get the increased attendance from their support.

The Symposium on Audio consisted of six papers presented at the rate of one a month from November 1952 to April 1953. A list of the speakers and a brief resume of the talks will give an idea of the scope.

1. Mr. E. W. Kellogg, formerly RCA: "The History of Recorded Music from the 19th Century to the Present."

   Mr. Kellog, one of the pioneers in the loudspeaker and disc recording fields described the methods of disc recording as they developed to the present state. The paper was supplemented by demonstrations of antique recordings including several wax cylinders played back on machines of the same vintage. The reproducing equipment was borrowed from RCA's historical library.

2. Winston E. Kock, Director of Acoustics Research, Bell Telephone Laboratories: "The Physics of Music and Hearing."

   Dr. Kock discussed the physical concepts of hearing and also the loudness and frequency range for optimum listening enjoyment. The remainder of the talk dealt with electrical means of synthesizing orchestral instruments. A film, "Action Pictures of Sound," was shown.

3. Frank H. Slaymaker, Chief Engineer Sound Equipment Division, Stromberg-Carlson Company: "Performance Criteria of Loudspeakers."

   Mr. Slaymaker described some of the many ways available to determine the relative merits of loudspeakers. A large part of the talk was concerned with a discussion and demonstration of effects due to resonances in the loudspeaker system.

4. Emory Cook, President, Cook Laboratories: "Recording and Reproducing Techniques."

   Mr. Cook placed special emphasis on the subject of "binaural" recording both from the recording and play-back viewpoint. He demonstrated many of his binaural records and played a Livingston dual-track pickup.

5. Lowell H. Good, Supervisor, Advanced Development Section, RCA: "Audio Amplifiers."

   Mr. Good brought the series back to a more practical footing with a down-to-earth discussion of audio amplifiers. He demonstrated some of the commonly experienced faults such as peak clipping, poor transient response, intermodulation and overdriving.

6. H. H. Scott, President, Herman Hosmer Scott, Inc. — "Component Integration of Sound Systems."

   Mr. Scott concluded the series with a summation of the characteristics of all the integrated units in a versatile sound reproducing system. He discussed impedance matching, tone controls, operating levels and equalization.

Registration and attendance at the meetings lived up to the most optimistic expectations. A total of 267 persons registered for the entire series and the attendance for the six meetings was slightly greater than 1600.

Observations made during the progress of the Symposium may be of interest to other groups.

1. Papers presented once a month tend to lose continuity because of the long gap.
2. The papers must be technical enough to have the listener leave with the feeling that he has learned something useful.
3. Speakers should be selected for speaking ability as well as for technical knowledge.
4. Demonstrations are invaluable, both for illustrating points and relieving monotony in a two-hour lecture.
5. In determining attendance, publicity is of first importance, prominent speakers rank second, and convenience of hour and location third.

* Manuscript received July 29, 1953.

REPORT ON TAPESCRIPTS COMMITTEE PGA*

Andrew B. Jacobsen, Chairman
Tapescripts Committee, IRE-PGA

The activities of the Tapescript Committee had covered two years, starting out in a very modest manner with papers given at Conventions. The last year has been bolstered materially by specially prepared papers produced by General Electric and Bell Telephone Laboratories. Such papers provide excellent program material for those Sections and Chapters who find it difficult to obtain speakers to appear on their programs.

It has been found that only a small percentage of convention papers is satisfactory for this type of presentation, and even this small percentage would be better if specially recorded. It is not necessary that the tapescripts be an elaborate production; but it *is* essential that they be presented by the author, with a series of well-organized slides to accompany the author's talk. In general tapescripts should be along lines of fairly general interest. In rare cases a very specialized tapescript is justified, but it should be kept in mind that the material will be presented to student Chapters and small Sections, Professional Group Chapters, and industrial group meetings.

To date there have been three outstanding tapescripts – a convention paper by Peterson and Sinclair of General Radio, presented by Peterson; "Germanium – The Magic Metal," produced by General Electric; and "Fundamentals of Acoustics" by Kock of Bell Telephone Laboratories. "Germanium – The Magic Metal" is rather an elaborate production using 78 slides in color. W. H. Doherty of Bell Telephone Laboratories has produced a series of seven tapescripts. All of these tapescripts have had wide distribution, and it is hoped that other organizations will see fit to produce equally outstanding material for future distribution.

The technical aspects of tapescripts are really very simple. At present, the best standard seems to be 7½ inches per second, full track magnetic tape on 1200 foot reels. Slides for distribution should be 2" x 2". It has become apparent in the distribution of this material that one copy can be utilized only on the average of twice a month.

The PGA is appropriating funds to provide prepaid transportation to the organization using the tapescript, and the organization will be expected to return it by the cheapest method. The PGA is also undertaking the production of standardized copies of future tapescripts which may be forthcoming. An effort will be made to contact people in the electronics and radio industries to obtain outstanding tapescript material for distribution, and further efforts will also be made to acquaint groups with tapescript material as it becomes available.

*Manuscript received June 22, 1953.

PGA BRIEFS

An *Awards Committee* has been appointed by Marvin Camras, Chairman of IRE-PGA. The chairman of the Awards Committee is Mr. John K. Hilliard and members are Messrs. John A. Kessler, D. W. Martin, Arnold Peterson and Vincent Salmon.

Additional recent appointments to the IRE-PGA *Nominations Committee* include Messrs. Frank Lennert, Hugh Knowles and Leo L. Beranek.

The semi-annual meeting of the *IRE Professional Group on Audio* was scheduled for 2:00 P.M. Monday, September 28, 1953, in the Ruby Room of Hotel Sherman, Chicago, Illinois. The *National Electronics Conference* session on audio was scheduled for the morning of the same day at the same hotel. The date of these meetings is approximately the same as the intended date of this issue of TRANSACTIONS of the IRE-PGA. A full account of the meetings will be carried in the next issue.

A Symposium on Measurement of Sound System Performance was held at the *IRE Western Convention and Electronic Show,* held in San Francisco, August 19-21. The symposium was conducted by Dr. Vincent Salmon, vice-chairman of IRE-PGA. Material from the symposium is expected to appear soon in TRANSACTIONS of the IRE-PGA. An additional session on audio was conducted by Roy Long, Stanford Research Institute.

Welcome to the Houston Chapter of the IRE-PGA! The new chapter was officially approved at the July 7th meeting of the Executive Committee of the Institute. Houston is the twelfth chapter of IRE-PGA. Mr. L.A. Geddes has been elected chairman of the chapter for the coming year.

The Chicago Chapter IRE-PGA has the following new officers:

Chairman:	Philip B. Williams, Jensen Manufacturing Company
Vice-Chairman:	R. Lee Price, Magnecord, Inc.
Secretary:	Theodore S. Pryst, Shure Brothers, Inc.

The fourth annual national Noise Abatement Symposium will be held at Armour Research Foundation on October 23 and 24. Further information may be obtained from Mr. G. L. Bonvallet, Armour Research Foundation, Chicago, Illinois.

The Acoustical Society of America is conducting its fall meeting at Case Institute in Cleveland, October 15-17.

Dr. W. O. Muckenhirn has accepted the chairmanship of the PGA *Ways and Means Committee.*

The Department of Defense is holding a symposium on Magnetic Recording in Washington, D.C. on October 12 and 13, 1953. Attendance is restricted to those directly engaged in some phase of magnetic recording development or application. Information may be obtained from: Department of the Navy, Bureau of Ships (Attn: Code 565E), Washington 25, D.C.

RTMA SE–8 COMMITTEE ON HIGH FIDELITY SOUND SYSTEMS*

Frank H. Slaymaker
Stromberg-Carlson Company
Rochester, New York

The RTMA Engineering Department activities in the field of high fidelity audio equipment are being handled by a special committee (SE–8). This committee met for the first time on October 30, 1952 in New York City. It was formed in an effort to dispel some of the mysteries that have enveloped high fidelity sound, whether one regards it from the point of view of either a business or a hobby. In accordance with the general purposes of all RTMA committees, one of its aims is to encourage the use, by various manufacturers of high fidelity equipment, of comparable terms to describe and rate their equipment. A long range objective of the committee is to find some common basis for specifically defining the term *high fidelity* itself. An immediate and more readily obtained objective, however, is to set up industrial standards on the means used to interconnect tuners, amplifiers, tape recorders and record players, as well as to establish mutually acceptable standards on the output levels and gains required for the various types of equipment.

At present, the non-technical high fidelity fan is never sure whether he can connect a Brand "A" record player to Brand "B" preamplifier to Brand "C" power amplifier to Brand "D" loudspeaker, or whether it is possible to connect another type of tape recorder, television chassis, or radio tuner into his amplifier and have the system work. He is not even sure whether the connectors will mate properly.

The need for such a committee had been recognized for some time, and at the 1952 RTMA Fall Meeting held in Syracuse in October, the Sound Equipment Section laid the plans for its organization and secured as its chairman Mr. Frank H. Slaymaker, Chief Engineer of the Sound Equipment Division of Stromberg-Carlson Company. This committee was designated SE–8. A subcommittee (SE–8.1) to specialize in the investigation and potential standardization of sound levels and inter-unit connectors is under the direction of Chairman H. H. Scott. As part of a plan to establish a definite program of activities for SE–8, it was decided to determine the present state of the art in the matters of interconnectors and operating levels. Therefore, the subcommittee, SE–8.1, recently prepared and distributed throughout the high fidelity industry, a comprehensive questionnaire covering these and other items. This survey of the field will be used in establishing the work schedules of several other subcommittees which will be established soon to cover all phases of the work. Some of these other problems, noted by the Committee as requiring future action, are as follows:

1. The problem of how to rate the output characteristics of an amplifier is to be studied.
2. A task force is to be set up to investigate the problems associated with UL tests and listings.
3. The record playback characteristics are to be investigated, along with associated matters. A task force appointed by the chairman has made initial studies here.
4. Ratings applicable to amplifier with variable turnover frequencies is another problem for study.
5. The possibilities of securing the cooperation of other groups in the matters of definitions, and correlating the definitions already established, is being determined together with methods of measurement of the various quantities involved. The IRE, SMPTE, NARTB, AES, and the Motion Picture Research Council are being consulted here.
6. The standardization of certain physical dimensions in the sound equipment field would also seem to promote better interchangeability.

The committees are staffed by competent engineering representatives of recognized manufacturers of high fidelity amplifiers, tuners, tape recorders, loudspeakers and associated equipment. At the present time, the committee welcomes representatives of any other high fidelity manufacturers having pertinent engineering topics to discuss.

Additional information concerning future meeting dates and locations may be obtained from the RTMA Engineering Office.

*Manuscript received July 27, 1953.

TECHNICAL COMMITTEE WORK ON AUDIO-FREQUENCY MEASUREMENTS*

Arnold Peterson
General Radio Company
Cambridge, Massachusetts

Among the IRE Technical Committees, there are three which are directly concerned with audio problems. These committees are the following: Audio Techniques (#3), Electroacoustics (#6), and Sound Recording and Reproducing (#19). Some of the other committees, such as Circuits (#4) and Electron Devices (#7), are so broad in scope that their work is of interest to audio engineers as well as to all other radio engineers. One of these committees of broad scope, namely, Measurements and Instrumentation (#25), has a subcommittee, Audio-Frequency Measurements (#25.4), which is working on audio problems. This subcommittee was the most recently formed of any of the committees dealing with audio. As an initial step, therefore, it surveyed the existing technical committee work pertaining to its field of interest. Since this survey can be useful in bringing standardization work to the attention of audio engineers, this report summarizes the results of that survey.

The organizations and committees listed below are those working in the field of audio-frequency measurement or fields closely related to it. The current standards applying to the field of audio-frequency measurements which have been prepared by these committees are listed. When a standard includes a specification of an audio test procedure, it is also listed.

I. *Institute of Radio Engineers*

Committee 3. Audio Techniques.
53 IRE 4 S1 Volume Measurements of Electrical Speech and Program Waves (see ASA C16.5-1942)
Committee 6. Electroacoustics
Committee 19. Sound Recording and Reproducing
53 IRE 19 S1 Methods of Measurement of Noise.
Subcommittee 25.4 Audio-Frequency Measurements

II. *American Institute of Electrical Engineers*

Joint Subcommittee on Electronic Instruments.
Special Communications Application Electroacoustics Subcommittee.

III. *American Standards Association*

A. IRE sponsored standards.

1. C16.4 – 1942 Loudspeaker Testing.
2. C16.5 – 1942 Volume Measurements of Electrical Speech and Program Waves.

B. AIEE sponsored standards.

1. C39.1 – 1951 Electrical indicating instruments.

C. Acoustical Society of America sponsored standards.

1. Z24.1 – 1951 Acoustical Terminology.
2. Z24.2 – 1944 Noise Measurement.
3. Z24.3 – 1944 Sound Level Meters for Measurement of Noise and Other Sounds.
4. Z24.4 – 1949 Pressure Calibration of Laboratory Standard Pressure Microphones.
5. Z24.5 – 1951 Audiometers for General Diagnostic Purposes.
6. Z24.7 – 1950 Test Code for Apparatus Noise Measurement.
7. Z24.8 – 1949 Laboratory Standard Pressure Microphones.
8. Z24.9 – 1949 Coupler Calibration of Earphones.
9. Z24.10 – 1953 Octave-Band Filter Set for the Analysis of Noise and Other Sounds.
10. Z24.12 – 1953 Pure-Tone Audiometers for Screening Purposes.
11. Z24.14 – 1953 Measurements of Characteristics of Hearing Aids.

D. Society of Motion Picture and Television Engineers sponsored standards.

1. Z22.51 – 1946 Intermodulation Tests on Variable Density 16-Millimeter Sound Motion Picture Prints.
2. Z22.52 – 1946 Cross-Modulation Tests on Variable Area 16-Millimeter Sound Motion Picture Prints.

IV. *Radio-Television Manufacturers Association*

REC-124 Output Transformers for Radio Broadcast Receivers; February, 1949.
REC-125-A Phonograph Pickups; July, 1949.
REC-128 Standard Frequency Test Record; May, 1949.
REC-134 Magnetic Recorders; Conditions for Measurement and Definitions; August, 1949.
SE-101-A Amplifier for Sound Equipment; July, 1949.

*Manuscript received July 31, 1953.

SE-103	Speakers for Sound Equipment; April, 1949.
SE-104	Engineering Specifications for Amplifiers for Sound Equipment; May, 1949.
SE-105	Microphones for Sound Equipment, August, 1949.
SE-106-A	Sound Systems; December, 1951.
TR-105-B	Audio Facilities for Radio Broadcasting Systems; November, 1949.
TR-118	Cable Connectors for Audio Facilities for Radio Broadcasting; December, 1949.
TR-121	Audio Transformers for Radio Transmitters; January, 1951.
TR-122	Audio Reactors; January, 1951.
TR-130	Basic Requirements for Broadcast Microphone Cables; July, 1952.

V. National Association of Broadcasters

N.A.B.	Recording and Reproducing Standards for Mechanical, Magnetic and Optical Recording and Reproducing; April, 1949.
N.A.B.	Engineering Handbook; 4th Edition, 1949.

VI. Audio Engineering Society

POWER CAPACITY OF LOUDSPEAKERS*

Paul S. Veneklasen
Consultant in Acoustics
Los Angeles, California

SUMMARY – A method of determining the power capacity of a loudspeaker is submitted which is based upon the departure from linearity of acoustic output versus electrical input curves using octave bands of thermal noise. The method is being considered for inclusion in a new Standard which is being prepared by the Committee on Electroacoustics of the IRE, W. D. Goodale, Chairman. Comments of interested readers are solicited.

INTRODUCTION

The Electroacoustic Committee of the Institute of Radio Engineers is presently writing a new Standard for Loudspeaker Testing. One of the most elusive criteria for which the Committee would like to write a recommended measurement procedure is power handling capacity. The lack of a realistic standard for the determination of this quantity is a continual source of embarassment to specification writers. It is the function of this paper to report a method which has been used only to a limited extent, but which has shown promise as a simple and useful method for defining a realistic measure of the ability of a loudspeaker to reproduce any type of program material without objectionable distortion.

METHOD

The proposed method defines power handling capacity in terms of a power input spectrum and a sound pressure output spectrum which are related on the basis of a specified departure from linearity of output as a function of input. The results of such a test on a particular loudspeaker are shown in Fig. I.

The procedure is as follows:

Bands of thermal noise are used for input material. The frequency limits of the bands are defined by the proposed ASA Standard Z-24, 10/272 for Octave Band Filter Sets of July 23, 1951 which is in agreement with MIL-S-3151 of March 10, 1950 and the Aircraft Industries Association, Communication of Sept. 27, 1946. The "thermal" noise used in these tests has uniform energy per cycle and a peak factor of about 12 decibels which is the ratio of peak power to RMS power. These bands of noise are fed, preferably through a calibrated attenuator, to a power amplifier which must have adequate power capacity to deliver the necessary peak power to the loudspeaker without distortion. A calibrated microphone is placed at a convenient distance on the axis of the loudspeaker and the output of the microphone is observed on a calibrated voltmeter. The acoustic environment of the microphone is not important for this test, if only the power input spectrum is required.

For each band of noise a curve of sound pressure output versus electrical power input is plotted. These curves are shown on the left of Fig. 1 and they are linear within the usual operating range of a loudspeaker. When overload is approached the output does not increase linearly with the input, so that the curve bends over. At

* Manuscript received July 6, 1953.

any point the departure of the curve from linearity can be determined, and is used as a measure of acceptable distortion. The degree of departure which is used to define a limit for power capacity can be chosen arbitrarily. For the loudspeakers which the writer has tested, the point of one db departure from linearity conforms with a significant aural observation.

It is characteristic of distortion in general that the output energy occupies a wider spectrum than the input energy. Exactly this effect can readily be heard when an octave band of sound energy causes a loudspeaker to overload. The sound energy is heard to spread out into a much broader spectrum. In the case of loudspeakers which the writer has tested, this phenomenon occurs quite abruptly at an input level which corresponds to one decibel departure from linearity. This value has therefore been selected as a suggested standard.

The output-input curve is plotted for each band of noise as shown on the left in Fig. 1. For each band the point of one decibel departure is located. When using a calibrated attenuator it is usually not necessary to actually plot each curve to locate this point. From these points the two curves on the right of Fig. 1 can be plotted The curve labeled "Maximum Output Level" is found by simply projecting each point of one db departure over to its corresponding frequency band. The curve of "Maximum Input Level" is found by plotting the abscissa of each point from the linearity curves over its corresponding frequency band.

The resulting curves clearly indicate an all-important fact, namely that the power capacity of a given loudspeaker cannot in general be stated in terms of a single number. The power capacity is clearly dependent upon the frequency spectrum of the program material. For example, if one is given the octave-band analysis of a certain electrical program signal, this spectrum can be compared with the maximum input level spectrum to determine the region of the spectrum at which overload will first become apparent. It also becomes clear how a spectrum can be modified, for example, by equalizing a speech signal, to make the maximum effective use of the loudspeaker's capacity.

It should be recognized that the power limitation of a loudspeaker may be determined by other factors, such as voice-coil heating or structural damage. However, in general, for a well designed unit, such limits will be well above those defined by distortion.

The signal used for these tests has a 12 db peak factor, hence the instantaneous peak power capacity for the unit shown in Fig. 1 is 12 db higher than the figures on the curve. However it is well to recognize that the limit might occur at a different level if a sinusoidal signal, or a warble tone is used. It is believed that thermal noise is a particularly appropriate signal for the intended purpose because the peak factor is very similar to that of typical program material.

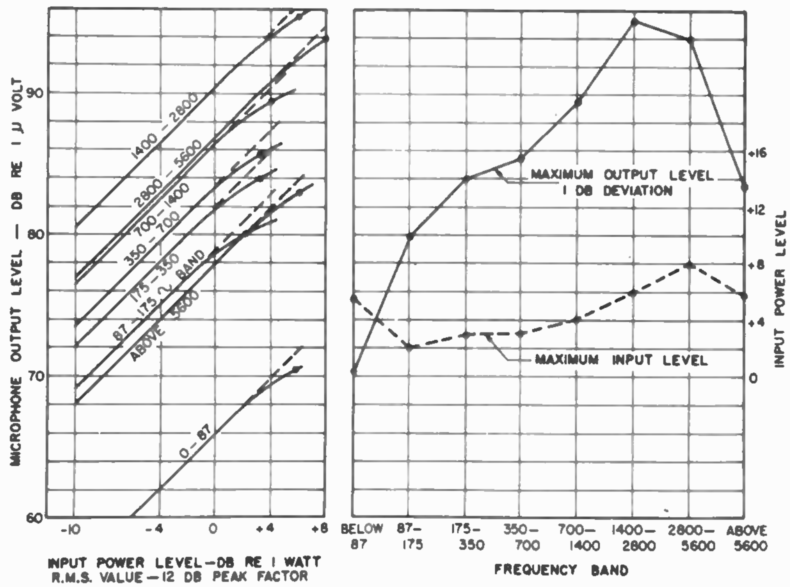

Fig. 1 – Determination of the power capacity of loudspeakers.

The method of determining power capacity which has been described has the advantage of giving a quantitative result from a relatively simple and rapid method, using input material which is similar to program material in peak factor. Limited experience with the method indicates that it correlates well with listening tests.

It is urged that all those who have a direct interest in Measurement Standards for Loudspeaker Performance consider and use this method, reporting their experience to the IRE Electroacoustic Committee, in the hope that a considered opinion may be derived as to its worthiness for inclusion in the forthcoming Standard.

SUBJECTIVE LOUDSPEAKER TESTING*

Harry F. Olson
RCA Laboratories
Princeton, New Jersey

INTRODUCTION

A subjective test of a loudspeaker involves a determination of some of the performance characteristics by direct listening to the loudspeaker operating under controlled program and environment conditions. Listening tests play an important part in research, development, and commercialization of loudspeakers. Listening tests range in scope from exceedingly simple comparison tests to elaborately controlled and conducted tests. In view of the importance of subjective testing of loudspeakers, it appears desirable to standardize the procedure. However, discussions with those familiar with establishment of standards indicate that the subject of loudspeaker listening tests has not been carried to the point where standards can be established. On the other hand, it seems timely and appropriate to outline some of the salient procedures used in listening tests of loudspeakers. Accordingly, it is the purpose of this paper to describe listening tests of loudspeakers.

LOUDSPEAKER ENVIRONMENT

The listening test of a loudspeaker should be conducted in the environment for which it was designed to operate. Specifically, a loudspeaker designed for home type radio receivers, phonographs, and television receivers should be tested in a room with dimensions and acoustics similar to those of the average living room in the home. A loudspeaker for an automobile radio receiver should be tested in an automobile. A loudspeaker for a sound motion picture system should be tested in a typical theater. A loudspeaker for a public address, sound reinforcing, or paging system should be tested under typical surroundings for these systems.

LOUDSPEAKER HOUSING, PLACEMENT AND MOUNTING

The horn, baffle, housing, or cabinet for loudspeaker listening tests should be similar to those used under actual operating conditions. The placement and mounting arrangement in the test environment should correspond to those used in actual installations.

SIGNAL SOUND LEVEL

The signal sound level produced by a loudspeaker in a listening test should correspond to the sound level under actual operating conditions in the field. The use of the proper level is very important in determining the balance of high, mid, and low frequencies, the distortion, the transient response, etc., under actual operating conditions. The upper sound levels in the description which follows do not necessarily represent the upper power capabilities of the systems. The signal sound level will be somewhere between 65 and 75 db for a radio receiver, phonograph, or television receiver operating in a typical or average living room. The signal sound level will be somewhere from 65 to 100 db for an automobile radio receiver. The signal sound level will be between 76 to 85 db for speech reproduction, and 75 to 95 db for music reproduction for a sound motion picture reproducing system operating in a theater. The signal sound level for a public address, sound reinforcing, or paging system will vary over wide limits depending upon the application. To summarize, the signal sound level of the test should correspond to the level under actual operating conditions.

AMBIENT NOISE SOUND LEVEL

The ambient noise under which the listening test is conducted should correspond to the ambient noise encountered under actual conditions. This involves two main factors, namely, the sound level and spectrum of the ambient noise. For example, the average ambient noise sound level in the average living room is 42 db. The average ambient noise sound level in a theater is also 42 db. In an automobile, the ambient noise sound level depends upon the speed, open or closed windows, the road, etc. In public address, sound reinforcing or paging applications, the noise sound level will vary over wide limits. This must be taken into account, and the noise conditions under which the equipment will be operated must be simulated in the listening tests. It is important that the spectrum of the noise encountered under the actual operating conditions should be simulated in the subjective tests as well as the noise level.

SIGNAL OR PROGRAM MATERIAL

The signal or program material used in listening tests should be similar to that encountered in the field. This is not so for the material presented under "Frequency Range" and "Power Handling Capacity." A radio or television receiver should be operated from typical broadcast or television transmitters. Under certain conditions it may be necessary to use the equivalent of a radio or television transmitter, as, for example, a modulated signal generator. A phonograph should be operated from

*Manuscript received July 22, 1953.

typical commercial records. A sound motion picture reproducing system should be operated from typical sound motion picture film. Sound reinforcing systems for use with music should be tested with musical program material. Public address and paging systems should be tested with speech as the program material.

REFERENCE SYSTEMS

Almost all listening tests on loudspeakers are conducted by comparing the loudspeaker under test with a reference loudspeaker. The reference system is, in general, a loudspeaker which is similar to the loudspeaker under test. The loudspeakers should be placed behind a light-opaque, sound-transparent curtain so that it is impossible to identify the loudspeakers by sight. A suitable indicator should show which loudspeaker is operating at any time. In general, the procedures in most listening tests are not formalized because the tests are conducted to determine the engineering and commercial aspects of rather small changes in design. If a jury type procedure is used, secret ballots should be taken of the preference. Statistical methods should be employed in planning and conducting such jury tests.

RELATIVE LOUDNESS EFFICIENCY

The relative loudness efficiency of a loudspeaker is determined from a loudness balance. High quality transformers should be used to match each loudspeaker to the appropriate impedance. In some cases it is desirable to include the driving means in determining the efficiency, because this is important in any practical design. The input to the loudspeakers should be adjusted so that the loudness levels of all loudspeakers are the same. The attenuation required to adjust to the same loudness gives a measure of the relative loudness efficiency. In these tests, the observers should move around to different locations to insure that no advantages are given to any loudspeaker due to a better listening location. For the same reason, the locations of the loudspeakers should also be interchanged.

RELATIVE DIRECTIVITY

The relative directivity of a loudspeaker is determined by listening at observation points removed from the axis. In order to reduce the effect of the difference in the angle during a comparison, the following precautions should be observed: Only two loudspeakers should be used at a time. The loudspeakers should be placed as close together as possible. The position of the two loudspeakers should be interchanged during the test. In determining the relative directivity, listening tests should be conducted along different angles with respect to the axis. This test indicates the loss in loudness level and frequency discrimination for observation points removed from the axis.

FREQUENCY RANGE

The approximate frequency ranges of loudspeakers may be determined from listening tests by employing program material which has a wider frequency range than the loudspeaker under test in combination with calibrated high and low pass filters introduced between the program source and the loudspeaker. It is very important that the program material contain adequate frequency components in both the high and low frequency ranges and thereby insure reliable results. The approximate frequency range can be determined by noting the settings of the filters for which there is no appreciable frequency discrimination, as determined by the quality of reproduction. The filters should have at least three cut-off steps per octave.

POWER HANDLING CAPACITY

The power handling capacity of a loudspeaker may be determined by employing a low distortion program source capable of overloading the loudspeaker without introducing distortion in the program source which is fed to the loudspeaker. The frequency range of the system which feeds the loudspeaker should be restricted by means of filters to correspond to that of the loudspeaker under test. The power level at which the distortion becomes intolerable may be considered to be the power handling capacity of the loudspeaker. In this connection intolerable distortion depends upon the application in which the loudspeaker is to be used. This requires a high order of judgment by the listener.

The test outlined above for determining the power handling capacity may appear to be oversimplified in view of the many factors involved. For example, the power handling capacity of a loudspeaker may be determined by failure of the diaphragm, the suspension system, the voice coil structure and heating of the voice coil. Of course, all these forms of failure will be manifested as intolerable distortion.

Again it should be emphasized that the crux of this test is the determination of what is considered intolerable distortion.

RESPONSE FREQUENCY CONTOUR

In most completely integrated systems, such as radio and television receivers and phonographs, there are distinct economic and technical advantages in employing components which individually do not exhibit a uniform response frequency characteristic but taken collectively do exhibit a uniform response frequency characteristic. In these applications, listening tests are very useful in checking the objective measurements for a proper balance of the frequency characteristic. This type of listening requires great skill obtained through practice. A reference system which is known to be acceptable is almost a necessity in tests of this type.

NON-LINEAR DISTORTION

Loudspeakers are used with other components in a sound reproducing system. Therefore, in a properly integrated system the limitations upon the allowable non-linear distortion of each element depends upon the allowable distortion of the system as a whole. For example, it would be technically and economically unsound to use a wide-range, high-quality loudspeaker in a reproducing system in which the components in the remainder of the system were of much lower quality. The quality of the loudspeaker required for the application can be determined from listening tests of loudspeakers of various degrees of quality. In this way it is possible to determine the loudspeaker which introduces distortion of such magnitude as to be perceptible above the distortion of the remainder of the system.

GENERAL ASPECTS

In most conventional, mass-produced, complete sound reproducing systems, technical compromises must be made in order to obtain a product which is commercial from economic considerations. The principal factors which are involved from a subjective standpoint are frequency range, response frequency contour, directivity, non-linear distortion, power handling capacity, and noise. For example, the objectionable effects of non-linear distortion and noise are reduced as the high frequency cut-off is reduced. On the other hand, some of the naturalness of a restricted frequency range system can be regained by a change of the response frequency contour. Listening tests are very useful for obtaining a practical compromise between these factors.

AIR-CORE COIL DESIGN FOR CROSSOVER NETWORKS *

Albert Meyer
The Baldwin Company
Cincinnati, Ohio

Much has been written on the several various crossover network circuits in general use, including equations for computing the values of the required elements. Insofar as the inductors are concerned, however, not much is said regarding how to achieve the desired value. Some information has been published by University Loudspeakers, Inc. The following investigation was made to determine the proper wire size and the optimum dimensions for an inductor to have a specified Q and inductance L. (Q in this analysis involves only the dc portion of the resistance.) An equivalent method for specifying the problem is, of course, in terms of inductance L and maximum allowable dc resistance.

A simplified equation for inductance of an air-core inductor is given by Wheeler.[1]

$$L = \frac{2 \times 10^{-7} A^2 n^2}{3A + 9B + 10C}$$

where L = inductance in henrys
n = number of turns
A = mean turn diameter, inches
B = winding width, inches
C = radial winding depth, inches

* Manuscript received August 17, 1953.

[1] H. A. Wheeler, "Simple inductance formulas for radio coils," *Proc. I.R.E.* vol. 16, p. 1398; October, 1928.

The number of turns for a random wound coil is

$$n = BC\phi$$

where ϕ = turns possible/square inch. This quantity is tabulated in Terman's *Radio Engineers' Handbook.* Thus, the general equation for inductance is

$$L = \frac{2 \times 10^{-7} A^2 B^2 C^2 \phi^2}{3A + 9B + 10C}$$

The dc resistance of the winding is

$$R = \left(\frac{\pi A}{12}\right) \left(BC\phi\right) \left(\frac{\rho}{1000}\right)$$

where ρ = ohms/1000 ft.

Based upon this dc resistance the coil Q is

$$Q = \frac{\omega L}{R} = \frac{2.4 \times 10^{-3} ABC\phi\omega}{\pi\rho(3A + 9B + 10C)}$$

For a frequency of 1000 cps

$$Q_{1kc} = \frac{4.8\, ABC}{(3A + 9B + 10C)} \; \frac{\phi}{\rho}$$

This function is to be maximized, with the three variables of dimension subject to the constraining equation of inductance. Before doing so, however, several simplifications may be made. The wire function $\frac{\phi}{\rho}$ is essentially monotonic (the values of ϕ are based upon average commercial practice) so there is no optimum wire size. Furthermore, much simplicity is gained by normalizing the dimensional variables.

$$Q\,lkc = \frac{4.8\,\phi}{270\,\rho}\;\frac{(3A)\;\;(9B)\;\;(10C)}{3A + 9B + 10C}$$

$$L = \frac{2 \times 10^{-7}\,\phi^2}{(270)^2}\;\frac{(3A)^2\;(9B)^2\;(10C)^2}{3A + 9B + 10C}$$

and upon putting

$$\alpha = 3A$$
$$\beta = 9B$$
$$\gamma = 10C$$

the equations may be expressed as

$$Q' = \frac{Q_{lkc}\,270\,\rho}{4.8\,\phi} = \frac{\alpha\beta\gamma}{\alpha+\beta+\gamma}$$

$$L' = \frac{(270)^2\,L}{2 + 10^{-7}\,\phi^2} = \frac{\alpha^2\;\beta^2\;\gamma^2}{\alpha+\beta+\gamma}$$

Now Q' is maximized, using the method of Lagrange for constrained maxima, by forming the partial derivative equations

$$Q'_\alpha - \lambda L'_\alpha = 0$$
$$Q'_\beta - \lambda L'_\beta = 0$$
$$Q'_\gamma - \lambda L'_\gamma = 0$$

where λ is the Lagrange multiplier.
For α there results

$$\frac{(\alpha+\beta+\gamma)\,\beta\gamma - \alpha\beta\gamma}{(\alpha+\beta+\gamma)^2} - \lambda\,\frac{(\alpha+\beta+\gamma)\,2\alpha\,\beta^2\gamma^2 - \alpha^2\beta^2\gamma^2}{(\alpha+\beta+\gamma)^2} = 0,$$

and since both

$$\alpha+\beta+\gamma \neq 0,$$

and

$$\beta\gamma \neq 0,$$

this simplifies to

$$\beta+\gamma - \lambda\alpha\,\beta\gamma(\alpha + 2\beta + 2\gamma) = 0$$

Because of the symmetry of the equations L' and Q' the other partial derivative equations are obtained *mutatis mutandis*.

$$\beta + \gamma - \lambda\alpha\beta\gamma\,(\alpha + 2\beta + 2\gamma) = 0$$
$$\alpha + \gamma - \lambda\alpha\beta\gamma\,(2\alpha + \beta + 2\gamma) = 0$$
$$\alpha + \beta - \lambda\alpha\beta\gamma\,(2\alpha + 2\beta + \gamma) = 0$$

The multiplier is readily obtained by addition

$$2\;(\alpha + \beta + \gamma) - \lambda\alpha\beta\gamma 5\;(\alpha + \beta + \gamma) = 0$$

$$\lambda = \frac{2}{5\,\alpha\beta\gamma}$$

so these equations simplify to

$$-2\alpha + \beta + \gamma = 0$$
$$\alpha - 2\beta + \gamma = 0$$
$$\alpha + \beta - 2\gamma = 0$$

from which it is found

$$\alpha = \beta = \gamma$$

and since

$$L' = \frac{\alpha^2\;\beta^2\;\gamma^2}{\alpha+\beta+\gamma} = \frac{\alpha^6}{3\alpha} = \frac{\alpha^5}{3}$$

so

$$\alpha = \beta = \gamma = \sqrt[5]{3L'}$$

$$3A = 9B = 10C = \sqrt[5]{\frac{(270)^2\;3L}{2 \times 10^{-7}\;\phi^2}}$$

$$Q' = \frac{\alpha\beta\gamma}{\alpha+\beta+\gamma} = \frac{\alpha^2}{3}$$

$$Q_{lkc} = \frac{4.8\,\phi\alpha^2}{270\,\rho\;3} = \frac{4.8\phi}{810\,\rho}\left(\frac{3\;(270)^2\;L}{2 \times 10^{-7}\;\phi^2}\right)^{2/5}$$

In the following equations, L is in millihenrys.

$$\delta = 3A = 9B = 10C = 64.23\;\left(\frac{L}{\phi^2}\right)^{1/5}$$

$$Q\max{}_{lkc} = 24.45\;\frac{\phi^{1/5}}{\rho}\;L^{2/5}$$

$$n = 45.84\;\phi^{1/5}\;L^{2/5}\ \text{turns}$$

$$l = 257\;\frac{L^{3/5}}{\phi^{1/5}}\quad \text{feet}$$

$$R = \frac{0.257\;L^{3/5}\;\rho}{\phi^{1/5}}\quad \text{ohms}$$

Since Q has been maximized for a given value of inductance and frequency, the winding resistance is therefore minimized, and the winding length is also minimum.

Fig. 1 is a plot of the dimension equation and the Q equation. Fig. 2 is a plot of the turns equation and the length equation. Fig. 3 is a plot of the resistance equation. In all three figures wire size is the parameter. The following examples illustrate the use of these curves, and the values are as read from them.

OPTIMIZED COIL DIMENSIONS FOR MAX. Q AND MAXIMUM Q AT 1KC

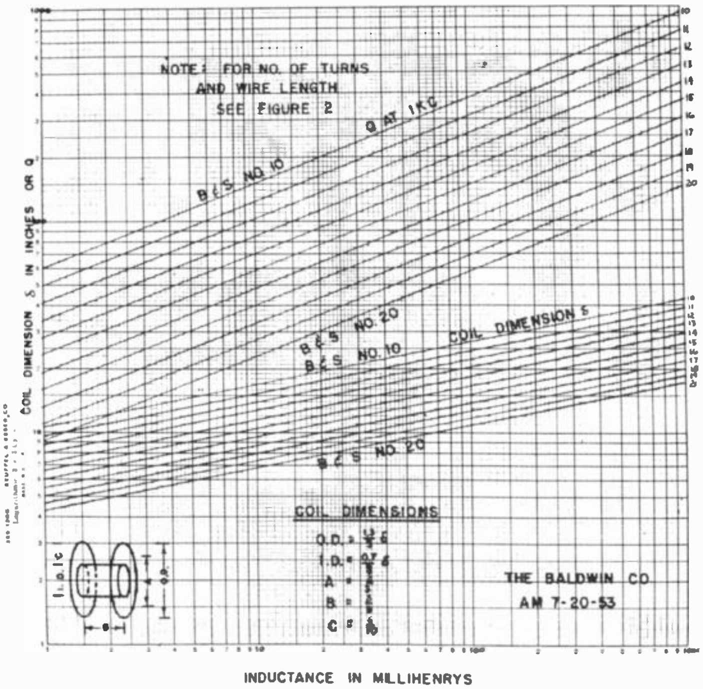

FIGURE 1

(*A*) A 30 mh inductor is to have a Q of at least 100 at 1 kc. From Fig. 1, B & S #14 (or larger) is required. Using #14, also from Fig. 1

δ = 15"
A = 5"
B = 1 2/3"
C = 1.5"

NO OF TURNS AND WIRE LENGTH FOR AIR CORE INDUCTORS HAVING OPTIMUM DIMENSIONS FOR MAXIMUM Q

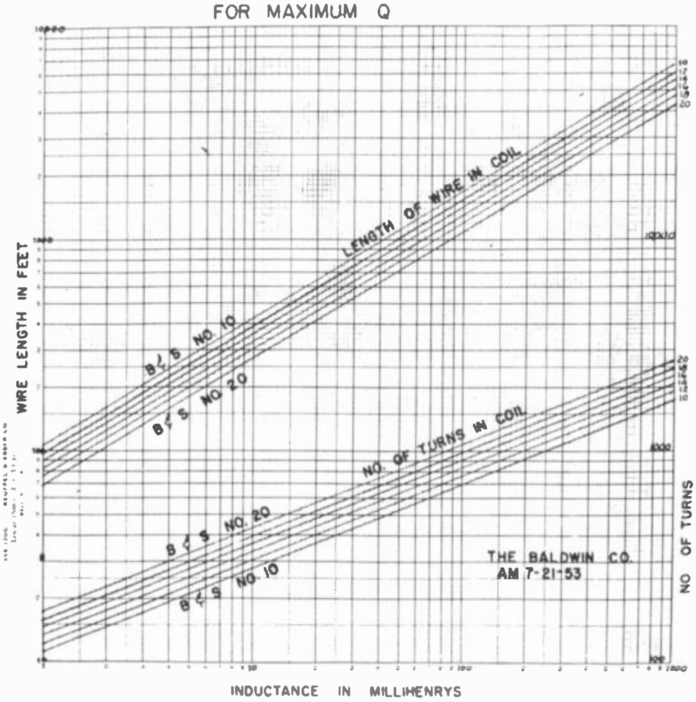

FIGURE 2

O.D. = 6.5"
I.D. = 3.5"
Q = 110

From Fig. 2

l = 680 ft.
n = 520 turns

and from Fig. 3

R = 1.7 Ω

(*B*) A 10 mh inductor is to have a dc resistance of less than 0.5 ohm.

From Fig. 3, B & S #10 will result in R = 0.42 ohm. From Fig. 2

l = 420 ft.
n = 280 turns

DC RESISTANCE OF AIR CORE INDUCTORS HAVING OPTIMUM DIMENSIONS FOR MAXIMUM Q

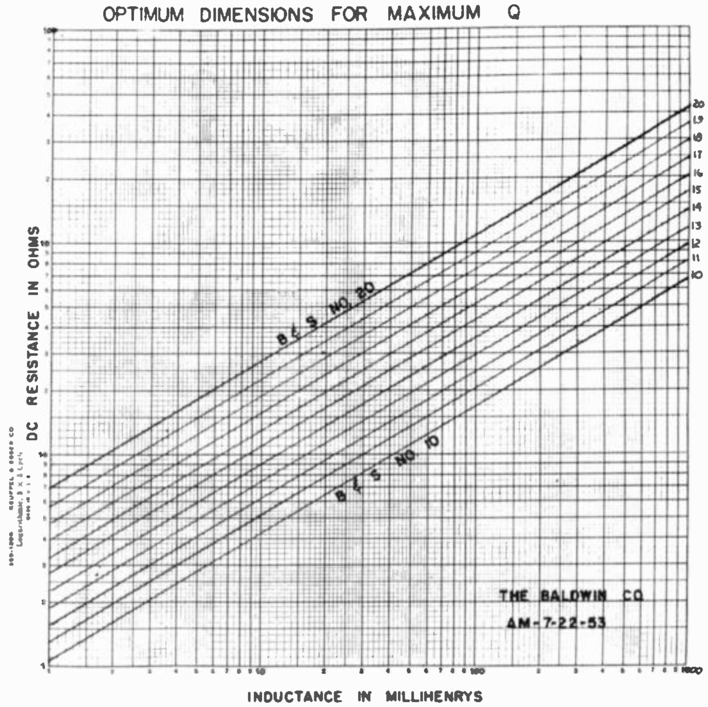

FIGURE 3

From Fig. 1

$$Q_{1kc} = 150$$
$$\delta = 17"$$
$$O.D. = \frac{1.3}{3} \times 17 = 7.37"$$
$$I.D. = \frac{0.7}{3} \times 17 = 3.97"$$
$$B = \frac{17}{9} = 1.89".$$

INSTITUTIONAL LISTINGS (Continued)

INSTITUTIONAL LISTINGS

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(Please see inside back cover for additional names)