# 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

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# The Institute of Radio Engineers

## IRE PROFESSIONAL GROUP ON AUDIO

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



### TRANSACTIONS of the I·R·E·®
### Professional Group on Audio


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# Editorial

CONSIDERATION of the scope of the items in the PGA Briefs section of this issue should prove impressive not only because of the diversity of organizational activity in the audio field, but because of the comprehensive publication effort to provide thousands of engineers and scientists, in various organizations both here and abroad, with the information required for advancement of audio engineering and technology.

TRANSACTIONS OF THE IRE PROFESSIONAL GROUP ON AUDIO is one of the important younger parts of the total technical publication effort in audio. Although the regular circulation is still limited to IRE-PGA membership (a condition likely to change in the near future), abstracts of TRANSACTIONS papers do appear elsewhere, and references to the papers in bibliographies are becoming more frequent all the time. Reprints can be ordered, and a number of the authors and the institutions they represent are taking advantage of this service. With the considerable help of the IRE editorial offices in New York, TRANSACTIONS OF THE IRE-PGA continues to improve in appearance. Thanks to the authors, the technical content of the papers is improving correspondingly.

Yet this record of IRE-PGA achievement is not enough. With the largest membership of any organization specifically devoted to the interests of audio, PGA should soon overcome any handicap imposed by its relative youth as an organization, within the framework of IRE.

This issue starts the third official volume of regularly scheduled IRE-PGA publication. The majority of the papers published so far have been written by people with considerable previous experience as technical authors. Yet quite a few papers of technical competence, even excellence, have been contributed by younger authors. The new awards system soon to be inaugurated will provide additional recognition and awards for outstanding authors in each of these categories.

Further progress of the IRE-PGA, and its TRANSACTIONS, depends in large measure upon individual technical contributions to audio technology, and the benefit given to others through professional willingness to share the knowledge through publication.

—D. W. MARTIN, *Editor*

# PGA News

## The Meeting of the IRE Professional Group on Audio Administrative Committee October 4, 1954

The Administrative Committee of the IRE-PGA met during the National Electronics Conference in Chicago. Owing to the absence of Chairman V. Salmon, who was unable to come to Chicago, the meeting was conducted by Vice-Chairman M. S. Corrington.

The Secretary-Treasurer reported that the bylaws change dealing with Section 11; i.e. the appointment of the Secretary-Treasurer, had been made effective by communication with the Executive Secretary of the IRE. The new bylaw reads as follows:

> "The Secretary-Treasurer shall be appointed by the Chairman of the Group with the approval of the Administrative Committee and may or may not be a member of the Administrative Committee. . . ."

The Secretary-Treasurer further reported that the constitutional amendment with regard to election of Chairman and Vice-Chairman has been approved by the Executive Committee and has now been prepared for letter ballot.

Chairman Troxel of the Chapters Committee reported that the project of inter-chapter news bulletin is now getting started. The approach is to work with Headquarters in getting chapter news, instead of trying to collect all of the information from the individual chapters or sections. Work will continue to the extent of getting the system set up during the 1954–1955 year. A suggestion from Mr. Corrington was made indicating that much of the above information would be available from the Chicago section secretary, since he generally receives section publications and bulletins.

Chairman Camras of the Nominating Committee presented a list of nominees who are to be contacted for acceptance of nomination for the Administrative Committee candidacy. The names of the candidates will be published as soon as a sufficient number has accepted the nomination. In the event of the approval of the new constitutional amendment by PGA membership, the Nominating Committee recommended including our Vice-Chairman, M. S. Corrington, as a candidate for Chairman in 1955–56.

Editor Martin reported for the record that there is considerable secretarial expense in connection with the office of Editor-in-Chief. If the organization with which he is connected did not support this activity, the secretarial aid would cost the PGA approximately $500 per year. The Administrative Committee has previously approved the principle of supporting budgeted secretarial assistance to the Editor in cases where institutional support cannot be obtained.

It was recommended to approve sales of PGA Transactions to institutions, and to public and private libraries. The price is to be established by the Executive Secretary of the IRE in cooperation with Editor Martin.

Ways and Means Committee Chairman Muckenhirn reported that 35 letters of solicitation were sent out regarding Institutional Listings, resulting in eleven renewals, two cancellations, and two new listings.

Awards Committee Chairman Hilliard is working on definitions and amounts of PGA Awards to authors of papers and other contributors to audio arts, and announcement of his plan will be available soon.

B. B. Bauer, Secretary-Treasurer
IRE-PGA

## "An Experimental Study in Stereophonics" in Cleveland

The Cleveland IRE-PGA chapter sponsored a Midwestern Regional meeting, Monday, November 29, 1954, at Radio Station WHK's 1300-seat Studio 1. The meeting consisted of an audience-reaction research program moderated by Dr. S. J. Begun, IRE Fellow, of the Clevite-Brush Development Company. The Cleveland Institute of Music graciously provided the services of their 60-member orchestra. Equipment for six high quality microphone-to-speaker audio channels was secured from a number of local parts distributors and national manufacturers.

The purpose of the meeting was to attempt to determine from an audience questionnaire the minimum number of audio channels required for the illusion of realism in a theater-sized auditorium. With the orchestra playing off-stage, the channel outputs were supplied to from one to six loudspeakers distributed across the front of the stage. At times during the experiment, the orchestra performed live for comparison purposes. A study of the hall and studio acoustics was made prior to the event to determine the best microphone types and loudspeaker placements, and to help in subsequent evaluation of the audience reaction in different locations of the theater.

The results of the experiment will be summarized for publication as soon as feasible. Other midwestern IRE sections and IRE-PGA chapters were well represented among the visitors. Stereo sound equipment was exhibited in the lobby. The interest by the general public was well demonstrated by the large turnout of guests.

Herbert H. Heller, Chairman
Midwest Regional Program, IRE-PGA

## PGA Briefs

The audio sessions of the National IRE Convention in New York City are being planned by Eastern Regional Program Chairman Michel Copel, appointed by Philip B. Williams, National Program Chairman of IRE-PGA. Mr. Copel's address is 156 Olive Street, Huntington, Long Island, New York, and he is engaged in audio engineering work at the Materials Laboratory, U. S. Naval Shipyard, Brooklyn, N. Y.

These sessions of the National Convention have been the high point of the audio year for IRE members during the several years since the Professional Group on Audio was formed. The advance program of the convention, which should be mailed to members by the time this issue of Transactions of the IRE-PGA is received, contains the details. Make plans to attend this program and also the annual meeting of the IRE-PGA membership.

The September 1954 issue of the *Journal of the Acoustical Society of America* is of particular interest to members of the PGA. This voluminous issue, commemorating the 25th anniversary of the Acoustical Society, contains a number of summary reports on various branches of the field of acoustics. Copies may be obtained from the American Institute of Physics, 57 East 55th Street, New York 22, N. Y.

At the November convention of the Acoustical Society, a new magazine, *Noise Control*, was introduced. Although this magazine will be of primary interest to industries, governmental agencies, and engineers faced with noise control problems, it will undoubtedly contain technical papers of interest to some of the membership of the IRE-PGA. The chairman of the committee inaugurating the new magazine was Dr. Leo L. Beranek, present president of the Acoustical Society, and past national chairman of the IRE-PGA. The editor of the new magazine will be Mr. Lewis Goodfriend, former editor of the *Journal of the Audio Engineering Society*.

1954–55 National Chairman of the IRE-PGA, Dr. Vincent Salmon, has agreed to assume the editorship of the *Journal of the AES*. A former associate editor of Transactions of the IRE-PGA, a patent reviewer for the *Journal of the ASA*, and author of a number of technical papers in the audio field, Dr. Salmon is well qualified for this new position.

*Acustica*, the European journal in the fields of acoustics and audio, devoted its large January 1954 issue to the republication of the entire program of the International Congress on Electroacoustics held in The Netherlands during the summer of 1953. Because of the large amount of technical information presented, many of the papers had to be condensed somewhat for publication, but they are very informative concerning worldwide activity in audio research and technology. The papers are published in English, French, or German. All major branches of audio were represented on the program.

The subject of hearing, which is at least of peripheral interest to anyone in the field of audio, is summarized from a recent research standpoint in an article entitled "Hearing," by Dr. James P. Egan, in volume 5, 1954, of the *Annual Review of Psychology*. Audio engineers having an acquaintance with the results of the fundamental research previously brought together in the book "Speech and Hearing in Communication" by Dr. Harvey Fletcher, formerly of Bell Laboratories, will appreciate this opportunity to stay abreast of the field of audiology. An extensive bibliography of current research literature is included. Dr. Egan is director of the Hearing and Communication Laboratory at Indiana University, Bloomington, Indiana.

The British Standards Institution, 2 Park Street, London, W.1, has recently published British Standard 2498:1954, entitled "Recommendations for Ascertaining & Expressing the Performance of Loudspeakers by Objective Measurements." The price of this twenty-page booklet is three shillings. Among the organizations cooperating in the preparation of the standard was the British Institution of Radio Engineers. The contents include definitions, conditions of measurement, and sections on frequency response, polar response, electrical impedance, nonlinear distortion, efficiency, power handling capacity, and transient response.

It is planned that at the National IRE Convention in March, the first awards by the IRE-PGA to authors of audio papers in IRE publications will be made. The purpose of these awards is to call attention to exceptionally meritorious papers and to encourage further improvement in both the quantity and quality of technical publication in audio.

## IRE Professional Group on Audio
## List of Chapter Chairmen*

| Chapter | Chairman |
|---|---|
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| Washington | Mr. Irving Levine (organizer)<br>Sound Section, NBS<br>Washington 25, D. C. |

* This list may not be entirely up to date. Any corrections or changes and chapter news should be sent immediately to Mr. Robert Troxel, IRE-PGA Chapters Committee Chairman, Shure Brothers Inc., 225 W. Huron St., Chicago 10, Illinois. Copies of all chapter news reports should also be sent to Mr. Albert Preisman, IRE-PGA Chapter News Editor, Capitol Radio Institute, Washington, D.C.

## CORRECTION

B. B. Bauer, author of the paper, "Equivalent Circuit Analysis of Mechano-Acoustic Structures," which appeared on pages 112–120 of the July–August, 1954 issue of Transactions of the I.R.E., PGA vol. Au-2, no. 4, has brought the following corrections to our attention.

Page 112, footnotes 1, 3 should be interchanged; page 114, Fig. 1, $M_A$ in three places should be $L_A$; page 120, col. 2, line 17, "purely" should be "passive."

# Equalization and Tone Controls on Phonograph Amplifiers*

F. H. SLAYMAKER†

*Summary*—**The necessity for equalization in phonograph amplifiers is explained, and numerous examples are given. The difference between the action of equalization controls and tone controls is explained. Examples are shown in terms of response curves for a particular amplifier.**

THE BASIC need for equalization in record playing equipment is so easy to understand that it usually seems necessary for a writer to confuse the issue with big words and cryptic symbols. RIAA, NAB, NARTB, AES, FFRR, ORTHO, FDS, rolloff, turnover, emphasis, de-emphasis, and many other frightening phrases are apparently a necessary part of any explanation of phonograph equalization.

Very simply, equalization is forced upon us by insurmountable laws of nature. To get the recorded signal a maximum distance above the record surface noise in the high-frequency range, and still not make the wiggles in the groove so sharp no stylus will follow them, or to keep the low-frequency signal above the turntable rumble, and still keep the wiggles from wandering over into the next groove, a frequency-weighting curve must be used. This weighting curve, known as the cutting characteristic, results in a cutting stylus velocity that increases more or less steadily as the frequency increases. Until the recent adoption of the RIAA (Record Industry Association of America) curve, recording companies had not agreed upon the exact shape of an ideal cutting characteristic. A recent tabulation showed about twenty different curves in use. A number of these curves, used either by different recording companies or by different technical organizations, are shown in Fig. 1 (page 6). Surprisingly enough all of them fall within approximately ±5 db of a straight line having a slope of 3 db per octave. Although ±5 db is a pretty tight tolerance for a loudspeaker it is rather loose for electrical equipment. Variations between two reproducing systems amounting to as much as 5 db are easily noticeable in a listening test involving direct switching between the two systems—especially if the differences exist over an extensive band of frequencies. If the records are to be played back in exactly the manner the record manufacturer intended, a playback characteristic should be used that is the exact counterpart of the cutting characteristic. This playback characteristic is also sometimes called "equalization."

* Manuscript received November 3, 1954.
† Stromberg-Carlson Company, Rochester, N. Y

## Equalization

A strict Hi-Fi fan would require a phono amplifier with some twenty steps on the selector switch to match each of the different cutting characteristics. Such a switch, however, would be unwieldy and excessively expensive. A much more flexible scheme is to separate the high- and low-frequency equalization controls. Such a separation allows the knob twiddler to obtain a much larger number of combinations than can be obtained from a single selector switch. Two switches, each with a finite number of steps, have been used in many instances to give the listener flexible control over both the high and low end of the equalization characteristic. There has been a recent tendency, however, to use two continuously variable potentiometers to control the equalization. With continuously variable equalizing controls, the intermediate settings between the points on the step equalization can also be obtained. Fig. 2 (page 7) shows an amplifier using continuously variable phonograph equalization.

The recently adopted standard characteristic (the RIAA curve) is given the prominent center position on the two left-hand knobs. The neophyte should set the equalization controls in this position and leave them alone. The center position is somewhat like the fixed-focus position on a box camera. Better results can be obtained if the focus is set correctly, but the beginner is better off if he doesn't attempt to handle too many adjustments at first.

The left hand control of the amplifier shown in Fig. 2 controls the "turnover frequency" of the playback characteristic. Below the turnover frequency the original recording was made so that a constant amplitude of input signal produced a constant amplitude of motion of the recording stylus. Above the turnover frequency, in the absence of any added high-frequency boost, a constant amplitude of input signal produces a constant velocity of the recording stylus.

Exactly at the turnover frequency the conditions change gradually from constant-amplitude to constant-velocity recording. (See Fig. 3, page 7.) Constant-amplitude recording works out very well in the low-frequency region, but at high frequencies the signal-to-noise ratio is not good if a strict constant velocity recording is maintained (i.e., "flat" in a graph similar to Fig. 3). High boost or pre-emphasis is added to the recording to improve the high-frequency signal-to-noise ratio. Instead of giving another turnover frequency to specify the amount of high boost or pre-emphasis, it is custom-

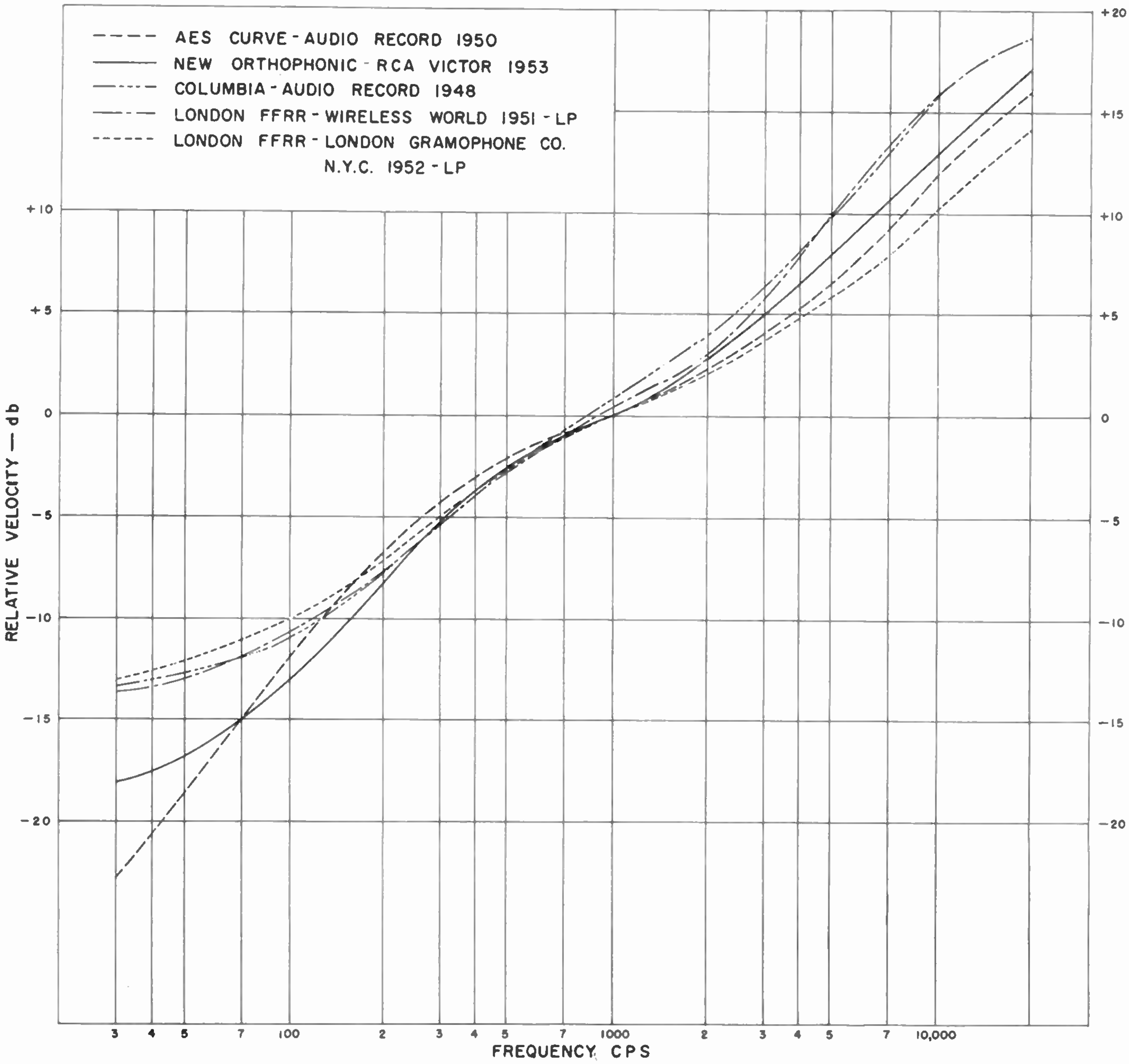


Fig. 1—Some cutting characteristics in common use (note expanded vertical scale).

ary to specify the amount of pre-emphasis used in recording at 10,000 cps or, conversely, the amount of de-emphasis necessary in the playback characteristic. The second knob from the left in Fig. 2 controls the amount of de-emphasis in the playback curve.

One more variation in the cutting characteristics is the inclusion of bass boost above the constant amplitude line to reduce the effect of mechanical rumble present in some cutting turntables and record players. The bass boost added in the recording can, if desired, be compensated by turning the bass tone control to give a small amount of bass attenuation. (See Table I.) Many listeners tend to use some bass boost anyway, so the inclusion of bass boost in the recording characteristic merely gives the listener less cause to use his bass-boost control.

TABLE I

RECOMMENDED RECORD EQUALIZATION CHART

| Curve | Turnover | De-emphasis |
|---|---|---|
| *RIAA | 500 cps | 13.7 db |
| AES (old) | 400 cps | 12.5 db |
| NAB | 500 cps | 16 db |
| LP (Col.) | 500† cps | 16 db |
| FFRR 33⅓ (original) | 500† cps | 16 db |
| FFRR 33⅓ (later) | 500† cps | 10.5 db |
| FFRR 78 | 300 cps | 5 db |

* Also new AES, NARTB, ORTHO.

† Since this recording curve has bass boost to minimize rumble, flat response is obtained with bass control at $-\frac{1}{2}$ setting.


Fig. 2—The AR-420 amplifier, using continuously variable equalization.

The cumulative effects of turnover, pre-emphasis, and bass boost overlap so much that the shape of the curve does not really indicate the individual factors producing it. The treble boost above constant-velocity high response begins before the shift from constant amplitude to constant velocity is complete. Also, the bass boost in recording is likely to begin before the bass response actually becomes constant amplitude. It is usually necessary therefore, to rely upon data published by the amplifier manufacturers to give the control settings appropriate for the various playback curves in use, rather than to attempt to deduce the turnover and de-emphasis from the cutting characteristic curve.

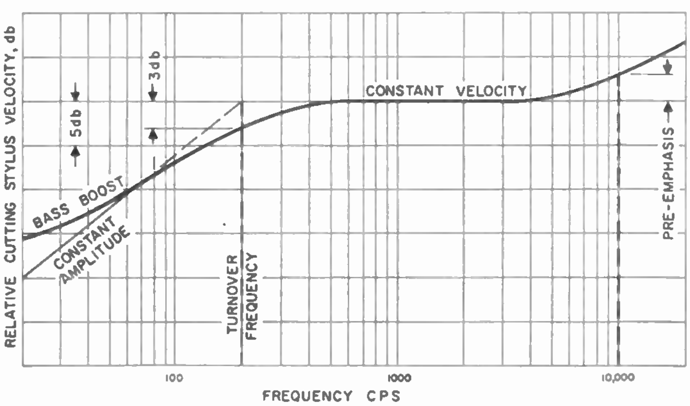


Fig. 3—Sample cutting characteristic, showing turnover frequency, pre-emphasis, and bass boost.

## Flat vs Altered Response

Considerable effort is expended in the design of microphones, amplifiers, and loudspeakers to make their response practically independent of frequency throughout the entire audible range. In other words, they are intended to be flat, and an over-all system that shows flat response should, according to one school of thought, give "concert hall realism." If this is true, why do high-fidelity amplifiers all have tone controls to alter the response of the amplifier? Let us follow the successive steps in the transmission of music from the studio to the home and find out why. Studio acoustics differ, of course. Some may sound brighter and harsher while some may be either dead or somewhat boomy. Microphones are not perfectly flat and variations of 3 or 4 db are quite common even in good studio microphones. Moreover, in some instances the high overtones of certain instruments can be intentionally accentuated to give the effect of "presence," by pointing a microphone that is directional at high frequencies at these instruments. The sound engineers listen to the orchestra over a monitoring system while they are broadcasting, or making a recording, and the frequency response of monitoring loudspeakers varies even more than that of microphones. If the over-all effect is not what the particular recording company or broadcast station wants, the orchestra is rearranged, microphones are relocated and tone controls are changed until the effect is satisfactory on the monitoring system. If the over-all monitoring system is not flat the modifications in the studio setup tend to compensate for deficiencies in the monitoring system. Also, tastes do not always agree, and it is quite possible that the sound engineer and the ultimate listener may have different tastes. All these factors can result in a recording that may differ from the ideal in the listener's mind. Tone controls are included to give the listener the ability to compensate for differences in room acoustics, loudspeakers, and personal taste.

## Tone Controls

Why are equalization controls necessary when there are tone controls on the amplifier, and why not use the tone controls to obtain the equalization? To a limited extent it should be possible to use the bass-boost position of the bass-boost control to give the turnover equalization, and the high attenuation positions of the treble tone control to obtain the de-emphasis. Once tone controls are used as equalizers, they lose some of their effectiveness as tone controls. Also, resultant equalization curves are likely not to have exactly the right shape.

Fig. 4 and Fig. 5 (page 8) show shapes of tone control and equalization response curves of the amplifier illustrated. In general, the tone controls have more effect on the response at the extreme ends of the frequency spectrum, while the equalization controls might be thought of as additional tone controls that raise or lower the entire low or high range uniformly. When used as tone controls the equalization controls are, in effect, musical balance controls. When the equalization controls are turned away from their normal setting for a given recording, the resulting over-all frequency response is the difference between two successive equalization curves. The shape of the over-all curve then is flat, when the two successive equalization curves are parallel and shows a gradual "step" when they change with respect to each other.

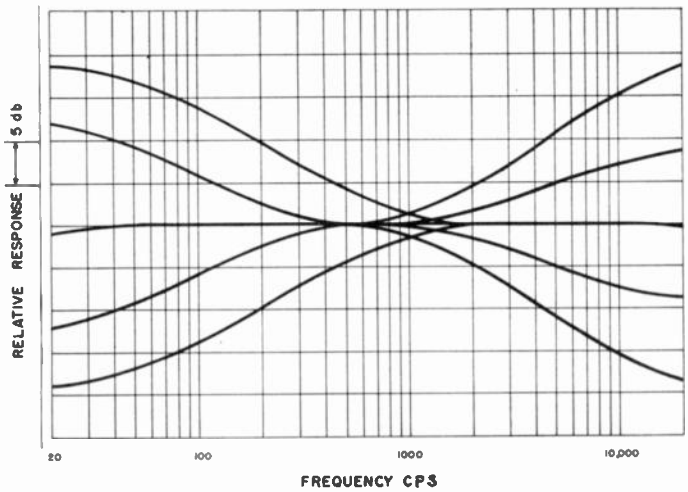


Fig. 4—Frequency response of tone controls.

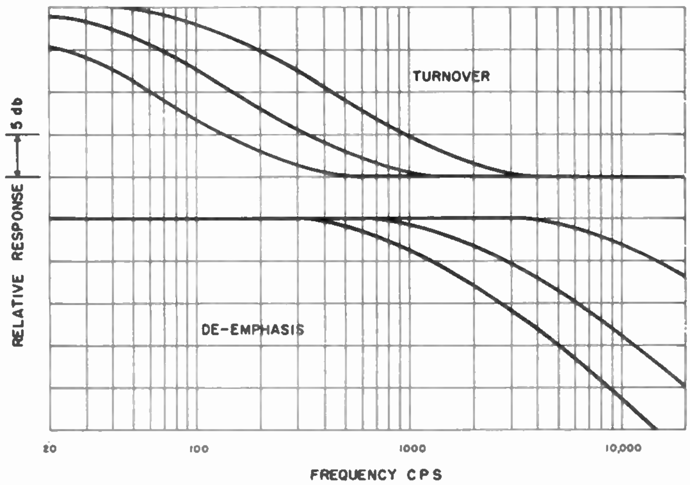


Fig. 5—Frequency response of turnover and de-emphasis controls used to give record equalization.

Changing the turnover control from the setting called for on a particular recording serves to raise or lower the entire low-frequency region, as shown in Fig. 6. Using too high a turnover frequency raises the low-frequency level, while using too low a turnover frequency lowers the low-frequency level. The de-emphasis control has a similar effect on the high-frequency region, as shown in Fig. 7. Too much de-emphasis lowers the amplitude of the high region, but once the slope of the required de-emphasis curve and the actual one used become parallel, no further reduction of high response is obtained as the frequency is increased. Just the opposite takes place if too little de-emphasis is used.

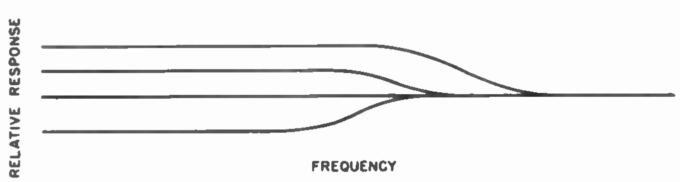


Fig. 6—Action of turnover control when turned away from the correct equalization position.

The emotional effect of conventional tone controls is considerably different from that of the equalization controls. The action of the treble tone control shows up first in the noise region and in the region of the higher overtones rather than in the musical balance. The extremely high-frequency record noise or tape hiss is either accentuated or reduced as the treble is boosted or cut. Treble boost sharpens the tone so that brass instruments sound "brassier," for example while treble cut tends to take the edge off of the tone and makes the instruments sound smooth or dull. In the human voice it is the sibilant and fricative sounds, such as "s," "p," "t," "th," etc., that are affected most by the treble tone control. To make the violins louder than the cellos is difficult for a conventional treble control without exaggerating the noise or higher overtones.

Since the bass tone control affects the extremely low frequencies more than the middle frequencies, the bass tone control is most useful in increasing or decreasing the sound of organ pedal tones, deep tones on the string bass, very heavy drums, and also turntable rumble. If a recording sounds thin or lacking in body the bass tone control may exaggerate deep tones and rumble to an unbearable degree before thinness is alleviated.

When the musical balance of the recording does not satisfy the listener, or if a record sounds muddy, thin, or shrill, the equalization controls can be changed from the nominally correct setting and the balance of the record changed completely. A record that sounds un-

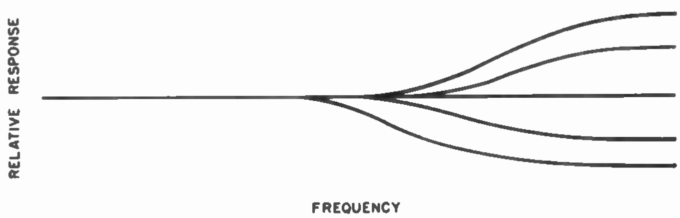


Fig. 7—Action of de-emphasis control when turned away from the correct equalization position.

pleasantly shrill or strident can be made to sound more rich by using more than the normal amount of de-emphasis. By so doing the extremely high overtones that give the characteristic color to the instruments would be retained. By using the de-emphasis control the violins can be made louder than the cellos without exaggerating the noise very much, or they can be made softer without losing the richness of the string harmonics. A thin-sounding record can be made to sound fuller by using a higher than normal turnover frequency, or a muddy-sounding one can be made much more clear by using a lower turnover frequency.

Thus, by using the equalization controls as tone controls in addition to the conventional tone controls, widely differing effects can be obtained. The conventional tone controls affect the extreme bass or the high overtones, sibilants, and noises, while the equalization controls affect the musical balance.

# The Manufacture of High-Fidelity Magnetic Tape Records*

R. C. MOYER†

*Summary*—**The equipment used in the manufacture of magnetic tape records by RCA is described. The choice of tape speed, track width, and pre-emphasis used is explained, and the desirability of standardization on these possible variables is emphasized.**

## Introduction

During June of 1954 the RCA Victor Record Division released the first series of recorded magnetic tape records to be offered by a major record company. This release included eight Red Seal classical, four Bluebird classical, and four special Popular tapes. All records are of the two-track, 7½ inch-per-second type which may provide up to an hour of music. These were followed in September by a two-channel stereophonic recording, also at 7½ inches per second. The recordings were intended particularly for playback on professional type equipment where, with proper reproduce equalization, a flat response from 30 to 15,000 cycles may be obtained.

This tape release is the culmination of work started several years ago in the Record Division Engineering Laboratory. Most of the technical problems and the development of suitable duplicating equipment were completed some time ago. However, it was decided not to release tape records then because of the apparently limited public interest and the small number of satisfactory tape reproducers on the market. The decision to offer tape records now was based on a growing popular interest in magnetic recording and an apparent demand for high-quality tape records, particularly on the part of the high-fidelity enthusiasts and the audio hobbyists.

## Duplicator Equipment

Our development program included the design and construction of a tape duplicator capable of production operation, as well as studies of tape characteristics and recording techniques. After careful consideration of various possible methods of duplicating tapes, it was decided to start with a common capstan machine capable of making ten copies simultaneously. We picked the common capstan design because of the theoretical advantage that average capstan speed is not critical and that a certain amount of capstan wow will tend to cancel out.

Because the finished tapes are recorded with the tracks going in opposite directions, we decided to record both tracks simultaneously with the No. 1 track recording backward. In this way, the finished tape is ready for playing without rewind.

The original design called for two master drawers operating at 30 inches per second and ten copy drawers operating at 7½ inches per second. The machine was later modified for double speed duplication using one double-track, 15 inch-per-second master running at 30 inches per second with the copy drawers running at 15 inches per second. Special amplifiers were built to give the correct response to above 30 kc so that no fidelity would be lost due to the higher recording speed.

With this system operating at full capacity, it takes fifteen minutes to make ten tapes of one hour playing time. This gives us a multiplication factor of forty to one in playing time. In production, however, this rate cannot be maintained because of the loading and unloading time on the machine.

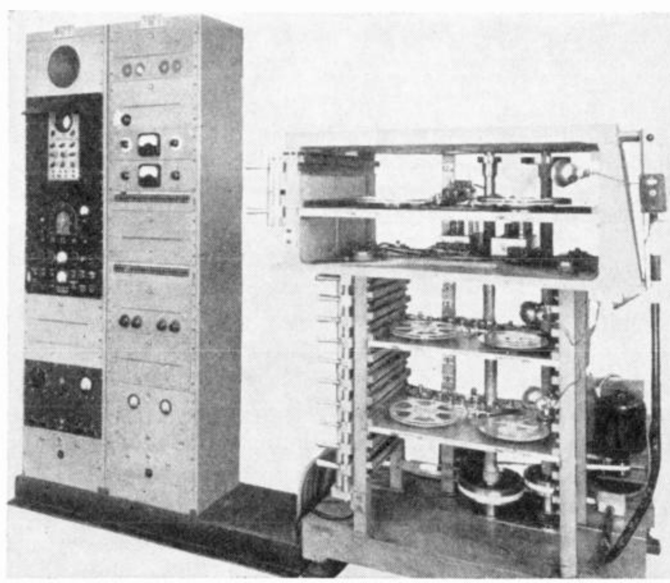

Fig. 1—Common capstan tape duplicator.

Fig. 1 shows the duplicator as it has been used for the production of most of our recorded tapes to date. The master drawer at the top and two copy drawers below are clearly visible. The three vertical members in the rear of the machine are, from left to right: the post for supporting head brackets, the tape drive capstan, and the take-up drive capstan. Each capstan is belt driven by its own 220-volt, 3-phase, ¼-horse-power synchronous motor. Preamplifiers for the two channels are located directly below the master drawer. Cathode-follower out-

* Manuscript received November 10, 1954. Presented at the Philadelphia IRE-PGA meeting, October 28, 1954.
† RCA Victor Division, Indianapolis, Ind.

puts feed the recording amplifiers located in the amplifier rack to the left. In addition to some test equipment, the rack also contains the record bias oscillator, dc heater supply, B supply, and a playback monitor system. The cables from the amplifier rack go through a distribution panel on the left side of the duplicator. This panel contains individual controls for bias and signal current in each record head. Jacks are also provided to plug in an external meter for checking these currents.

The head assembly for the master drawer includes three playback heads so spaced that stereophonic tapes can also be made simply by selecting the proper head combinations. Each copy drawer has two record and two playback heads; the latter for monitoring and routine checking of frequency response and flutter. Experience has shown, however, that monitoring is of little value, since the music is playing at double speed and one track is also playing backward.

## Flutter

One of the thoughts behind the building of a common capstan type duplicator was the theoretical advantage that capstan speed variation is automatically cancelled out. In practice this turned out to be only partially true. Good isolation from supply and take-up reels and good stabilizer operation are essential and, with good stabilizers, moderate capstan wow is generally eliminated. With the present system, the peak flutter from master tape to 7½-inch copy measured approximately 0.2 per cent which is probably something less than 0.14 per cent RMS.

## Specifications

### *Track Placement*

A proposed RETMA standard for track placement on dual-track tapes states that the track in use shall be the track at the right, when the coated surface of the tape is in view and moving away from the observer. To the best of our knowledge, all manufacturers of tape recorders have followed this proposal on dual-track equipment. This has made it possible to release dual-track tapes which will play on most machines now on the market or in the hands of consumers. Fig. 2 shows this track placement and spacing used for RCA Victor tapes. For stereophonic recordings, the No. 1 track carries the material for the left-hand speaker as viewed by the audience. This is an arbitrary standard, although it does conform to a SMPTE proposal for three-channel stereophonic track placement.

As mentioned above, the master drawer position has three reproduce heads which are used in different combinations. One of these is for the No. 1 track and two are for the No. 2 track. For regular half-track tapes, track displacement is of no consequence, since each track carries different music and the tracks are not reproduced simultaneously.

For stereophonic tapes, however, we have to consider two different systems which are in use—one with the two tracks directly "in line" on the tape and the other with the tracks displaced by 1¼ inches. In making tapes for either of these two systems, we start with a 15 inch-per-second in-line master. Because this is double the speed of the copy tapes, we get in-line 7½-inch tapes if the spacing between master reproduce heads is double the spacing between the copy record heads. On this duplicator the record heads are 2¼ inches apart, so the reproduce heads for the master tape are 4½ inches apart when making in-line copies.

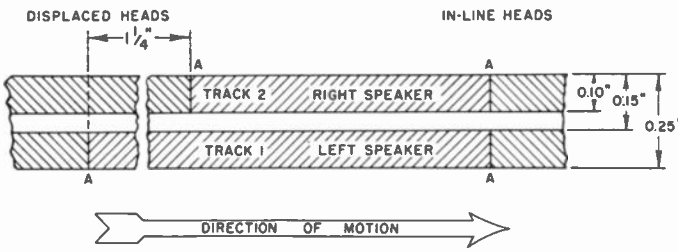


Fig. 2—Track placement. Half-track or two-track stereophonic tapes. View looking at coated side of tape.

For making 1¼-inch displaced-track copies we simply use another reproduce head on the track to be displaced, which is located 2½ inches from the head which produces the in-line copy. In our method, it turns out that 2 inch spacing between reproduce heads gives the required 1¼ inch displacement of tracks on the 7½-inch copy tapes.

Crosstalk between tracks depends upon track placement, head design, head placement, and tape path. Tests have shown that for single-channel, double-track tapes, .050-inch spacing between tracks is more than adequate to prevent crosstalk, even with high level music on one track and no music on the track in use. This is .020 inch more separation than suggested in the original RETMA standard.

In the case of two-channel stereophonic records, the crosstalk does not appear to be important. The actual amount of crosstalk is dependent upon head design where in-line or "stacked" heads are used. In this connection we run into a definite problem when playing regular half-track tapes on in-line stereophonic heads. The performance from the track in use is satisfactory. However, the signal from the adjacent track is picked up by the second head and appears as crosstalk due to the coupling between heads. With most stacked heads tried so far, this condition has been very objectionable. Unfortunately, shorting the second head only makes the condition worse.

While two-track machines using displaced heads do not encounter this problem, they do introduce an interchangeability problem for recorded tapes where accurate track displacement is required for timing purposes. However, our experiences so far indicate that slight timing errors are not of great importance for stereophonic work with loudspeakers, whereas level differences are of considerable importance in establishing directional effects.

I wish to emphasize that RCA is offering stereophonic tapes of both types. We realize that there are engineering and commercial problems connected with both systems, and at this point each has its advantages. We hope that the industry can make standard one system or the other in order to eliminate the confusion which is likely to result with two systems. At present we hold no brief for one system over the other and, as new stereophonic selections are released, we shall continue to make them both ways, provided sufficient demand exists. Tapes for in-line heads are numbered TCS- and for displaced heads, TCSD-.

*Frequency Response*

The ability to obtain good frequency response and low noise output at $7\frac{1}{2}$ inches per second is dependent to a large extent on the quality of the reproduce head and the equalization of the reproduce amplifier. It is a well-known fact that magnetic recording at low tape speeds requires a series of compromises in order to obtain satisfactory results. Bias level must be held to a moderate value. Otherwise, severe high-frequency losses will result. Any significant amount of high-frequency post-emphasis in the reproduce amplifier will result in excessive amplifier and tape noise, while excessive pre-emphasis in recording will result in overloading the tape at high frequencies unless the over-all recording level is reduced to an impractical value.

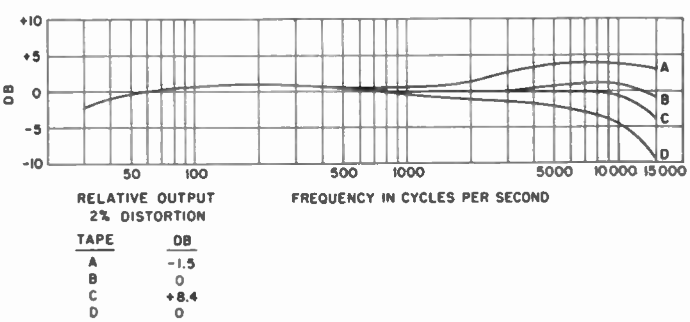


Fig. 3—Typical tape responses. Bias set for maximum 400 cycles output on each tape. $7\frac{1}{2}$ inches per second tape speed.

With these factors in mind, we set out to find what seemed to be the best compromise to produce high quality $7\frac{1}{2}$ inch-per-second tapes. Previous work in the laboratory had shown that recording and reproducing wavelengths as short as $\frac{1}{2}$ mil (15,000 cycles at $7\frac{1}{2}$ inches per second) was feasible with high quality tape and reproduce heads.

The effect of tape itself on response at short wavelengths is considerably greater than many people realize. To illustrate this, Fig. 3 shows the relative responses of several commercially available and experimental tapes which we have tested recently. Each tape was tested using the bias which gave maximum output at low frequencies and in each case the record current was held constant. We find that there is about 5 db difference in sensitivity among the tapes at low frequencies and, with the curves all referenced to zero at low frequencies, the variation at $\frac{1}{2}$ mil wavelength amounts to 12.5 db. As a matter of interest, the relative outputs of these tapes at 2 per cent third-harmonic distortion is also shown.

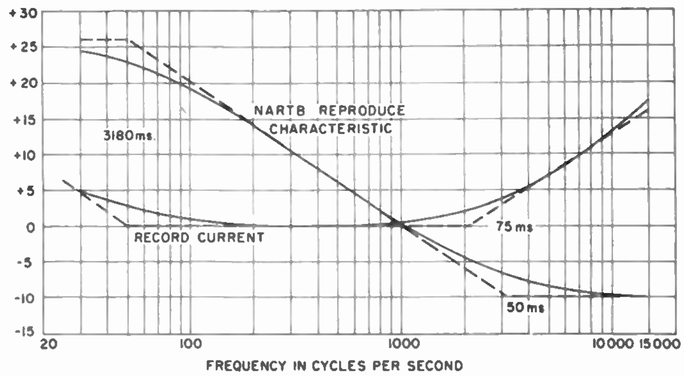


Fig. 4—Record and reproduce characteristics, RCA Victor prerecorded tapes.

The actual playback equalization curve which we use and recommend is the NARTB standard for 15-inch-per-second tape as shown in Fig. 4. This curve provides for the same amount of low-frequency recording pre-emphasis as is used on the RIAA standard disc recording curve. The high-frequency portion of the curve was adopted by NARTB as a satisfactory compromise after studying the practices of the various manufacturers of professional tape recorders. In our opinion, any increase in the high-frequency response above this curve will result in an unsatisfactory signal-to-hiss ratio for high quality reproduction. We therefore adopted this curve as standard for a reproducer, and equalized the record channel to obtain the best possible overall response. The record current curve is also shown in this figure.

It should be pointed out that this system of equalization is quite different from that used on most home recorders, in which a good part of the low-frequency compensation is in the record circuit. This simplifies the hum problems in the playback position, but it also means that reproduction from recorded tapes made for use with professional type equipment will be somewhat lacking in low-frequency response.

So far we have had very few complaints from the field. Of the few that have come in, some complain of too many or too few highs, and others make the same complaints about bass response. Frankly, we expected this from the start. Our real surprise is that we haven't heard more. It is obvious that some form of standardization is going to be essential if we expect tape records to achieve an important place in the home music system. We all hope that the industry or professional societies

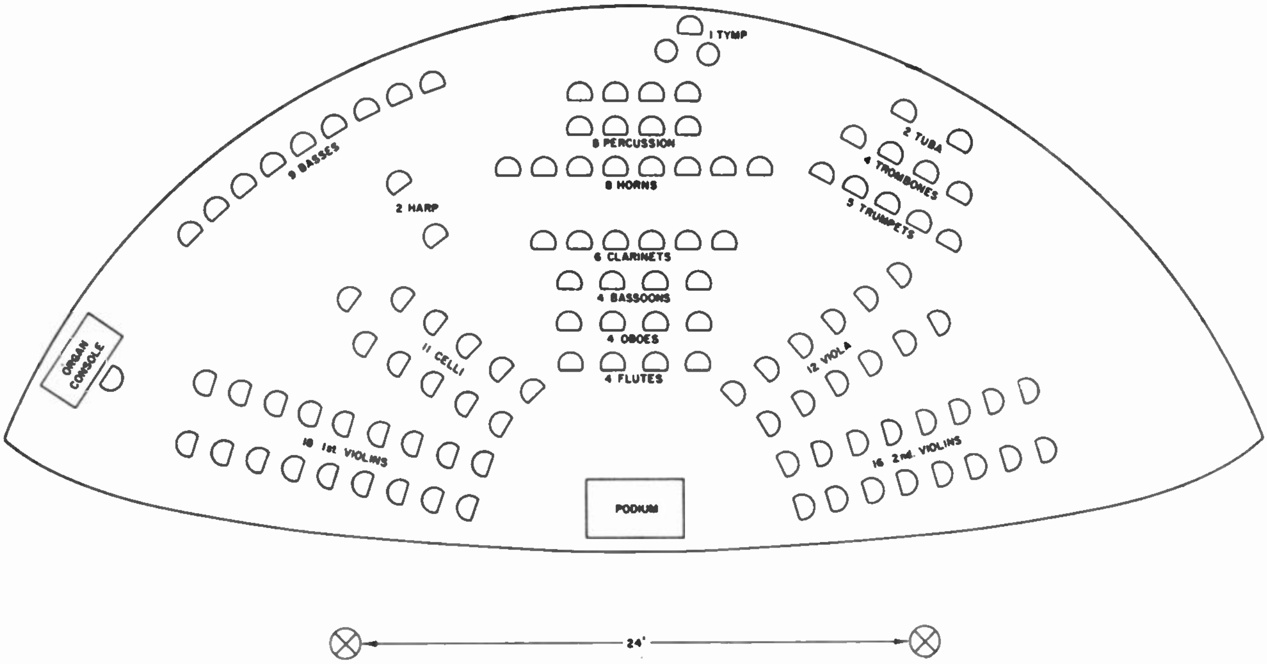


Fig. 5

will consider the problem in the near future and come up with a satisfactory standard which will serve as a guide for equipment and tape record manufacturers.

In conclusion, attention is called to the stereophonic tape recording of "Also Sprach Zarathustra" by Richard Strauss. The recording was made in Orchestra Hall, Chicago, by the Chicago Symphony Orchestra conducted by Fritz Reiner. Two microphones spaced 21 feet apart were used. They were located about 4 feet in front of and about 11 feet above the stage. Fig. 5 shows the orchestra seating arrangement and microphone placement that was used for making this recording. This tape also contains excerpts from three other recent stereophonic recordings.

In making this and other two-channel stereophonic recordings, we have attempted to get a reasonably good over-all pickup on each channel. Each microphone, of course, is directed to favor instruments on its side. We believe that a pickup of this sort provides good directional and spatial effects and excellent over-all sound without the distracting condition that results when the sound appears to come all from one speaker or the other. This is particularly important for home listening where use of more than two channels is generally impractical.

# Loudspeakers and Microphones*

LEO L. BERANEK†

*Summary*—**This paper covers the development of loudspeakers and microphones and gives many illustrations of commercially available units dating from 1915 to the present time.**

## Introduction

On this occasion of the 25th Anniversary of the Acoustical Society of America, it is fitting and proper that we should pause and look at the progress that has been made in the United States in the development of loudspeakers and microphones. The practical utilization of these devices began about a decade prior to the formation of the Society. In about 1915 the first reliable vacuum tubes became available, making possible adequate audio power so that experimenters were able to listen to speech and music with earphones and "loudspeaking telephones." By 1929, the year of the formation of our Society, dynamic loudspeakers of respectable quality were available and radio manufacturing had become a large industry. Good quality condenser and carbon-button microphones were available, and talking movies were already well launched.

Prof. F. V. Hunt of Harvard has recently completed a text on electroacoustics[1] containing an extensive historical section that is more inclusive than space allows here. As a consequence, this presentation is largely in the form of illustrations. The examples are nearly all chosen from merchandised devices so that they are not inventors' laboratory models.

By the selection of illustrations and examples herein it is not intended to endorse the product of any particular manufacturer. American manufacturers not mentioned here include: American Microphone, Astatic, Brush Electronics, Carbonneau Industries, Cinaudagraph Speakers, Connecticut Telephone and Electric, General Electric, James B. Lansing Sound, Permoflux, Racon, Rola, Tibbetts Industries, University Loudspeakers, Turner, and others.

## History of Loudspeakers

Sounds may be produced by loudspeakers having the following mechanisms of transduction: electrodynamic, electrostatic, magnetic, magnetostrictive, and piezoelectric. Mostly, we encounter electrodynamic loudspeakers, although there has been a revival of interest in the electrostatic type during the last few years.

The basis for the modern electrodynamic loudspeaker originally arose from the works of Oersted, in 1820, in connection with the discovery of the magnetic effect of an electric current, and of Arago (1820), and Davy (1821), who discovered that magnetism could be induced in a piece of iron by action of electric current.

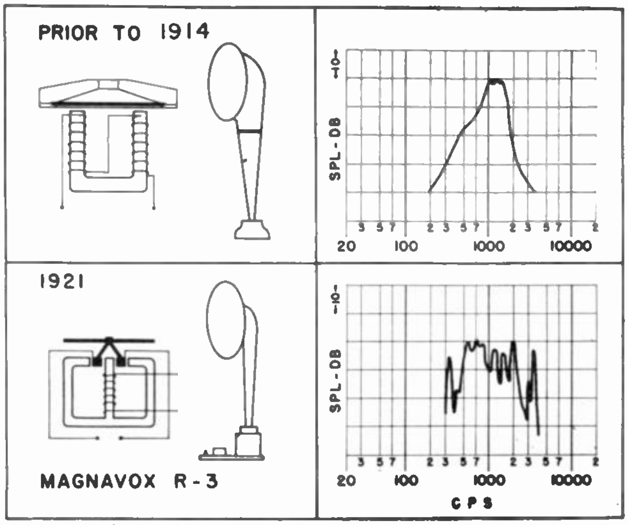


Fig. 1—Upper: Bipolar induction-type transducer connected to simple conical horn. Lower: Magnavox moving-coil transducer connected to a short tapered horn. Field excitation supplied by a 6v battery.

In Figs. 1 and 2 we see two of the early loudspeakers in common use in the United States and their response curves. The loudspeakers prior to 1914 were often the combination of an earphone from the telephone and a horn taken from the mechanical phonograph. Egerton of Western Electric developed a rocking-armature driver unit of considerable importance in about 1914. In 1915, however, the foundations were laid by Pridham and Jensen of Magnavox for the first commercial good-sounding loudspeaker. The first versions of their loudspeaker consisted simply of a straight piece of copper wire placed between the poles of an electromagnet. From the center of this wire a short wooden connecting rod was glued to a diaphragm. At first, sound was brought to the ears of a listener using listening-ear tubes of the stethophone type which were connected to the airspace in front of the diaphragm. The clarity was excellent even at very low frequencies. Then, quite by accident, a phonograph horn was inserted into the sound box. The results were amazing to the experimenters; clarity with volume resulted. In San Francisco, the Christmas celebration of 1915 was made memorable by

* Invited paper for Commemorative Session A of the Acoustical Society of America's 25th Anniversary Celebration, New York, N. Y.; June 23, 1954. Reprinted from *Jour. Acous. Soc. Amer.*, vol. 26, pp. 618–629; September, 1954.

† Elec. Engrg. Dept. & Acous. Lab., M.I.T., and Bolt Beranek & Newman, Inc., Cambridge, Mass.

[1] F. V. Hunt, "Electroacoustics," John Wiley and Sons, Inc., New York, N. Y., and Harvard Univ. Press, Cambridge, Mass.; 1954.

the playing of Christmas Carols from the Tower of Jewels. This demonstration was enjoyed by thousands who came from miles around. The most successful version of the Magnavox loudspeaker was the R-3, introduced in 1921 or 1922 and shown in Fig. 2.

Fig. 2—Photograph of Magnavox R-3 loudspeaker (Pridham and Jensen, 1921).

An improvement on the early rocking-armature transducer was the 4 air-gap balanced-armature type by Egerton (1918) that permitted greater amplitude of movement of the moving-iron type of diaphragm without distortion. This development, shown in Fig. 3, was used in the Western Electric Model 518W.

The first public use of a combination of power amplifier and balanced-armature units with long horns was made in April, 1919, on Park Avenue, New York, in connection with the sale of Victory Bonds. The installation was widely publicized at the time. President Harding's address in Arlington, Va. of November 11, 1921, was transmitted by loudspeakers in Madison Square Garden, the adjoining park, and in the Civic Auditorium in San Francisco. For the first time, 150,000 people listened to a person speaking. In these installations, by W. E., Egerton's 4 air-gap balanced-armature units were employed.

Then came loudspeakers with large radiating diaphragms instead of horns. Between 1900 and 1924 important developments were made in the choice of materials, dimensions, and methods of manufacture of sound-radiating diaphragms. It was Ricker of W. E. who described the use of two large wide-angle cones cemented at their base to form a light rigid structure that could be freely suspended from the apex of one and driven from the center of the other. This led to the Western Electric Model 540-W "loudspeaking telephone," shown in Fig. 3. Prof. Hunt says, "One might almost draw the conclusion that this unit was too good, and that its availability . . . may have dulled the incentive for improvement and delayed by several years the study of moving-coil systems by Western Electric and A. T. and T. engineers."

The moving-coil, electro-dynamic loudspeaker is the one with which we are so familiar today. This loudspeaker seems actually to have been invented in almost its present-day form in 1877 by Charles Cuttriss and Jerome Redding of Boston (patent filed 28 November, 1877), and independently by E. W. Siemens of Germany (patent filed 14 December, 1877). The sketch shown in Fig. 4 (opposite page) is taken from Siemen's patent. Lamentably, there were no amplifiers in that day, so that the efforts of those gentlemen went unrewarded except to cause later claimants to complain "the ancients have stolen our inventions."

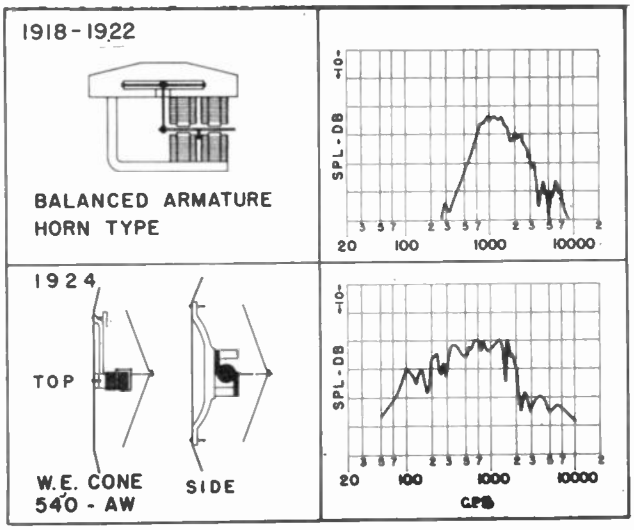


Fig. 3—Upper: Balanced-armature transducer connected to short exponential horn. Lower: W. E. 540-AW balanced-armature type unit utilizing two large paper cones joined at outer edges.

The present-day loudspeaker was brought out of the category of being a loud device into being a faithful device by the excellent work of C. W. Rice and E. W. Kellogg of the General Electric Company in 1925. They made a very careful and thorough study of direct radiation, and capitalized on the importance of locating the resonance frequency of the diaphragm at the bottom of the frequency spectrum so that the diaphragm vibrates as a mass-controlled device. Under these conditions, a flat response is obtained in the frequency region above the resonance frequency. The concept of low-resonance frequency probably originated with Sykes in about 1919.

Rice and Kellogg assured themselves of a market for their loudspeaker by also developing a power amplifier yielding one-watt of available audio power. The combination loudspeaker-amplifier-cabinet was sold, in 1926, under the trade name of "Radiola Loudspeaker Model 104" for a sum of $250.00. This loudspeaker also supplied filament and plate power for a radio receiver (Radiola Model 28), and thus began the end of battery-operated radios. Other companies soon came forth with direct-radiator loudspeakers. Magnavox put one on the market in 1927, and Jensen claims the first high-efficiency auditorium loudspeaker in 1928. Permanent-magnetic loudspeakers were first commercially available from the Jensen Manufacturing Company in 1931.

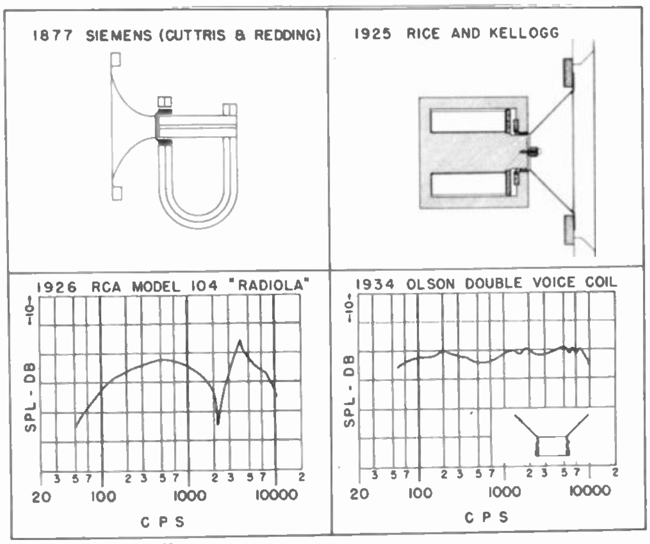


Fig. 4—Upper left: Design of direct-radiator, moving-coil from Siemens' patent application. Upper right: Design of Rice and Kellogg of 1925. The actual cone was 6 inches in diameter. Lower left: Response of 1926 version of Rice-Kellogg loudspeaker. Lower right: Response and construction of Olson double-voice coil loudspeaker.

Many later improvements were to follow of the multi-coil, multi-diaphragm type. One of these, the double-voice coil by Olson, of the Radio Corporation of America, and described in 1934, is shown above.

Horns were also undergoing development and change during the first part of this century (see Fig. 5). The exponential horn was first analyzed by Webster in 1919. The first commercial use of such horns was in the Orthophonic phonograph developed by Maxfield and Harrison of BTL in about 1923. They dramatically showed the importance of proper matching of impedances at the transition points in a mechanical system. A version by Western Electric using the efficient Type 555W "receiver" attached to a coiled exponential horn is shown in Fig. 5. A simple horn like this, with large mouth openings, was highly directional at the higher frequencies. This difficulty was overcome by using several pointed in different directions (W. E., 1919 and RCA, 1932) and by the development of the multicellular, single-throated horn, in 1933, by W. E. The multicellular horn was filed for in patents by Hanna in 1925 and Slepian in 1926. These horns usually operate in the range between 400 and 10,000 cps when used with a suitable driving unit. More recently, we find a horn being terminated by an acoustic lens that has a more uniform radiation pattern than the multicellular horn. This type of horn was first described by Kock and Harvey of Bell Telephone Laboratories in 1949. A lens with a width of 36 inches, as shown in Fig. 5, operates in the frequency range between 600 to 12,000 cps, with a directivity pattern whose width is nearly constant at 120 degrees.

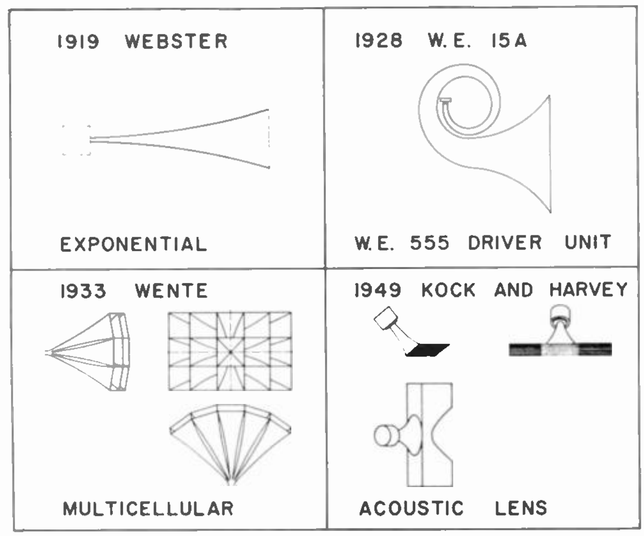


Fig. 5—Three horn-type loudspeakers and one acoustic lens loudspeaker.

We must not lose sight of the development of baffles for direct-radiator loudspeakers. These developments are shown pictorially in Figs. 6 and 7 (page 16).

Another interesting development of recent date is loudspeakers with especially planned "synthetic bass." By producing nonlinear distortion, either electrically or in the units themselves, of such a nature that the distortion increases and response decreases as frequency is decreased below about 200 cps, the bass apparently remains. Sheppard merchandised an electrical synthetic-bass circuit to Zenith in 1940. A carefully designed loudspeaker-baffle arrangement, using this principle, was developed in 1952 by Baruch and Lang of the Massachusetts Institute of Technology, and is now commercially avilable. Earlier embodiments of this idea in small radios have been alluded to in European and American news items.

It is interesting to observe the actual commercial development of loudspeakers during the life of the Acoustical Society of America. We shall do this by looking at the products of four manufacturing companies. These companies' products, and the dates of their commercial introduction, are shown in Figs. 8 through 11 on page 17.

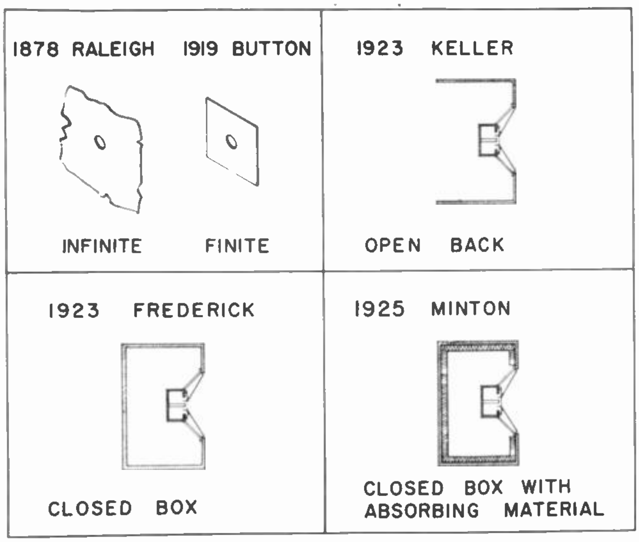


Fig. 6—Simple loudspeaker baffles. It now appears that both Minton and Wente filed for patents in 1925 showing lined boxes. Obviously, the dynamic units shown in the drawings were not available prior to 1925.

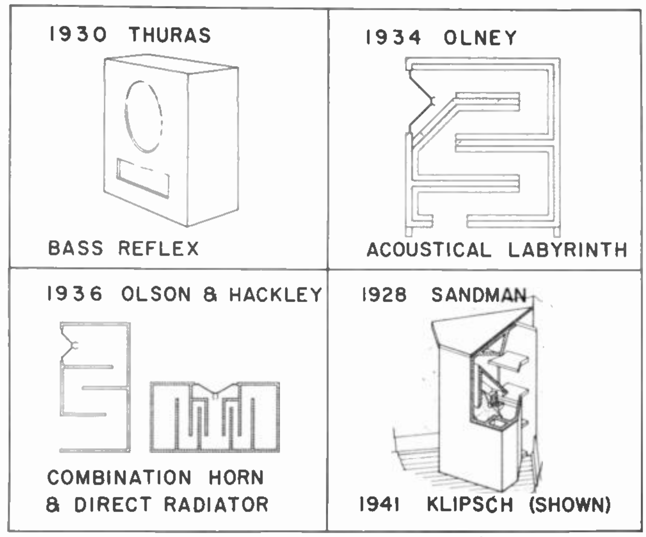


Fig. 7—Loudspeaker baffles for enhancing bass response.

The talking motion picture was responsible for the development of efficient high-fidelity, higher-power loudspeaker systems. With due respect to others who played an important part, there were two contributors who dominated the sound motion picture scene prior to 1938, namely the Western Electric Company and the Radio Corporation of America. The first RCA systems consisted of a vertical column of Rice-Kellogg direct-radiator loudspeakers located on either side of the screen. Although these units sounded very good, their efficiency was very low. In 1926–1927 the Western Electric Company came out with the Type 555W receiver, developed by Wente and Thuras and commercialized by W. C. Jones, all of BTL. This horndriver unit, when used with a 10- to 15-foot long exponential horn, was so efficient that, with $2\frac{1}{2}$w of available audio power, a fairly creditable job was done even in large theaters in the frequency range of 100 to 5,000 cps. I am told that the Western Electric Company received a large part of the motion-picture business between 1927 and 1933 because of this unit. Its electrical power handling capacity was 30w, and its efficiency was about 50 per cent throughout the frequency range between 150 to 4,500 cps. Even today, the high frequency units of theatre systems are designed in accordance with the teachings of Wente and Thuras.

In 1933, the Jensen Company brought out the first commercially available tweeter units. That same year, the Western Electric Company also introduced the Bostwick Type 596 tweeter unit. These units extended the frequency range of reproduced sound up to better than 12,000 cps, and brought about the widespread use of two-way systems. The low-frequency portion of the spectrum was extended below the cut-off frequency of the coiled horn through the development of high-efficiency direct-radiator units such as the Jensen DA-4, thus bringing into existence the first three-way systems. RCA introduced similar systems in this period, in particular, the Radio City Music Hall System of 1932, using large cone loudspeakers coupled to exponential horns.

In Fig. 12, page 18, is one of the W. E. 3-way systems first introduced in 1933. The photograph is probably of the version of equipment merchandized in 1935. This system first brought into the open the importance of acoustical phasing. The low frequencies were radiated from a flat baffle, the middle frequencies from an 11-foot horn, and the high frequencies from a 6-inch horn, all with their openings in the same plane. J. Maxfield of W. E. and his colleagues, and J. Hilliard, then of Metro-Goldwyn-Mayer, each showed by listening tests using impact sounds, such as those from tap dancing, that there was a distinct "echo" because of the difference in path lengths for the three frequency ranges. If the high-frequency horn were pulled back by 8 to 11 feet and no bass units were used, the echo disappeared.

In about 1933 the Western Electric Company introduced the multi-cellular hf horn which radiated hf sounds uniformly over the seating areas of even very large theaters, and the tweeter units became obsolete. These multi-cellular horns were not too efficient below 400 cycles. To avoid phasing problems, and because of limited depth available on movie-theater stages, the short-horn baffle for lf units was developed. This baffle consists of a very short length of horn that effectively increases the area of a direct-radiator loudspeaker and mass-loads the diaphragm, thereby lowering its lf cut-off. Large wings are provided on either side of the short horn so that a near-infinite baffle is also achieved. RCA, Altec, and Jensen merchandised two-way systems comprising multi-cellular horns and directional baffles after about 1935. In 1938, W. E. transferred its domestic

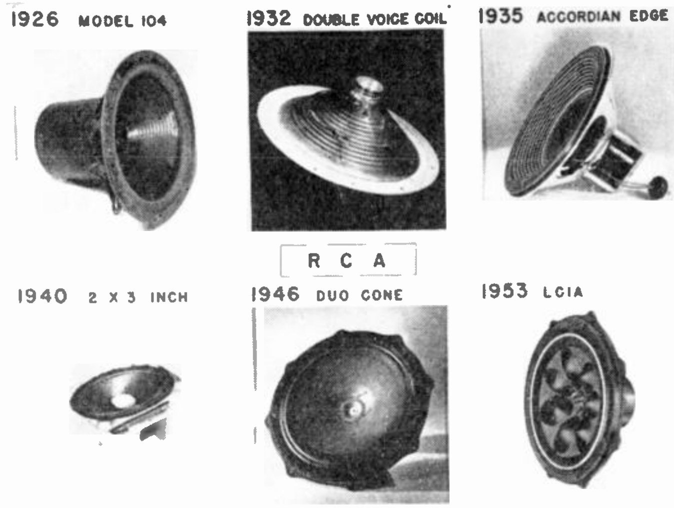


Fig. 8—RCA loudspeakers. Reading across top: (a) Rice-Kellogg direct-radiator dynamic loudspeaker. (b) Double-voice coil loudspeaker, advertised as the first wide-range high-fidelity loudspeaker. (c) Accordion-edge loudspeaker. (d) 2×3-inch personal radio receiver loudspeaker. (e) Original LC1A duo-cone loudspeaker. (f) Latest LC1A 15-inch loudspeaker with "domes" and hf deflectors. Not shown, the Olson-Hackley combination horn and direct-radiator loudspeaker commercialized in 1936, the double-cone loudspeaker in 1938, and the 515S1 duo-cone loudspeaker in 1949.

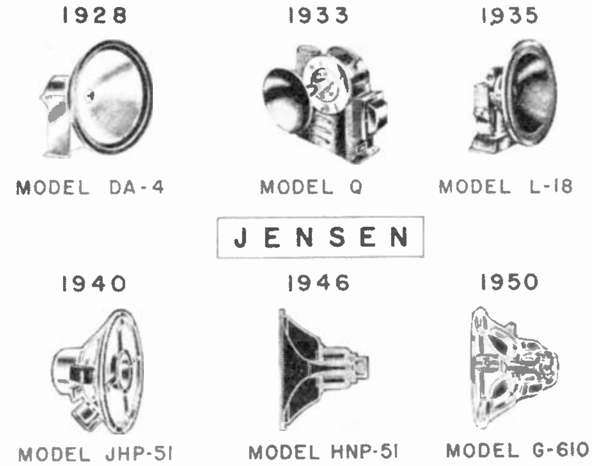


Fig. 9—Jensen Manufacturing Company. (a) Model DA-4, high-efficiency auditorium loudspeaker. (b) Model Q, hf tweeter unit. (c) L-18 15-inch auditorium. (d) JPH-51 coaxial loudspeaker. (e) HNP-51 articulated compression driver coaxial. (f) G-610 3-way integral loudspeaker with crossover at 600 and 4,000 cps. Not shown, KM-15 "bass reflex" cabinet commercialized in 1937 and PM-1 permanent magnet loudspeaker in 1931. Present-day units include H-530 coaxial with 15-inch lf unit, multicellular horn, and 2,000 cps crossover; and 4 lower-priced coaxials.

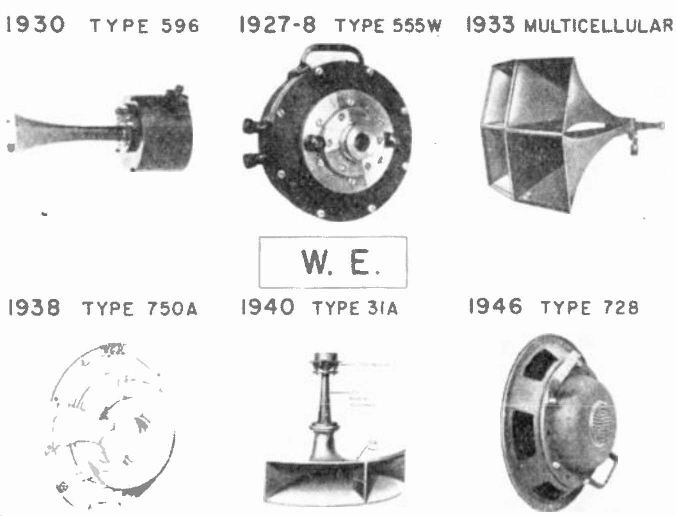


Fig. 10—Western Electric Company. (a) Bostwick hf tweeter. (b) Type 555W mid-frequency horn-driver unit. (c) 2×4 multicellular horn. (d) Aluminum cone direct-radiator loudspeaker with large-voice coil with permanent magnet field. (e) Cobra horn for use in locations with limited accessibility. (f) 12-inch direct-radiator loudspeaker. Not shown, other direct-radiator loudspeakers with different diameters and power-handling capacities, and other types of horns and horn-driver units with different cut-off frequencies and angles of coverage.

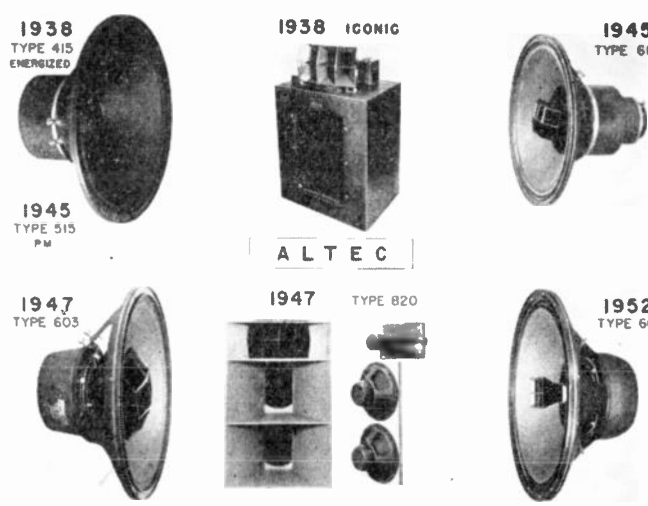


Fig. 11—Altec loudspeakers. (a) Type 415 or 515 15-inch dynamic. (b) Iconic comprising 415 lf unit and 802-A hf unit with 800 cps crossover and 6-cubic-foot bass-reflex cabinet. (c) Type 604 duplex loudspeaker with 15-inch lf unit and crossover at 1,000 cps. (d) Type 603 dia-cone 15-inch frame with mechanical crossover and aluminum dome in the center and hf diffusor. (e) Type 820 comprising two 15-inch lf units and 802-B hf units on H-808 multicellular horn with 800 cps crossover. (f) Type 601 duplex with 12- or 15-inch lf unit and L-1 hf unit with 3,000 cps crossover. Not shown is the 400-B high-quality 8-inch unit commercialized in 1947.

theater operations to Altec, and in 1947 the remainder of its commercial amplifier, microphone, and loudspeaker operations went to Altec.

In Fig. 12, the free-field measured response curves are shown on two large theater sound systems for 1936 and 1950. Two modern theater systems with two-way loudspeakers are shown in Fig. 13 on page 18.

## History of Microphones

The development of microphones prior to the formation of the Society was discussed in some detail by Frederick in 1931.[2,3] The telephone was possible only

[2] H. A. Frederick, "The development of the microphone," *Jour. Acous. Soc. Amer.*, vol. 3; 1931. Supplement to July issue.

[3] H. A. Frederick, "The development of the microphone," *Bell Tel. Quart.*, vol. 10, pp. 164–188; July, 1931.

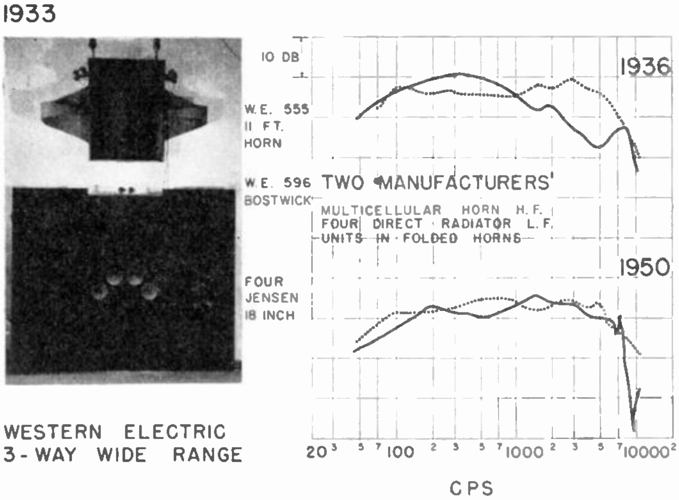


Fig. 12—Theater loudspeaker systems. Left: W. E. 3-way wide-range system of 1935 vintage using two Bostwick tweeters, four Jensen 18-inch direct-radiator loudspeakers in simple baffles, and a Roxy horn with four Type 555 driver units. Upper right: Axial response of two 1936 theater loudspeaker systems. Lower right: same in 1950.

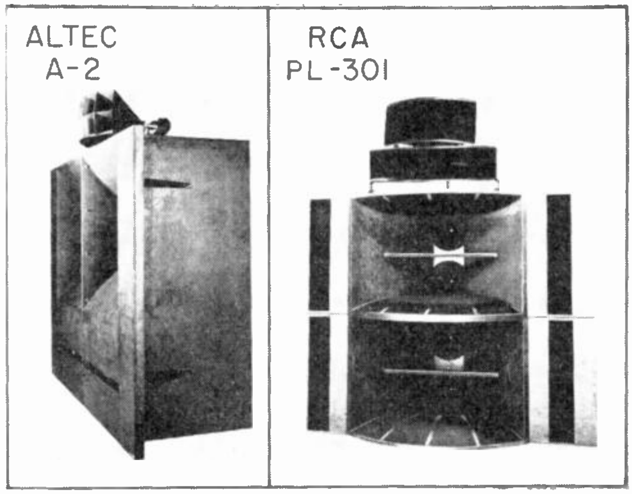


Fig. 13—Recent large theater loudspeaker systems.

with suitable microphones. The carbon-button, moving-iron, moving-coil, and variable-resistance-in-a-liquid types of transducers were discovered in the 1870–1880 period. However, because of its high sensitivity and adequate audio quality, the carbon type of microphone was more highly developed in the early years than other types. It was invented by Edison (1877) and was contributed to by Blake (1877), Berliner (1877), Hughes (1878), Hunnings (1878), and many others in later years (see Frederick).[2,3]

In Fig. 14, we see the principal developments in microphones prior to 1929. The Blake single-contact microphone is chosen as the forerunner of our present-day telephone microphone. In 1917, Wente described the condenser microphone which, with the vacuum tube amplifier, made possible high-fidelity music transduction. In 1917 Langevin developed the first crystal microphone for use underseas. Parenthetically, we should note that Jacque and Pierre Curie discovered piezoelectricity in 1880, but the lack of suitable amplifiers prevented its use in microphones. In 1921, the stretched-diaphragm, double-button carbon microphone was developed by W. E. and, for ten years, it played an important part in radio broadcasting wherever microphones were needed for speech reproduction only, or where long microphone cables were necessary.

In Fig. 15, we see the microphones developed in the first ten years of the Society's history. With the development, in 1931, of a truly high-fidelity moving-coil transducer (Type 630-A) by Wente and Thuras of BTL,

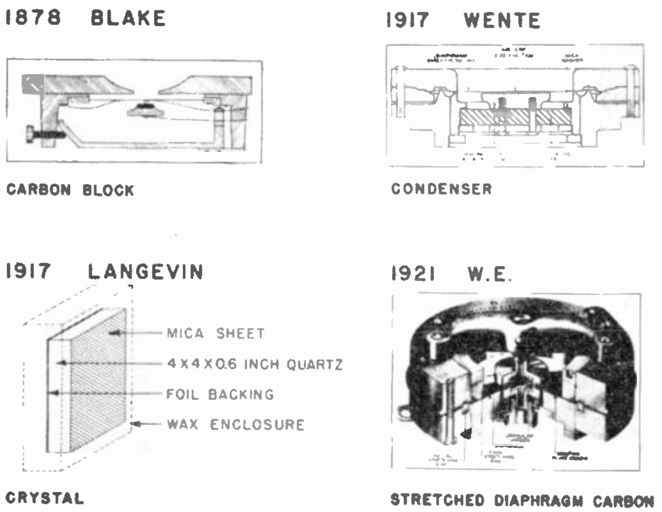


Fig. 14—Typical microphones developed prior to 1929. Cady (1920) and Nicholson (1918–1923) also contributed to the early piezoelectric art.

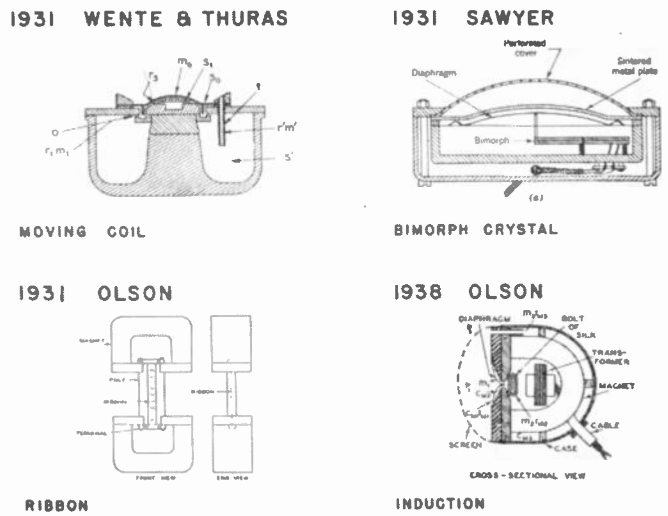


Fig. 15—Four types of microphones employing (a) moving coil, (b) Bimorph crystal, (c) pressure gradient ribbon, and (d) moving conductor.

modern broadcasting was freed from the microphone preamplifier. This microphone has a response that is very nearly flat from 40 to 8,000 cps. It is quite sensitive and may be used with very long cables. The development of the Bimorph crystal microphone by Sawyer, in 1931, brought to us another type of high-fidelity microphone (called the "sound-cell") capable of being used with long cables. An early nondiaphragm version of this microphone was used during the Century of Progress celebration in Chicago in 1933–1934 at nearly all music-pickup and announce positions, and its high-quality response, extending from 20 to 10,000 cps, created much interest in the radio and public address fields. Still another significant addition was achieved with the development of the ribbon (velocity) microphone by Olson in 1931. This microphone also has a very flat response from 40 to above 10,000 cps, and in addition has a figure-eight directivity pattern. It was soon apparent that this microphone gave engineers in radio broadcasting stations an additional degree of freedom, because they could orient the microphone directivity pattern so as to avoid undesirable acoustic conditions in the studios. In 1938, Olson described the moving conductor (induction) type of microphone.

Another important development was that of the unidirectional (cardioid) microphone that has a heart-shaped directivity pattern. Discussion on a microphone with this type of directivity pattern was first published by Weinberger, Olson, and Massa in 1933. This microphone was constructed from two short ribbons, one acting as a velocity microphone and the other as a pressure microphone. The pressure element was obtained by terminating the back side of one of the ribbons in a long absorbing acoustical tube. The outputs of the two ribbons were then combined in a magnitude and phase so as to produce the familiar cardioid pattern.

Other types of undirectional microphones using *single elements* were patented by Braunmuhl and Weber in Germany, in 1935, by Bauer (then Baumzweiger), in 1938, and by Olson, in 1938. Braunmuhl and Weber's microphone consisted of a solid sheet of brass, approximately $\frac{1}{4}$-inch thick, through which a number of small holes were drilled. On either side of this plate, spaced a few thousandths of an inch from the brass, was stretched a plastic diaphragm with a gold-leaf covering. One of the diaphragms was connected at its center to an electrical contact. The other diaphragm was inactive electrically. Braunmuhl found that, if the spacing between the inactive diaphragm and the solid brass plate was very small so that the diaphragm was highly damped because of viscous action of the air, the device exhibited a directivity pattern having a "kidney" shape. From reading his disclosure it was not possible to deduce how cardioid patterns employing a single element with a different type of transduction could be constructed.

Bauer contributed to the state of art in his 1938 patent application by making an analytical study of the problem of producing a cardioid directivity pattern in a microphone using *single* transducing elements of various types. He showed that, by embodying the proper acoustical phase-shifting network in the microphone, it could be made to have a cardioid directivity pattern using either a crystal or a moving-coil or a single-ribbon type of transducer element. Olson, in 1942, was issued a similar patent dealing with a single-ribbon transducer with an appropriate phase-shifting network. His application also shows an adjustable plate that can be used to change the acoustical network so as to shift the directivity pattern over a continuous range, starting from omnidirectional, going through bidirectional, and ending as unidirectional.

Other types of special gradient microphones having higher-order directivity patterns have been discussed by Ellithorn and Wiggins (1946), and Olson (1946). The use of parabolic reflectors for enhancing the directivity pattern was discussed by Olson and Wolff (1930), Hanson (1931), and Dreher (1932). Line microphones were described consisting of a number of small tubes with the open ends equally spaced along a line and the other ends connected to a common junction to a transducer element. These microphones were discussed by Mason and Marshall of BTL (1939), and Olson (1939). Military microphones have included throat microphones and dipole microphones. Reference to these types of units is made by Olson.[4]


Fig. 16—RCA microphones of eight types as indicated.

In Fig. 16, we see as an example the products of one leading manufacturer (RCA) from the early days of broadcasting to the present time.

[4] H. F. Olson, "Elements of Acoustical Engineering," D. Van Nostrand Co., Inc., New York, N. Y., 2nd ed.; 1947.


Fig. 17—Currently available microphones of six types, as indicated.

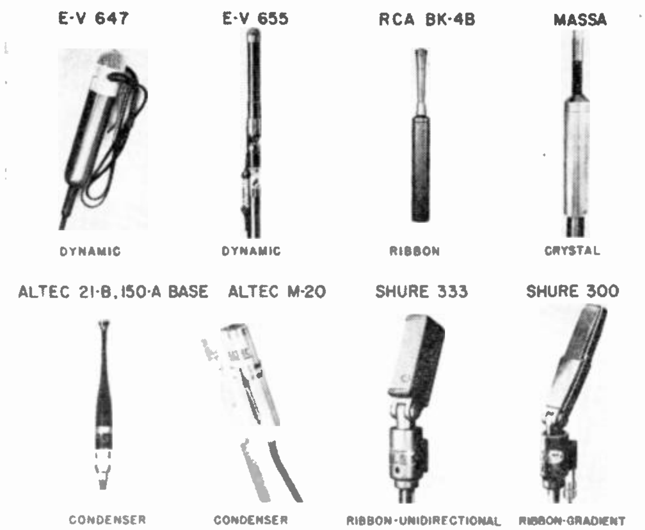


Fig. 18—Currently available slender microphones of eight types, as indicated. E-V stands for Electro-Voice.

In Fig. 17 (page 20), we see a group of present-day microphones. The Shure 9898 and 9899 are diaphragm crystal-type microphones that are extensively used on sound-level meters because of their low cost and high sensitivity. The W. E. 640-AA is a widely-used laboratory standard microphone having a diameter of about 1 inch. The Kellogg Midget microphone is of the same type as the W. E. 640-AA. It has a diameter of 1.25 inches and uses an aluminum diaphragm instead of a stainless-steel diaphragm. The Altec 633-A moving-coil microphone is a direct outgrowth of the Wente-Thuras development of 1931. The Shure 55S is a unidirectional dynamic microphone and is the direct outgrowth of the Bauer patent discussed in the previous paragraph. The Altec 670 is a cardioid microphone of the single-ribbon type.

In Fig. 18, we see a group of eight microphones of the "slender" type now coming into vogue on television programs because of their less objectionable shielding of the actors. The caption is self-explanatory.

It is difficult to predict the direction of future development that loudspeakers and microphones will take. It seems certain that in the case of loudspeakers many of our basic problems of phasing would vanish if we could obtain adequate sound radiation over the frequency range from 30 to 12,000 cps from a single vibrating surface shaped so as to provide a desirable directivity pattern. Hunt and his colleagues at Harvard may have pointed the way through the renewal of research on electrostatic loudspeakers.[1,5] Some direct-radiator loudspeakers are approaching this desirable goal at the present time, although their power-available efficiency is generally low.

In the field of microphones, the principal need for development would seem to be in the direction of providing an adequate microphone for the sound-level meter. This microphone would need to be low in cost, have a wide dynamic range, high stability, nearly flat frequency response from 20 to 12,000 cps, and be free from effects caused by temperature, humidity, and day-to-day changes in barometric pressure.

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[5] A. A. Janszen, R. L. Pritchard, and F. V. Hunt, "Electrostatic Loudspeakers," Tech. Memo. No. 17, Acoustics Res. Lab., Harvard Univ.; April 1, 1950. See also A. A. Janszen, U. S. Patent No. 2631196, filed October 5, 1949, issued March 10, 1953.

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