Bell Laboratories Record

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Reproducing Sound and Scene

Theatrical audiences throughout the United States have been enjoying for many months audible motion-pictures, recorded and reproduced by methods and apparatus developed in Bell Telephone Laboratories and made available to producers and exhibitors by Electrical Research Products, Incorporated. A furor has arisen in the theatrical and motion-picture professions, excited by the wondrous possibilities and amplified by public demand and interest.

Relating to this new art of talking motion-pictures much has already been published, for it is based upon years of telephonic research in speech and hearing, the conversion of energy between acoustic and electrical systems, and electrical methods for recording, amplifying and reproducing sound.

Publication of the technical processes involved, however, is following the actual accomplishment in accordance with the tradition of the Laboratories that demonstration shall precede exposition and the hazard of prophesy be avoided.

During September a series of papers was presented to the Society of Motion Picture Engineers by members of the technical staff of the Laboratories. These dealt with the fundamental principles of synchronized recording and reproducing of sound and scene, and with some of the apparatus developments of the Laboratories in that field.

In this issue of BELL LABORATORIES RECORD the authors of those technical papers present in a series of articles the substance of their original expositions.

Contents

Fundamentals of Speech, Hearing and Music
JOHN C. STEINBERG, *Research Department*

General Principles of Sound Recording
EDWARD C. WENTE, *Research Department*

Recent Advances in Wax Recording
HALSEY A. FREDERICK, *Research Department*

Sound Recording with the Light Valve
DONALD MACKENZIE, *Apparatus Development Department*

Speed Control for the Sound-Picture System
HUGH M. STOLLER, *Apparatus Development Department*

Sound Projector Systems for Motion-Picture Theaters
EDWARD O. SCRIVEN, *Apparatus Development Department*

Installation and Adjustment of Western Electric Sound-Projector Systems
HOWARD B. SANTEE, *Electrical Research Products, Inc.*

Fundamentals of Speech, Hearing and Music

By JOHN C. STEINBERG
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SOUND-PICTURES unite two long lines of development: one of the recording and reproduction of sound, affecting the sense of hearing; the other of the recording and reproduction of visual objects, affecting the sense of sight. The success attained in these lines has been largely due to research continually carried on in the fundamental facts of each and to the perfection of apparatus modified with each advance in knowledge.

The present paper briefly recounts some of the outstanding facts of the science of sound as it affects the development of the sound-picture. It compasses in reality five sub-sciences: one pertaining to hearing, the sense organ on which all perception of sound depends, two covering speech and music, the types of sound most commonly reproduced, and two covering musical instruments and the voice, the generators of the two main classes of sounds.

Speech is produced by streams of air forced out through the vocal passages by the lungs. The trachea or wind pipe is terminated at the upper end by the larynx which contains two muscular ledges, known as the vocal cords, forming a straight slit through which the air stream passes. During speech these cords vibrate so that the slit is alternately opened and closed and by this action a train of sound waves is set up in the lower part of the throat. As these waves pass out into the air, certain resonant and transient characteristics are impressed upon them by the vocal cavities and the movements of the tongue and lips, and it is these variations that are interpreted as speech.

All speech sounds are produced in this manner, except those symbolized by the letters p, k, t, f, s, ch, sh, and th (as in thin). These, called unvoiced sounds because the vocal cords play no part in their production, are

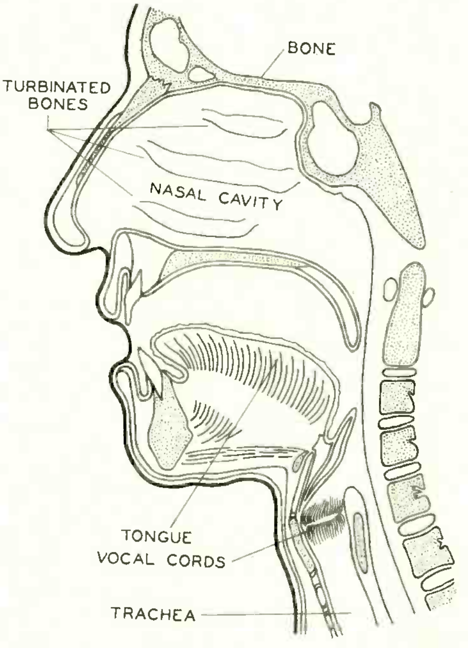


Fig. 1—*A cross-section of the human head showing relative positions of the vocal organs.*

produced by frictional vibration set up in the mouth itself. Both voiced and unvoiced sounds may be divided into two classes: those produced by a continuous flow of air, called the continuants, and those produced by the sudden stoppage of the air, called the stops. In the former class are such sounds as a, v, and f, and in the latter class such sounds as p, g, d, and t.

Although the vocal cords lend quality to the voice they do not give, to any great degree, the distinguishing characteristics of the speech sounds. These are produced mainly by the mouth and nose cavities, as is evidenced by the fact that we can understand whispered speech, in which the vocal cords play no part. As a matter of fact counterparts of the lungs and vocal cords can be located quite outside the body and still produce intelligible speech. This is actually accomplished by the artificial larynx, a piece of apparatus developed by Bell Telephone Laboratories for those who have undergone an operation known as tracheotomy, in which the larynx is removed and the wind pipe is terminated by a small hole in the patient's neck, through which he breathes.

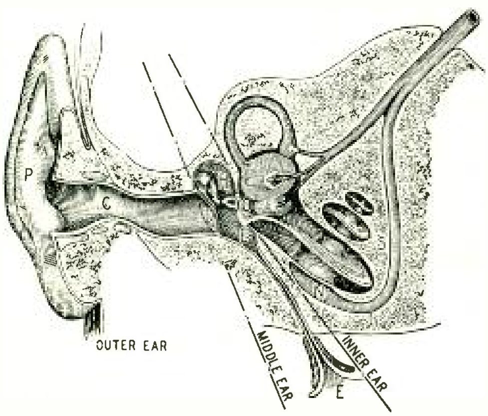


Fig. 2—A cross-section of the ear canal can only suggest its complex structure.

The mechanism of hearing may be divided into three parts: the outer, the middle, and the inner ear. The outer ear, consisting of the external parts and the ear canal, terminates at the drum. The middle ear contains three small bones, the hammer, anvil, and stirrup, which connect the drum with the small window or diaphragm, "O," of the inner ear. The inner ear is a spiral cavity, "S," in the bone, which is filled with liquid, and into it, as may be seen from the illustration, projects a spiral ledge. The liquid above this ledge is separated from that below it by a flexible membrane along which are distributed the nerves of hearing. Two windows, "O" and "E", retain the liquid at the base but at the apex there is a small hole through the membrane which allows liquid to flow from the upper side to the lower.

Sound enters the ear as successions of minute changes in the air pressure which are known as sound waves. These cause the ear drum to vibrate, and it is supposed that the liquid in the inner ear vibrates similarly, affecting the central membrane in different positions depending upon the frequency—the high tones disturbing one end of the membrane and the low tones disturbing the other end. This membrane may be compared to the keyboard of a player piano in operation, the keys at different parts of the scale being disturbed successively with the progress of the music. With the ear the pattern of the disturbance on the membrane is carried to the brain and there interpreted as speech sounds.

The range of pressure and frequency that the ear can perceive is represented on Figure 3 where the scale of abscissas is frequencies in cycles per second, and the ordinate is pressure in dynes. Frequencies above about 20,000 cycles are not perceived as sound nor are those below about 20. Any frequency between these limits, however, is recognized as sound if its pressure is above the lower boundary curve marked "Threshold of Audibility." The upper boundary, marked "Threshold of Feeling" indicates the pressure at which feeling begins. Above this line the sounds are felt, actually causing pain by their excessive pressure.

Frequency and pressure are only the physical characteristics of a sound; our mental responses are called pitch and loudness. Both of these vary logarithmically with their stimulus, difference in pitch between two sounds corresponding to the logarithm of the ratio of their frequencies, and similarly, differences in loudness are proportional to the logarithm of the difference in pressure, but with loudness the proportionality is not quite constant so that constant loudness lines are not truly horizontal. Because of this logarithmic law the illustration is plotted with logarithmic scales, and in addition an arbitrary loudness scale is shown on the right, the units of which, called sensation units, are defined as twenty times the logarithm of the pressure.

Studies on the wave forms of speech sounds have shown that the pitch of man's voice is of an order of 128 cycles per second, that of woman's voice of an order of 256 cycles, and with both, overtones of the fundamental cord tone occur. These studies have shown further that frequencies as high as 8000 or 9000 cycles exist in various speech sounds. Studies on the interpretation of speech sounds have indicated the presence of tones covering a large part of the audible frequency range. The location of the various parts of speech on the entire sound area is indicated in the illustration. Although in this figure the speech sounds have been grouped in sharply defined areas, actually the sounds overlap somewhat, and the indicated areas are those which are most important in the interpretation of the sounds. The three voiced consonants, symbolized by the letters v, z, and th (as in them), are exceptions and belong in the unvoiced consonant area.

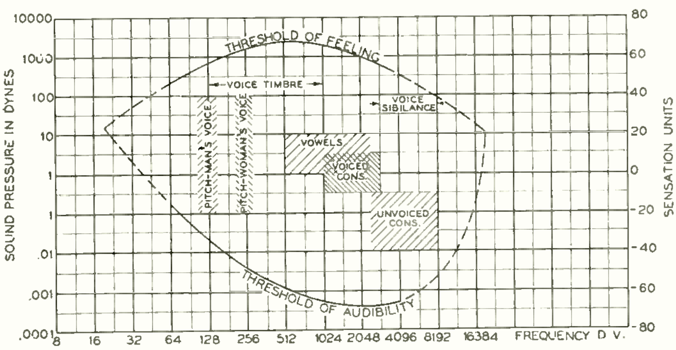


Fig. 3 — Any sound that can be heard lies within the field outlined here. Areas covered by the most prominent speech sounds are indicated.

In general, woman's speech is more difficult to interpret than man's, which may be due in part to the fact that woman's speech has only one-half as many tones as man's, so that the membrane of hearing is not disturbed in as many places. The greatest differences occur in the case of the more difficult consonant sounds which in woman's speech are not only fainter but require a higher frequency range for interpretation. The range from 3000 to 6000 cycles for man's voice corresponds roughly to the range from 5000 to 8000 cycles for woman's voice and since the ear is less sensitive at these higher frequencies and the sounds are initially fainter, their difficulty of interpretation is of course proportionately greater.

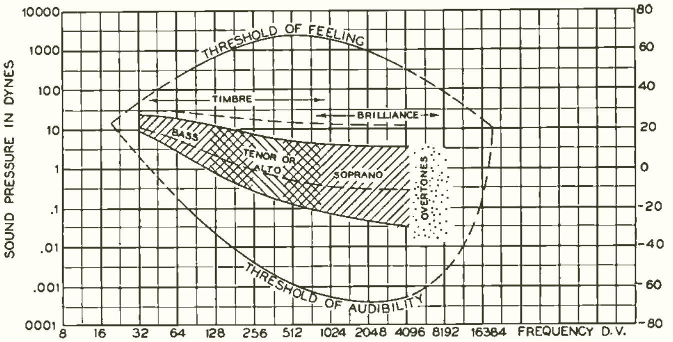


Fig. 4 — Constant loudness lines are not quite horizontal but slope down with increasing frequency as shown.

Musical sounds, like those of speech, consist of a fundamental frequency and various overtones, but unlike speech are sustained for appreciable lengths of time, and changes in them usually take place in definite steps, known as musical intervals. The frequencies that are present depend upon the type of instrument and the character of the music but the pitch of the tone is determined by the fundamental frequency which, however, need not be present in the musical tone, as the overtones, which are multiples of the fundamental, may cause the correct pitch sensation.

Musical instruments may be divided into two general classes, string instruments and wind instruments. Tones of string instruments, produced by plucking, striking, or bowing, are usually reenforced by resonating air cavities and sounding boards. Tones of wind instruments may be produced by the aid of reeds as with the clarinet or with the flute, or by the lips of the player acting as reeds, as with the horns. Each class may be further subdivided into melody and harmony instruments. In the former class only one note is usually produced at a time; in the latter class several notes are usually produced simultaneously. In general, harmony instruments are capable of producing notes over a much wider frequency range than melody instruments and a given type of instrument of the latter class may, therefore, include several instruments each covering different frequency ranges, such as the bass, tenor, and alto trombone.

Experiments have indicated that notes of different frequency or pitch as produced by a musical instrument appear about equally loud to the ear, which might be expected as the ear has played an important part in their design. In Figure 4 contour lines of equal loudness are shown for the frequency range from 32 to 4000 cycles, which has been divided into three parts, the bass, tenor or alto, and soprano registers, corresponding to the notes produced by various instruments. The contour lines indicate that the notes of the lower registers have greater sound pressures than those of the higher. The range of pressures for various instruments, however, is smaller for low notes, as has been determined by direct measurements of the pressures produced when played by musicians. Contour lines for loud tones show a smaller change in pressure in going from low to high notes than do the contour lines for faint tones so that it would seem that music played faintly would cover a greater pressure range than loud music.

Percussion instruments such as drums and the various accessory traps produce the greatest pressures that are used in music and although the fundamental frequency of the notes which they emit is fairly low, the complete notes are particularly rich in tones of higher frequency, extending as high as 10,000 cycles. Although these higher tones die out rather rapidly, they are essential to good definition.

The organ, the piano, and the harp have the greatest span, covering a frequency range from about 16 to 4000 cycles. All three of these instruments are characterized by a rather prominent first overtone, so that their effective range extends as high as 8000 cycles.

Melody instruments, owing to their limited range, are among the easiest to reproduce. In any given register, wind instruments produce greater intensities than string instruments, of which the violin produces the faintest sounds. As a class these instruments produce notes covering the frequency range of 32 to 4000 cycles.

From the auditory sensation area, we have seen that the ear is able to perceive a large number of tones of different intensity and frequency. We have also seen that the voice and various musical instruments produce tones which cover a large portion of the auditory sensation area. In order to obtain information as to the relative importance of various parts of this area to the sensory characteristics of speech and music, experiments have been performed in which the tones falling in various parts have been eliminated from the sounds by means of filters.

When frequencies below 100, 200, 300, or on up to 1000 cycles are progressively eliminated from speech, its character changes markedly, the terms "timbre" or "tone color" best describing the characteristic lost. This characteristic appears to be associated with the fundamental and the first few overtones of the voiced sounds and their presence is necessary, therefore, in order to convey this quality, but for the correct interpretation of the speech sounds frequencies below 300 cycles do not appear to be essential.

When frequencies above 8000, 7000, or on down to 3000 cycles are eliminated, the character of the speech again changes markedly; the term "sibilance", appearing to describe best the characteristic lost, refers to the prominence of the hissing or frictional character of speech. If attention is directed to such sounds as s, f, th, and z, the elimination of frequencies above 6000 or 7000 cycles is readily detectable, but it requires rather close attention to detect the elimination of frequencies above 8000 cycles. Elimination of frequencies above 7000 cycles, however, slightly impairs the interpretation of the s and z sounds of woman's voice and elimination of frequencies above 6000 cycles those of the f and th sounds of man's voice, and of the f, th, s, and z sounds of woman's voice. The impairment due to eliminating higher frequencies is usually greater in the case of female voices.

As with speech, the tone color or

timbre of musical tones also appears to be associated with the fundamental and the first few overtones of the note produced. Timbre is probably more important in music than in speech as it is one of the things that distinguish the tones of various instruments. In general, the fundamental and the first three or four overtones are necessary in order to distinguish the tones of various instruments. When overtones higher than these are eliminated the tones lose a characteristic best described by the terms "brilliance" or "definition"; they seem to lose life and become dull. The prominence of these characteristics varies with the type of instrument, the composition of the music, and the personality of the musician.

The notes which are used most in music are contained in the octaves below and above middle C, or from 128 to 512 cycles, and as the fourth overtone of 512 cycles has a vibration frequency of 8192 cycles, tones of this frequency and below occur frequently in music. A trained ear could no doubt detect the elimination of frequencies above this range from the ordinary run of music, but the average individual would have difficulty in detecting the elimination of frequencies above even 6000 or 7000 cycles, unless he gave particularly close attention to the percussion instruments.

Another phenomenon of hearing which enters into the sensation of sound is called masking. Lower pitched tones in a sound deafen the auditor to the higher tones, and this deafening or masking effect becomes very marked when the sound pressures of the lower tones are greater than twenty sensation units. The optimum loudness for the interpretation of speech corresponds to a sound pressure between 0 and 20 sensation units. If the sound pressure is less than this the fainter sounds are inaudible while if it is greater, the masking effect impairs the interpretation. When sounds are increased in loudness the lower registers are accentuated because of this masking effect so that for most faithful reproduction sounds should be reproduced with about the same loudness as the original sounds.

General Principles of Sound Recording

By EDWARD C. WENTE
Research Department

THAT sound is perceived by the ear as the result of a disturbance in the air was known to the ancient Greeks, and that objects are set in vibration by intense sounds must have been observed by primitive man, but it was not until 1857, or less than a century ago, that the first instrument was constructed for making a graphical record of sound waves. In that year Léon Scott patented in France an instrument (Figure 1) which he called the phonautograph. A piece of smoked paper was attached to the cylindrical surface of a drum, so mounted that when rotated by hand it moved forward at the same time. A stylus was attached to the center of a diaphragm through a system of levers in such a manner that it moved laterally along the surface of the cylinder when the diaphragm vibrated. Over the diaphragm was placed a barrel-shaped mouthpiece. When the drum was rotated, words spoken into the mouthpiece caused the stylus to trace a wavy line upon the smoked paper. This wavy line was the first known record of sound vibrations.

It was twenty years later, in 1877, that Edison brought out an epoch-making invention. He constructed a machine very similar to the phonautograph but differing in two important details. The smoked paper was replaced by a sheet of tinfoil, and the stylus was attached directly to the diaphragm so that it traced an impression of variable depth, as the diaphragm vibrated, instead of a wavy line as with the phonautograph. After such a record had been made the drum was returned to the starting point and, with the stylus in place, again rotated as before. The recorded sound was then intelligibly reproduced. Thus Edison gave us the first phonograph.

In subsequent models the tinfoil was replaced by a wax cylinder. For many years the wax record, either in cylinder or disc form, was used almost exclusively for the recording and reproducing of sound. Although many other methods of recording have been suggested, it is only in the last few years that records made photographically have come into the

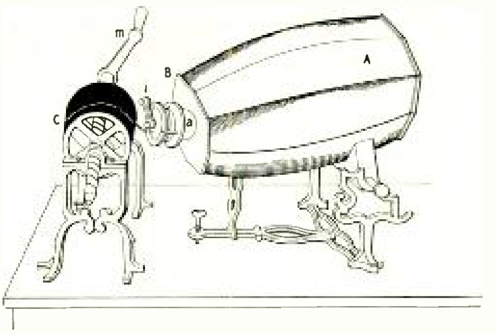


Fig. 1 — Sound was first recorded on the phonautograph of Léon Scott.

commercial field as competitors. At the present time both the wax and the photographic records are used in conjunction with motion pictures.

Photographic records are now being made by many different types of apparatus, but they may be divided into two general classes. In one of these, the record is a trace of constant photographic density but of variable width, while in the other the width is constant but the density varies. In one or two proposed methods the record is a combination of both types.

Almost all systems experimented with today have at least one element

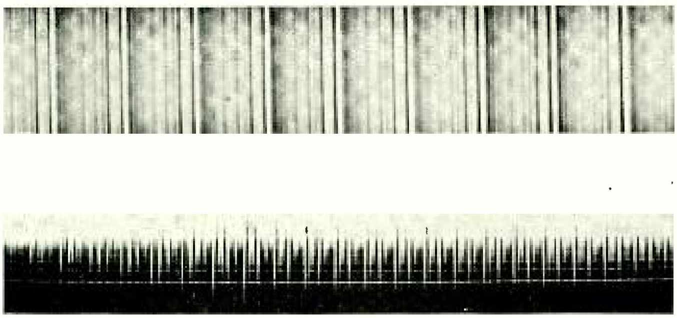


Fig. 2—Photographic records of sound may be either of constant width and varying density, shown above, or of constant density and varying width, show below.

in common with the phonautograph: a diaphragm that is set in vibration by the sound to be recorded. The diaphragm may be mechanically connected to the engraving mechanism or recorder as in the phonautograph, or, it may be electrically connected as in most modern systems. In practically all systems the diaphragm forms an essential element.

Unfortunately a diaphragm does not in general have the same response at all frequencies. A favorite experiment in lectures on elementary physics is to sound a tuning fork and with it, through the air, set in vibration a second tuning fork. In this experiment it is important that the pitch, or the resonant frequency, of the two forks be very nearly the same, or the motion set up in the second fork will be too small to be observable. Diaphragms, and in fact almost any other type of mechanical system, will have at least one resonant frequency, which means that, under the action of sound waves, the response will be much greater at this frequency than at any other.

In the older methods of recording resonance was purposely introduced in order to obtain records of sufficient amplitude. The frequencies lying in the resonance region were then much over-emphasized. The sound reproduced from such records had a blasting and metallic quality, and well deserved the title "canned music."

Because of the complex nature of speech and music and of the great amount of distortion introduced by the early recorders and reproducers, the surprising thing is not that the quality of reproduction was poor, but that the reproduced sounds were at all intelligible. In fact it has been suggested that the invention of the telephone, which preceded the phonograph, might have been delayed for many years had the complex nature of speech sounds been generally known at the time, since its inventor probably would have dismissed his ideas as altogether impracticable.

Although considerable distortion may be introduced by the recording and reproducing systems before the character of the sounds is so changed that they can no longer be recognized, the amount of distortion must be kept extremely small, if all classes of sounds are to be reproduced to such a degree of fidelity that the ear cannot distinguished them from the original. It is necessary, therefore, to diminish the distortion by the diaphragm to a negligible value.

The electrical method of recording, which is today widely used in the production of commercial sound records, has been developed primarily so that a diaphragm giving a uniform response may be used and at the same time a record of sufficient amplitude be obtained. In the modern method the pick-up diaphragm is made a component part of the recording microphone. Here a small amplitude of motion will serve, as the voltage generated may be amplified to an amount sufficient for operating a rugged and distortionless recorder. A comparison of the diaphragm in the Edison recorder with that of the microphone used in the majority of present recording systems is interesting. In the former the maximum amplitude required for the loudest sounds is about 0.001 inch, whereas in the latter under ordinary recording conditions it is only about one-tenth of this amount, and the weight of the microphone diaphragm is only one-twentieth as great as that of the Edison recorder. It can thus be seen how the problem of design of a pick-up diaphragm is greatly simplified in the electrical method.

It is important, of course, that the rest of the recording system shall also be free from distortion. If a microphone of uniform response is available, however, the design of a distortionless recorder is made comparatively easy, for its sensitivity may to a large extent be disregarded, as the required power can be obtained by vacuum-tube amplifiers. In the electrical method, extraordinary improvements have been made over the older systems in elimination of distortion.

The problem of developing recording apparatus is in many respects identical with that of developing high quality radio transmitters. With recording apparatus, however, there is the additional problem of distortion introduced by the record itself. If, for instance, a record is run at a speed of ten inches per second, and a tone having a frequency of 5,000 cycles per second is recorded, the length of one cycle on the record will cover a distance of only 0.002 inch. In the case of wax records the needle must have a very fine point; and in the photographic record the width of the light beam as measured along the direction of motion of the film must be extremely small. At whatever speed the record may be driven, there will always be some frequency beyond which all tones will become more and more attenuated. Although the loss of the higher frequencies does not

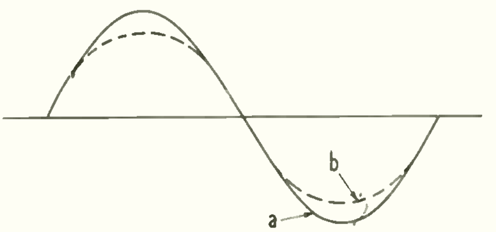


Fig. 3—Non-linear distortion changes the shape of a sine wave form from "a" to the flatter top type of "b".

impair the tone quality as much as does the presence of sharp resonance regions, yet it reduces the intelligibility of speech and the richness and brilliancy of musical sounds.

There is another type of distortion commonly present in reproduced sound, which is frequently designated non-linear distortion. It is introduced when the response of any element of the system is not proportional to the stimulus. A pure tone, for example, of sine wave form, as shown in "a" of Figure 3, may be reproduced so as to have a wave form like that of "b". Distortion of the wave form in this manner is equivalent to the introduction of extraneous frequencies. If the magnitude of these added frequencies is too great, the tone quality will be very disagreeable. A small amount of distortion of this kind, however, is not noticeable, because the primary tone will mask the extraneous one. It is a well known fact that a tone must be much more intense to be heard if another, and particularly a lower, tone is sounded simultaneously.

A type of distortion peculiar to recording is that introduced by a non-uniform speed of the medium on which the record is being engraved. This may not always be serious, but in certain cases of sustained tones, speed variations cause a disagreeable flutter and in some types of music a decided harshness of tone.

One of the most serious problems with which the radio engineer has to contend is static interference. This also has its counterpart in sound reproduction from records. As the ether through which the radio waves are sent is non-homogeneous because of extraneous electrical disturbances, so the sound record is non-homogeneous on account of the non-uniformity of the material on which it is engraved. The noise resulting from these irregularities is often designated as surface noise. With the wax record, most of this noise has its origin in the minute irregularies of the material and with the photographic record, in the finite size of the grains forming the photographic image.

The difficulties of eliminating this noise arise from the fact that the physical intensity of audible sounds covers an exceedingly wide range. The ratio of pressures of the maximum to the minimum is about ten million. If a record of this extreme range of volume were to be recorded the amplitude of the loudest tone would have to be ten million times as great as for the faintest tone. There is a maximum amplitude that a record can accommodate, which in the case of the wax record is about 0.002 inch. If a tone having an intensity near the maximum level is recorded at this amplitude, the amplitude of a tone just audible would be only 0.000,000,000,2 inch. It is difficult to get a material having a degree of homogeneity corresponding to this value.

A similar condition exists with photographic records where the pattern is formed by grains in the emulsion which have a magnitude somewhat less than 0.000,05 inch, depending upon the type of emulsion used. The range of volume considered here is extreme, of course, and in practice it is not necessary to record a range of this extent, but it serves to illustrate the extraordinary requirements placed upon the recording medium. When the range of frequencies that are to be reproduced is increased, the surface noise effect becomes greater. As in the case of the different types of distortion discussed above, the difficulties to be met are increased as the quality of reproduction is improved.

Recent Advances in Wax Recording

By HALSEY A. FREDERICK
Research Department

SUCCESS of recording and reproduction of sound by the so-called "electric" method with a disc record may be considered as depending on several factors. In order, these are: the studio, with its acoustic conditions; the microphone; the amplifier; the electro-mechanical recorder; the "wax" record; the copying apparatus and procedure; the hard record, or "pressing"; the electric pick-up; the amplifier; the loud speaker; the auditorium. The chief problem is that of making the speech or music reproduced in the auditorium a faithful duplicate of the original sounds, using this chain of apparatus. Cost, reliability, and the time required for the process of recording are among a number of other considerations, but these are all subordinate to the problem of fidelity. While it may be convenient or even necessary to introduce distortion into certain of the steps to compensate for such distortion as may be unavoidable in others, experience shows that it is desirable for the sake of simplicity, reliability and flexibility to reduce such corrective warping to a minimum, and to make each step in the process as nearly perfect as possible.

Perfection of a complete recording and reproducing system may be judged by the practical method of listening to the overall result. Each element of the system must be analyzed thoroughly, however, if outstanding excellence is to be attained. One of the most useful of the means of analysis is study of the response-frequency curve. In order that all frequencies be reproduced equally and that the ordinary faults of resonance be avoided, this curve must be flat and, particularly, free from sharp peaks. Good reproduction requires that frequencies from 50 to 5,000 cycles be included without discrimination. If however frequencies down to 25 or 30 cycles be included, a noticeable improvement will be obtained with some classes of music, while if the upper limit be increased to 8,000 or even 10,000 cycles, the naturalness and smoothness of practically all classes of reproduction will be noticeably improved.

A second important criterion of any system is that the ratio of output to input shall not vary over the range of currents or loudnesses from the minimum up to the maximum used. If this requirement be not met, sounds or frequencies not present in the original will appear in the reproduction. This is the type of distortion commonly produced by an overloaded vacuum-tube amplifier; it is often called non-linear distortion.

A third requirement not entirely dissociated from the first two is that any shifts in the phase relations shall be proportional to frequency.

Since our standards of perfection in sound-reproducing systems are growing constantly more exacting, over-all results that seemed excellent a short time ago are only fair today, and before long may seem intolerable. It has, therefore, been necessary for the analysis of each step of the system to be constantly more searching and fundamental.

Of the eleven links in the chain of apparatus for electrical recording and reproduction, only five are pe-

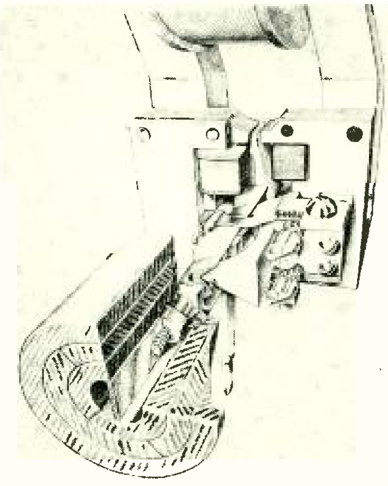


Fig. 1—Section of electrical recorder.

culiar to the wax method. These are the electro-mechanical recorder, the wax record, the copying apparatus, the "pressing," and the pick-up or reproducer. The extent to which the wax method is capable of the highest quality of reproduction will be disclosed by an examination of these five links. Any consideration of the practical advantages or disadvantages of the method can logically follow this examination into the quality possibilities. The considerations which follow refer to the so-called lateral-cut records, in which the grooves are of constant depth and oscillate or undulate in each case about a smooth spiral. This type of record is used in the Western Electric Company method of synchronized motion pictures which uses disc records. Some, but not all, of the considerations might apply to "hill and dale" records, but the characteristics of these records will not be discussed.

The first piece of apparatus in the chain unique to the wax process is the electro-mechanical recorder, whose function is to receive power from the amplifier, and with it drive a mechanical recording stylus. The present-day recorder is a highly developed apparatus based on extensive experimental as well as theoretical studies. Recorders which have been supplied by the Western Electric Company have been designed to operate over a range of frequencies from 30 to 5,500 cycles. The device operates in linear fashion over the range of amplitudes involved in speech and music. As is seen in Figure 2, the response falls off below about 250 cycles. This falling characteristic is necessary in order that the maximum loudness be obtained from a record for a given spacing between grooves without cutting over from groove to groove. A characteristic of the pickup is that the voltage induced in its windings is proportional to the velocity with which the armature moves. In order therefore that a lateral oscillation of the needle point may furnish constant output voltage, it is necessary that the lateral velocity of the needle point be constant. For a sine wave, velocity is proportional to the product of amplitude and frequency, so that as frequency increases, amplitude must decrease proportionately. With the characteristic shown with these recorders, constant velocity is obtained from about 250 cycles to 5,500 cycles. Below 250 cycles an approximately constant amplitude is obtained. If,

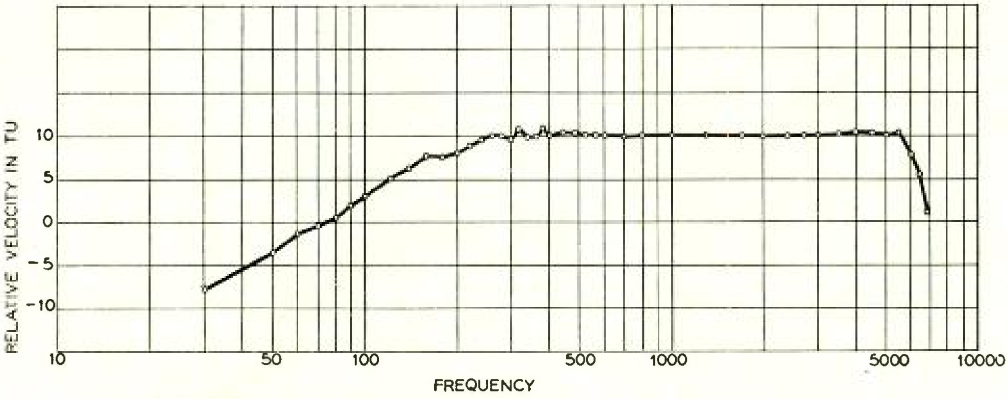


Fig. 2—Typical frequency characteristic of a commercial recorder.

therefore, sounds of constant absolute intensity are to be recorded over this range of 30 to 250 cycles, there is equal tendency for sounds of the different frequencies in this range to over-cut the record groove. Attenuation of the lower frequencies by the recording apparatus may be corrected in reproduction by a suitable electric network. Such a network will increase the subsequent amplification required but, as this additional amplification occurs in the first stages, it is not expensive. Practically it has not been found necessary or desirable to introduce such a corrective network since the correction has been largely cared for by the characteristics of the pickups which are used.

Recent development studies have established the possibility of flattening the response at the low-frequency end and of raising the high frequency cut-off of the recorder. The characteristic obtained with a laboratory model shows uniform performance within ± 1 TU from 250 to 7,500 cycles and within ± 4 TU from 30 to 8,000 cycles. Although its immediate practical value may be limited by other portions of the system, this device is of great interest in that it establishes beyond question the fact that an extremely broad range of frequencies can be successfully recorded in the wax.

The broad, flat characteristic obtained with electric recorders has

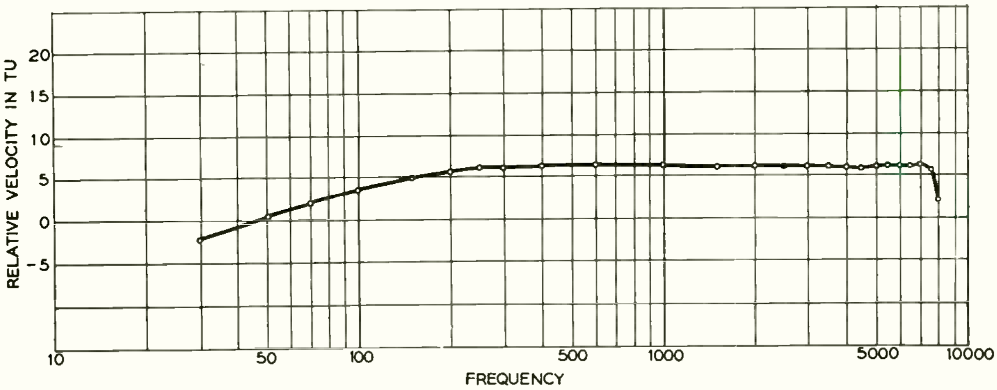


Fig. 3—Frequency characteristic of a recent laboratory recorder.

been made possible by so designing their elements that they constitute correctly designed transmission systems. In such a transmission system, whether it be an electrical recorder or a long telephone line, a correct terminating impedance is required. The load imposed by the wax is somewhat variable but fortunately is rather small. It has been found desirable to make the other impedances in the recorder relatively large so as to dominate the system and thus minimize the effects of any changes in the impedance imposed on the stylus by the wax. The mechanical load used as a terminating impedance and to control the device has consisted of a rod of gum rubber ten inches long. Torsional vibrations are transmitted along this rod at about one hundred feet per second so that its length is equivalent to an ideal electrical line of about 1,500 miles. Loss of energy along this rubber rod is such that a vibration is substantially dissipated by the time it has travelled down the line and back. Thus the rod constitutes a substantially pure mechanical resistance, whose magnitude is approximately 2,500 mechanical abohms, referred to the stylus point as its point of application.

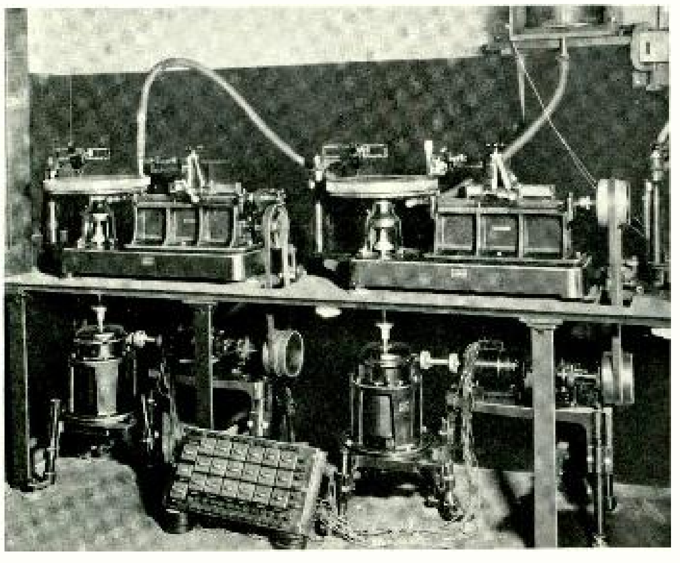


Fig. 4—Two recording machines arranged to be driven synchronously with cameras.

In recording, the usual procedure is to use a disc from one inch to two inches thick and from thirteen to seventeen inches in diameter, composed of a metallic soap to which small amounts of various substances have been added to improve the texture. This disc, commonly called a "wax," is shaved to a highly polished surface on a lathe, and then is placed in a recording machine, essentially a high-grade lathe by which the wax is rotated at a very uniform rate and in definite relation to the film with which it is being synchronized. The recorder with its cutting tool is moved radially across the surface of the disc, common phonograph procedure being to record from the outer edge of the disc toward the center, whereas with records for Western Electric sound pictures the direction of cutting is reversed. After a record has been cut the wax may be handled, and with proper precautions may be shipped from place to place.

The shape of the groove varies somewhat in commercial practice. That used in records for Western Electric apparatus is approximately

0.006 inch wide and 0.0025 inch deep, and the pitch of the spiral is between 0.010 and 0.011 inch, so that the space between the edges of the grooves is about 0.004 inch. Thus the maximum safe amplitude is about 0.002 inch. If this is reached at 250 cycles the corresponding amplitude at 5,000 cycles, assuming that the sound is constant in absolute intensity over the intervening range, will be only 0.0001 inch.

In the records used with Western Electric apparatus the linear speed of the groove past the reproducer point ranges from 140 feet per minute, at the outside of the spiral, to 70 feet per minute at the inside. The rate of rotation is dependent upon the outer diameter of the grooves which is determined primarily by the length of time to be covered by a single disc. When the minimum linear speed and the groove spacing are decided upon, there is an optimum relation between the size of the record, the rate of rotation and the playing time.

Since any roughness in the walls of the groove introduces extraneous noise in the reproduced sound, it is important that the groove be kept truly smooth. Before starting, the surface of the disc must be shaved to a high polish, and the texture must be fine and homogeneous. Not only must the composition be correct, but the proper temperature must be maintained during recording. Waxes may be obtained commercially whose texture is satisfactory over the ordinary range of room temperatures. The disc must be levelled in the recording machine with reasonable care, and the stylus must be sharp and of a shape to insure a clean cut. The wax shaving is removed as cut by air suction. To aid in maintaining the cut at the correct depth there is a so-called advance ball which rides lightly on the surface, supporting the stylus at the proper height in spite of small inaccuracies in levelling the disc or deviations from planeness. For adjusting the advance ball with respect to the stylus, the groove is observed with a calibrated microscope. Maintenance of the necessary adjustments and satisfactory operation of the recording machine requires an ordinarily skilled mechanic with reasonable experience.

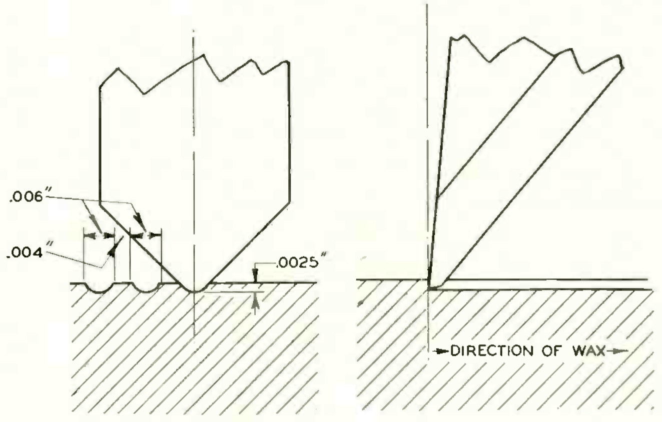


Fig. 5—Details of the stylus point of the recorder. Left, a radial section through the wax; right, a section looking from the stylus point to the center of the disc.

After a record has been cut, the sound may be reproduced directly from the wax by means of a suitable pick-up or reproducer. Ordinary reproducers rest much too heavily on the records to be used on wax; the vertical pressure between needle point and record in an ordinary phonograph is of the order of 50,000 pounds per square inch. Obviously any such pressures would destroy a groove in the wax.

These high pressures have been necessary in order that the groove might drive the needle point of the reproducer properly; their reduction requires reduction of the impedance offered by the needle point to transverse vibration. Such reduction of the impedance of a "playback" mechanism requires that both its mass and its stiffness be cut down to a minimum. That now available has been designed with those requirements in view, and represents a large advance toward ideal reproduction. Whereas playbacks formerly in use failed to reproduce the higher and lower frequencies with much satisfaction, response of the new piece of apparatus is not widely different from that obtained from finished records with the best electric pick-ups now available. The response is sufficiently good to serve as a most valuable criterion in judging the quality of a record immediately after recording. At the same time, a record may be played a number of times without great injury. At low frequencies there is little change and at the higher frequencies a loss of about 2TU per playing. The opportunity thus made available for an artist to hear and criticize the results of his efforts, immediately at the end of his performance, can hardly be overestimated in its value to studio and recording operation.

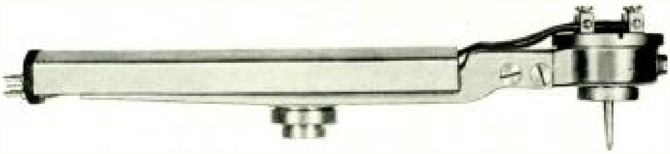


Fig. 6—Playback for reproduction directly from wax discs.

After a groove has been cut into the wax record, the usual procedure is to render the surface conducting by brushing into it an extremely fine conducting powder. It is then electroplated. The technique in this step varies somewhat among the various companies producing records, although fundamentally the process is the same with all. The electro-plate thus made, a negative of the original wax, is called a "master." From it two test pressings are usually made, using a molding compound such as shellac containing a finely ground filler. If they are satisfactory the master is then electro-plated after being treated to permit easy removal of the positive plate. From the positive, commonly called an "original," there is plated a second negative—a metal mold, commonly called a "stamper." From it, duplicate "originals" may be plated, and from them, duplicate "stampers." These successive plating processes involve no measurable injury to the quality of the record, and are comparatively simple and extremely safe in practice. By the custom of making a number of duplicates the master is protected from accidents to which it would be subject were it to be used directly for making finished records. The stampers instead are used to mold the final product, or "pressing"; it is not unusual to make a thousand pressings from a single stamper. Test pressings are commonly obtained from the wax in twelve hours, and recent refinements have so reduced the time for the various processes that finished pressings may now, when necessary, be obtained within three hours after

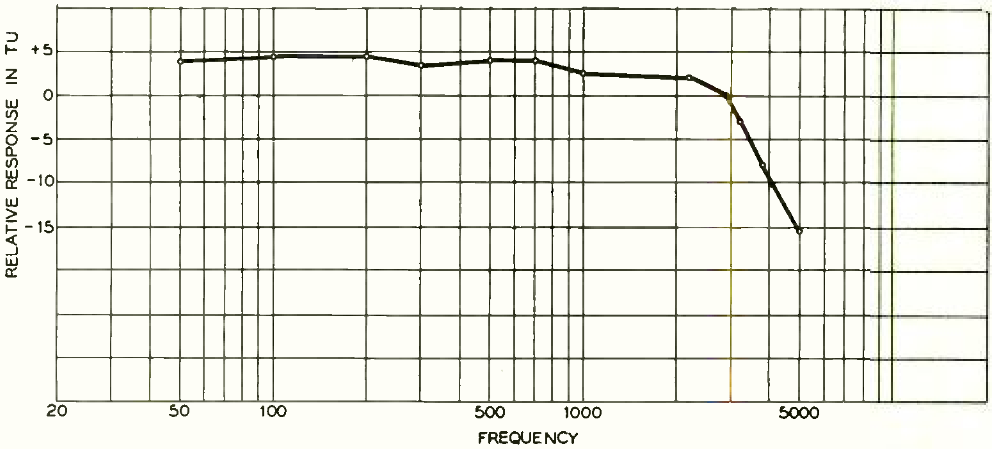


Fig. 7—Response of the wax playback of Fig. 6 driven by a constant-velocity wax record.

delivery of the wax. The pressing copies the wax record with such a high degree of accuracy that if frequency characteristics alone be considered, it shows almost complete perfection. Moreover it is cheap and durable, and as with an ordinary phonograph allows reproduction of sounds without careful adjustments or complex apparatus.

Various materials have been used in making the pressings. In some cases the material has been homogeneous, and in others the surface and the body of the record have been of different materials. Some records have been of laminated structure. There has not, however, been much latitude allowed the experimenter in his selection of materials. The records must be quite hard and, to have a reasonable life, must contain enough

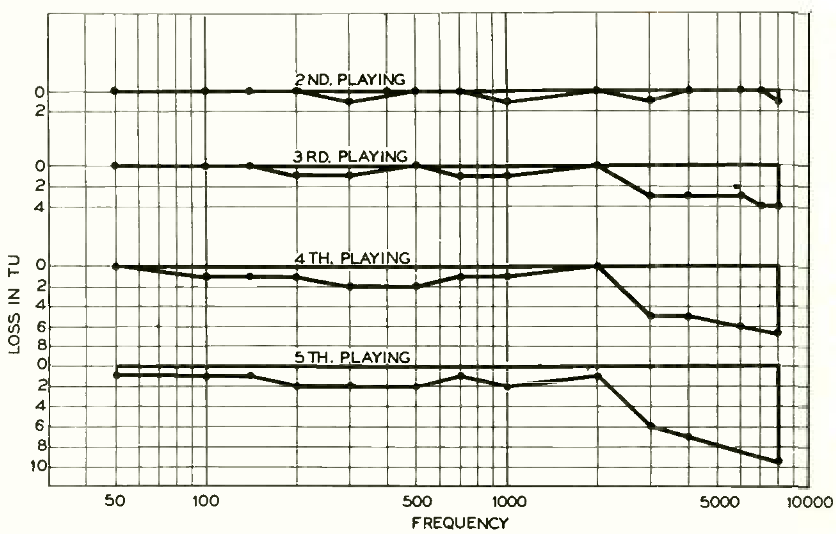


Fig. 8—Loss in response of a wax playback driven by a constant-velocity wax record, on successive playings.

abrasive to grind the needle quickly to a good fit. At the beginning of the run of a new needle the pressures are very high, on account of the small bearing surface. They decrease rapidly however, so that with an ordinary loud steel needle in a phonograph of the usual type the bearing surface is increased to such an extent after one minute's wear that the pressure is only about 50,000 pounds per square inch. The high pressures and the necessary abrasive characteristics have introduced irregularities which are responsible for most of the extraneous noise commonly known as "surface" or "needle scratch."

Recent development in the material of the finished records, together with refinement in the plating processes, have reduced the surface noise of records used in Western Electric Company theatre equipment by fifty to seventy-five per cent within the last two years. It is not necessary to reduce the level of surface noise to the zero-point, but merely to the threshold of audibility under the minimum auditorium noise. Moreover, the important point is not the absolute amplitude of the imperfections giving rise to surface noise but their relative magnitude with respect to that of the useful sound amplitudes. Thus an effective reduction in "surface" could be made by using larger records or reducing the playing time of the present records, in either case increasing the spacing of the grooves and the amplitude with which they are cut. Conversely, any large reduction in surface noise made by an improvement in the record material would make it possible to increase the playing time for records of a given size. There is no known absolute or fundamental reason why further improvements in record materials may not be expected, with corresponding reduction in surface noise. Furthermore large advances in pick-up design offer distinctly new possibilities for reduction in "surface."

It has sometimes been thought that in order to reproduce high frequencies properly, the linear speed of the record would have to be increased or the size of the needle point reduced. The factor determining whether a needle will follow the undulation of the groove is not its diameter relative to the length of the undulation, but the relation between the radii of curvature of the needle and the bend of the groove. At present the bearing portion of a representative needle

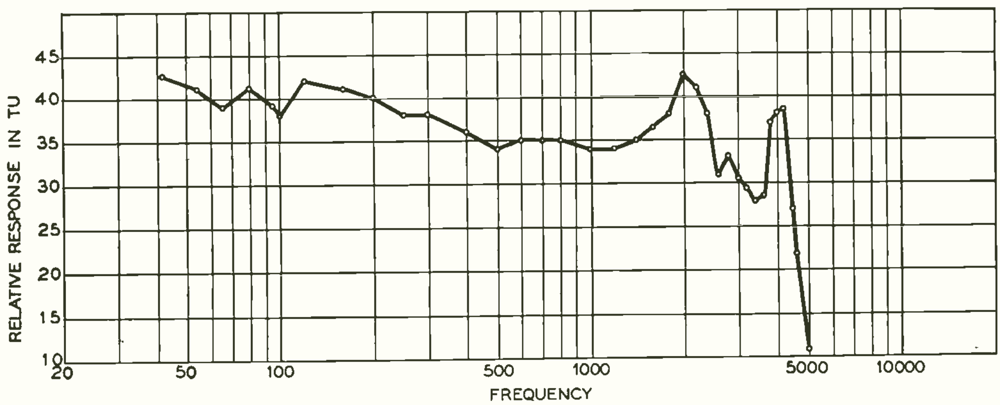


Fig. 9—Response of a 2-A pick-up driven by a constant-velocity pressing.

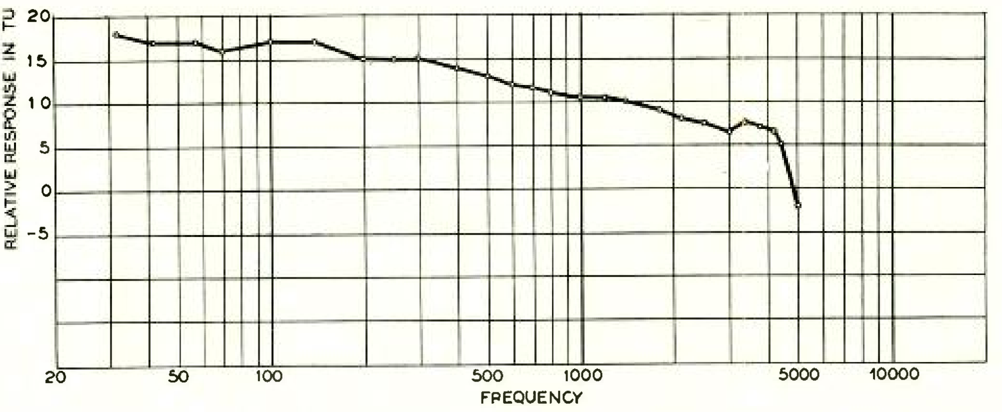


Fig. 10—*Response of a 4-A pick-up driven by a constant-velocity pressing.*

is about 0.003 inch in diameter whereas the half wave-length for a 5,000 cycle wave is 0.0014 inch. As mentioned before, the amplitude at 5,000 cycles would be only about 0.0001 inch if sounds of that frequency were as intense as those of lower frequencies. With the assumption of an amplitude of 0.0001 inch at 5,000 cycles and a linear record speed of seventy feet per minute, the minimum radius of curvature of the undulation is 0.00193 inch. On a corresponding basis, the radius of curvature of the undulation becomes equal to that of the needle point at about 7,000 cycles. As a matter of fact, sounds of 5,000 cycles or more in speech and music are characterized by lower intensity than those of lower frequency, and the amplitude of their undulations is correspondingly less. Present commercial needle points are therefore quite capable of following the undulations up to frequencies of at least 10,000 cycles. The limitations to high-frequency reproduction commonly found in the past have come from imperfections in the design of the pick-up or reproducer. They were caused mainly by inability of the record groove to drive the needle point, with resultant chatter, and by failure of the pick-up structure to transmit high-frequency motions from the needle point to the armature.

Large advances have been made within the last two or three years in designing electric reproducing structures. The mechanical impedance at the needle point has been reduced so that the point follows the undulations of the groove truthfully without the necessity of somewhat destructive bearing pressures. At the same time the mechanical transmitting structure has been so designed that a very broad range of frequencies is conveyed properly from the needle point to the armature. Moreover, proper mechanical loads have been provided so that the vibrations are absorbed after they operate the armature; resonance as ordinarily considered has been eliminated.

The curves shown in Figures 9 to 11 show the improvement which has been made. The pick-up shown in Figure 10 is free from the resonances shown in Figure 9. In the earlier pick-up there were high needle-point impedances in the region of these resonances, involving large driving forces destructive to both needle and record. Certain records were injured by only a few playings with this reproducer.

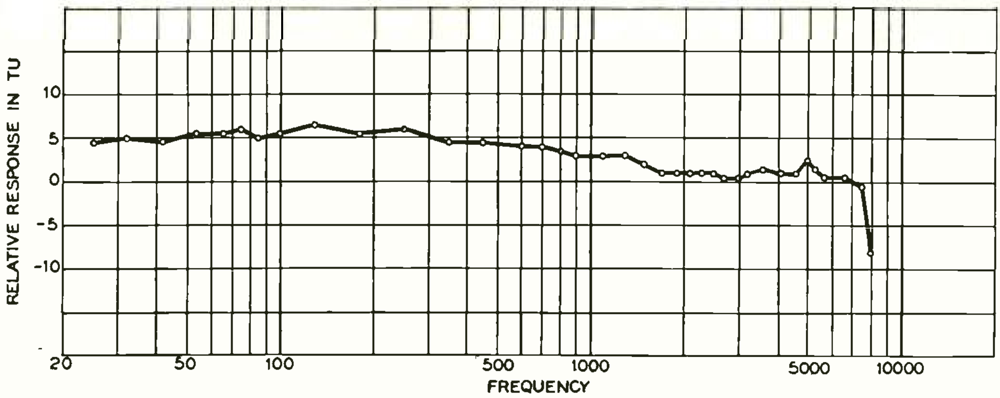


Fig. 11—Response of experimental pick-up driven by a constant-velocity pressing.

The reproducer of Figure 10 is characterized not only by considerably reduced average needle-point impedance but, as shown on the curve, by a practical elimination of resonance. Hence there is an even greater reduction from the maximum impedances which occurred at resonance in reproducers of the earlier type. Both needles and records have a longer life with the later type pick-up, which has been in commercial use for several months. In addition, as is seen, the higher frequencies are reproduced in considerably better fashion. A third curve, Figure 11, was obtained with a more recent experimental model in which a lighter, though very much more rigid, structure is used to connect the needle point with the armature. In this model a further large reduction in needle-point impedance has been effected, with corresponding reduction in wear on the records; in addition greatly improved reproduction has been secured at the high-frequency end of the scale.

The developments and inquiries heretofore discussed, although in many cases undertaken for their application to sound pictures, are of direct application to phonograph reproduction for any purpose, irrespective of whether the sound is to be accompanied by a film. Application of the processes to records which are to be synchronized with motion pictures has in addition involved meeting a number of conditions not previously encountered in the phonograph field. One of the most important of these relates to editing, cutting and rearranging of a picture, with the attendant necessity of rearranging the speech or music. Various methods have been used to copy or "dub" a disc record by playing it and recording on a new wax the parts that are wanted. The prime requirement is that the sacrifice in quality be kept at a minimum. To attain this end records have sometimes been copied at very low speed. This method appears unnecessarily laborious and slow and the results obtained are not altogether satisfactory in the light of possibilities presented by pick-ups and recorders of the characteristics shown above. Rearrangment of material on records is entirely practicable, and portions may be deleted, new portions added, or new sounds added to those already recorded; in fact any changes of this type may be made which can be made in the picture. Although the detailed technique of rearranging, or "dubbing," is not highly developed at present, its advancement appears to offer no serious technical difficulty. Hence the refinement reached will probably depend on the rate at which improvement takes place, and the extent to which the method is used in the field of sound pictures.

Sound Recording with the Light Valve

By DONALD MacKENZIE
Apparatus Development Department

OF the several ways by which sound can be recorded on motion-picture film, one has seemed to engineers of Bell Telephone Laboratories to offer most immediate promise. This employs a light beam of constant intensity and varying width to produce a trace of varying density. Modulation of the light beam is effected by an electromechanical light valve actuated by speech currents which have been amplified to a suitable volume.

The light valve consists of a loop of duralumin tape suspended in a plane at right angles to a magnetic field. When the assembly of magnet and armature is complete, the two sides of the loop constitute a slit 0.002 by 0.256 inches, its sides lying in a plane at right angles to the lines of force and approximately centered in the air gap. The ends of the loop are connected to the output terminals of the recording amplifier. If the magnet is energized and the amplifier supplies an alternating current, the loop opens and closes in accordance with the current alternations.

When one side of the wave opens the valve to 0.004 inches and the other side closes it completely, full modulation of the aperture is accomplished. The natural frequency of the valve is set by adjusting the tension of the tape; for reasons which involve many considerations, the valve is tuned to seven thousand cycles per second. Under these circumstances about ten milliwatts are required for full modulation at a frequency remote from resonance; about one one-hundredth of this power at the resonant frequency. The impedance of the valve with protecting fuse is about twelve ohms.

If this appliance is interposed between a light source and a photographic film we have a camera shutter of unconventional design. Figure 2 shows a diagram of the optical system for studio recording. At the left is a light source, a ribbon-filament projection lamp, which is focussed on the plane of the valve. The light passed by the valve is then focussed with a two-to-one reduction on the photographic film at the right. A simple achromat is used to form the image of the filament at the valve plane, but a more complicated lens, designed to exacting specifications by Bausch and Lomb, is required for focussing the valve on the film. The undisturbed valve opening appears on the film as a line 0.001 by 0.128

inch, its length at right angles to the direction of film travel. The width of this line varies with the sound currents supplied to the valve, so that the film receives exposure to light of fixed intensity during the varying time required for a given point to traverse the varying aperture of the slit.

Recording in the studio is carried out on a film separate from that which receives the picture. This practice permits the use of two machines to make duplicate sound records, an insurance which is well worth its cost. The practice of separate negatives for sound and picture also permits the picture negative to be developed and printed according to well-established technique, and allows the necessary latitude in developing the sound record. The recording machine is driven by a motor synchronously with the camera. Lest there be any variation in the velocity of the film past the line of exposure, the sprocket which carries the film at that point is driven through a mechanical filter which holds the instantaneous velocity constant to one part in one hundred.

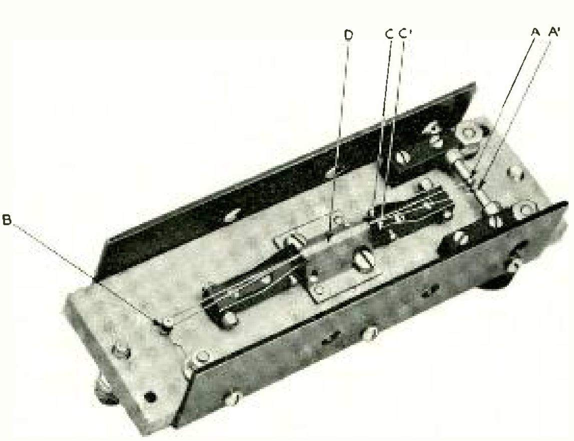


Fig. 1—*The light valve. A duralumin tape,* 0.006 *inch wide and* 0.003 *inch thick, is secured to windlasses A and A' and stretched tight by the spring-held pulley B. At points C and C' insulated pincers confine the central portions of the tape between windlasses and pulley to form a slit* 0.002 *inch wide. Supporting this loop and adjusting devices is a slab of metal with central elevation D, which constitutes the armature of an electromagnet. The central portions of the loop are supported on insulating bridges just above the face of D; here the sides of the loop are centered over a tapered slot. Viewed against the light, the valve appears as a slit* 2 *mils by* 256 *mils.*

In the recording machine a photoelectric cell is mounted inside the left-hand sprocket which carries the film past the line of exposure. Fresh film transmits some four per cent of the light falling on it, and modulation of this light during the record is appreciated by the cell inside the sprocket. This cell is connected to a preliminary amplifier mounted below the exposure chamber, and with suitable further amplification the operator may hear from the loud speaker the record as it is actually being made on the film. Full modulation of the valve implies complete closing of the slit by one side of the wave of current; this modulation may not be exceeded or photographic overload will abound.

Adding sound to the picture introduces no complication of studio technique other than to require sufficient rehearsing to make sure of satisfactory pick-up of the sound; microphone placement must be established and amplifiers adjusted to feed to the light valve currents which just drive to the edge of overload in the fortissimo passages of music or the loudest utterances of speakers. Provision is made for combining if desired the contributions of several microphones on the set. This combination is under the control of the mixer operator in the monitoring room, who views the set through a double window in the studio wall. The mixer controls also the gain of the amplifiers for the recording machines. Relays permit the mixer to connect the horn circuit either directly to the recording amplifier or to one or the other of the monitoring photoelectric cells in the film recorders. The direct connection is used in preparing the sound pick-up in the studio: the program is rehearsed until satisfactory arrangement of microphones and of amplifier gain is effected. The electrical characteristic of this direct monitoring circuit is so designed that the sound quality heard in the horns shall be the same as the quality to be expected in the reproduction of the positive print in the theater. Acoustic treatment of the walls of the monitoring room secures the reverberation characteristic of the theater, and the monitoring level is so adjusted that the mixer operator hears the same loudness that he would wish to hear from the theater horns. It is capitally important that the operator judge his pick-up on the basis of sound closely identical in loudness and quality with that to be heard later in theater reproduction.

After the pick-up has been established on the direct monitoring circuit, the output of the recording amplifier is applied to the light valves and the monitoring horns are connected to the photoelectric cell amplifiers on the recording machines. With no film in the machine and at a convenient lamp current a complete rehearsal is made to verify the operation of the valves at the proper level. Film is then loaded, cameras and sound recorders are interlocked and starting marks made on all films by punches or light flashes.

A light signal from the recording

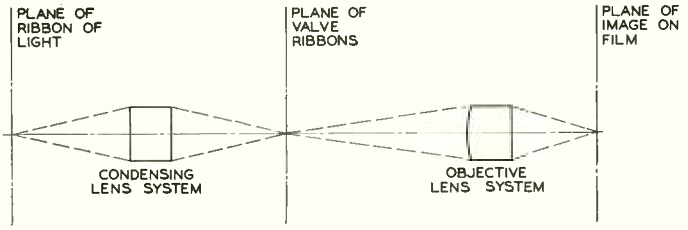


Fig. 2—Optical system for studio recording.

room warns the studio, which after lighting up signals back its readiness to start. The machine operator starts the cameras and sound recorders, brings up the lamp current to the proper value, and when the machines are up to speed signals the studio to start. During the recording, the mixer operator monitors the record through the light valves, thereby assuring himself that no record is lost.

In printing these sound negatives in combination with pictures for projection in the theater, it is customary at the present time to print one negative, masking the space needed for the other, then to run the positive again through the printer with the other negative, masking the space already printed. In printing the sound negative, the light is regulated to result in thirty-five per cent transmission of the unmodulated track after positive development. Provision of suitable masks in the camera has been made to show in the finder and expose on the film only the portion which will be available for picture projection. In the theater projector, the sound gate is located fourteen and one-half inches below the picture

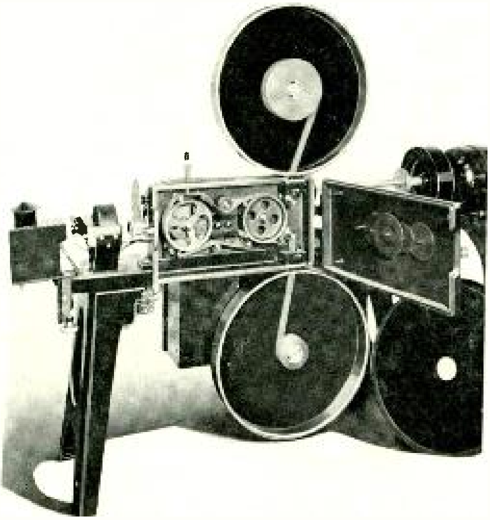


Fig. 3—A studio recording machine with the door of the exposure chamber open. The left-hand sprocket engages twenty perforations and is driven through a mechanical filter.

gate, in order to project the sound record at a point where the film is in continuous motion.

As with other systems for sound-transmission, that which includes film recording and reproduction has certain inherent faults which may be minimized by careful design. These are background noise, irregular response at various frequencies, and distortion due to non-linear characteristics.

Background noise results principally from casual variations in the light-transmission of both positive and negative films. Raw stock that is entirely satisfactory for pictures may be too irregular for sound records, since the photoelectric cell recognizes variations of 0.1 per cent while the eye ignores contrasts under two per cent. The remedy is to use "positive" stock for the sound negative as well as for the print and to use developer as little granular as possible in its effect. Fortunately, it is necessary to reduce the background noise only to a point below the threshold of audibility which will exist in the theater during the softer parts of the program. This point determines the level of the faintest sound-record which can be reproduced unmarred by noise.

Due to the facts that the element of illumination is 0.001 inch wide, instead of infinitely narrow, and that the film is travelling at ninety feet per minute, at a frequency of 18,000 cycles per second it will require the time of one cycle of a sound wave for a given point on the film to cross the slit. Then as each successive element of film crosses the slit, it will receive an exposure proportional to the integral of a complete cycle of the valve. Since the integral of one cycle is the same regardless of the phase at which the integral starts, each successive element will receive the same exposure, and the film will develop to a uniform density. Consequently no record will be made of the sound. Fortunately this frequency is far outside the range of interest to us, and the effect decreases as frequencies become lower. The drooping characteristic resulting, called the film transfer loss, may be largely offset by judicious choice of electrical characteristics and by tuning the light-valve mechanically to a frequency near 7000 cycles. How successful these measures are, in the range of importance in program reproduction, is evident from the curves of Figure 4.

When the curve connecting power input to the film system with its power output is not a straight line, distortion results, as in purely electrical systems. This takes the form of an introduction of harmonics of the frequencies normally present. The curve which connects exposure of photographic emulsions with resulting opacity is a straight line only when development is so controlled as to produce a contrast-ratio* of unity. Picture-recording practice is to develop the positive print to a contrast-ratio greater than unity. Development of the sound-negative is therefore so controlled as to give a contrast-ratio the reciprocal of that to be expected in the positive, so that the overall ratio is unity. Distortion from this and a liberal crop of harmonics is inevitable. However, the range of positive film is about twenty to one, and with the combination of light-source and optical system developed in Bell Telephone Laboratories, it is not difficult to set the unmodulated light at a value which will give an exposure of ten times that corresponding to the beginning of under-exposure. Then ninety per cent modulation of the light can be permitted without running into exposure on the "faint" side of the wave. For sound currents reaching one hundred per cent modulation of the light, ninety per cent of the wave is free from dis-

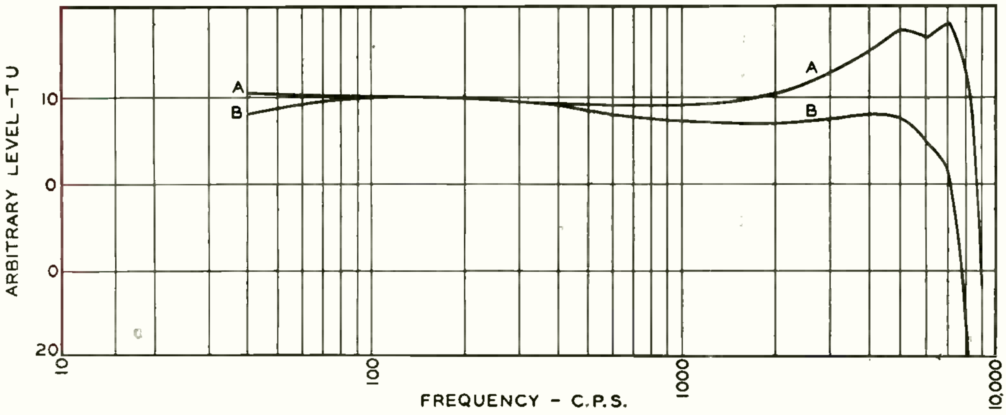


Fig. 4—Recording and reproduction characteristics: from acoustic pressure at microphone diaphragm to (A) light modulation by valve and to (B) current delivered to loud speaker in theater.

cause is then so completely annulled that the resulting harmonics are undetectible.

The correction just outlined is available over only that part of the photographic range where exposure is correct. For exposures outside this range, the characteristic curve of film becomes curved in a way which cannot be compensated in the printing, tortion; if the average light were halved, still eighty per cent would be free from distortion. There is therefore considerable latitude in the average exposure, and the negative is satisfactory if the transmission of the unmodulated track lies between fairly wide limits.

The volume of reproduced sound for a given reproducing light source varies directly with the average track density and the per cent modulation of this average. In printing the sound

* *Technically known as "gamma," it is the slope of the Hurter and Driffield characteristic curve.*

negative, a uniform density for the print of the unmodulated track is desired, lest there be changes in the sound output during the showing. For Eastman positive film a suitable transmission of the unmodulated portion of the sound print is thirty-five per cent. At this average transmission only the peaks of the recorded sound will encroach on the region of under-exposure. For the reciprocally-developed negative track the region of under-exposure will have been reached by occasional peaks on the other side of the wave, and whatever photographic distortion exists will be balanced between positive and negative.

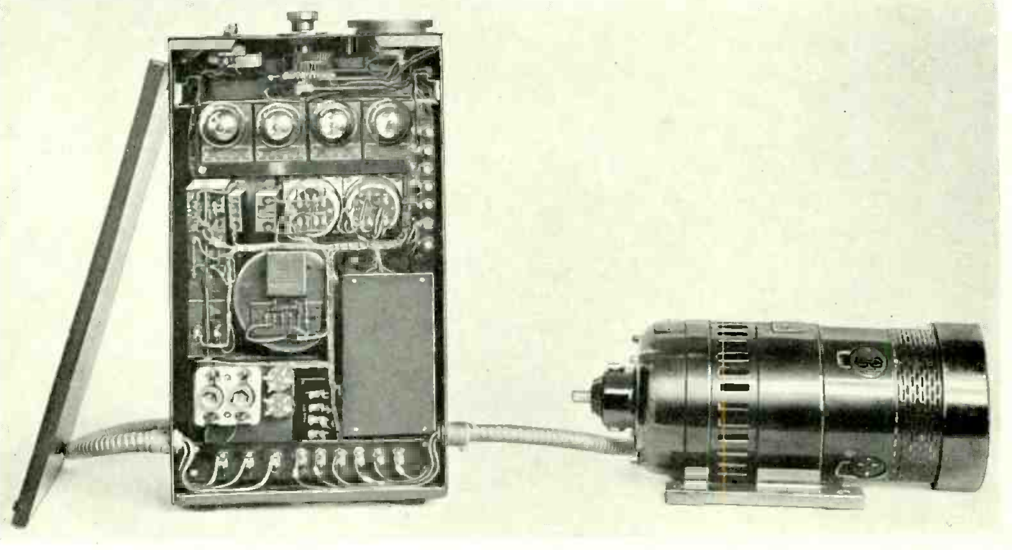
If the entire negative exposure has been confined to the under-exposure region of the emulsion chosen, a huskiness in the reproduction will result which can not be corrected by any known technique. But with correct exposure, which is readily possible with the light-valve method, ninety per cent of the wave will be clear of under-exposure, and experience shows that the ear detects no distortion. In telephonic terms, everything at a level one TU below full modulation will be free from distortion, and the peaks will be substantially perfect.

Speed Control for the Sound-Picture System

By HUGH M. STOLLER
Apparatus Development Department

SYNCHRONIZATION between sound record and film is required for all types of sound-pictures. In the Western Electric System it is secured by electrical methods for the recording apparatus and, for the reproducer, by mechanically coupling the picture projection machine and the sound record. With satisfactory synchronization thus secured, there still remains, however, the problem of speed control. Musical pitch varies directly with frequency or rate of vibration. The faster the record is rotated, the higher the pitch of the sound given out. In order, therefore, that the reproduced music may be of the same pitch as that recorded, the record must run at an assigned speed, and to keep the pitch from varying during the playing of the record, this speed must be prevented from changing. To attain these ends, the speed of the driving motor must be accurately controlled.

In determining how nearly constant this should be held, the criterion is the smallest pitch change that is noticeable, and it has been found that abrupt variations are more readily perceived than slow ones. A good musical ear will detect sudden changes in pitch produced by a change in speed of only one-half of one per cent. To make sure, therefore, that a discernible change in pitch never arises, speed regulation better than one-half of one per cent is required at all times. As further allowances seemed desirable to provide a suitable factor



An alternating-current drive motor for the sound picture connected to the governor.

of safety, a regulation of two-tenths of one per cent was agreed upon.

A survey showed that no commercial governing mechanism was available which would meet the requirements. The most suitable was probably the governor used with ordinary phonographs. This governor applies friction as the speed increases,

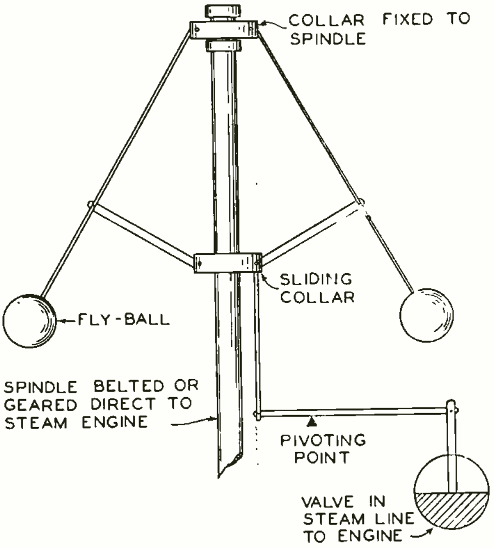


Fig. 1—Diagramatic representation of a fly-ball governor showing how sensitivity may be changed by moving the pivoting point to the left or right.

and it becomes increasingly difficult, because of maintenance difficulties, to design a satisfactory governor of this type for the larger motor required to drive both the projecting machine and turntable. A completely new design seemed the only satisfactory course.

The nature of the problem and the difficulties to be overcome are perhaps most readily brought out by considering a simple fly-ball governor controlling the speed of a steam engine, shown in Figure 1. Rotation tends to make the balls move outward due to centrifugal force. As they move out, however, they pull up a sliding collar and this action, through a system of levers, closes the steam valve supplying the engine, or in some other manner decreases the supply of steam, and the engine slows down. The tendency of the balls to fly outward is opposed by their weight so that there is a definite equilibrium position for each speed.

As a result of this the engine will run at a given speed for only one load. A load greater than this will require a wider valve opening so as to admit more steam, and this in turn will require a lower position of the fly-balls to allow it. This necessary drop in speed to allow a wider valve opening may be reduced, however, by moving the position of the pivoting point of the lever to the left. This changes the lever ratio so that smaller and smaller movements of the sliding collar will produce greater and greater valve openings. Inherently, however, some speed change must be permitted in order that the valve may be moved to accommodate the new load. To enable the engine to run at one speed regardless of the load requires an additional mechanism that will admit enough more steam to the engine to carry the increased load at the desired speed.

When, however, the sensitivity of the governor is made too great by moving the lever pivot too far to the left, or when the additional mechanism is added to make the engine always run at the same speed, an unstable condition is brought about. Under these conditions, the engine, at each action of the governor, tends to over-shoot its mark, either not attaining equilibrium speed at all or reaching it only after several oscillations. This instability may be overcome by adding a dashpot or some similar contrivance to the governor which, allowing an initial rapid adjustment, will later introduce a slower compensating force that prevents oscillations of speed.

The same governing principles apply whatever may be the type of governing apparatus. A change in speed must be able to cause some force to act on the prime mover tending to counteract this change and, if the governing is to be made very close, some dashpot equivalent must be provided to prevent the tendency to hunt or oscillate back and forth before the equilibrium speed is reached.

The prime mover for the sound-picture equipment is an electric motor. Either direct or alternating current may be used but as the principles involved are the same with each, only the latter need be discussed. The speed of the motor used is controlled by changing the impedance in its armature circuit. With high line voltage or light load the impedance is made a maximum, while with low line voltage or heavy load the impedance is made a minimum. A suitable governor, therefore, must be arranged to change this armature impedance at a very small change in motor speed (below 0.2 of one per cent) and must incorporate some arrangement to prevent oscillations.

In the sound-picture system the somewhat cumbersome fly-balls with their sliding collar and connecting levers to the steam valve are replaced by a few comparatively simple electrical circuits which act silently and instantly to correct the slightest change in speed of the driving motor. The electrical governing apparatus may be split up into three parts corresponding to those of the fly-ball governor. One part will substitute for the driving link (not shown in Figure 1) between the engine and the governor spindle, another for the fly-balls themselves and their connecting levers, and a third for the steam valve that changes the torque of the engine.

The driving link for the electrical system is a 720 cycle generator coupled to the main driving motor of the projector unit.

The governing circuit proper is a special bridge circuit shown as Figure 2. One arm of the bridge has a fixed inductance and condenser in series, which are adjusted to tune the circuit to 720 cycles. At this frequency the impedance of this arm is a resistance only and the impedance of the arm D is made a resistance of the same value. At 720 cycles the ratio of these two arms, therefore, is unity, as is that of the other two arms, made up of the primary of a transformer divided at its half tap. The small

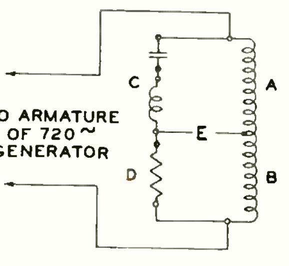


Fig. 2—The heart of the sound-picture governor. Potential E shifts 180° in phase as the speed changes from any value below 1200 r. p. m. to any value above it.

alternator, connected across the transformer, thus becomes the source of power for the bridge.

This arrangement makes an extremely sensitive analogy to the fly-ball governor and lever system. The potential, E, from the mid-point of the coils A and B to the junction of arms C and D, which is zero at 720 cycles, shifts its phase 180° as the speed changes from any frequency below 720 cycles to any above it. Below 720 cycles the current in C is leading due to the predominance of the condenser and above 720 it is lagging due to the predominance of the inductance. Instead, therefore, of a gradual change as the speed changes from its desired value there is an abrupt one which furnishes a basis for accurate speed control.

Acting as the steam valve to control the speed of the motor is an impedance coil with three legs shown as Figure 3. The two outer legs, L_1 and L_2, are connected to the motor armature and serve as the impedance controlling the speed. The middle leg, G, carries a direct current winding. As the current in this winding increases the magnetic flux in the two outer branches increases to saturation and their impedance decreases. The torque of the motor varies inversely with the reactance of the coils, L_1 and L_2, and as a result the greater the direct current flowing into the coil G, the higher will be the torque of the motor.

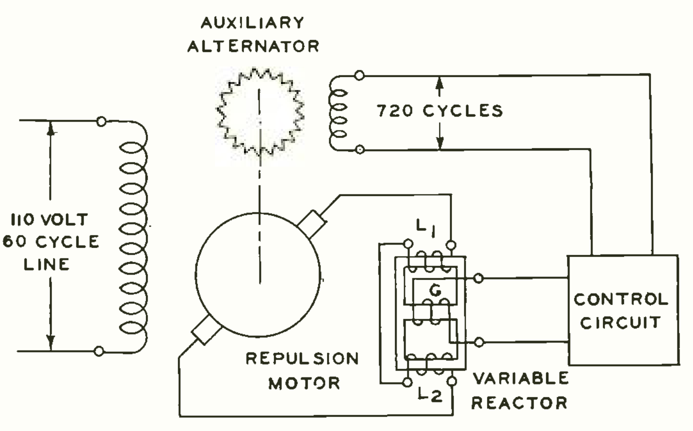


Fig. 3—Torque control for the driving motor is obtained by a three-legged inductance coil, the impedance of which is changed by direct current flowing around the middle leg.

The link between the bridge and the three-legged inductance is a vacuum-tube circuit which causes more direct current to flow as the motor speed tends to fall. This complete circuit, shown in Figure 4, includes the detector tube V_4, and two tubes V_1 and V_2 which supply current for the middle winding of the impedance coil. Tube V_3 is a rectifier to supply excitation for the 720 cycle alternator and grid biasing voltage for V_1, V_2, and V_4.

Plate potential for V_4 comes from the alternator through the transformer T_4, and its phase is fixed. Grid potential for this tube is from the bridge output circuit, E, the phase of which shifts 180° as the alternator speed changes from below to above 1200 r.p.m. This 180° shift of phase changes the potential of the grid relative to the plate from negative to positive or vice versa, and thereby causes a relatively large change in the plate current, which, flowing through R_1 causes a correspondingly large change in the grid potential of tubes V_1 and V_2, and thus in the direct current to the impedance coil.

The bridge circuit makes a very sensitive governing device but with it alone some permanent change in speed would be required to compensate for each change in load or line voltage. Something else must be added if the speed is to be constant

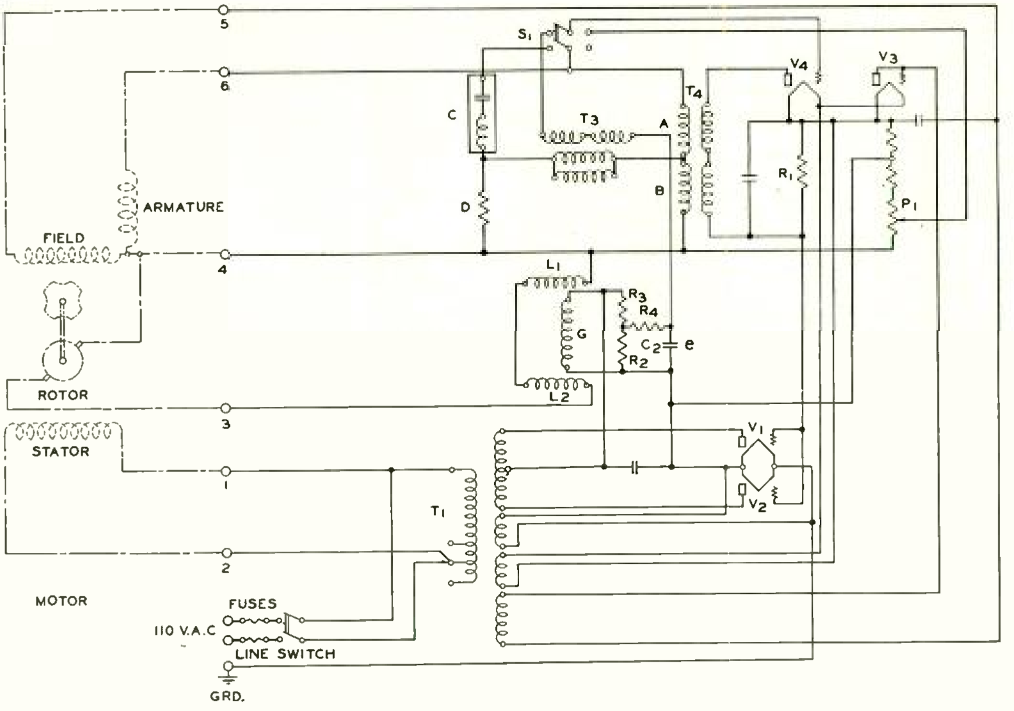


Fig. 4—Complete diagram of the governing circuit showing the three-legged reactance coil in the center. Switch S_1 is normally thrown to the left.

for all conditions. Also, some dash-pot equivalent must be used to prevent the speed oscillations mentioned.

These two functions are accomplished by a network composed of R_2, R_3, R_4, and C_2, properly connected to the other circuits. Current flowing in the plate circuit of V_1 and V_2 to the coil of G flows also through R_2 and R_3. The drop across C_2 which after a short preliminary period is the same as that through R_2, feeds back a potential to the grid circuit of V_4, and thereby causes the additional regulation required. To slow down the action of this feed back, however, R_4 in series with C_2 is connected in parallel with R_2 as shown. The feed back potential is that across C_2 and this rises or falls slowly as the condenser must be charged or discharged through the high resistance R_4.

By these means, in the comparatively simple and compact electrical circuit shown in the accompanying cut, is provided a governor, similar in its functioning to the fly-ball governor of Figure 1, that will control the speed of the driving motor under all ordinary conditions to within the required two-tenths per cent. The switch S_1 was added to the circuit so that, when the picture-projection machine was used for ordinary silent motion-pictures, when such close speed regulation is not required, it could be thrown to the right and hand regulation obtained by the potentiometer P_1. This is needed to vary operating speed of the projector to meet a definite time schedule for showing the picture. When the schedule permits, however, accurate speed regulation is preferred since it enables a leader to keep his orchestra in better step with the picture.

Sound Projector Systems for Motion-Picture Theaters

By EDWARD O. SCRIVEN
Apparatus Development Department

IN theaters at which motion pictures accompanied by synchronized speech or music are presented, the records come in two forms. Some are composition discs similar to ordinary phonograph records, while others are standard motion-picture film bearing at one side a track of alternate light and dark bands, of varying density. In either case there must be apparatus synchronized with each projector to derive from the records an electric current in which all the variations in pitch and loudness are accurately represented. There must in addition be apparatus to amplify the current, to effect its conversion into sound and so to direct the sound into the theater auditorium as to create the illusion that it emanates from, rather than merely accompanies, the picture. When a theater is being prepared for presenting sound pictures, the film projectors in use are ordinarily retained but each is fitted with a new motor and driving mechanism; it is provided with a turntable and electric pick-up for disc records, and with analogous equipment for film records, or both. The pick-up used for disc records is in some ways similar to the reproducer of an ordinary acoustic phonograph, with a needle holder connected to a clamped diaphragm of highly tempered spring steel. To the diaphragm there is fastened an armature made of a special high-permeability alloy, so arranged that as the diaphragm and the armature vibrate, the flux in the air-gap of a permanent magnet varies correspondingly; in appropriately placed coils currents are induced which are the electric representation of the wave groove which moves past the needle. Although this instrument delivers energy at a comparatively low level, it has a very uniform response over a wide range of frequencies. That result has been secured largely by preventing distortion which would arise from resonance in any part of the system; the members have been designed with natural periods

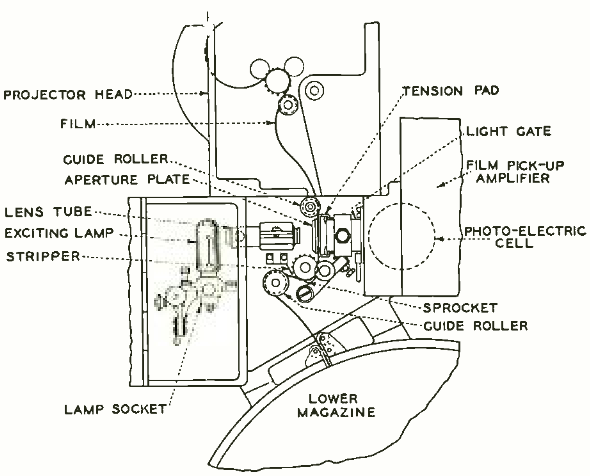


Fig. 1—Arrangement of projector for reproducing from sound films.

beyond the range of frequencies to be transmitted, and the magnet chamber back of the diaphragm is filled with a heavy oil to damp free vibration.

Fig. 2—Photoelectric cell of the type used for reproducing from sound film.

The films used with the disc records, called synchronized films, differ from ordinary films only in that one frame at the beginning of each is marked to give the starting point.

With the optical or film records, the sounds are represented by parallel bands, alternately light and dark. Intensity or loudness is represented by differences in density of the record, and pitch by the closeness of the bands. For reproduction from these another apparatus group is required, and it too is connected to the projector. A narrow light beam of high intensity passes through the film record and falls upon a photoelectric cell to produce a current corresponding to that from the original recording transmitter. There is fastened to the projector an "exciting" lamp and a system of lenses for focusing its light upon an aperture 0.0015 inch by 3/16 inch; by other lenses the image of the aperture is then brought to focus upon the film record as a line 0.001 inch by 0.080 inch. Since the track on the film is 0.100 inch wide, there is an allowance of 0.010 inch on each side for variation in its position. The position and focus of the lens tube are fixed, but the exciting lamp is mounted on a movable carriage so that new lamps as installed may be brought properly into focus.

A photoelectric cell of the type used is shown in Figure 2, and the circuit in Figure 3. When polarized by a proper voltage, the cell passes a current proportional, within limiting values, to the intensity of the light falling upon it. The polarizing voltage is supplied to the cell through such a high resistance that in operation there is obtained from the cell a voltage across the resistance proportional to the incident light. The

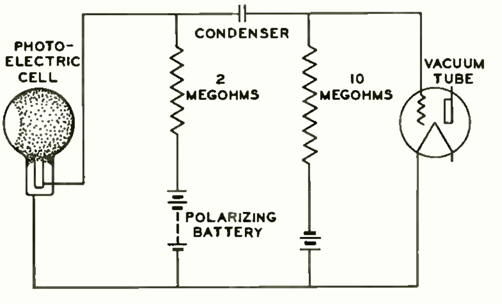


Fig. 3—Circuit from the photoelectric cell to the adjacent amplifier.

voltage bears therefore at any time an inverse relation to the density of that part of the sound track then between the exciting lamp and the cell.

The photoelectric cell circuit is inherently one of high impedance. In such a circuit local interference—"static," to use the radio expression—is readily picked up, and since the energy level is low, the current so acquired may be appreciable in comparison with the sound currents themselves. In addition the shunting effect of the capacity between the conductors

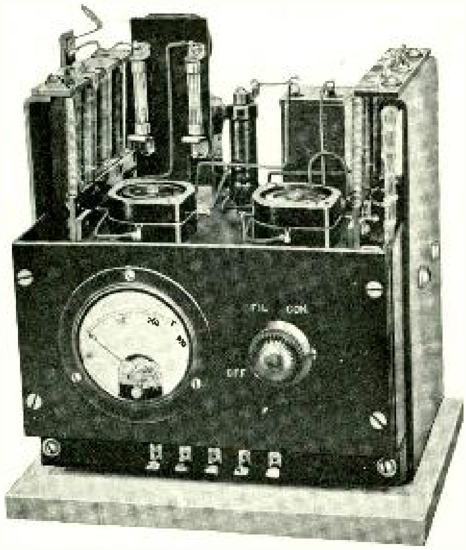


Fig. 4—Amplifier to which the photoelectric cell is connected, showing the suspension for absorbing vibrations. The tubes are not in place.

is noticeable, particularly at the higher frequencies. Hence a vacuum tube amplifier, which serves both to increase the energy and to make that energy available across a low impedance circuit, is closely associated with the cell upon the projector itself. Cell and amplifier are enclosed in a heavy metal box made fast to the frame of the projector, and the frame is carefully grounded. As a further precaution, the amplifier is supported within the enclosing box by a rather elaborate flexible suspension, lest vibration of the vacuum tubes introduce noise components into the current. The amplifier brings up the energy level to about that obtained from the magnet coils of the reproducer for disc records.

It is evident from the relative location of apparatus, shown in Figure 1, that it is not feasible to print the film with the pictures directly opposite corresponding parts of the sound record. Furthermore the pictures move intermittently before the projection lens, while the sound record must of course move uniformly in front of the photoelectric cell. Picture and sound record are therefore separated longitudinally by 14½ inches, and a certain amount of slack is allowed between the sprocket carrying the film in front of the projection lens and that carrying it before the photoelectric cell. To prevent vibration of the projector or variations in the supply voltage or load from varying the speed of the latter sprocket, it is connected to the other moving parts of the system by a mechanical filter which absorbs any abrupt changes in speed. The driving motor is held electrically at the correct speed, but at will the automatic control can be disconnected and the speed regulated manually by the operator.

As with ordinary motion-pictures, two projectors must be used alternately to present a continuous program. At the end of a record, the music or speech coming from one machine must be blended imperceptibly into that from the other just as the picture from one reel is faded into that from the next. At the end of each sound film or disc the music overlaps that at the beginning of the next; to make the transition there is a device called a fader, a double potentiometer. As the starting projector goes into operation, the fader knob is turned and the current delivered to the amplifiers is changed quickly until it comes entirely from the new record. Ordinarily the fader is installed with auxiliary dials and handles, so that the operator can control it from any position around the projectors. In its lower range, used in changing between projectors, the steps are rather large, whereas in the upper range the volume changes in scarcely perceptible steps. The fader thereby fills another use; it makes possible any volume of sound desired, within reasonable limits, by choice of the proper step in the upper range, and thereby permits equalizing the level of sound obtained from different records. There is provided as well a switch for changing from film to disc records, and the reverse, and a key for connecting a spare projector in place of either of the regular machines.

After passing through the fader, the sound currents go to the main amplifier, where their energy is raised to a level adequate for the loud speakers of the particular theater. This combination of apparatus is capable of multiplying the energy 100,000,000 times, and is so designed that all frequencies in the range from 40 to 10,000 cycles are amplified about equally. A potentiometer is provided on the amplifier but after it has once been adjusted at the time of installation it is ordinarily not changed; necessary adjustments in energy level are made on the fader instead. The amplifier* is built in three units, of which the first consists of three low-power tubes connected in tandem, resistance coupled, with the filaments heated by a twelve-volt battery. In the second unit there are two medium-power tubes with a push-pull connection, whose filaments are heated by low-voltage alternating current. Two similar tubes in this unit act as a full wave rectifier, and supply rectified alternating current for the plate circuits of the amplifier tubes in the first

* *Described by H. A. Dahl in the* RECORD *for May,* 1928.

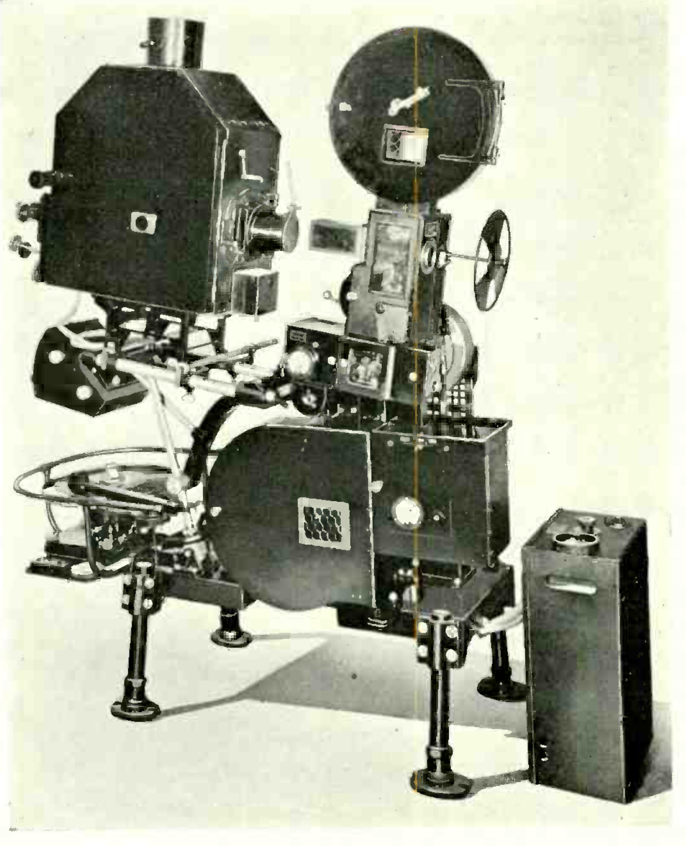


Fig. 5—Western Electric projector for sound pictures, using a Simplex head. A Powers or Motiograph head may also be used.

and second units. The third unit has a single stage of high-power push-pull amplifier tubes and push-pull rectifier tubes; like the second, it operates entirely on alternating current. The three units can be arranged to meet any conditions. In small the-

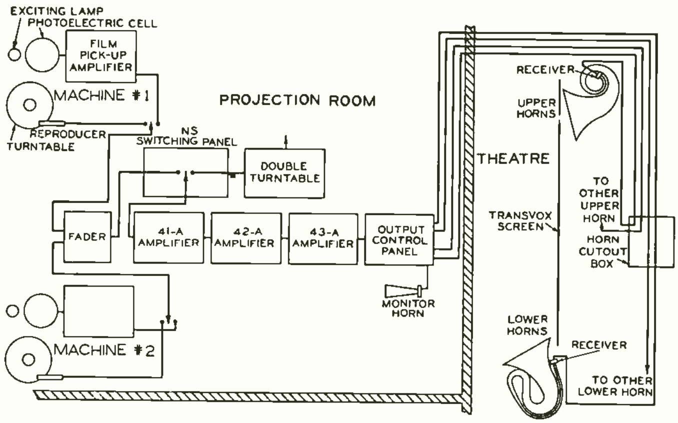


Fig. 6—Layout of a typical theater for presenting sound pictures.

aters only the first two are required, and in larger houses the high-power unit, the third, is used as well. For unusual conditions two or more of the high-power units may be operated in parallel from the output of the second unit to give a greater volume of sound.

Following the amplifier there is an output control panel consisting of an autotransformer having a large number of taps which are multipled to a number of dial switches. To the switches are connected the loud-speaking receivers, so that the impedance of the amplifier output can be matched to the desired number of horns. Thereby there is secured the most efficient use of the power available, and adjustment of the relative volumes of the individual horns is made possible at any time.

A theater installation ordinarily contains four horns. They are mounted behind a transvocent screen, on which the pictures are shown, so that the sound may seem to come directly from the picture. Two horns are mounted at the line of the stage and pointed upward toward the balconies and two are mounted at the upper edge of the screen, or above it, and directed downward.

One or more Western Electric No. 555 receivers* are used with each of the horns. Since these show extremely high efficiency, converting into sound energy thirty per cent of the electrical energy supplied them, they reduce to a minimum the output required from the amplifier. A horn is ordinarily fitted with one receiver, but for outdoor use or other special requirements it may be fitted with two, four or nine by a throat such as that shown in Figure 8. The maximum electrical input to a horn for continuous safe operation is ap-

* *Described by A. L. Thuras in the* RECORD *for March,* 1928.

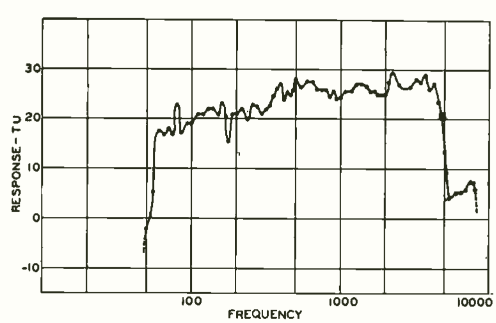


Fig. 7—Response-frequency characteristic of exponential horn and 555-W receiver.

proximately five watts per receiver. To disperse the sound-waves over a large angle, more horns are needed than for a comparatively small angle. This directive characteristic of the horns is important, since it is responsible for the illusion that the sound comes directly from the mouth of the horn, that is, from the screen. When the horn is replaced by a loud speaker of otherwise identical characteristics which radiates its sound over a very wide angle, the sound seems to come from a point some distance behind the screen, so that the illusion of coming from the picture is destroyed.

Fig. 8—Throat by which a horn may be fitted with nine receivers, for outdoor use.

In addition to its function as a part of the talking motion-picture equipment the sound projector system may also be used as a public address system for voice reenforcement.

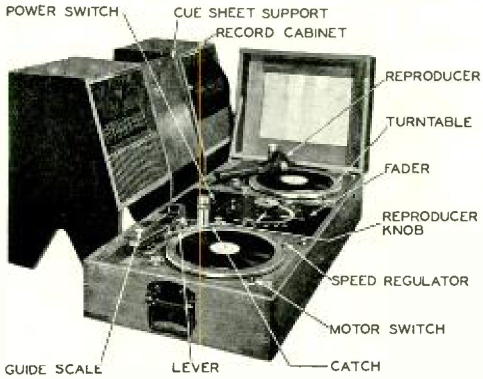


Fig. 9—Cabinet for reproducing from disc records not synchronized with pictures.

Microphones may be concealed in the footlights, and the horns so placed as not to affect them; for announcements ordinarily there will be a transmitter in the manager's office.

By means of auxiliary equipment provided, the system can also be used to provide non-synchronized music as an accompaniment to pictures. There is a cabinet containing two turntables, each with a pick-up and means for locating it accurately upon a record, and a fader to make possible continuous playing. The same amplifier and loud speakers are used as for the synchronized speech and music.

Installation and Adjustment of Western Electric Sound-Projector Systems

By HOWARD B. SANTEE
Electrical Research Products, Incorporated

THAT there may be realized the full advantages which a Western Electric Sound-Projector System can bring to a theater, each installation is planned and directed individually by engineers of Electrical Research Products, Incorporated, the organization which provides the apparatus. Preceding the installation, engineers of that company conduct a detailed preliminary investigation to decide upon the exact apparatus, and to determine any changes that may be needed in the theater building. The equipment is installed under supervision of an engineer of the organization who in addition sees that whatever supplementary work was needed in the building has been carried out properly. As the work proceeds he sees that the equipment is so placed and so regulated as to give the best results, and as the various pieces of apparatus are made ready for use, he trains the projection-room employees in their operation. Finally the completed installation is kept at the highest standard of operation and maintenance through supervisory visits made at intervals by a field engineer, and routine maintenance work is directed by the organization's service group.

Although its need may not at first be fully apparent, the preliminary survey receives the most careful attention to insure that everything will be in readiness for the work of installation to progress smoothly, and that the apparatus best suited for the particular theater will be used. Acoustic characteristics of the stage and auditorium receive thorough study, upon which in many cases the success of the installation rests. Size and location of the stage are noted, for their bearing on placing of the horns and of the special screen needed. Where blue-prints of the theater building are not available, the engineer must measure the dimensions himself and must prepare sketches showing the size and shape of the auditorium and the number and arrangement of the seats. He must also appraise the acoustic characteristics, discovering any sections where there is an echo, interference, noise from an extraneous source, or any other hindrance to proper hearing. A final study of acoustic conditions is best made on completion of the installation, but data obtained during the preliminary survey give a useful basis for the installation work.

In the projection room the engineer notes the type and condition of the projection machines, the power supply and its regulation, the angle of projection. He sees whether there is room between the machines to allow convenient operation after installation of the sound apparatus, and whether there is a suitable space for the amplifier and the associated controls. In cases where the room is inadequate he decides upon the rearrangement or enlargement that is needed.

At the end of the study, the engineer's recommendations, along with the sketches and detailed information on which they are based, are submitted to the home office. There all the circumstances are examined again, and a report embodying a final set of recommendations is prepared.

When details of the installation are fully determined, dates are assigned for shipping the apparatus and for the start of the installers' work, and the theater management is informed. The management is in addition notified at this time if architectural changes are needed in the projection booth or elsewhere, so that they can be finished before the work of installation is commenced.

The entire work of installation is directed by a field engineer whose main function is to see that all parts of the work, and all supplementary work in preparing the theater, are so carried out that the completed system will operate at its full possibilities. He first establishes satisfactory contacts with the theater manager and staff, and with information obtained from them coordinates the work of installation, testing and rehearsal with circumstances necessary for operation of the theater during the preliminary period. Likewise he chooses an electrical contractor, if possible one already familiar with the wiring in the theater. Thus he insures that the work will proceed smoothly, and that everything will be ready for the scheduled opening.

Most commonly the work starts at the projectors themselves. While these remain practically intact in other respects, on each the driving motor is replaced with one whose speed is regulated electrically. As these motors require from four to five seconds to come up to running speed, it is desirable to have them in place early, that the projectionists may become accustomed to them and so be able to give full attention to handling the records by the time sound programs are to be presented. Next the batteries are installed, with their switching panel and charging apparatus, and a motor-generator if that is to be used. The rack for the main amplifier is placed in position, and the units mounted upon it. Next the fader is installed, and its auxiliary controls put in place and connected to it. Likewise the monitoring horn is mounted at a carefully chosen location in the operating booth, so that the projectionist will be able to hear the program clearly at all times and thus be prepared for the fader changes between records. Usually the turntable and pick-up for disc records are then installed on each machine and, for film records, the exciting lamp, lenses, photoelectric cell and associated amplifier, and subordinate equipment; in some cases however these members are assembled on the projectors before the main amplifier and fader are installed. Although the reproducing apparatus adds materially to the mechanism of a projector, the parts have been so designed for each of the commonly-used makes of machines that their installation does not involve loss or extensive change of parts not immediately involved. Since the conduit and wiring work have been keeping pace with the installation of equipment, it should now be possible to connect the pieces of apparatus and check their correct installation and the wiring work.

Installation procedure is constantly being improved, and within a few months a noteworthy advance is to be made. In the present arrangement the driving motor and disc turntable are mounted on individual pedestals, the film reproducer and associated amplifier are supplied as separate units to be mounted on the projector, and the film-discs transfer panel is mounted on the wall of the room. Instead there will be a single pedestal bearing all of these members. The change will facilitate the work of installation and reduce the wiring needed, and furthermore will make the work of operation more convenient as well.

With the work well advanced in the projection room, the engineer next turns his attention to the stage. The horns are placed on their mountings, which should be ready by this time, at locations presumably correct for the size and shape of the auditorium. After the loud-speaking receivers are attached and connected, there is the first opportunity to produce sound through the complete system. A cursory test follows to assure that no major errors are present, and any immediately obvious imperfections are corrected. Comparative tests are then made between the reproducers on the projectors, so that any discrepancies in volume can be overcome. Each receiver and horn is heard separately, and then they are operated in unison so that the engineer can check their proper poling. Before the work proceeds further, the semi-porous screen on which the pictures are to be shown is installed immediately in front of the horns. Through this the sound will pass, seeming to come from the pictures themselves.

Although for hearing of speech reverberation is objectionable as preventing good articulation, when not excessive it is desirable for music since it tends to give the effect of fullness and roundness.* A varying factor complicating the situation further is the absorbent property of the audience itself. There are theaters which empty, are entirely too reverberant, but which are thoroughly satisfactory when filled. Attendance varies at different performances of course, so that at best a compromise must be tolerated in considering acoustic adjustments.

While the use of ordinary drapes and similar material causes absorption of the higher frequencies to a somewhat greater degree than the lower, it is about the only practical method which can be employed to overcome acoustic difficulties from excessive reverberation and echo. Excessive damping must be avoided, to prevent a deadness in the sounds which may almost be depressing. Heavily damped houses require greater amplification than would otherwise be necessary but the presence of the audience has less effect than in a somewhat more reverberant house.

Correction of specific acoustic faults may be made with almost complete success, however. Echoes may sometimes be corrected by moving one or more of the horns, but the reflecting surface must be covered with heavy drapes when it is so located that no suitable echo-free position

** For a consideration of auditorium acoustics see Speech Interpretation in Auditoriums by E. C. Wente,* BELL LABORATORIES RECORD, *October,* 1928.

is available for the horns. Interference usually results from reflection of sounds, and likewise can be prevented by adequate covering of the surfaces responsible. Resonance occurs when a surface made up of a thin, hard material, free to act as a diaphragm at its own natural frequency, is in the path of the sound waves. Distortion necessarily results, since only that part of the sound near the natural period of the resonator is reenforced. Here again covering is ordinarily the treatment used.

Bearing in mind the three prime requisites to good hearing, that sound be sufficiently loud for all auditors without being unnaturally loud for any, that successive sounds be clear and distinct, and that the components of complex sounds retain their relative intensities, the engineer makes the acoustic adjustments. He usually tests first for sound distribution, arranging the horns so that as far as possible all parts of the house receive the same volume. Proper flaring and tilting of the horns is usually sufficient to give adequate distribution. Any acoustic peculiarities are next investigated, and where possible corrected. Many hours are often spent in moving the horns and adjusting their placing, since slight changes in position sometimes produce marked differences in the acoustic effect. When the best results demand further acoustic treatment of the auditorium, involving alterations to the building or extensive change of the wall surfaces, the manager is so informed.

One standard practice followed in all cases is to cover the horns, and the back of the screen except the areas occupied with the horns, by absorbent drapes. It is usual also, where the screen is set back from the proscenium arch, to hang drapes around it, in shadow box effect. By these precautions back-stage echoes and reflections are avoided.

After the horn locations have been definitely fixed and the equipment given a final check, the engineer calibrates the amplifying apparatus for the particular theater. He has at hand several test records which make available a wide variety of the types of entertainment to be shown, each marked with the fader setting determined in a theater which has been chosen as "standard." By playing these records with the fader set at the marked value and adjusting the main potentiometer until the proper effects are obtained, he sets the potentiometer at a presumably permanent adjustment, in keeping with the size of the theater, so that in the future good results can be obtained from any records by adjustment of the fader only. In addition, various types of records require that varying volumes be obtained from the different horns. From the tests the engineer can choose the relative volumes for different types of selections, and establish the horn settings which will normally be required.

During progress of the installation, the projectionists and their assistants are instructed in the operation and maintenance of the new equipment. At the outset each man is given a complete operating instruction bulletin, which gives detailed information on every necessary point. By the time the theater is calibrated the men should be familiar with their new duties, and should be able to present a complete program without assistance. An opportunity soon comes to show their facility, in the rehearsal of the opening program.

At the early performances the closest attention is given, to be sure that the system is being operated to give the desired effects. In addition, however, watchful attention should be continued as a permanent function of the theater management, if the best results are to be secured. Whenever a sound program is in progress either the manager or somebody specially appointed should be present in the audience. By his own reactions, and by noting the effect on the audience, he observes the need for any changes in volume or otherwise. Likewise he watches for any extensive change in the degree to which the house is filled, or any other circumstance having a bearing on the picture as presented. A buzzer signal and a telephone are provided for communicating instructions to the operating room.

The installation engineer remains at the theater until it is evident that the local staff are fully competent to continue independently. At that time the installation is transferred to the service organization of Electrical Research Products, Inc. The service engineer in whose district the theater is located is available for emergency calls at all times. In addition, he makes scheduled visits to check the equipment and recommend any minor adjustments which may seem advisable. In this way each installation is given constant engineering supervision, to keep the sound equipment operating at the peak of performance which is possible.

Inspection Engineering in the Field

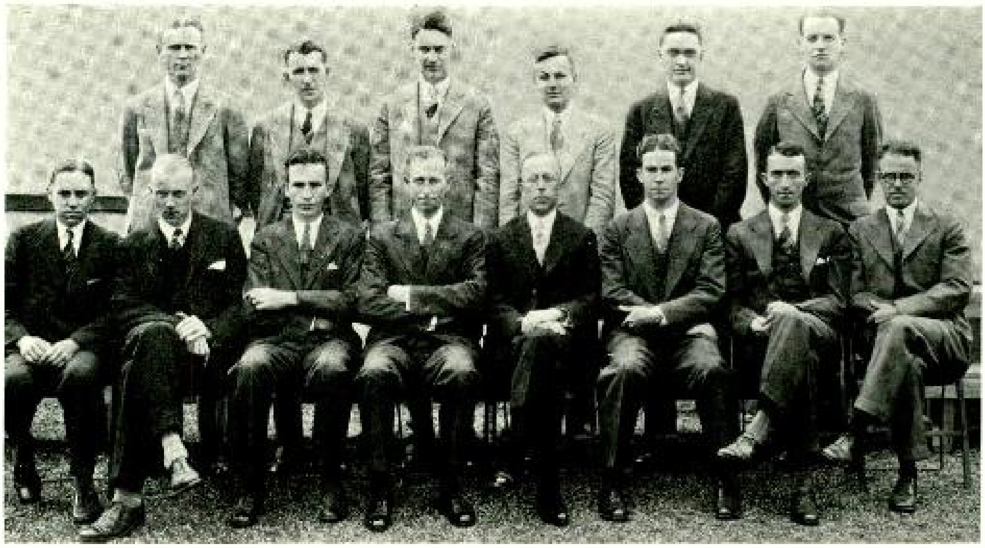
By A. G. DALTON
Inspection Engineering Department

DURING the week of October 1st to October 6th, there was held at the Laboratories a conference attended by all field engineers, by members of the American Telephone and Telegraph Company, the Northern Electric Company and the Western Electric Company, and by executives and members of the technical staff of the Laboratories. Members of the Inspection Engineering Department read several papers dealing with new quality standards and with progress in the art of determining the quality conditions of equipment in process of manufacture and in service. Recent developments in related matters of interest were discussed by other members of the Laboratories' technical staff. Social features of the conference served to bring the field engineers in closer personal contact with members of the Bell System with whom their relations in the past have involved only business matters.

The field engineering force was organized by the Inspection Engineering Department four or five years ago. Its members are recruited largely from the development departments, and are normally assigned to a particular group of telephone company operating areas for one or two years, making their headquarters with the Engineering Department of an Operating Company or with one of the Western Electric Company's departments in a city in the area.

The main function of this force is to keep the Inspection Engineering Department in touch with the performance of equipment developed by the Laboratories and with special conditions relating to its operation, maintenance or quality. The field engineer also acts as a general agent of the Inspection Engineering Department, and assists Operating Companies in preparing complaints and obtaining technical information or aid from the Laboratories. Through regularly scheduled review conferences with the Engineering Departments of the Operating Companies and the Installation Department and Distributing Houses of the Western Electric Company, the field engineer maintains the active contacts vital to his intermediary work. Suggestions from these organizations relating to the design or quality of systems, apparatus or supplies pass through the field engineer to New York for consideration, and his personal observation of the performance of communication equipment assists the Laboratories in studying the adequacy of current quality standards.

At the present time, there are ten field engineers assigned to telephone company operating areas, for the performance of this work throughout the country. The group is headed by R. J. Nossaman, a graduate of the University of Colorado, class of 1922, with field experience in New York, St. Louis and San Francisco.



Bell Telephone Laboratories' field engineers: back row: G. Garbacz, W. E. Whitworth, J. A. St. Clair, W. K. St. Clair, I. W. Whiteside, R. C. Kamphausen; seated: D. S. Bender, H. W. Nylund, T. L. Oliver, A. G. Dalton, G. D. Edwards, R. J. Nossaman, A. M. Elliott, H. J. Knowlton

From headquarters in New York, D. S. Bender covers the New England Telephone and Telegraph Company, the Southern New England Telephone Company and the New Jersey Bell Telephone Company, and A. M. Elliott the four areas of the New York Telephone Company. Mr. Bender, a 1923 graduate of Rensselaer Polytechnic Institute, came to the field engineering group in 1926, after instructing in mathematics and science for three years at the University of Cairo, Egypt. Mr. Elliott received his degree from the Carnegie Institute of Technology in 1921, and became associated with radio work in Arizona. In 1923 he entered the Western Electric Company and four years later was transferred to the Systems Development Department. His present assignment dates from August of this year.

The Bell Telephone Company of Pennsylvania and the Chesapeake and Potomac Telephone Company are served from Philadelphia by W. K. St. Clair. Since his graduation from the University of Montana in 1922, Mr. St. Clair has been continuously connected with engineering inspection work.

Atlanta is the field engineering headquarters for the Southern Bell Telephone and Telegraph Company; as his first field engineering assignment, T. L. Oliver is handling the work in this territory. Mr. Oliver came to the Inspection Engineering Department from the Systems Development Department, which he joined after receiving an engineering degree from Virginia Polytechnic Institute in 1923.

The Ohio Bell Telephone Company and the Cincinnati and Suburban Bell Telephone Company areas are handled by G. Garbacz, whose Bell System experience includes work with the New England Telephone and

Telegraph Company and the Western Electric Company. Mr. Garbacz was graduated from the Milwaukee School of Engineering in 1922.

R. C. Kamphausen began his work in telephony in 1914 with the Cincinnati and Suburban Bell Telephone Company, remaining with that company until the entry of the United States into the World War. Upon his discharge from the Signal Corps in 1919, he entered the University of Cincinnati to complete previous work, receiving the E. E. degree in 1921. Mr. Kamphausen is now stationed in Detroit, for contact with the Indiana Bell Telephone Company and the Michigan Bell Telephone Company.

Chicago is the headquarters for the field engineer covering the Illinois Bell Telephone Company and the Wisconsin Telephone Company areas. This position is filled by I. W. Whiteside, who also has had considerable experience in inspection engineering. After graduation in 1922 from the University of Colorado, he took up central office inspection work at West Street and was later given field engineering assignments in Seattle, Cleveland and Detroit.

H. W. Nylund is the field engineer for the Southwestern Bell Telephone Company area, with headquarters in St. Louis. He was graduated from Iowa State College in 1925, and worked with the Systems Development Department until early in 1927 when he was assigned to his present duties.

The largest geographical area handled by one field engineer is that served by the Northwestern Bell Telephone Company and the Mountain States Telephone and Telegraph Company. W. E. Whitworth is assigned to this territory, and covers it from headquarters in Omaha. Mr. Whitworth also came to this work from the Systems Development Department, which he joined after graduation from the University of Wisconsin in 1924.

The three areas of the Pacific Telephone and Telegraph Company are covered by J. A. St. Clair, with headquarters in San Francisco. On obtaining his degree from the University of Colorado in 1922, Mr. St. Clair entered the Western Electric Company for central office inspection work, transferring to the Inspection Engineering Department of the Laboratories in 1924.

Introducing the College Man

THE Bell System, approaching the 400,000 mark in personnel, takes pride in the fact that the history of its development reveals growth at an ever increasing rate, and advancement based on sound engineering principles. The laboratory development and research activities of the system are centered in Bell Telephone Laboratories.

It is in a measure through this organization that the system insures the meeting of an obligation to which it has pledged itself. As expressed by President Gifford,* " . . . It is fundamental in our plan of organization to have at headquarters and in our laboratories several thousand people whose sole job is to work for improvement. They are engaged in studying what is used in the telephone business and how it is used and endeavor to find a better thing or a

* *Addressing the National Association of Railroad and Utilities Commissioners. See* BELL LABORATORIES RECORD, *Volume* 5, *page* 75.

Top Row: W. E. Reichle, Michigan; J. B. Bishop, Cornell; L. E. Abbott, Brooklyn Poly.; J. F. Byrne, Ohio State; A. S. King, Lehigh; L. W. Curtis, Idaho; H. I. Romnes, Wisconsin; L. A. Woote, North Carolina; E. J. Bonnesen, Iowa State; A. C. Beck, R. P. I.; T. E. Davis, Arizona; E. Mottram, Columbia; G. N. Loomis, Yale; A. A. Burgess, Yale; H. L. Quam, South Dakota State; B. Stallard, Kansas; A. L. Hopper, R. P. I.

Middle Row: P. B. Drake, Virginia Poly.; C. R. Eckberg, Minnesota; E. E. Thomas, University Coll. Wales, G. B.; A. L. Hall, Worcester Poly.; V. E. Reilly, N. Y. U.; F. A. Coles, California; W. A. Yager, Union; A. G. Bousquet, Tufts; E. Lakatos, Stevens; E. A. Bescherer, Purdue; A. W. Hawley, Yale; R. A. Dexereux, Columbia; M. C. Gauthier, Pratt Institute; D. B. Herrmann, C.C.N.Y.; B. F. Lynip, Jr., California

Bottom Row: R. B. Mears, Penn. State; D. J. Salley, North Dakota; M. S. Gudger, Georgia Tech.; D. C. Smith, Union; A. Decino, Colorado; C. D. Owens, Indiana; F. I. Smith, Coe; H. M. Knapp, Stevens; E. J. Donohue, Stevens; W. R. Neisser, Bucknell; C. B. Green, Ohio State; R. M. Kalb, Ohio State; J. F. Dillinger, Ohio State; W. H. Bartosh, Penn. State

Top Row: M. W. Bryant, Washington State; S. M. Sutton, Missouri; A. E. Sayler, Southern California; E. A. Schramm, Washington; A. M. Koerner, Minnesota; B. Foulds, Yale; C. B. Dalphin, Fordham; J. H. Zimmer, Cornell; C. T. Owlett, Cornell; D. W. Grant, Kansas State; R. L. Taylor, Washington State. Middle Row: P. A. Lasselle, Oregon; W. M. Goodall, California Tech.; C. L. Watson, Stanford; K. G. Jansky, Wisconsin; H. W. Augustadt, North Dakota; W. E. Burke, Oregon State; W. F. Brown, N. Y. U.; W. H. Stephens, Nebraska; F. E. Masek, Kansas State; E. E. Wright, Brooklyn Poly.; D. T. Sharpe, Iowa State; J. D. Tebo, Johns Hopkins. Bottom Row: B. E. Stevens, Minnesota; E. S. Dobson, Lafayette; F. S. Wolport, Newark Col. of Eng.; A. L. Samuel, M. I. T.; E. E. Mott, M. I. T.; C. F. Benner, Purdue; J. A. Bagdon, Brown; A. B. Crawford, Ohio State; S. Bobis, Grenoble, France; E. J. Basch, Union

better way. . . . progress is assured by having a large group of scientists and experts devoted exclusively to seeking ways of making the service better and cheaper."

In order that Bell Telephone Laboratories may cope with the ever increasing demand placed upon it for engineering advice many new men are encouraged each year to come from educational institutions and elsewhere and affiliate themselves with us. These young men quite naturally feel that our business is extremely complex, and that a considerable groundwork of information is necessary before they can take up their new duties with confidence. To help lay this foundation it is the custom of our Educational Department to conduct a brief but intensive introductory survey during the summer of each year.

During this instruction the general organization of the Bell System is explained in order to present the purpose of the Laboratories and its place in that system. This is followed by a general description of departmental functions and activities. Members of the technical staff represent their own departments in explaining their particular field, the problems encountered and their facilities for solving them. These talks are often followed by visits to appropriate laboratories where further explanations and demonstrations are given. Trips to telephone central offices of both manual and dial types are conducted to show typical examples of the conditions under which service is rendered to the public as a result of activities in the Laboratories. Having described the many parts of the business and,

Top Row: C. A. Grierson, M. I. T.; S. S. Neill, Miss. A. & M.; J. O. Israel, Lafayette; F. E. Blount, Oregon State; E. T. Pierce, Yale; B. Page, Brown; J. H. Shepard, Jr., Brown; W. M. Sharpless, Minnesota; W. K. Caughey, Stevens; C. B. Aiken, Harvard; J. W. Bailey, Cornell; H. W. Baltazzi, U. S. Naval Academy; L. H. Whitman, Michigan; J. A. Hitz, Pratt Institute; B. A. Fairweather, Wisconsin. Middle Row: W. E. Dorland, Cornell; I. L. Bateman, Southern California; J. R. Fisher, Brooklyn Poly.; J. F. Eckel, Carnegie Tech.; J. V. Kurtinaitis, Illinois; A. P. Huchberger, Columbia; D. M. Black, Kansas; C. E. Nelson, Brigham Young; P. H. Smith, Tufts; R. J. Fluskey, N. Y. U.; C. L. Frederick, George Washington; H. E. Mendenhall, California Tech.; C. H. Prescott, California Tech.; F. West, Johns Hopkins; E. D. Gibbs, Worcester Poly.; C. S. Knowlton, Lowell Institute. Bottom Row: A. T. McNeill, Wisconsin; E. M. Keillor, Michigan; M. L. Martin, Wisconsin; D. T. Bell, Georgia Tech.; E. C. Walsman, Ohio Wesleyan; M. A. Specht, Cornell; A. J. Tatarcuk, New Hampshire; H. Kahl, Washington State; P. H. Richardson, Harvard; E. H. Toney, Miss. A. & M.; W. R. Lundry, Iowa State; D. C. Lloyd, Delaware; J. E. Tarr, Maine

in so doing, having shown their interrelationship, the survey is concluded by a summary of company policies and of opportunities provided for continued study. Each new member is assigned to a type of work consistent with his training and propensities before he enters the survey in order that during the course he may be alert for those bits of information which will aid his orientation in his chosen field of work.

The group just issuing from the introductory course, like its predecessors, represents educational institutions in every section of the United States and in some foreign countries as well as various other departments of the Bell System. Wide representation is distinctly advantageous in that it brings together men with common interests but with varied backgrounds of experience. The Associated Operating Telephone Companies by keeping in close contact with the engineering colleges and describing our work to qualified students have greatly assisted our Personnel Department in the selection of new employees.

The Laboratories expects these new members to bring with them the habit of study and the susceptibility to instruction which has characterized their previous training and hopes that they will utilize the facilities offered for further study and advancement.

They will soon begin to realize—what those of us who are older at the business know so well—that employment marks not the end of one's education but rather its beginning. On its side, the Laboratories will not forget that although dedicated to the achievement of distinctly practical ends, it must cooperate with the members of its organization in broadening their knowledge of electrical communication. To this end and to supplement the introductory courses, many other courses both in and out-of-hours are offered to those who have the necessary background.

Key Town Selling

Members of the Laboratories have probably seen the advertisements of the "key town selling" plan recently placed by the American Telephone and Telegraph Company in prominent magazines. The plan encourages the use of the telephone to sell, from bases of operation in market centers. Specifically to facilitate this use, the Bell System offers general and regional key town maps, dividing the country in such a way as to afford maximum convenience to telephonic coverage from recognized centers of distribution. From business-classified directories, a travelling representative can compile a call list of logical prospects, then file it in advance for rapid completion by a specially assigned operator through the "sequence" calling service. Telephone Companies are providing in key town exchanges comfortable rooms from which salesmen can make these calls, and have instituted a credit plan enabling them to have their telephone expenses charged to their home offices. Organizations are recognizing that large scale production economies must not be offset by large scale selling expenses; the response to the offer of key town service has been gratifyingly large.

JOHN J. LYNG

"Effective October first J. J. Lyng has been appointed Vice-President of Electrical Research Products, Incorporated.

"It is with a feeling of regret, and yet of pleasure that I make this announcement, regret because we lose the direct advice and competent counsel of a friend long associated with our particular business, and pleasure because of the general advancement that this move means to him personally. All of his friends in the organization, and he has many, join with me, I know, in assuring him of our continued friendship and of our assistance in the success of his undertaking, which will be intimately associated with our work for the Electrical Research Products, Incorporated." E. B. CRAFT, *Executive Vice-President.*

News Notes

Mr. Jewett was present at a luncheon and meeting of the Corporation of Massachusetts Institute of Technology at Boston on October 10. He also attended the Presidents' Conference at Yama Farms, New York, from October 2 to 8. On October 18 he spoke on "The Ideals, Opportunities and Difficulties of the Engineering Career" at a public lecture given at Dartmouth College.

Mr. Craft spoke at the General Staff Luncheon of the Western Electric Company on October 5, on "Some Aspects of Aircraft Communication Development."

With the resignation of J. J. Lyng to become Vice-President of Electrical Research Products, Incorporated, R. L. Jones has been appointed Director of Apparatus Development. With the Apparatus Development Department there will be merged the work, already under the direction of Mr. Jones, of the Outside Plant Development Department and of the Inspection Engineering Department. Reporting to Mr. Jones in charge of the latter will be G. D. Edwards, Inspection Engineer.

At the opening meeting of the Colloquium for the year, K. K. Darrow spoke on "The Raman Effect", and Dr. D. P. Mitchell of Columbia University told briefly of results of his experimental work in that field. The meeting closed with a talk by H. E. Ives on "Parallax Relief Pictures" and a demonstration of pictures produced. Preceding the evening's program, the president, W. S. Gorton, appointed R. V. L. Hartley, E. C. Wente and A. L. Johnsrud as the Committee on Procedure for the season. At the following meeting, on October 22, R. M. Bozorth spoke on "Discontinuities in Magnetization", telling of recent experimental results obtained by him in a quantitative investigation of the Barkhausen effect in permalloy and in single crystals of iron.

The American Society for Steel Treating held its annual convention at Philadelphia on October 10 and 11. Those present from the Laboratories included W. Fondiller, H. N. Van Deusen, H. A. Anderson, J. R. Townsend, C. R. Wohrman and C. H. Greenall. While in Philadelphia, Messrs. Anderson, Greenall, Townsend and Van Deusen also attended the Fall Meeting of the Die Casting Committee of the American Society for Testing Materials.

Apparatus Development

B. Freile was in Chicago during the week of September 17, to confer with engineers of the Automatic Electric Company and Hawthorne Works on modifications in the design of step-by-step apparatus.

N. Bishop visited Winnipeg during the week of October 9 to supervise the testing of a 105-C radio telephone broadcasting equipment recently sold to the Provincial Government of Manitoba.

H. H. Glenn attended a conference of the Textile Committee of the American Society for Testing Materials in Washington on October 11.

A. H. W. KAACK observed a new method of hardness testing, using the monotron, at the Shore Manufacturing Company in Jamaica.

F. F. LUCAS delivered a paper on "Further Observations on the Microstructure of Martensite" before the Annual Convention of the American Society for Steel Treating in Philadelphia on October 10. He addressed the New York Microscopical Society on October 19, on "High Power Metallurgy and the Ultra-violet Microscope."

MR. LUCAS was appointed a member of the consulting staff, Ordnance Department, United States Army, and spent October 2 to 5 at the arsenal at Watertown, Massachusetts, in connection with his duties. He later discussed with members of the staff of the Harvard Medical School the application of the ultra-violet microscope to cancer research.

J. C. WRIGHT AND N. INSLEY spent the last week of September at Hawthorne in connection with the development of switchboard lamps.

W. E. MOUGEY was elected to membership in Edward J. Hall Chapter, Telephone Pioneers of America, on October 9.

C. A. WEBBER visited Philadelphia October 5 to discuss with representatives of the Bell Telephone Company of Pennsylvania splicing of distributing frame wire.

H. N. VAN DEUSEN lectured October 5 in the Auditorium before the members of the General Apparatus Development Group on the nature and method of solving of materials problems in the Laboratories.

W. V. WOLFE, C. F. BOECK AND J. D. SARROS attended the Convention of the Pacific Coast Section of the A. I. E. E. from August 28 to 31. Mr. Wolfe and Mr. Sarros were the co-authors of a paper presented at that time, entitled "Some Problems in Power Line Carrier Telephony, and Apparatus Developed to Meet Them."

E. C. SOFIO visited Hawthorne from September 10 to 13 in connection with the manufacture of disc recording machinery.

R. V. TERRY supervised the installation of a new type universal base for reproducing synchronized sound pictures, at the Convention of the Society of Motion Picture Engineers at Lake Placid. He also visited the Bausch and Lomb factory at Rochester.

OUTSIDE PLANT DEVELOPMENT

C. S. GORDON AND C. A. CHASE visited the plants of the Henry L. Scott Company and the New England Butt Company of Providence on September 20 to select equipment for a wire-testing laboratory.

F. D. POWERS, with J. H. GRAY of the American Telephone and Telegraph Company, visited Providence on September 18 in connection with the development of cotton sleeving.

V. B. PIKE AND D. T. SHARPE conducted pressure tests on a toll cable installed at Reading, Pennsylvania, on September 25 and 26.

E. ST. JOHN visited Harrisburg, Pennsylvania, on September 13 to discuss matters relating to the use of electrically welded steel ladders.

PATENT

MR. JEWETT addressed the first Patent Department luncheon of the season, held at the Fifth Avenue Hotel on October 16.

G. M. CAMPBELL visited Camden,

New Jersey in connection with the prosecution of applications for patent. E. V. Griggs, W. C. Kiesel, J. F. McEneany, G. T. Morris and T. P. Neville visited Washington for the same purpose.

DURING JULY, AUGUST AND SEPTEMBER, applications for patent were granted to the following members of the Laboratories staff:

G. A. Anderegg
H. C. Baumann
H. S. Black (2)
J. H. Bower
O. E. Buckley
H. C. Caverly
I. B. Crandall
A. M. Curtis (2)
J. F. Dahl
G. W. Elmen (2)
H. T. Friis (2)
M. E. Fultz
J. C. Gabriel
J. J. Gilbert
E. V. Griggs
A. E. Hague
R. W. Harper
H. C. Harrison (2)
R. A. Heising (2)
F. A. Hubbard
H. E. Ives (2)
M. J. Kelly
M. B. Kerr
A. W. Kishpaugh
J. J. Kuhn
C. D. Lindridge
G. A. Locke
W. P. Mason
R. C. Mathes
D. T. May
C. G. McCormick
L. A. Mortimer
E. L. Norton
A. A. Oswald
E. Peterson
P. H. Pierce
L. F. Porter
H. O. Siegmund
K. O. Thorp
E. B. Wheeler
J. H. White
R. R. Williams
S. B. Williams
W. V. Wolfe
J. C. Wright

SYSTEMS DEVELOPMENT

F. B. ANDERSON AND A. J. PASCARELLA visited the toll repeater station at Harrisburg, Pennsylvania during the week of September 15.

J. B. SHIEL AND F. VAN VOORHIS investigated the installation of 84-F interrupter equipment at Watertown, Connecticut.

W. A. PHELPS, J. L. HYSKO, R. B. STEELE AND W. F. MALONE have completed tests to provide additional telegraph facilities for the Key West-Havana cable.

J. A. MAHONEY visited Toronto, Smiths Falls and Montreal, Canada, in connection with the introduction of carrier telegraph equipment on the Canadian Pacific Railway System.

A. E. PETRIE observed tests on new gas engines at the factory of the Buffalo Gas Engine Company at Buffalo, New York.

J. L. LAREW inspected the new power equipment at the repeater stations on the Washington-Atlanta cable at Greensboro, Burlington, Durham and Norlina, North Carolina.

J. H. SOLE visited the General Electric Company at Pittsfield, Massachusetts, on September 15 and 17.

J. W. WOODWARD discussed the new Los Angeles Toll Project with engineers of the Pacific Telephone and Telegraph Company at Los Angeles.

RESEARCH

D. G. BLATTNER, H. A. FREDERICK, H. C. HARRISON AND W. C. JONES visited the Victor Talking Machine Company at Camden on October 2.

R. E. WATERMAN made a study of the preservation of telephone poles at Bridgeton, New Jersey, on September 17.

J. E. HARRIS AND E. E. SCHUMACHER observed the manufacture of cable sheath at Hawthorne during the week of September 16.

C. W. BORGMANN, R. M. BURNS, B. L. CLARKE, C. L. HIPPENSTEEL, A. R. KEMP, P. A. LASELLE, J. A. LEE AND R. R. WILLIAMS attended a meeting of the American Chemical Society at Swampscott, Massachusetts during the week of September 10.

R. M. BURNS attended meetings of the American Electro-Chemical Society at Charleston, West Virginia, on September 21 and 22. He subsequently made a study of metal finishes at Hawthorne.

C. J. DAVISSON gave a paper "Scattering of Electrons by a Crystal of Nickel" before the Glasgow meeting of the British Association for Advancement of Science on September 11, describing the experiments performed by himself and L. H. Germer.

K. K. DARROW addressed the Colloqium of the Washington Square College of New York University on October 10, on "The Raman Effect and the Corresponding Effect with Electrons."

WILLIAM D. NOBLE died at his home at Newark on Saturday, September 15. Mr. Noble joined the Bell System on November 27, 1917, and for a number of years had been a member of the group interested in the development of transmission instruments.

A. C. WALKER was present at a conference of the Textile Committee of the American Society for Testing Materials in Washington, October 11.

H. E. IVES described television apparatus and its operation at a meeting of the Montclair Rotary Club on October 30.

GENERAL STAFF

S. P. GRACE addressed the regional convention of the American Institute of Electrical Engineers at Atlanta, Georgia, on October 29, on "Delayed Speech and Other Recent Discoveries and Inventions of Bell Laboratories."

JOHN MILLS spoke to the faculty and students of the Massachusetts Agricultural College at Amherst, Massachusetts, October 25, on the subject of balanced rations of work. On September 24 he described to the Society of Motion Picture Engineers in convention at Lake Placid the work and organization of the Laboratories. Among the films shown to that Society was "The Magic of Communication." Mr. Mills also spoke at the annual banquet of the Society.

RICHARD MALZER, a journeyman instrument maker in the Engineering Shop, died on October 6. He entered the Laboratories in 1922, and was a graduate of the Instrument Makers' Apprentice Course.

FRANK W. ANDERSON, an assistant foreman in the Building Shop, died on October 20. He had been a member of the Laboratories since 1923.

W. C. F. FARNELL accompanied G. K. Thompson of A. T. & T. on a trip to Washington on October 23 to represent the Bell System in presenting a sectional model of a telephone transmitter and receiver to the National Museum of the Smithsonian Institution.

* * * *

A TYPOGRAPHICAL ERROR in the October RECORD should be noted. In the article "The Nobel Laureates" by Karl K. Darrow, page 40, right-hand column, line 16 *et seq.* should read:

. . . . . Michelson, however performed an experiment from the result of which there was no possibility of escape . . . .

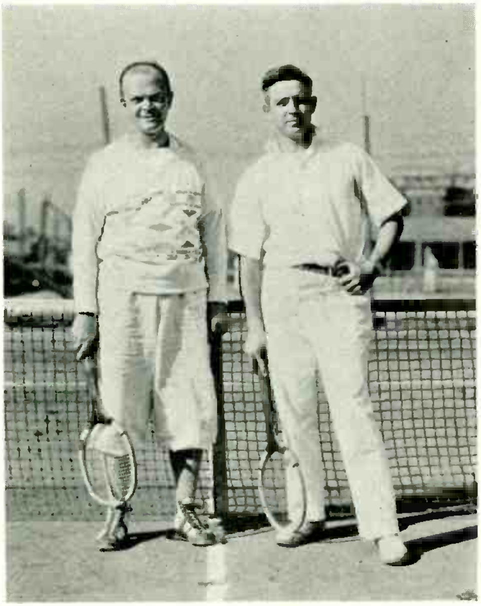
Bell Laboratories Club

THERE is to be a Christmas poster contest this year open to all members of the organization. Those interested in participating in the contest should submit their posters to D. D. Haggerty by December 1. All posters should measure twelve by sixteen inches, be made in not more than three colors, and have space for a Christmas greeting which will be inserted after the winning entry has been chosen. The posters will be judged by an impartial committee and one or more of the best will be reproduced and displayed on the company bulletin boards during the holiday season. A ten-dollar gold piece is offered as a prize for the winning poster.

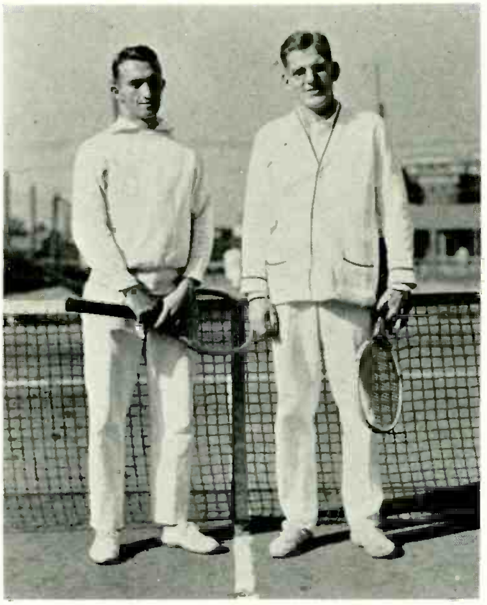
Tennis

Saturday, September 29, for which the first two rounds of the men's doubles tennis tournament were scheduled, saw a morning conference in Dave Haggerty's office, pondering the leaden skies. The conclusion was that the day would have to do, and thirty-six contestants, assembling in the afternoon, deployed without debate over the Mammoth Courts and started lifting the ball past the occasional raindrop. Aside from intermissions for wiping spectacles, the

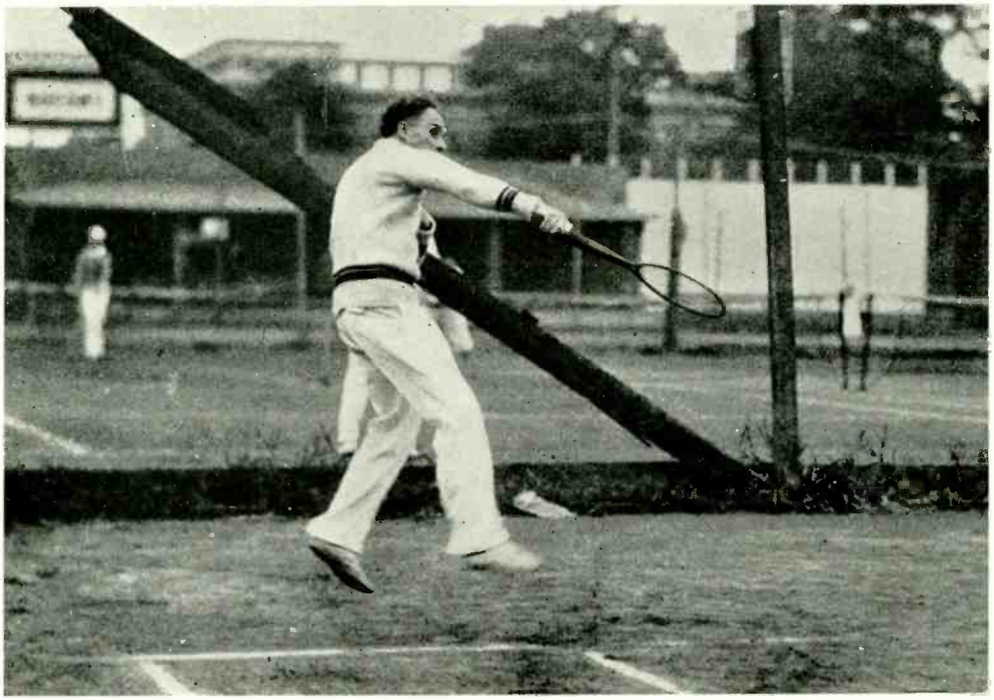
H. T. Reeve follows through a drive.



P. Norton and W. E. Stevens



A. M. Elliott and F. S. Entz



R. H. Wilson takes it on his backhand

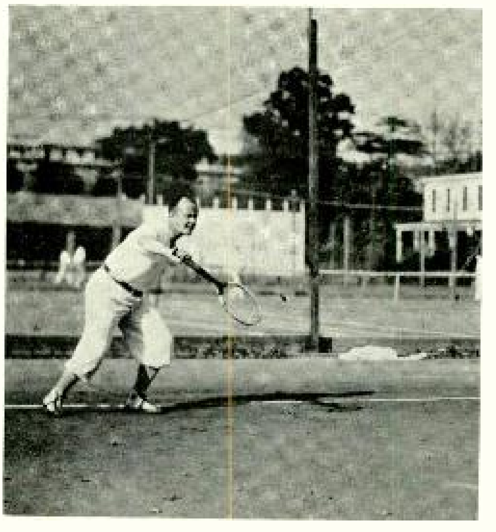
weather called forth during the first round only grim earnestness and spirited determination. The hardest fought and most brilliant of the first round matches was probably that of W. C. Lamoreaux and E. M. Tolman, playing together for the first time, against H. T. Reeve and R. H. Wilson. Lobbing, and Wilson's spectacular gets at net, kept the new combination hard at work through three sets. Fast and sturdy tennis finally brought Lamoreaux and Tolman out ahead.

Most of the first-round victors decided to let well enough alone and abandoned the field in favor of dry shelter. But K. S. Johnson and M. B. Kerr, the redoubtable left-handers, and W. E. Stevens with his partner, the veteran P. Norton, who had won their first-round matches in straight sets, recklessly agreed to have at one another. And Lamoreaux and Tolman advanced on A. M. Elliott and F. S. Entz, who had beaten R. M. Bozorth and J. M. Eglin somewhere far from the spectators. Mr. Johnson's chops and kills and Mr. Norton's well-diversified playing made their match nip and tuck. The opponents won game for game until the score stood two all, then four games and the first set went to Johnson and Kerr. Stevens and Norton came back to take the second set 6-4.

About this time the rain began to come down with a will, soaking the doughty players' rackets and plastering with mud the hard-working tennis balls. But the undaunted combatants merely took fresh balls and courts and continued.

At last, with the score two all in the third set, Mr. Norton suggested postponing settlement, out of regard for the rivulets on Mr. Kerr's spectacles. The other match, spectacles and all, persisted to the bitter end, Elliott and Entz beating Lamoreaux and Tolman 6-4, 6-3.

Next Saturday, and the Friday following, beamed more favorably on the Mammoth Courts and saw the completion of all but the finals. E.



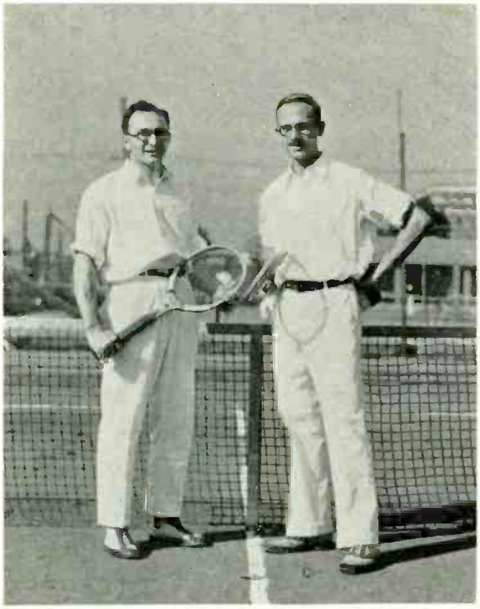
P. Norton picks up a low one

H. Chatterton and J. Blanchard, barging through all comers in straight sets, reached the final bracket by defeating H. I. Miller and W. Kuhn, 6-4, 6-3, then taking out H. M. Yates and P. Kuhn, 6-1, 6-2, 6-3. Johnson and Kerr allowed Stevens and Norton only one more game in their interrupted match and then struggled past Elliott and Entz, 6-3, 0-6, 4-6, 6-4, 6-2.

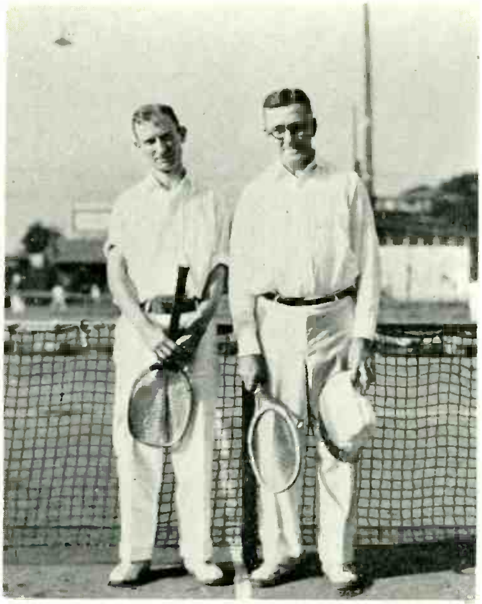
The finalists met in the stiff breeze of October 20; Johnson and Kerr broke through the steady play of Chatterton and Blanchard, 6-3, 6-3, 7-9, 6-2, for the championship.

Basketball

The Bell System League will open the 1928-29 season on Monday evening, November 12, at Stuyvesant

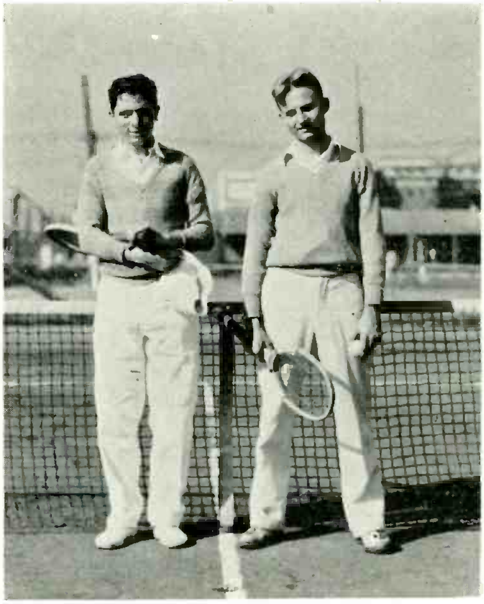


M. A. Boccalery and D. H. Pennoyer



J. Blanchard and E. H. Chatterton

K. S. Johnson and M. B. Kerr



W. Kuhn and H. I. Miller

High School, First Avenue and Fifteenth Street, New York. League games will be played on Monday and Friday evenings at Stuyvesant High School and on Wednesday evenings at Erasmus Hall High School, Church and Flatbush Avenues, Brooklyn. Two games will be played each evening and there will be dancing after each game. Season tickets which will admit the holder to all twenty-seven sessions of the league will cost one dollar, tickets for individual games costing twenty-five cents. The Basketball Committee hopes that last season's attendance will be not only sustained but surpassed. For further information, call D. D. Haggerty, Extension 542.

Golf

The regular Fall Golf Tournament was held at the Salisbury Country Club on Saturday, September 22, but the entire tournament was played on one day instead of two, as heretofore. This method proved very popular, since the entries exceeded by far those of any previous fall tournament. The seventy-four players were divided into three classes on the basis of handicaps.

Each class played for prizes of equal value. The low gross prize in each class was a wrist watch. In Class A, G. E. Kellogg and H. W. Wood tied for the prize with an eighty-seven and in the subsequent play-off Kellogg won. R. C. Koernig won the watch in Class B with a ninety-three and J. F. Dalton was low man in Class C with a one hundred and ten. The low net prize, a Parker desk set, was won in Class A by R. E. Collis while the winners of similar prizes in Classes B and C were E. Peterson and F. A. Korn, respectively. The second low net prize in Class A was a musical water jug, won by F. F. Farnsworth. W. F. Johnson received a golf sweater as the winner of second low net in Class B, and a dozen U. S. Royal Golf Balls, donated by Alex Taylor and Co., were awarded to T. P. Ingram as the second low net prize in Class C. Due to the fact that there were so many more entries in Classes B and C than there were in Class A, a third low net prize was added in these classes. A. N. Gray received a half-dozen Kroflite Golf Balls as the third low net winner in Class B, and E. J. Daniels and C. L. Goodrum who tied in third position for Class C, received a pair of golf stockings each.

Bowling

The Bowling League began its season on Friday evening, September 28, at Dwyers Manhattan Alleys, 1680 Broadway. "D" league was increased from four to eight teams, the Committee having received entries from over two hundred men wishing to bowl as regulars. This means that for the coming season the Club will have thirty-two teams competing for a total of twenty-eight weeks.

In addition, there were received the names of one hundred men who wish to bowl as substitutes. Men may have their names placed on the substitute list by communicating with R. L. Quass.

All league games will start promptly at 5:45. The cost of each evening's bowling will be seventy-five cents per man, which is thirty-five cents less than the fee charged last season.

Women's Basketball

The prime objective of the Women's Basketball Squad, now practicing each Monday night, is the formation of a Bell Laboratories team to be entered in the Bell System Basketball League. The first game is on November 14. This and subsequent games will be played each Wednesday night prior to the Men's League game, at Erasmus Hall High School, Flatbush and Church Avenues, Brooklyn. Admission is covered by the season ticket issued by the Men's League.

Glee Club

The Glee Club held its first rehearsal of the season on Wednesday evening, November 17, under the direction of Mr. V. S. Richards, a professional instructor. Ada Van Riper and P. H. Betts will be glad to furnish further information to those interested in joining this group, and rehearsals will be held each Wednesday evening at 5:10 in the Women's Rest Room.

Indoor Golf

Another Women's Indoor Golf Tournament will be held on Tuesday, December 4, the place to be announced later.

Club Calendar for November

THURSDAY, 1: Basketball, Men, Labor Temple, 5:30
Orchestra Rehearsal, 11th floor Rest Room, 5:30

FRIDAY, 2: Dance, Hotel McAlpin; Bridge, Women, 11th floor Rest Room, 5:10

MONDAY, 5: Basketball, Women, St. Lukes gymnasium, 5:30
Bridge, Men, Room 275, 6:00
Women's Swimming Class, Carroll Club, 7:00

TUESDAY, 6: Hike, Englewood to Alpine

WEDNESDAY, 7: Women's Swimming Class, Carroll Club, 5:30
Glee Club, 11th floor Rest Room, 5:30

THURSDAY, 8: Basketball, Men, Labor Temple, 5:30
Orchestra Rehearsal, 11th floor Rest Room, 5:30

FRIDAY, 9: Bowling, Men, Dwyers Manhattan Alleys, 5:45
Bowling, Women, Dwyers Manhattan Alleys, 5:45
Bridge, Women, 11th floor Rest Room, 5:10
Athletic Dancing Class, Women, Louis Vecchio Studio, 5:30

MONDAY, 12: Basketball, Women, St. Lukes gymnasium, 5:30
Basketball, Men, Bell System League Tournament, Stuyvesant High School, 8:30; dancing after game
Bridge, Men, Room 275, 6:00
Women's Swimming Class, Carroll Club, 7:00

TUESDAY, 13: Basketball, Men, Labor Temple, 5:30

WEDNESDAY, 14: Glee Club, 11th floor Rest Room 5:10
Women's Swimming Class, Carroll Club, 5:30
Basketball, Men and Women, Bell System League Tournament, Erasmus Hall High School, 7:30; dancing after game

THURSDAY, 15: Basketball, Men, Labor Temple, 5:30
Orchestra Rehearsal, 11th floor Rest Room, 5:30

FRIDAY, 16: Bowling, Men, Dwyers Manhattan Alleys, 5:45
Bowling, Women, Dwyers Manhattan Alleys, 5:45
Bridge, Women, 11th floor Rest Room, 5:10
Athletic Dancing Class, Women, Louis Vecchio Studio, 5:30
Basketball, Men, Bell System League Tournament, Stuyvesant High School, 8:30; dancing after game

SATURDAY, 17: Hike, along Bronx River Parkway

MONDAY, 19: Basketball, Women, St. Lukes gymnasium, 5:30
Basketball, Men, Bell System League Tournament, Stuyvesant High School, 8:30; dancing after game
Bridge, Men, Room 275, 6:00
Women's Swimming Class, Carroll Club, 7:00

TUESDAY, 20: Basketball, Men, Labor Temple, 5:30

WEDNESDAY, 21: Glee Club, 11th floor Rest Room, 5:10
Women's Swimming Class, Carroll Club, 5:30
Basketball, Men and Women, Bell System League Tournament, Erasmus Hall High School, 7:30; dancing after game

THURSDAY, 22: Basketball, Men, Labor Temple, 5:30
Orchestra Rehearsal, 11th floor Rest Room, 5:30

FRIDAY, 23: Bowling, Men, Dwyers Manhattan Alleys, 5:45
Bowling, Women, Dwyers Manhattan Alleys, 5:45
Bridge, Women, 11th floor Rest Room, 5:10
Athletic Dancing Class, Women, Louis Vecchio Studio, 5:30
Basketball, Men, Bell System League Tournament, Stuyvesant High School. 8:30; dancing after game

SUNDAY, 25: Hike along Mianus River

MONDAY, 26: Basketball, Women, St. Lukes gymnasium, 5:30
Basketball, Men, Bell System League Tournament, Stuyvesant High School. 8:30; dancing after game
Bridge, Men, Room 275, 6:00
Women's Swimming Class, Carroll Club, 7:00

TUESDAY, 27: Basketball, Men, Labor Temple, 5:30

WEDNESDAY, 28: Glee Club, 11th floor Rest Room, 5:10
Women's Swimming Class, Carroll Club, 5:30
Basketball, Men and Women, Bell System League Tournament, Erasmus Hall High School, 7:30; dancing after game

FRIDAY, 30: Bowling, Men, Dwyers Manhattan Alleys, 5:45
Bowling, Women, Dwyers Manhattan Alleys, 5:45
Bridge, Women, 11th floor Rest Room, 5:10
Athletic Dancing Class, Women, Louis Vecchio Studio, 5:30
Basketball, Men, Bell System League Tournament, Stuyvesant High School, 8:30; dancing after game

Telephone Service Between the United States and Spain

On October 13*th telephone service between the United States and Spain was inaugurated by conversation between President Coolidge in Washington and King Alfonso XIII in Madrid. Proceeding by the usual transatlantic routes between Washington and London, their voices passed over land lines of the British General Post Office, a submarine cable in the British Channel, lines of the French Ministry of Posts and Telegraphs between Boulogne and the Spanish border, and lines of the National Telephone Company of Spain, a total distance of* 6,500 *miles. News which it required Columbus's returning ships two months to bring to Spain from the New World can now be communicated in about one-fifth of a second.*

Telephone Stock

American Telephone and Telegraph Company stock totalling $1,000,000 *in market value has been delivered during the past year to members of the Laboratories. This cost its owners about* $600,000 *in actual payments; the American Company added to the payments an interest allowance of about* $70,000.

You, as a member of the Bell System, can subscribe to the stock at $130 *per share, of which* $115.75 *will be deducted from your pay and* $14.25 *will be paid you as interest by the American Company. Thus purchased, the investment will give you a return of* 6.9% *on the price, or* 7.7% *on the amount actually deducted from your pay.*

Your opportunity is enviable; you can make no mistake in availing yourself of the Stock Plan.