History of Sound Motion Pictures

by Edward W Kellogg

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Our thanks to Tom Fine for finding and scanning the Kellogg paper, which we present here as a "searchable image".

John G. (Jay) McKnight, Chair
AES Historical Committee
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FIRST INSTALLMENT

History of Sound Motion Pictures

By EDWARD W. KELLOGG

Excellent accounts of the history of the development of sound motion pictures have been published in this Journal by Theisen[5] in 1941 and by Sponable[6] in 1947. The present paper restates some of the information given in those papers, supplementing it with some hitherto unpublished material, and discusses some of the important advances after 1930.

One of the numerous omissions of topics which undeniably deserve discussion at length, is that, except for some early work, no attempt is made to cover developments abroad. The subject of 16mm developments is discussed with a brevity altogether out-of-keeping with its importance. This has been on the theory that basically the problems are similar to those of 35mm sound, and that whatever has brought improvement to one has been applied to both.

Edison invented the motion pictures as a supplement to his phonograph, in the belief that sound plus a moving picture would provide better entertainment than sound alone. But in a short time the movies proved to be good enough entertainment without sound. It has been said that although the motion picture and the phonograph were intended to be partners, they grew up separately. And it might be added that the motion picture held the phonograph in such low esteem that for years it would not speak. Throughout the long history of efforts to add sound, the success of the silent movie was the great obstacle to commercialization of talking pictures.

Early Sound Pictures Using the Phonograph

The idea of combining recorded sound with the motion pictures is as old as the motion picture itself[33] (if we exclude the early "zoetrope" invented in 1833 by W. G. Horner).[39] In a paper, "What Happened in the Beginning," F. H. Richardson[7] reproduced a letter in which Thomas A. Edison quoted from his early notes: "In the year 1887, the idea occurred to me that it would be possible to devise an instrument which should do for the eye what the phonograph does for the ear, and that by a combination of the two all motion and sound could be recorded and reproduced simultaneously." The letter proceeds to tell of the development of the motion picture (and is followed by letters from Thomas Armat, George Eastman, C. Francis Jenkins and others, related to motion-picture inventions). Edison in 1895 tried on the public the combination of a phonograph with his "peep show" moving picture.[5,11] He built at least 50 (and probably more) of the combination machines.

Gaumont. Leon Gaumont, in France,[5] began as early as 1901 to work on combining the phonograph and motion picture. He worked on the project during several widely separated intervals. Theisen[5] refers to a series of shows of the "Film Parlant" at the Gaumont Palace in Paris in 1913 and to demonstrations in the United States. After 1926 the "Etablissements Gaumont" used the system developed by Peterson and Poulsen.

Laemmle. An attempt by Carl Laemmle of Paramount in 1907 to exploit a combination of phonograph and motion picture is mentioned in Sponable's paper.[6] This was a German development called "Synchroscope." It was handicapped by the short time which the record would play, and after some apparently successful demonstrations, was dropped for want of a supply of pictures with sound to maintain programs in the theaters where it was tried.[13]

Pomerede, Amet, Bristol. Theisen's paper[5] mentions combinations of phonograph and motion pictures using flexible shafts or other mechanical connections, by Georges Pomerede[2] (1907 patent), and E. H. Amet[14] (1912 to 1918) who used electrical methods for the sound. Wm. H. Bristol[15] began his work on synchronous sound about 1917.

Siren Type of Amplifier. An ingenious attempt to obtain amplification in reproduction used the movements of the phonograph needle to vary the opening of an air-valve, connected to a source of air pressure. This device was employed for sound pictures by Oskar Messter[5,16] (Germany 1903–4). In England, where it was known as the "Auxetophone," it had some use for phonographs. Its invention is credited by the Encyclopedia Britannica to Short (1898), with improvements by the Hon. C. A. Parsons.

Edison. In 1913 Edison made a serious effort to provide synchronized phonograph sound. The equipment is on exhibit at the Edison Museum in West Orange, N.J. The phonograph is of special construction, to provide maximum volume and long playing, the cylinder record was oversize, and the horn and diaphragm considerably larger than those of home phonographs. Between the reproducing stylus and the diaphragm was a mechanical power amplifier, apparently using the principle of capstans used on shipboard. There was a continuously rotating amber cylinder and a hard rubber brake-shoe subtending about 130° of arc. One end of the shoe was connected to the reproducing stylus in such a manner that an upward displacement of the stylus would increase the pressure between shoe and cylinder; and the other end of the shoe was connected through a slender rod to the diaphragm, in such a way that the shoe movement resulting from increased friction would give an upward push on the diaphragm.[17] One may well imagine that the adjustment of this device to give substantial gain without producing chattering must have tested the skill of the best of operators. Nevertheless, it must have worked, for the record indicates that the Edison talking-picture show ran for several months in Keith's Colonial Theatre in New York, with much acclaim, and was shown in other large cities of America and in other countries.

The arrangement for synchronizing was not in accordance with present practices. The phonograph behind the screen determined the speed, being connected through a string belt to a synchronizing device at the projector. The belt pulleys were about 3 in. in diameter. The belt passed from the phonograph up over idler pulleys and overhead, back to the booth. The synchronizing device applied a brake to the projector, and the brake-shoe pressure depended on the relative phase of phonograph and projector, increasing rapidly as the projector got ahead in phase. With an even force

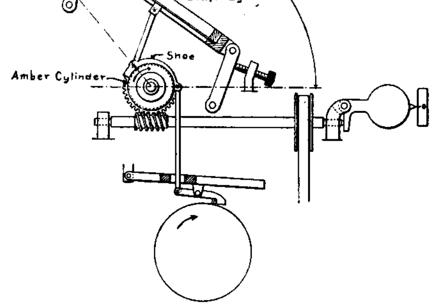

Fig. 1. Mechanical power amplifier of Thomas A. Edison and Daniel Higham.

Presented on May 5, 1954, at the Society's Convention at Washington, D.C., by Edward W. Kellogg, Consulting Engineer, 276 Merion Ave., Haddonfield, N.J.
(This paper was received on October 25, 1954.)

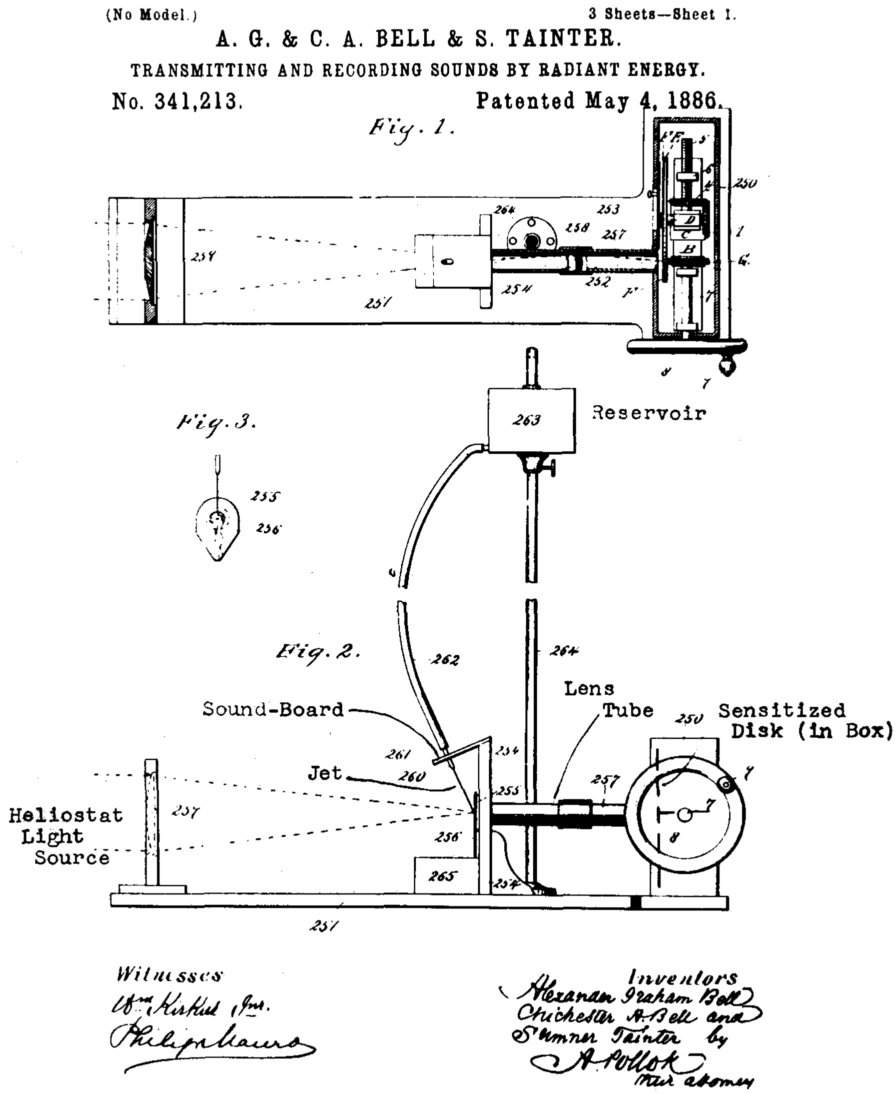

Fig. 2. Variable density recording system of A. G. Bell, C. A. Bell and Sumner Tainter, 1886.

on the projector crank, normal phase relation was maintained. The projectionist watched for synchronism and had a slight degree of control by turning the crank harder if the picture was behind or easing it off if it was ahead.

So far as I have learned, there were few further efforts (at least in the U.S.) to provide sound for pictures by means of phonograph (mechanical) recording until the Warner Brothers' Vitaphone system of 1926.

Photographic Sound Recording

A history of sound pictures necessarily includes the many efforts to record sound photographically, whether or not the experimenters made any attempt to combine the sound with pictures, or were even interested in that application. Despite the obvious advantages, from the synchronized-sound standpoint, of a photographic record of the sound on the same film with the picture, it does not appear that this consideration was necessarily an important factor in directing experimentation toward photographic recording, nor even that ultimate application to synchronous sound for motion pictures was (in many cases) a main objective. It was rather that photographic recording represented a new medium, which seemed to offer promise of much superior results. A mechanical system seems inherently crude where such delicacy is needed as in reproducing sound; in contrast to which recording by a beam of light would seem ideal. The experimenters have all been conscious of the handicap imposed by the necessity of making ponderable mechanical parts vibrate at high frequency.

So we find that efforts to record sound photographically began before there were such things as motion pictures on strips of film. Before the invention of the telephone, Alexander Graham Bell, interested in aiding the deaf, had made photographic records of "manometric flames," showing voice waves. His patent, No. 235,199, filed in 1880, shows a system for transmitting speech over a beam of modulated light, and uses a light-sensitive device (selenium cells) to detect the received fluctuations, thus anticipating the essential principle of the reproducing system which was used in many later experiments.

Blake. Prof. E. W. Blake of Brown University in 1878 made photographic records of speech sounds on a moving photographic plate, using a vibrating mirror.[6,18]

Fritts. U.S. Patent No. 1,203,190, filed in 1880 by Charles E. Fritts,[5,6] discloses photographic soundtracks and a great variety of devices for recording and reproducing, but there does not appear to be evidence of much significant experimental work.

Bell and Tainter. In the Smithsonian Museum in Washington, D.C., are a number of large glass disks carrying spiral sound tracks. These were made by a method described in U.S. Patent No. 341,213 (filed 1885) to Alexander Graham Bell, Chichester A. Bell and Sumner Tainter. Light from a steady source was transmitted in a relatively narrow beam through a piece of stationary glass, and then further restricted by a slit where it reached the circular photographic plate. Just above the place where the light entered the stationary glass, a tiny jet of ink (or other light-absorbing liquid) was directed against the surface. The nozzle was attached to a "sounding board" (small plate) which picked up the sound vibrations. The jiggles of the nozzle caused waves in the stream of ink which flowed down over the surface, and these modulated the transmitted light.

Some years ago it became desirable, in connection with a patent suit, to demonstrate that the spiral track was really a soundtrack. Contact prints (on celluloid films) were made of several of the most promising looking of the glass plates, and a reproducing system arranged, giving the record the benefit of modern equipment in this respect. The approximate best speed was found by trial. (The original recording machine was hand-cranked). The photographic image had suffered from age and was very noisy, and the total recording lasted only a few seconds. But it was with something of the thrill of an antiquarian that we listened to the voice from the past. "This is . . . . I am . . . in the . . . laboratory." The date was given too " . . . , eighteen eight- . . .?"

Others. Sponable's historical paper mentions numerous other workers and their patents. Several of these modulated the light by means of a small mirror connected to a diaphragm so that vibration caused rotation, thus anticipating features of equipment used by C. A. Hoxie in the work at General Electric Co. Of the developments which, although not leading to any commercial system, deserve special mention, I shall speak of several inventions or discoveries which laid foundations for later developments, and of the direct contributions to photographic recording of Rühmer, Lauste, de Forest, Reis and Tykociner.

Basic Inventions and Discoveries

Selenium Cells. For many years, reproduction from photographic-sound records was made possible by the selenium cell. The photoconductive properties of selenium were discovered by Willoughby Smith in 1873, and a practical selenium cell was made by Werner Siemens in 1876.[19] The response of a selenium cell to changes in illumination is sluggish, making it a very imperfect tool for sound reproduction, whereas the photoemissive effect on which photocells depend is practically instantaneous, but the electrical output from a selenium cell is very much greater.

The Photocell. The first indication of photoemission was discovered by Hertz in 1887 and later studied by Hallwachs (1888), Stoletow (1890) and Elster and Geitel (1889 to 1913).[19,20] Although by 1900 much had been learned, practical photocells did not become generally available till some years later, nor were they of help toward sound reproduction without electronic amplifiers.[21,22]

Thermal Emission — The "Edison Effect." Edison discovered in 1883 that a small current could flow through evacuated space in a lamp bulb, between a hot filament and a separate electrode. The Fleming "Valve," invented in 1905, made use of this principle, played an important part in early wireless telegraphy and was the forerunner of thermionic amplifiers.[26]

The Audion. The invention of the "Audion" by Lee de Forest in 1907 marked the beginning of the electronic era. As has been emphasized by many writers, it was the electronic amplifier which unlocked the door to progress and improvement in almost every phase of sound transmission, recording and reproduction. However, amplifying tubes did not become generally available to experimenters for over a decade. The de Forest patent[23] (acquired by the Telephone Company) was basic and unchallenged, but the vacuum techniques of some of the foremost laboratories of the country[24] were needed to make of the audion a dependable and reasonably rugged tool.*

The Oscillograph. The oscillograph, consisting of a small mirror mounted on a pair of conductors, close together, in a strong magnetic field, was invented by Blondel in 1891 and improved in 1893 by Duddell, who put it into practically the form still used. It has played a vital part in photographic sound recording.

Magnetic Recording. The invention by Poulsen of Copenhagen in 1900 of recording magnetically on a steel wire laid the foundation for modern tape recording, which has almost revolutionized methods of making original recordings.[27]

Auditorium Acoustics. The modern science of room acoustics and acoustic treatment dates from the work of Prof. Wallace C. Sabine of Harvard in the years 1895 to 1900.[28] With little other equipment than a whistle, a stop watch and brains, he worked out the acoustic principles on which successful sound recording and reproduction so largely depend.

Gas-Filled Incandescent Lamps. Beyond a certain point, optical-recording systems cannot give increased exposure by increasing the size of the source, but only by increasing the intensity (candles per square centimeter), which means higher temperature. Early incandescent lamps were well exhausted because all gas results in loss of heat by convection and hence lowered efficiency. In 1911–13 Irving Langmuir of General Electric Co. studied the effects of inert gas not only on heat loss, but also on the rate of evaporation of tungsten from the filament surface, which is the factor which determines permissible operating temperature. He showed that such gases as nitrogen, or better yet argon (the heavier the better), at pressures well up toward atmospheric or even higher, could with suitably formed filaments so retard the evaporation of tungsten that the higher permissible temperature much more than compensated for the added heat convection, thus giving several-fold increase in efficiency as well as whiter light. With the gas, the evaporated tungsten is carried to the top of the bulb instead of blackening the sides, in the optical path.[29]

Magnetic Materials. The development of several alloys of iron, nickel and cobalt having extraordinary magnetic properties is reported by H. D. Arnold and G. W. Elmen in the *Bell System Technical Journal* of July 1923, and by Elmen in the January 1929 and July 1929 issues. The extremely high permeability and low hysteresis of Permalloy have made it possible to greatly reduce distortion in transformers and in many electromechanical devices, and to provide more successful magnetic shielding than would otherwise be possible. In another alloy which has been called Perminvar, constancy of permeability and low hysteresis (making for low distortion) have been carried still farther. Another alloy named Permendur can carry very high flux densities before saturation, making it possible to produce intense fields which make for sensitivity and damping in devices of the moving conductor type.

Important for the reduction of cost and weight of magnetic devices was the discovery by the Japanese physicist T. Mishima of the properties of certain aluminum-nickel-cobalt alloys for permanent magnets,[30] and subsequent improvements.

Improvements in Vacuum Tubes and Phototubes. In any list of the advances which contributed in an important way to the technical attainments in modern sound reproduction, several improvements in amplifier tubes deserve an important place. Among these are:

(1) The Wehneldt (oxide coated) cathode and other low-temperature emitters, which in turn made indirectly heated unipotential cathodes possible.

(2) The screen-grid tube.

(3) The pentode.

(4) Remote cutoff or exponential tubes, and other variable gain tubes.

(5) The caesium phototube with its high sensitivity to infrared light.

(6) The gas-filled phototube with its increased output.

Early Work on Sound on Motion-Picture Film

Rühmer. Ernst Rühmer in Berlin[5,6,31] in 1901 began publication of the results of his work on photographic sound recording, which extended over a period of about twelve years. As sources of modulated light he superimposed voice currents on the continuous currents in electric arcs. He used considerably higher film speeds than those used for pictures. Sponable reported (ref. 6, p. 278) that some of Rühmer's Photographophon films were brought to this country by the Fox Film Corp., and that the articulation was clear; also, this reference shows a sample of Rühmer's soundtrack. A variable-area track by Rühmer is shown in the Theisen history (ref. 5, p. 421), the *Scientific American* of 1901[31] being cited as reference. Presumably Rühmer experimented with both systems.

Lauste. This Society has taken special note of the work of Eugene Augustine Lauste, in a 1931 report of the Historical Committee,[32] in a paper by Merritt Crawford[32] and in placing his name on the Society's Honor Roll. The young Frenchman joined the staff of Thomas A. Edison in 1887, where he did construction and experimental work till 1892. For two years he worked on another project and then, in association with Maj. Latham, developed a projector which was the first to incorporate the extra sprocket and free loops with the intermittent. Lauste's interest in photographic sound recording was first aroused when in 1888 he found in an old copy of the *Scientific American* (May 21,

* Much higher vacuum than de Forest had been able to obtain was necessary. This was independently accomplished by I. Langmuir of General Electric Co. and H. D. Arnold of Western Electric Co.[24]

1881) an account of Dr. Bell's experiment in transmitting sound over a modulated light-beam, and converting to electrical modulation by means of a selenium cell. This suggested the thought of recording the sound photographically on the same strip with the picture. It was not till about 1900 that he began to find opportunity to work on this project. He worked for several years in the United States and then went to England where he pursued his experiments. A British patent (No. 18,057, filed in 1906) shows a well thought-out system. Lauste received some financial backing in 1908 from the manager of the London Cinematograph Co.

To modulate the recording light, Lauste used rocking mirrors and what have been described as "grate-type light-valves." The mirror system was too sensitive to camera vibrations, and the grate-type valves which he was able to build had too much inertia. In 1910 he began working with modulators of the string galvanometer type, with excellent results. The historical account by Theisen,[5] shows photographs of some of Lauste's apparatus. He spent some time with Ernst Rühmer in Berlin, a stimulating and profitable association. He visited America in 1911 and as part of his demonstration made what was probably the first actual sound-on-film motion picture made in the U.S. A necessary return to England, shortage of capital, and the war, halted Lauste's sound-picture researches. In his paper on Lauste, Crawford expresses the thought that had it not been for this unfortunate interruption, plus very limited resources, and had electronic amplifiers been available to Lauste, commercialization of sound pictures might well have gotten started a decade before it actually did.

E. E. Ries filed application in 1913 for a patent (No. 1,473,976, issued in 1923) in which broad claims were allowed on the essentials of a single-film system. The patent became the basis of later litigation.[6]

Tykociner. In 1918 and following, Prof. J. T. Tykociner of the University of Illinois carried on experiments and developed a system. This work was described before the American Institute of Electrical Engineers and in the *SMPE Transactions*.[34] After pointing out that three new tools had in comparatively recent times become available for the solution of the sound-picture problem, (namely, high-frequency currents, photoelectricity, and thermionic amplifiers), Prof. Tykociner gives a broad discussion of requirements and possible arrangements. As a source of modulated light he used for the most part a mercury arc with either modulated continuous current or modulated high-frequency current, and for reproduction a Kunz (cathode of potassium on silver) photocell. The light from the mercury arc is particularly potent photographically, but is sluggish in following the input modulation, which results in some loss of the higher audio frequencies.

Foreign Developments Which Led to Commercial Systems

Tri-Ergon (meaning "the work of three"). Josef Engl, Joseph Massole and Hans Vogt, in Germany, began in 1918 the development of a system of sound pictures which later was commercialized under the name Tonbild Syndicat AG (abbreviated to Tobis).[6,35] They used a modulated glow discharge for recording, and a photocell for reproducing. Of chief concern in this country were the Tri-Ergon patents,[35] in which numerous claims allowed by the U.S. Patent Office were so broad that had their validity been sustained they would have almost swamped the industry. In particular, one patent (1,713,726) which claimed the use of a flywheel on the shaft of a roller or sprocket which carries the film past the translation point, to take out speed variations, was the basis of prolonged litigation, being finally declared invalid by the U.S. Supreme Court (1935).[114] But in the meantime the efforts to avoid what were thought to be dangerous infringements of the Tri-Ergon flywheel claims, had for seven years steered the course of mechanical designs on the part of the major equipment manufacturers into inferior or more complicated constructions. (See section on Mechanical Systems.)

In Germany the Tri-Ergon patents controlled the situation. The large picture producing companies, U.F.A. and Klangfilm (a subsidiary of Siemens & Halske and A.E.G.), took licenses under the Tri-Ergon patents. A brief account of the patent negotiations and agreements in this company and in Germany will be found in the Sponable paper.[6]

Peterson and Poulsen in Denmark developed a system (1923) which was commercialized in Germany under the name Tonfilm.[6] They used an oscillograph as the recording light modulator (giving a variable-area soundtrack), and a selenium cell for reproduction. (One of the Tri-Ergon U.S. patents[35] claimed the use of a photocell for this purpose, and it is likely that a German patent accounts for the use of a selenium cell by Poulsen and Peterson.) This system was used by Gaumont in France and by British Acoustic Films, Ltd.

The de Forest Phonofilm

Dr. de Forest tells the story of this work in the 1923 *Transactions*.[36] The account is particularly interesting because he tells much of his viewpoint as he started, and then, after describing the system which he had evolved, gives his reflections on the applications and future of sound motion pictures.

The man whose invention gave us amplifiers in which the heaviest object that had to be moved was an electron, surely had a right to wish to do away with moving mechanical parts in microphones, light-modulators and loudspeakers. For microphones he experimented with the conductivity of gas flames and of open arcs as affected by sound waves, and with fine platinum wires heated to a dull red by a direct current and subjected to the cooling effect of the air vibrations superimposed on a slight continuous air movement. The changes in resistance of the wires with variations of temperature gave rise to telephonic currents.

For light modulators he tried "the speaking flame" (probably the "manometric" flame of König) and a tiny incandescent lamp, carrying voice currents superimposed on direct current. The lamp was designed to have very rapid filament cooling (partly by using a short filament, so that heat conduction to the lead-in wires would be high). On listening to these sources by means of a photocell and amplifier, de Forest was convinced that they gave exceptional quality (even compared with the condenser microphone), but they proved entirely inadequate for making a useful soundtrack giving very small percentage of modulation and probably also underexposure. Finally a successful source of modulated light for recording was found in a gas-filled tube excited by modulated high-frequency currents from a 5- to 10-w radio telephone transmitter. This was named the "Photion." A slit, $1\frac{1}{2}$ to 2 mils wide and 3/32 in. long, adjacent to the film, was used to restrict the size of the exposing beam.

A similar slit was used in reproduction. Both potassium photocells and Case Thalofide[37,40] cells were used in reproducing equipment, the greater sensitivity obtainable with the Thalofide cell being a consideration offsetting the faster response of the photocell. The design and construction of amplifiers using his Audion were of course very familiar to de Forest.

Lament is expressed that loudspeakers depending on some principles other than diaphragms and horns were not to be had, but after some discouragements with "talking arcs" and sound radiators on the thermophone principle, the commercially available horn and diaphragm speakers were accepted as the only solution at the time.*

Practical models of recording and reproducing equipment were built, and re-

* It is of interest that in the early part of our investigation which led to the direct radiator dynamic speaker (*Trans. AIEE*, 1925, p. 461) Chester W. Rice and I tried talking arcs and thermophones, and also a corona discharge device — all of which avoid mechanical moving parts — but none of these appeared promising.[38]

cordings made, using principally a combined camera and recorder, and many demonstrations given.

The de Forest paper[36] reviewed earlier history of efforts to record sound photographically, and gave appreciative acknowledgment of the help that had been given by Theodore W. Case.[37]

To have guessed wrong on some subject is no reflection on the insight of an experimenter, but several instances are striking, in the light of later developments. Speaking of the efforts to provide sound by means of the phonograph, the author said: "The fundamental difficulties involved in this method were so basic that it should have been evident from their inception, that commercial success could hardly be achieved in that direction." (Consider the Warners' Vitaphone.) Speaking of loudspeakers, after saying that the loudspeaker has been developed "to a high state of perfection" but left much to be desired, he said: "I am convinced that final perfection will come not through any refinements of the telephone and diaphragm, but by application of entirely different principles." (Yet phenomenal improvements were made with the identical elements, through refinements.)

In speaking of the future of sound pictures, Dr. de Forest gave a definite "No" to the question whether the existing type of silent drama could be improved by the addition of voice. But he foresaw the evolution of an entirely new type of dramatic scheme and presentation, taking advantage of the freedom which had been such an asset to the silent moving picture (as contrasted with the stage) but using sound and voice where these could be effective. He also had visions of great utility for travel films, newsreels, records of notable persons, and educational films.

The work just described was done from 1918 to 1922. About a year and a half later[36] Dr. de Forest gave a brief account of progress, reporting improvements in many details, better articulation, thirty theaters equipped, much interest on the part of operators, films made of a number of celebrities and contracts with leading chain exhibitors. Again the opinion was expressed that the talking picture would not ever take the place of the silent drama.

The Phonofilm system was used in numerous theaters, with sound films made under Dr. de Forest's direction; but he did not succeed in interesting the established American picture producers. Perhaps the industry was prospering too well at the time, but judging from the initial coolness of film executives to the technically greatly improved systems a few years later, it is easy to imagine that numerous imperfections which undoubtedly existed (as, for example, defective film-motion, limited frequency range, and loudspeakers that gave unnatural voices, and perhaps too, demonstration films that were uninteresting) contributed to loss of the impressiveness needed for doing business.

Several years later the "de Forest Phonofilm Co." was bought by Schlesinger of London and South Africa.

Work at the Theodore W. Case Laboratory (Movietone)[6]

Theodore W. Case[37] became interested in modulating light and deriving telephonic currents from it in 1911, while a student at Yale. In 1914 he organized his laboratory at Auburn, N.Y., devoting special attention to the study of materials whose resistance is altered by light, of which selenium was the best known example. These studies resulted (1917) in the development of the Thalofide cell, in which the photosensitive material is thallium oxysulfide.[40] These cells, which are especially sensitive in the near infrared range, were widely used in Navy communication systems during World War I. Case was joined in 1916 by E. I. Sponable. Experiments were continued with the help of an Audion amplifier obtained from de Forest. One of Case's postwar developments was the barium photoelectric cell.

In 1922 attention was turned seriously to sound pictures. Manometric* flames (oxyacetylene) were tried as a possible source of modulated light. Soon afterward Case found that the light from an argon arc in one of the tubes that had been used for infrared signalling could be readily modulated and was photographically potent. These tubes had oxide-coated hot cathodes. A tube for recording, based on this principle, was developed and named the Aeo-light.[6,41] It operated at between 200 and 400 v. Helium was substituted for argon in 1922, with benefit to the actinic power and also to the speed with which the light followed the current variation. The commercial Aeo-lights were rated at 350 v.

From 1922 to 1925 Case cooperated with de Forest, furnishing numerous items of experimental equipment.

Several sound cameras were built under the direction of Sponable, in 1922, 1923 and 1924. The 1924 model was a modified Bell & Howell camera rebuilt to Sponable's specifications by the Bell & Howell Co. The film motion in this and other cameras was unacceptable until they had been reworked for greater mechanical precision. In the final designs of sound camera the sprocket was driven through a mechanical filter, consisting of damped springs and a flywheel on the sprocket shaft. The sound was recorded on the sprocket. The Aeo-light was mounted in a tube which entered the camera at the back. Directly against the film was a light-restricting slit made by silvering a thin quartz plate, ruling a slit 0.0006 in. wide in the silver, and cementing over it a thin piece of glass which was then lapped to a thickness of about 0.001 in. The slit was thus protected from collecting dirt from the film. The end of the Aeo-light, where the glow was concentrated, was close behind the slit. A Bell & Howell contact printer was modified to make possible the independent printing of picture and sound.

Up to the fall of 1925, when the working arrangement with de Forest was terminated, the Case laboratory efforts were directed largely to recording principles and apparatus. It was decided then to work on a system independently of de Forest, and one of the next projects was to build reproducing equipment in the form of an attachment which could be used with existing picture projectors. It was in this design that the decision was reached to place the soundhead under the projector, and the offset of 20 frames or 14½ in. between picture and sound was established. The speed of 90 ft/min was adopted for the Case system. In the first projector attachment a light-restricting slit was used similar to the one used in the camera, but later a straight tungsten filament was imaged on the film, and in a still later model, a concentrated straight-axis helical filament was imaged on a slit which was in turn imaged on the film.

With the essential elements of a sound-on-film system developed, Case and Sponable began study of the patent situation, with a view to obtaining licenses, if necessary, for the commercial use of their system. There appeared to be no very strong patents to interfere, except those on the use of thermionic amplifiers. A contract between General Electric, Westinghouse and Radio-Corporation on the one hand and Western Electric Co. on the other, was in effect, specifying the fields of activity in which each might use amplifiers, but, if I have not misinterpreted the account in Sponable's historical paper, sound-pictures had not been specifically mentioned, and there was some question as to the right to license use in the Case system, the eventual decision being that both groups had rights. The Bell Telephone Laboratories were interested themselves in developing sound pictures, and so were not immediately ready to license what would be a competing system. However their engineers were much interested in the performance attained, and there was some thought of combining efforts. There were demonstrations of both systems, but no plan to merge them was reached. The experience of Case and Sponable at

*A gas jet so arranged that sound vibrations produce changes in the gas supplied to the jet.

General Electric Co. was rather similar.

In 1926 demonstrations were made to representatives of the Fox Film Corp., who became greatly interested, and finally to William Fox. After thorough testing on their own premises, the Fox Film Corp. purchased rights to the Case developments (July 23, 1926), leaving the question of amplifier rights to be worked out later. The Fox-Case Corp. was organized to exploit the system, which was given the name Movietone. Courtland Smith, who had been with the Fox Film Corp. and had been instrumental in bringing about the purchase, was made president of the Fox-Case Corp. The Movietone News service was established.

Sponable left the Case organization to give his services to the new company, one of the first of his activities being the design of recording studios in New York and later in Hollywood. In 1927 he developed a screen which transmitted sound freely, permitting loudspeakers to be located directly behind the picture. The first public showing of Movietone recordings was in January 1927.

The Fox-Case Corp. obtained license to use amplifiers, first in 1926 through the Western Electric Co. and the Vitaphone Corp., and the next year revised contracts were made with Electrical Research Products, Inc. (ERPI), which was formed in January 1927 to handle the sound-picture business for the Western Electric and Telephone companies.

In the Movietone reproducing system, Western Electric amplifiers and loudspeakers were used. The years 1928 and 1929 were marked by rapid expansion in facilities and personnel, successful showings and stepped-up schedules of newsreel releases. In March 1929 the making of silent pictures by Fox was discontinued. Six months later the Fox and Hearst newsreel services were united.

The British Movietone News was organized in 1929. In 1930 William Fox sold his interests in Fox Film and Fox Theatres.

As the Fox Film Corp. was already an ERPI licensee, and therefore had rights to use other Western Electric developments, the Western Electric light valve was adopted for the Movietone service (as well as for Fox studio recording), displacing the Aeo-light.

Work at Western Electric Co. and Bell Telephone Laboratories

The Western Electric Co. brought to a commercial stage almost simultaneously a sound motion-picture system based on disk records, and one based on sound on film. Various developments which laid the foundations for these systems had been taking place through a number of years. The citation of the life and work of Edward B. Craft in this *Journal*[42] indicates that his interest and enthusiasm were in large measure responsible for the undertaking of a full-scale project for developing systems of sound for motion pictures. Craft was assistant chief engineer of the Western Electric Co. from 1918 to 1922, when he became chief engineer. With the transfer in 1924 of research activities to the newly organized Bell Telephone Laboratories, Craft was made executive vice-president, and continued to guide activities.[42]

Whether or not there was a definite policy of not putting all of the eggs in one basket, work on both systems was stepped up at about the same time (1922) and pushed with equal vigor.

The two systems had identical requirements with respect to many elements, but, in particular, microphones, amplifiers and loudspeakers. The Western Electric Co. had acquired rights to de Forest's Audion in 1913 and made great improvements in it during the next few years, building up wide experience in its applications and circuitry.

Second only to electronic amplifiers in importance for the development of high-quality recording and reproducing systems was a microphone of uniform response and with low distortion. With amplifiers available Dr. E. C. Wente[43] was able largely to ignore the question of output level, and to develop by 1916 a microphone of the condenser type, having extraordinarily high fidelity and freedom from distortion and noise.[44–47]

In the loudspeaker field, the company had had considerable experience and had developed units for public address work. The public address installations had afforded experience with auditoriums and requirements for intelligibility, while experience in acoustics for sound pickup had been gained in radio broadcasting.

With respect to the recording itself and reproduction, I shall separate the two stories of the disk and photographic systems.

The Disk System

In 1946 there was published a history of sound recording in the laboratories of the Western Electric Co.[48] Since the transmission of speech was the main business of the Telephone Co., a program of studying every aspect of speech waves was initiated about 1912, and as part of this project, efforts were directed to recording the sound. The interest soon spread to include music. In connection with work with disk records, Crandall and Kranz built an electromagnetic reproducer in 1913. In 1915 H. D. Arnold suggested that the improvement of disk recording be undertaken, using the then available electrical equipment (which included amplifiers). By this time the electrical reproducer had been improved.

The war interrupted these projects, but they were resumed soon after its close. A group under J. P. Maxfield undertook the improvement of wax recording and the phonograph. The story of this development was told in 1926 to the American Institute of Electrical Engineers.[49] The recording system made use of a magnetically driven cutter so designed that with constant current input, the vibratory velocity of the cutting stylus was substantially constant from about 200 to 5000 cycles, while from 50 to 200 cycles the amplitude was constant, a characteristic practically necessary to avoid overcutting by the low notes. Two features of the design were of special interest: (1) the separation of the total mass that must be driven into three parts (armature, stylus-bar and coupling disk), connected together through portions of shaft whose torsional flexibility was carefully calculated to make of the structure a mechanical low-pass filter of calculable mechanical impedance; and (2) a mechanical resistance consisting of a thick-walled rubber tube (which may be thought of as practically a rod of soft rubber) subjected at one end through the coupling disk to torsional vibrations. The propagation of torsional waves in such a soft rubber rod is so slow that in a length of about 6 in. there would be many wavelengths for all but the lowest frequencies.

Vibrations imparted to the rubber reach the far end very much attenuated, are reflected, and propagated back toward the start, but are of neligible magnitude when they reach it. Under such conditions the rubber line acts as a nearly pure mechanical resistance to load the filter, and, if properly matched to the filter impedance, results in practically complete (and therefore uniform) transmission through the filter structure, throughout the frequency band below the filter cutoff. The features just described are, I believe, the inventions of H. C. Harrison. The great improvement in records which electrical recording brought, is well known to all of us.

Without a better reproducing system than the phonographs of the types in use about 1920, the improvements in the records would have been largely lost, so there was developed a greatly improved (nonelectrical) phonograph called the Orthophonic (also largely the outcome of H. C. Harrison's approach to the problem). However this part of the program had no direct bearing on the talking-picture project. In early 1925 the Columbia and Victor Companies took licenses from Western Electric Co. to use the recording methods and apparatus, and to build phonographs of the Orthophonic type.

Sound-on-Disk Synchronized With Pictures. Little time was lost in trying and demonstrating synchronized sound and pictures using the new electrically recorded disks. Craft arranged for a demonstration at Yale University in 1922 and another in February 1924, the equipment and many details of the system having been developed and improved in the interval.

To provide sound for pictures, using the disk-record system,[50] it was necessary to have records which would play continuously for at least the projection time of a 1000-ft reel (about 11 min), to plan a synchronous drive, and to use electrical reproduction in order that, with the help of amplifiers, adequate sound output could be had.

It was not desirable (in view of background noise) with record materials then available, materially to reduce amplitudes of cuts, and so groove pitch had to be kept nearly the same as then in current use (about 100 grooves per inch). To maintain quality the minimum linear groove velocity must not be reduced. With a given groove pitch and minimum velocity, the maximum playing time for a given record diameter is obtained by recording to half the maximum diameter, and the required playing time determines the needed size and corresponding rotation speed. While the engineers could take some leeway, the choice of 16 in. outside diameter and $33\frac{1}{3}$ rpm, approximately met the conditions indicated.

For synchronous recording, the camera and the recording turntable can be driven by selsyn motors, which driving system gives the equivalent of both being geared together and driven from one shaft. Starting marks on both film and disk are of course essential.

For reproducing, the turntable and projector were mechanically geared together. A simple magnetic pickup, if not damped, has a high-frequency resonance in which the armature whips, giving excessive output and high mechanical impedance at the needle tip.[51] The magnetic pickup used in the sound-picture system was designed for use with replaceable steel needles and damped by enclosing the moving elements (except the needle-holder and needle) in oil.[52]

The turntable driving systems[52–54] evolved for the sound pictures are discussed in the section on "Mechanical Systems" — the great problem being (as had been the case throughout the history of sound recording) to obtain sufficiently nearly constant speed.

The loudspeakers which had been developed for public address applications[55] were of the "balanced armature" type, had good power-handling capacity, and were regarded as fairly satisfactory from the standpoint of articulation. Designs of horns had been evolved which fairly successfully controlled the directivity for auditorium purposes. In 1923 Dr. Wente built a speaker of the moving-coil type which gave greatly improved quality[56] (especially the better bass response which is possible with the moving-coil drive), but in terms of efficiency and power-handling capacity it was not satisfactory. It was not until 1926 that a speaker of the moving-coil type was developed by Wente and Thuras[57] which met the requirements for quality, efficiency and power-handling capabilities. Speakers of this design rapidly superseded those of earlier design, and continued in use for years.

According to the account of Lovette and Watkins[48] the sound-on-film system, on which another group of engineers had been engaged, was capable in 1924 of matching the quality of the disk system, but the latter represented an older art in which there were fewer uncertainties. The greater confidence with which the company could offer the disk system, and with which a potential customer would consider it, were responsible for choosing it as the first to be pushed. However, interest on the part of most of the picture producers was cool, nor did Craft, conscious of the numerous failures of previous efforts by others, think it desirable to hasten the commercialization of either system until its weaknesses were worked out.

Samuel Warner and Vitaphone.[58] With many details omitted, the foregoing is the description of the sound-on-disk system which became known as Vitaphone. Col. Nathan Levinson,[48] then serving the Western Electric Co. in the Pacific district where he had had close association with Samuel L. Warner, made a business trip to New York early in 1925 and saw a demonstration of the sound pictures. He felt sure that Mr. Warner would be interested, and arranged for a demonstration at the first opportunity. Samuel Warner was more than convinced, and his enthusiasm quickly spread to his brothers. More thorough tests were arranged, using cameramen, technicians and artists of the Warner staff, in cooperation with Western Electric engineers. The adoption of sound by a large picture-producing company would mean a huge outlay, and its success was a question not only of technical performance, but of the artistic, dramatic and psychological results which could be achieved through the addition of sound. The tests were convincing to the Warner Brothers, if not to the executives of some other picture companies who witnessed them. To develop and market sound motion pictures and equipment, the Vitaphone Corporation was organized in April 1926, with Samuel L. Warner as its president.

The first major Vitaphone sound picture to be released was *Don Juan*,[1,48] (August 1926) in which music by the New York Philharmonic Orchestra was featured. The new loudspeaker developed by Wente and Thuras was ready in time for this. Preparations were made for producing sound pictures in Hollywood, where sound stages were erected embodying the recommendations of the foremost experts in acoustics. The production of *The Jazz Singer* with Al Jolson, was begun in the spring of 1927 and it was shown in New York on October 6. Its success was such that the industry was convinced "overnight" that the day of sound pictures had arrived.

Improvements in the Disk System. Under the title "Recent Advances in Wax Recording"[50] H. A. Frederick tells of a number of advances subsequent to the 1926 account by Maxfield and Harrison. By improvements in record material and wax processing techniques, it had been possible to reduce surface noise by 3 to 6 db. A new pickup (4A) is described with smoother response and good to about 4500 cycles, as compared with 4000 cycles for the previous model. A response curve for the commercial recorder shows practically uniform response to 5500 cycles. Laboratory models of recorder and reproducer are mentioned as carrying the response to 7500 cycles. The new recorder used a longer rubber damping line. Frederick gives the groove pitch as 10 mils and the minimum groove velocity as 70 ft/min. He also reported very satisfactory results with re-recording.

Western Electric Sound on Film

Mention has been made of fundamental studies of speech waves, begun in 1912 and carried on through several years until interrupted by the war. Amplifier tubes became available as laboratory tools in 1913. Photographic records of speech waveshapes were made, using at first a carbon transmitter, an amplifier and a Duddell oscillograph. The weakest link in this chain of equipment was the transmitter, whose response varied greatly with frequency and which had a high level of background noise, making it difficult to get reliable traces of consonants and other relatively weak speech sounds. The development of a better transmitter was one of the first undertakings of Edward C. Wente,[43] who came to the company in 1914.[44–47]

The Condenser Transmitter. If the charge on a pair of condenser plates is maintained through a sufficiently high resistance, the voltage is directly proportional to the separation of the plates, so that a transmitter based on this principle is an amplitude-sensitive device. If the diaphragm, which is one of the condenser plates, is so stiff in relation to its mass that resonance occurs above the required frequency range, the diaphragm deflection is proportional to the instantaneous air pressure. Wente met this mechanical requirement by using a stretched steel diaphragm 0.002 in. thick and spaced 0.001 in. from a relatively massive backplate. The very thin layer of air contributes greatly to the stiffness of the diaphragm, but the flow of air through the narrow space toward and from a relief space around the edges causes damping, so

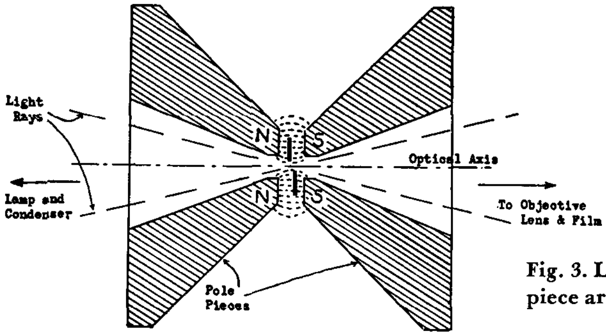

Fig. 3. Light-valve ribbon and pole piece arrangement; section at right angles to ribbons.

that a nearly flat (uniform) response was obtained up to about 15,000 cycles.

Wente left the company in 1916 for graduate study and returned in 1918. In the meantime Dr. I. B. Crandall had made a theoretical analysis of the air-film damping, and improved the instrument by means of grooves of appropriate size and shape in the backplate.[45] For measurement purposes it was essential to calibrate the condenser transmitter, and Wente accomplished this by working out the theory of the thermophone, which enabled him to make a reliable pressure calibration.[46] Free field calibrations were made later, using a Rayleigh disk as reference. In a later design,[47] which was used commercially for sound recording, the sensitivity was greatly increased, in part by use of aluminum alloy 0.001 in. thick instead of 0.002 in. steel for the diaphragm, and in part by not carrying the response as far into the high-frequency range. (In 1931 W. C. Jones published a pressure calibration curve for a #394 transmitter which showed a rapid drop above about 7000 cycles.[47]) The condenser tramsmitter is rated as a a very insensitive device, but it is of interest that a diaphragm deflection of a millionth of an inch will give a fifth of a volt, the gradient in the space between electrodes being 200 v per mil. It is the extreme stiffness of the diaphragm which makes the sensitivity low.

Photographic Recordings. The condenser transmitter with amplifier gave better waveshape traces, but the narrow mirror of the bifilar (or Duddell) oscillograph causes diffraction effects which make the light-spot at the film blurred or fuzzy. Prof. A. C. Hardy showed[59] that this trouble could be largely eliminated by radical changes in the optical system in which the oscillograph vibrator is used, but his analysis was not published until 1927 (in time to be of much help in the General Electric recording developments, but the Western Electric experiments with the oscillograph were before 1920).

An article in a British Journal (1920) came to Wente's attention, describing experiments of Prof. A. O. Rankine in transmission of sound over a beam of light. The light modulator, in which a rocking mirror caused an image of one grating formed on another grating to move transversely to the bars, appeared well adapted to making photographic records of the variable-density type. While a variable-density record would not give as much information to the eye as a variable-area record, it could be analyzed by instruments of the microdensitometer type. The faithfulness of the recording could be checked by playing it back. (The previous oscillographic recordings had not been designed for playing back.)

Some of the recordings were played in May 1922 for Craft and others. A few months later apparatus-development engineers were requested to construct an electrically interlocking driving system for camera and recorder. Further demonstrations were given in December 1922. In these recordings the principle was recognized, that for linear relations between exposing light and print transmission, the product of positive and negative "gammas" should be unity.[61,62]

Light Valve. The grating type of modulator had several drawbacks, one of which was diffraction by the grating. Because of these difficulties, Wente in January 1923 proposed using a two-string light valve.[63–65,4] Such a valve was ready for test a month later. The tension on the ribbons was adjusted to bring their resonance to 6500 cycles. Condensing lenses imaged the light source on the slit between the ribbons, and an objective lense imaged the valve slit on the film.

Results with the light valve were definitely better than with the previous modulators, and arrangements were made for tests on a larger scale. A recording studio was set up in 1923 and sound pictures made for demonstration purposes.

In the latter part of 1922 and subsequently, much of the study of film emulsions, exposures and developments was carried on by Dr. Donald MacKenzie. He showed that by running the lamp at slightly over-voltage, it was possible adequately to expose positive film, which thereafter was the standard sound-recording stock. The relatively fine grain of the positive stock was of great benefit from the standpoint of resolution and low background noise.

In 1928 MacKenzie described the light-valve model in use at the time, and recording and processing practice (exposure ranges and developments) as worked out at the Bell Telephone Laboratories.[64] The valve is mounted with the slit between ribbons horizontal — so that its image on the film is transverse to the film. The ribbons are in a strong magnetic field and currents in the two are in opposite directions, so that they are deflected (edgewise) to increase or decrease their separation depending on the direction of the current. The width of the slit with no current in the ribbon was 0.002 in., and it was masked to a length of about 0.2 in. It was imaged on the film with a 2 : 1 reduction. With the slit width 0.002 in., the light could be modulated 100% by a vibration of each ribbon of 0.001 in. amplitude. Since the ribbon need be only slightly wider than its double amplitude, thick enough to be opaque, reasonably easy to handle and long enough between supports to make the deflection substantially uniform throughout the length of the slit, it can be extremely light and readily put under enough tension to place its mechanical resonance above the required audio range. Rather than attempting to control the resonance by damping beyond that obtainable electromagnetically, an electrical low-pass filter was used in the input, to prevent the passage of any impulses of high enough frequency to excite the resonance. However the cutoff was not too far below the frequency of resonance to permit a considerable rise in amplitude just before cutoff, the maximum being at about 7000 cycles. This rise was regarded as advantageous in that it compensated for loss of high-frequency response due to image spread in the film. For monitoring, a photocell behind the film picked up some of the light which went through the film.

The subject of sensitometry for soundtracks of the variable-density type also received attention from many other writers for a number of years after the advent of photographic sound.

In the matter of the frequency range attained in the early light-valve recordings, MacKenzie shows an overall (light-valve input to photocell output) curve which was substantially flat to 5000 cycles, a figure not far from what could be obtained at the time with disks.

Recorder. The Western Electric recording machine employed a sound sprocket, having a filtered drive and protected by a feed sprocket from jerks from the magazines.[4] The film was exposed while on the sound sprocket. For synchronism the camera and recorder were driven by selsyn motors.

Soundhead. For reproduction from photographic soundtracks the Western Electric Co. built a "soundhead," to be mounted under the picture projector,[52–54] similar in many respects to that previously mentioned as used in the Fox-Case development. I shall come back to the subject of the mechanical features of the film-motion system, so shall mention here only some optical and electrical features. The scanning light on the film was an image of a mechanical slit, illuminated by a low-voltage incandescent lamp, with condensing lenses. The filament was a close-wound helix with straight horizontal axis. The photocell and preamplifier were cushion-mounted to prevent microphonic noises. Owing to the very high impedance of the photocell and its small output, a very short (low-capacity) connection to the first amplifier tube is important. The preamplifier brought the level up to about equal to that of the disk pickups.

Standard Speed. In the early theater installations most projectors were equipped for both disk and film reproduction. It was obvious that for sound pictures the recording and reproducing speeds must be closely held to a standard. The practice had become widespread of projecting silent pictures at considerably higher speeds than that of the camera, which had for years been nominally 16 pictures/sec or 60 ft/min. The higher projection speeds shortened the show so that more shows could be run in a day, and the public had become inured to the fast action. But there was a better justification in that flicker was much reduced.

For pictures with sound on film there was further benefit from increased speed in that it resulted in better high-frequency response and, in some degree, reduced percentage of speed fluctuation. A speed of 85 ft/min for silent pictures had been recommended for a standard, but practice varied widely. A speed of 90 ft/min or 24 frames/sec was chosen for both of the Western Electric sound-picture systems (sound on disk and sound on film) and this became the standard. On the theory that exhibitors would demand the option of running silent films at other speeds, the Western Electric engineers adopted a driving system with an accurate control which could be made inactive at the option of the projectionist.[54] Either a repulsion motor or a d-c motor might be used. For 90 ft/min a 720-cycle generator fed a bridge with one arm tuned to 720 cycles. At the correct speed the bridge was balanced, but if the speed was not correct the unbalance gave rise to a correcting current which increased or decreased the motor speed as required.

Commercialization. In January 1927 Electrical Research Products Inc. was formed as a subsidiary of Western Electric and the Telephone Co. to handle commercial relations with motion-picture producers and exhibitors.

The adoption of sound systems by the motion-picture industry (except for the case of Fox Movietone and Warner Vitaphone) is discussed in another section of this paper.

Developments at General Electric Co.

Interest in photographic sound recording at the General Electric Co. in Schenectady stems from the development prior to 1920 of a photographic telegraph recorder for radio reception,[66] by Charles A. Hoxie. Transoceanic radio service was by long waves, and static interference caused the loss of many letters. It was thought that a visual record of the incoming signals, even though mutilated by static, might be deciphered at leisure in many cases in which the signals were forever lost if the operator, depending on ear alone, failed to recognize a letter.

For the usual reception, by ear, the incoming continuous-wave code signals were heterodyned to give interrupted tones of audio frequency, short for dot and longer for dash. Hoxie's recorder made an oscillographic record of these code signal tones, on a moving strip of sensitized paper. Instead of actuating a receiver diaphragm the electrical signals vibrated a reed armature, which, through a delicate knife-edge arrangement, imparted rotary motion to a mirror, which caused a small spot of light to dance back and forth across the sensitive strip.

Since the code recorder vibrated at audio frequency, it was a short step to try it and modifications of it for recording voice, and this was one of the many experiments which Hoxie tried which started him on more systematic experimentation in the field of photographic sound recording. Negative film was used at first, in order to get adequate exposure, but Hoxie was among the first to appreciate the advantage of the finer-grain positive film.

As in the case of the telegraph recorder, the track ran down the middle of the film, and was nearly an inch in width. In Hoxie's recording and reproducing machine the film was drawn over a physical slit on which intense light was concentrated. The width of the slit was about 0.001 in. Since an open slit would quickly fill with dirt, a wedge of fused quartz was ground to a thin edge and cemented in place between the metal edges which formed the slit. The face against which the film was to run was then lapped and polished. A photocell close behind the film picked up the transmitted light, and an amplifier and loudspeaker completed the reproducing system. The results were highly gratifying. Theisen[5] says that Hoxie's first sound recorder was completed in 1921, and with it he recorded speeches by President Coolidge, the Secretary of War and others, and the recorded speeches were broadcast over Station WGY (Schenectady) in 1922.

Hoxie called his optical phonograph the Pallophotophone, meaning "shaking light sound." We do not know the identity of the Greek scholar. In another experimental development, Hoxie caused the vibration of a sound-pickup diaphragm to rock the mirror. This device, called the Pallotrope, was used with a photocell as a photoelectric microphone.

Narrow Sound Track Found Sufficient. Hoxie continued his experimenting for several years before any decision was reached to embark on an all-out program of developing a system of sound for motion pictures. One of Hoxie's experiments which undoubtedly played a part in interesting executives in such a program was that of reproducing with part of his track width masked. The development of the General Electric model of the Duddell oscillograph had centered in the General Engineering Laboratory (where Hoxie worked) and it was extensively used as a laboratory tool throughout the company. With such a background it would be natural to think of a photographic sound track as showing the outlines of the sound waves.

In any case the wide soundtracks made in the Hoxie equipment were of the variable-area type. A spot of light moved parallel with the slit, illuminating a larger or smaller fraction of its length. However, the active edge of the light spot was by no means sharp. While experimenting with reproduction from this sound track, Hoxie observed that masking off part of the track had little effect on the sound except some reduction in volume. He repeated the experiment with still more of the track masked off, until he was using only a sample, about $\frac{1}{16}$ in. wide. This experience was sufficient to demonstrate that a track wide enough to show the wave outlines was by no means necessary for sound reproduction. The narrow strip being scanned was obviously a variable-density record of the sound.

At that early stage of the experimenting we had not seen it demonstrated by actual accomplishment that a satisfactory variable-area recording could be confined within so limited a band, but at any rate this test proved that a photographic sound record could be placed along the side of the picture without stealing more picture width than could be tolerated.

Loudspeaker and Phonograph Developments. Another factor which undoubtedly influenced General Electric executives toward increased interest in sound was the success of the loudspeakers developed by C. W. Rice and myself for broadcast radio reception.[38] The coil-driven (or "dynamic") paper cone, freely suspended, surrounded by a baffle and driven by an amplifier with adequate undistorted power, so far surpassed its predecessors in quality of reproduction that within a few years its use for radio receivers and phonographs became practically universal.*

Following the loudspeaker development, the success of the electric phonograph helped to make the sound motion picture seem like a logical next project.

Chester W. Rice. I trust that I will be excused if I take this opportunity to pay a brief tribute to my colleague, whose vision and initiative were largely responsible for our undertaking the loudspeaker project. His thoroughness and tireless energy insured that no hopeful lead was left unexplored. He brought to bear on his work an extraordinary measure of ingenuity and mastery of engineering and physical principles, which he was constantly supplementing by study, and his standards of excellence would permit no compromise with an inferior result.

No one could have been more scrupulously fair and generous in giving credit to other workers. His death in 1951 was a great loss to his associates and to science.

C. W. Stone's Leadership. In addition to L. T. Robinson, head of the General Engineering Laboratory, the man who played the major role in initiating and promoting a large-scale project for developing talking pictures, was C. W. Stone, manager of the Central Station Dept., who had taken great interest in all of the sound developments. His enthusiasm, confidence and influence encouraged those who were engaged in development, helped to secure the financial backing and established fruitful contacts outside the company.

Practical designs; Assistance of Prof. A. C. Hardy and L. E. Clark. When, about 1925, a program of developing commercial sound-on-film equipment was undertaken, Robinson was made responsible for the general program, and, together with others in the Research Laboratory, I was asked to assist in problems where there seemed to be call for research. Engineers in the General Engineering and Research Laboratories had had experience in sound, first with loudspeakers[38] and then in cooperation with the Brunswick Balke Callender Co., electrical recording and reproduction for phonographs[51] (the work represented in the Brunswick Panatrope[51] and the Brunswick electrically recorded disks). Our part in the phonograph project was tapering off, freeing some of the personnel to devote time to the newer development. Our group, however, had inadequate background in optics and photography. Professor A. C. Hardy was engaged as consultant and soon did us two invaluable services: he straightened us out on a number of optical and photographic questions, and he recommended that we engage the services of L. E. Clark, then completing some advanced work at Massachusetts Institute of Technology. "Pete's" presence was a guarantee that we would not again get off the beam on optical questions, but his associates at General Electric, then at Photophone headquarters in New York, and later in Hollywood, carry a memory of something far more cherished than his valuable technical help.

Variable-Area System Chosen. A fundamental question on which we took Prof. Hardy's advice was in regard to the advantages of the variable-area type of soundtrack.[61] At the time of Hoxie's tests with a masked track, the only tracks that had been made, sufficiently narrow and still fairly satisfactory, were of variable density. A better understanding and application of optical design was needed to make clear, sharp-edged variable-area tracks within permissible limits of width.[59,60]

With the right kind of lenses and optical design, an imaged slit soon displaced the contacting physical slit with which the first tracks had been made. Hoxie's special galvanometer was not adequately damped, but General Electric had long since been building oil-damped oscillographs of the Duddell type, whose response was good up to 5000 cycles. The optics of the recording system are similar in principle to those of the oscillograph, as explained in one of Hardy's papers.[59] Prof. Hardy had shown how important design improvements could be made, greatly increasing the light intensity at the film. An optical system was designed[60] using a regular oscillograph galvanometer, and following suggestions of Prof. Hardy and of L. E. Clark.

The general mechanical features of the first recording machines were due principally to Hoxie, while H. B. Marvin (of the General Engineering Laboratory) designed amplifiers, optical systems and other necessary equipment. High-quality microphones were available in the Western Electric Condenser Transmitter (developed by E. C. Wente of the Bell Laboratories)[44–47] which was used in broadcast studios and had been an essential tool in the loudspeaker[38] and phontograph developments.[51]

General Electric had a well established motion-picture laboratory under the direction of C. E. Bathcholtz, for general company and publicity service, so that with the cooperation of that department, pictures with sound could be made. A number of demonstrations were given in 1926 and 1927, using this equipment. Motion-picture producers showed interest, but no contracts were made at that time.

An incident of much interest to those who were connected with the photographic recording project was a visit to Schenectady in December 1925 by E. I. Sponable from the Case Laboratories.[6] He showed and demonstrated the combined camera and sound-recording system which he and his associates had developed, giving us the benefit of his experience and participating in some demonstrations. However, no arrangements for combining the efforts resulted.

The Road-Show Wings. The first public entertainment picture to be shown, with the General Electric developed sound system, which by this time had been named the Kinegraphone, was a story of the Air Force activities in World War I, entitled *Wings* and produced by Paramount. The sound effects were added after the picture had been shot. The system and equipment were demonstrated and briefly described by H. B. Marvin.[67]

Wings was exhibited in 1927 as a "road show" (about a dozen sets of equipment having been supplied), for few motion-picture theaters at the time *Wings* was shown were equipped for optical sound reproduction. Multiple-unit cone-and-baffle type loudspeakers[38] were used, with a bank each side of the screen. The sound-reproducing device or "head" was mounted on the top of the projector, no standard sound offset having been established at the time the apparatus was designed. The picture width was reduced from 1 in. to $\frac{7}{8}$ in. to make room for a soundtrack. Ninety ft/min had by this time been agreed upon for film speed.

There were many, even of the most enthusiastic advocates of sound-picture development at General Electric, who did not think of the chief function of the synchronized sound as giving speech to actors in plays, but there was high confidence that there was a large potential market for sound systems for furnishing sound effects and background music and providing voice for lectures and speeches.

G.E.–Westinghouse–RCA Working Arrangements

At the time that the synchronized sound development was taking shape, the three-cornered arrangement between General Electric, Westinghouse and RCA was in effect. RCA was the sales outlet for all radio and kindred equipment. Manufacturing was divided between General Electric and Westinghouse. Research and development continued to be carried on at both manufacturing companies, and before production was

* Many of the elements of this type of loudspeaker, such as coil drive, cone diaphragms and the baffle had been proposed individually by early inventors, but not in the full combination. Nor, I believe, was the principle of placing the mechanical resonance of the diaphragm (with its suspension) at or below the lowest important frequency proposed, except that Adrian Sykes (U.S. Pats. 1,711,551 and 1,852,068) advocated it for a microphone. The Farrand loudspeaker (U. S. Pat. 1,847,935, filed 1921. See Radio Club of America, Oct. 1926) had a large cone, coil-drive and low resonance-frequency, but no baffle or associated power amplifier. It had considerable commencial success during the 1920's.

started, designs were coordinated between them and had also to be acceptable to RCA, which maintained a Technical and Test Dept. in New York, to pass on performance.

At Schenectady, in view of the prospects of manufacturing on a much larger scale than could be handled in the General Engineering Laboratory, the film project had been transferred (1927) to the Radio Dept. where it was under the direction of E. W. Engstrom. The change brought new personnel into the activity. The names of E. D. Cook and G. L. Dimmick deserve mention.

Developments at Westinghouse

Engineers at the Westinghouse Electric and Manufacturing Co. in East Pittsburgh did not turn their attention to photographic sound recording until about 1926 when the project at Schenectady had gained some momentum.

One of the first research projects undertaken was to adapt the Kerr cell to photographic recording. The development was described to this Society in 1928 by V. K. Zworykin, L. B. Lynn and C. R. Hanna.[68] Nitrobenzene has the property of rotating the plane of polarization of a light beam, when the liquid is subjected to an electrical field at right angles to the direction of the light. The amount of rotation depends on the square of the field gradient. Practically, several hundred volts per millimeter are required. Nicol polarizing prisms are used on each side of the cell and rotated to extinguish the light at minimum applied voltage. With increase of voltage, the transmitted light then varies as the sine of the increase in angle of rotation.

One of the design problems is to keep within satisfactory limits the distortion resulting from the nonlinear relation between voltage and transmitted light. Another difficulty is that commercial nitrobenzene is yellow, absorbing the photographically valuable blue light. The investigators were able by double distillation to reduce very largely the absorption of blue light. A third problem was avoidance of electrical arcs through the liquid, which quickly contaminate it. Proper choice of electrode material and surfaces, and purification of the liquid made it possible to produce cells which were regarded as practical.

The unique property of the Kerr cell light modulator which makes it of special interest is its extreme speed. The only limitation is in the ability of the modulation-voltage supply system to charge the extremely small capacity of the cell. As contrasted with this, other light-modulation systems either involve moving mechanical elements, or electrical discharges through gases, which have definite frequency limitations.

Zworykin, Lynn and Hanna were in the Westinghouse Research Laboratory, which was under the direction of Mr. Kintner. A group under Max C. Batsel was responsible for development and design of commercial equipment. One of this group was J. D. Seabert, whose contribution to the theater loudspeaker problem will be described in the paragraph with that heading. Hanna's analysis of the damped flywheel problem[69] laid the foundation for the highly successful rotary stabilizer discussed under that heading in the section dealing with Mechanical Systems.

Organization of RCA Photophone, Inc.

RCA Photophone, Inc. was organized in 1928 as an RCA subsidiary to carry on commercial exploitation of the sound-on-film system. Carl Dreher (later with RKO) was its first chief engineer, followed in 1929 by Max C. Batsel from the Westinghouse Co. A laboratory was established in New York to which a number of engineers were transferred from the Technical and Test Dept. of RCA.

New Designs of Commercial Units. Between the launching of the *Wings* show and the offering by RCA Photophone, Inc., of a commercial sound system,* a number of design changes and advances had been made. C. L. Heisler had designed a new recording machine (R-3) and a combined picture and sound projector (P-2),[70] both of which embodied new principles in film motion. A sound attachment or "soundhead" was developed, by which existing silent projectors could be adapted for sound. The offset between picture and sound had meantime been standardized at 14½ in., with the soundhead mounted under the projector. Because of the much more stringent requirement for accurate and constant speed for sound than for picture, the driving motor was made part of the soundhead, and the projector mechanism driven from the soundhead through gears. The first commercial soundhead to be offered by the RCA group (designated as PS-1) was of Westinghouse design, but the manufacturing was carried on by both companies.

Theater Loudspeakers. The flat baffle type of loudspeaker[38] used in the *Wings* equipment and in almost universal use for home receivers, while excellent for music and sound effects, had not proved satisfactory for *speech* reproduction in reverberant theaters. While a certain kind of directivity can be had by using arrays of direct-radiator loudspeakers, vibrating in phase, this did not confine the radiation in the direction of the audience as successfully as the use of short horns. The first successful units of this type were developed by J. D. Seabert in 1929 (then of Westinghouse). The horns used at first expanded from about the cone area to an opening abut 3 ft by 4 ft. The name "directional baffle" was used to distinguish these horns, whose primary function was to confine the radiation within a limited angle, from the small-throat horns whose basic function was to load the diaphragm, in addition to confining the radiation. The directional baffle type of unit was the subject of later developments by Dr. H. F. Olson and his associates.[71–73]

In spite of the benefits of directive baffles, in many motion-picture theaters satisfactory speech reproduction was not achieved until absorption had been applied to reduce reverberation.

Location Equipment. The RCA equipment also included a truck for location and newsreel service.[75] With batteries for power supply, the truck carried a motor generator for driving apparatus designed for 60-cycle operation, and a studio-type film recorder, to be driven in synchronism with a cable-connected camera. For more remote or inaccessible locations, a single-film system was provided, with portable batteries and amplifier, governed direct-current camera motor, and a sound attachment, mounted on the top of the camera.[74] The first commercial uses of RCA Photophone recording equipment were for newsreel service. Two types of light modulator were employed in the earliest Photophone single-film location equipments, one of which used a galvanometer designed by W. O. Osborn and K. A. Oplinger, under the direction of C. R. Hanna, with optics generally similar to those of the studio system, and the other the Kerr cell (or Carolus cell) system developed by L. B. Lynn and V. K. Zworykin.[68]

Location equipment (sound trucks) of improved design followed within a short time. Of special interest was a new optical system requiring only 3 w for the lamp.[76]

Disk Equipment. Although the RCA group was convinced of the inherent advantages of sound on film for motion-picture sound, disk equipment was wanted in all of the earlier theater installations, and accordingly combined sound-on-film and synchronous disk equipment was designed and built by the G.E. and Westinghouse companies and supplied by RCA Photophone, Inc.

A number of developments and inventions took place at both of the manufacturing companies which did not come into commercial use for several years, and these will be described presently.

Commercialization. The establishment of commercial relations with picture producers is described in the latter part of the following section.

* H. B. Franklin in *Sound Motion Pictures*[2] gives May 14, 1928, as the date of an announcing advertisement in New York and Los Angeles papers; however the Progress Report, *Trans. SMPE*, No. 31, 438, May 1927, states that Photophone equipment is to be sold direct to theaters, and that recording efforts would be concentrated on music scores.

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