A Brief History of Early Motion Picture Sound Recording and Reproducing Practices*

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0 INTRODUCTION

Many attempts were made prior to the year 1928 to provide talking motion pictures for general theater use. The inability to provide recording and reproducing equipment on a practical commercial scale resulted from limitations in microphones, amplifiers, loudspeakers, and disk and film techniques, and the lack of general research needed to provide tools for their commercial application.

Col. Nathan Levinson, the Pacific Coast representative of the Western Electric Company for broadcast and public address systems, rented a public address system to Universal Studios, who used it in the production of "The Hunchback of Notre Dame." By supplying this equipment, he became acquainted with motion picture executives. Levinson was a friend of Ralph Brown, who was in charge of radio facilities for the Western Electric Company and who told Levinson that Western Electric had experimental talking motion picture equipment ready for a demonstration.

Early in 1926 Levinson talked with MGM, Goldwyn, and others to determine their interest in seeing a demonstration. Sam Warner of Warner Brothers was the only one technically interested in this new development. His brother was opposed, as were other studio executives, who believed movies with sound would ruin their business. Sam Warner sneaked Col. Levinson into the Warner lot by covering him up in a blanket as they passed the guard gate. After several meetings at Warner Studios, the Warners agreed to witness a demonstration at the Bell Telephone Laboratories in the early part of 1926.

The Warner brothers were so enthusiastic over the preliminary tests that they arranged for full-scale tests, using their own cameramen, artists, and technicians in cooperation with the Bell Laboratories staff. After several tests, the Warner brothers were convinced that a coporation should be organized to provide and market sound motion pictures and equipment. A short subject with Bryan Foy was then made in the Manhattan Opera House in New York City. George Groves was the mixer, and he relates that many times recording was stopped due to subway noise. The first theater sound equipment was transported and installed with armed guards because of the mistaken fear by producers and exhibitors that sound was not compatible with motion pictures, and equipment sabotage was possible.

In 1926 April the Vitaphone Corporation was organized with "Sam" L. Warner as president, and the first major Vitaphone sound picture was "Don Juan," released in August 1926, in which music from the New York Philharmonic was featured. Plans for production in Hollywood were started immediately, and sound stages were built using the recommendations of the best acoustical experts. "The Jazz Singer" with Al Jolson was placed in production in 1927 April and exhibited in New York City in 1927 October 6. It was so successful that almost every motion picture producer was convinced—sound motion pictures were here on a real basis. The Vitaphone equipment consisted of a synchronized 33⅓ r/min 16-in (406-mm) disk, a turntable geared to the projector using a Western Electric 4-A pickup, and their amplifiers and loudspeakers.

At this point it is necessary to review the work of several individuals who were largely responsible for the ability of Western Electric to design, manufacture, and provide the neces-

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sary hardware needed for this important step. Edward C. Wente came to the company in 1914, and in 1917 he designed the forerunner of the famous Western 394-W condenser microphone which was produced commercially in 1926. This microphone provided the necessary sensitivity and frequency range to record speech and music adequately with excellent quality. E. C. Wente and A. L. Thuras also designed a dynamic-type driver, the Western Electric 555-W receiver which, when coupled with a horn consisting of a 1-in (25-mm) throat and a 40-ft^2 (3.7-m^2) mouth area, was capable of a range of 100–5000 Hz and with an average mid-range efficiency of 25%. With 5-W input it could create more than 1 W of acoustic power. By using multiple-driver units and several horns, it was then possible to fill the larger theaters (3000–5000 seats) with ample sound power to reproduce speech, sound effects, and music adequately. This efficiency of 25%, compared to less than 1% on a present home high-quality cone-type loudspeaker, was needed because only 2.5- and 10-W amplifiers were available. These amplifiers used filamentary-type vacuum tubes requiring direct current from batteries or motor generators for both filament and plate supplies. The power amplifiers were of the 205-D type in single-ended and push-pull circuits. The recording amplifiers were of the type that was used so successfully in the first 500-W broadcast transmitters, studios, and public address equipment. The 8-A and 9-A amplifiers provided the amplification from the 394-W condenser transmitter amplifier, which fed the recording equipment. A speed of 90 ft/min (27.5 m/min) and 24 frames per second was chosen for both the sound disk and the sound on film equipment, which was released in 1927. Accurate speed was possible due to the work of H. M. Stroller, who used a bridge-balanced driving motor. Unbalance of the bridge provided the necessary change of current which increased or decreased the motor speed as required.

In 1927 January Electrical Research Products, Inc. (ERPI) was formed as a subsidiary of the Western Electric Company to handle commercial relations with the motion picture producers and exhibitors. At this time both disk and film recording methods were made available. Again, Wente was responsible for another important device, the light valve. This was a string valve using two ribbons suspended in a plane at right angles to a magnetic field. The ribbons were 6 mil (0.15 mm) thick and stretched to a reasonable point of 8500 Hz. A fixed source of incandescent light illuminated the opening between the ribbons spaced 1 mil (0.025 mm) apart. Current from the recording amplifier moved the ribbons from the normal spacing of 1 mil (0.025 mm) either to complete closure of the slit or to double width of 2 mil (0.05 mm) as a maximum for 100% modulation of the fixed source of light. This slit was focused on the film by an optical system with two-to-one reduction. This is the variable-density-type sound recording on film system.

1 MAJOR STUDIOS START SOUND DEPARTMENTS

In 1928 April, six months after the showing of "The Jazz Singer," Paramount, United Artists, MGM, Universal, and others signed agreements with ERPI for licenses and recording equipment. One can only imagine the intense activity resulting from these contracts. Western Electric utilized all of its telephone plant manufacturing facilities at Kearney, NJ, and the Hawthorne plant in Chicago to produce the required 16 recording channels delivered in late 1928. What hectic days these were! Sound stages were erected with Dr. Vern Knudsen of UCLA serving as acoustical consultant. Sound directors, transmission engineers, and recording staffs were recruited from the broadcast industry, the telephone companies, phonograph recording companies, and any related field since there were few sound experts, and none with talking picture experience. An augmented staff of writers, composers, and stage actors were also assembled. The training of staff kept pace with material developments. The Academy of Motion Picture Arts and Sciences, funded by the eight major producers, gave night school instruction to 900, and this course resulted in the publication in 1931 of the book, *Recording Sound for Motion Pictures*, published by McGraw-Hill Book Company. I was privileged to be one of the authors.

Hollywood, the capital of the silent motion picture, now, in its reincarnation, had a voice! Stars of the silent screen recorded their voices, and many failed to qualify for the sound pictures. The success of outdoor pictures, such as "Arizona," shook off the belief that a sound stage was essential.

RCA Photophone, Inc., was organized in 1928 to promote the commercial exploration of their sound on film system. The Photophone group was organized from a three-cornered arrangement between General Electric, Westinghouse, and RCA. The Photophone system of recording used the variable-area method. The sound track is produced by actually moving a light beam of uniform intensity back and forth lengthwise across a slit whose length and width are fixed. The resulting sound track in its early form had the appearance of a serrated or sawtooth edge of uniform density and adjoining a uniform transparent area. Otherwise all sound recording and reproducing equipment is essentially alike. By the end of 1929, ERPI and RCA had equipped more than 5000 theaters in the United States and 2000 abroad.

Warner Brothers continued the Vitaphone method of sound on disk up to 1933, at which time they switched to sound on film because of the obvious advantages of synchronization, editing, and standardization with the other studios.

Both disk and film equipment was installed in duplicate since at the time of contract signing it was thought that both would be used. Actually the disk equipment was used for instant playback of the recording, using the soft wax for this purpose. The wax was processed into a pressed record and used as a backup in case the film recording was not adequate. This duplication was dropped after a few pictures since the use of two film machines proved to supply adequate protection.

The experience of Western Electric did not involve a full feature length film, including editing and release printing of the hundreds of prints needed for simultaneous exhibition. Thus we were immediately faced with the problem of creating "dubbing" facilities. This consisted of providing a number of reproducing sound heads in rerecording rooms where a number of recorded films could be synchronized, including music and sound effects along with the original dialogue. A new single negative was then available for the final release. As many as 16 separate sound tracks were used to composite all of the individual sound tracks.

The Western Electric 394-W condenser microphone was initially used from 1925 to 1932. At this time, dynamic-type microphones such as the 618 and 633 types were extensively used.

Later the Western Electric type 639-B cardioid microphone and the RCA 77-type direction microphone were used extensively.

2 DIALOGUE EQUALIZATION

The rush to release sound motion pictures in 1928 did not allow for a real analysis of naturalness. However, it was soon recognized that a flat overall frequency response characteristic resulted in an unnatural quality in speech. It was gradually recognized that voices were more natural when the low frequencies were attenuated by suitable equalizers at the time of original recording. They were called "dialogue equalizers" (voice effort equalizers). The shape of the equalizers was arrived at empirically for best natural sound. In later years, studies arrived at basic concepts of why these equalizers provided a subjectively flat quality.

The Fletcher–Munson curves, shown in Fig. 1, give equal-loudness contours over the hearing range. Each of the curves represents the various sound intensities required to produce a constant sensation of loudness for the listener throughout the audible range. One of the first examples to be recognized was that dialogue in the theater needs to be reproduced at a level 5 to 10 dB higher than in face-to-face communication. The higher level is required since the picture image is larger, the distance to the listener is much greater, plus the background noise is low and the performer talks at a lower than average level.

Fig. 2 shows the average voice characteristics of men and women. Normal and soft-spoken dialogue has a high content of low frequencies as compared to the loud voice where there is a large shift to higher output in the 500–700-Hz region.

There was also a large variation in the amount of initial equalization used. This resulted from the fact that in some studios the actors were permitted to speak at a low volume, while in other studios they were required to use a loud voice because of the varying ambient background levels. Fig. 3 illustrates the minimum and maximum amount of attenuation in the dialogue equalizers under the conditions discussed. The maximum equalization is similar to the A-weighting networks in the sound level meter.

There was a decided difference in the amount of dialogue equalization needed for outdoor scenes as compared to indoor scenes, similar to the response of loudspeakers outside and inside. Outdoor scenes required less dialogue equalization because the sound spreads uniformly in all directions. The low frequencies are less directional and are, therefore, more attenuated than the higher noise frequencies, which have marked directional characteristics. Indoors, reverberation builds up the low-frequency response.

The editing of a film sound track for orchestra and voices became very complex at the very beginning of sound pictures. Artists who were beautiful on the screen in many cases were not capable of singing an entire number without a flaw. This was overcome by making as many as 10 takes of a number. Imperfect notes were then cut out of the sound tracks and a perfect note was inserted. Most musical sound film editors become so skillful in using this technique that the audience was totally unaware that there may be as many as 50 notes or bars inserted in a completed song.

Early in sound motion picture recording the need for added artificial reverberation became apparent. Time delay for echoes and added reverberation to music were desirable, but such equipment was not available. First attempts included using several prints of sound tracks spaced one or more frames apart and delayed from the original track. These were then mixed together with results which fell short of the goal. Another attempt was to use a long pipe, 300–500 ft (90–150 m) in length, driven by a loudspeaker on one end and picked up on microphones at 100-ft (30-m) intervals and added to the original sound. This gave better results than the spaced tracks, but limited the type of reverberation.

In 1934 the Hammond Electronic Organ had as an accessory a "reverberstat" which supplied artificial re-

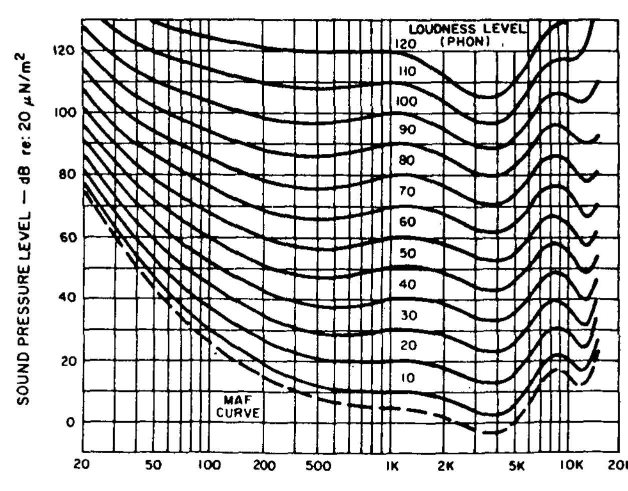

Fig. 1. The Fletcher–Munson curves.

verberation to the organ notes. This unit was composed of a series of coil springs of different lengths and diameters driven by a loudspeaker, with the opposite ends of the springs energizing the microphones. This was the first method that achieved a desirable added reverberation to original sounds.

Later, reverberation rooms were built consisting of special rooms with little absorption so that reverberation periods of up to 3–5 s were available. These rooms were energized by a loudspeaker and picked up by one or more microphones. At a later date, drum, disk, and tape delays augmented the supply of sources for artificial reverberation.

3 MUSIC PRESCORING

The need to record music with vocal selections became obvious at a very early date in sound motion picture recording. Stage noise caused by the hum of arc lights, cameras, ventilators, improper acoustics, placement of orchestra, and many special handicaps forced the techniques of prescoring all musical portions of the picture. This was done by placing the orchestra and soloists in a stage designed specifically for music. (The noise levels were below 35 dBA.) The orchestra was picked up by several microphones to obtain the desired balance, and the solo and choral groups used separate microphones. Up to 1935 only nondirectional microphones and the RCA ribbon microphone were used. The soloists were isolated acoustically from the orchestra with panels (flats) as much as possible, but it was always necessary to have the soloists hear the orchestra and face the musical director.

4 THE ACADEMY RESEARCH COUNCIL

The Motion Picture Research Council became effective in 1934 March, when the major producing companies formed and funded the technical bureau of the Academy. Gordon S. Mitchell was appointed manager. Under him, subcommittees were organized to study all phases of the technical aspects of motion picture production. The first subcommittee on sound was established after the Shearer two-way horn system had been installed in several major preview theaters in the Los Angeles area in 1936. Previously it had been customary to adjust theater reproducing equipment to satisfy individual groups. The adjustments made with a sound track from one studio did not always meet with the approval of other studios. This practice produced a cycle of theater adjustment and studio compensation. This deviation was as great as 20 dB in the very-low-frequency spectrum. Such a situation was so impractical that the sound department heads appointed the Committee on Standardization of Theater Sound Projection Equipment Characteristics, of which I was the chairman.

The committee issued a full report in 1938 April. It contained instructions on the essential specifications for all theaters using two-way theater loudspeaker systems. A sample test reel contained segments of pictures and sound considered representative of the recording of each of the eight major studios. This resolved the dilemma of individual adjustments and was a dramatic step toward worldwide standardization in theaters. This was reinforced when the Research Council prepared and distributed various test reels to major theater service groups, which adjusted the theaters to specific Academy standards.

The major studios, through the Research Council of the Academy, began to organize courses and teach techniques on sound recording and reproduction for their employees. This was necessary because no formal courses on sound recording were offered in educational institutions. In 1938 the Academy published a book entitled *Sound Motion Picture Recording and Reproduction*. This book incorporated lectures composed by the eight major studio staffs selected for the course. (An earlier book had been published in 1930 by the Academy.) Bulletins on sound track standards were issued in 1940. Desired

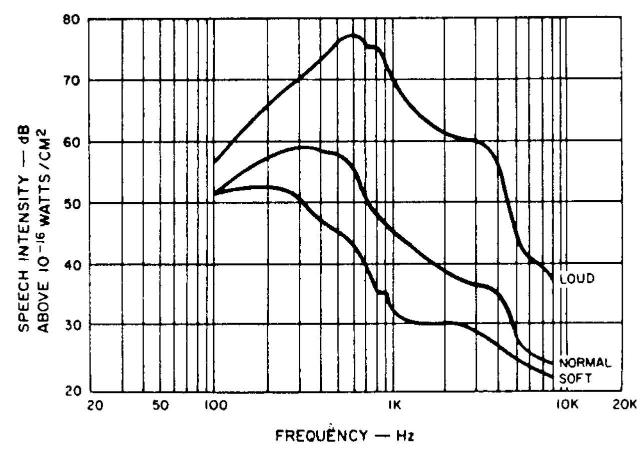

Fig. 2. Average voice characteristics of men and women.

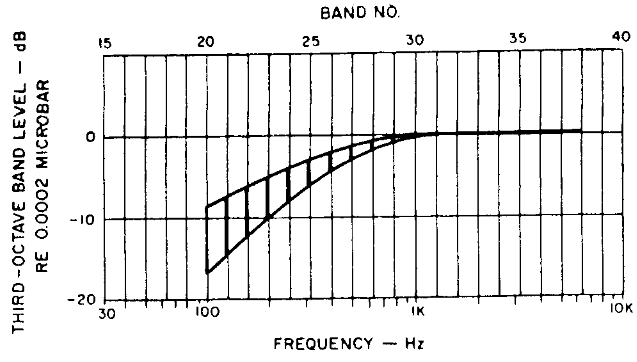

Fig. 3. Dialogue equalizer minimum and maximum range.

theater acoustics and the required electric power for different-sized theaters were charted.

The Academy curve was created when there were two fundamental film and recording equipment characteristics over which there was no immediate control:

1) Basic film grain noise limited the signal-to-noise ratio.

2) Noise reduction components at near subaudible frequencies extending up to 30–40 Hz.

The film grain size results in hiss in the varible-density system, whereas pin holes and track abrasion result in hiss in the variable-area systems. Recordings with basic modulation distortion, due to intermodulation and cross modulation, limited the high-frequency reproduction response. All recordings used 8000-Hz low-pass filters. Therefore the reproducing curve was lowered at least 18 dB at 8000 Hz. The gradual drop from 3000 Hz to cutoff was chosen after many standardization committee meetings in which the films of all major studios were reviewed. This portion of the curve was agreed on as the best compromise.

5 SOUND QUALITY IMPROVEMENTS

Flutter, due to nonuniform speed control in recording and reproducing equipment, was a great source of annoyance in the early years. The RCA rotary stabilizer sound head was an outstanding design that reduced the flutter to a point where it was no longer a factor in the quality of reproduction. John Frayne and Ray Scoville developed the intermodulation test for nonlinearity in variable-density sound recording.

The test combined a high frequency, such as 7000 Hz, with a low frequency of 60 Hz. The 7000-Hz tone, when reproduced, was examined to determine the amount of 60-Hz modulating tone present. This valuable tool was used in the film-processing control procedure to reduce distortion, and it was also applied by others to test the linearity in disk rerecording and amplifier design.

J. O. Baker and R. H. Robinson at RCA developed a cross-modulation method used in the variable-area system. 9000 Hz was modulated at a 4000-Hz rate. Minimum output provided the lowest distortion. E. Kellogg discussed the nonslip printer principle, which resulted in improved constant speed in the printing process, and helped both picture and sound. DuPont developed a fine-grain negative film for variable-density recording that materially increased the signal-to-noise ratio. At this time a change in the developed density was observed every 3 ft (0.9 m) resulting in an amplitude change of 2 dB. Investigating the phenomenon, H. Moyse of DuPont discovered that this was due to stick marks created when the film was drying over supports at this spacing. A continuous-drying process was then developed, and variation was reduced to 0.2 dB.

Both Eastman and DuPont provided blue-sensitive fine-grain films in 1938–1939. To offset the slow film speed, a mercury lamp was used for exposure; since it was many times more efficient, only violet and ultraviolet light was needed. It was also applied to Bell & Howell printers.

O. L. Dupy developed the squeeze-track method of noise reduction at MGM. This technique consisted of a variable-width matte that reduced the width of the variable density recorded for low modulation. When the matte reduced the width of the track on a manual operation, an attenuator geared to the matte position unit compensated for the decreased level of a narrow track by increasing the electric signal by the same amount. This resulted in noise reduction up to 10 dB on low-level signals. Warner Brothers studios developed a "de-esser" which electronically decreased the excessive sibilant energy in speech as full modulation was approached. In 1939 Walt Disney's "Fantasia" used stereo and multitrack sound effects with surrounding loudspeakers, and provided the industry and the public with an example of what they could expect in the future.

In 1938 the U.S. government issued a consent decree to Bell Laboratories and the Western Electric Company, forcing them to divorce themselves from the theater sound reproducing supply and theater sound service. A separate company, called the Altec Service Company, was formed by former Western Electric employees to take over these contracts. Altec and RCA then provided the major staff for theater sound service. The release-film footage from one major studio in 1940 was 40 000 miles (64 360 km) of film, or enough 35-mm film to wrap one-and-a-half times around the equator.

As World War II approached, the studios lost many technical staff workers who were in the military reserve or were recruited by scientific agencies. This resulted in such a severe reduction in staff that only essential workforce was used to maintain limited production. In my opinion, the first 12 years of development in motion picture sound techniques provided a technical base that has not been changed materially to this date.

With this background, and the fact that variable-density reproduction is no longer in use, since it was replaced by the variable-area method, there is a need for a new Academy curve which represents the present situation, rather than one limited by 1940 conditions. The same applies to loudspeaker designs. The 1936 Academy Award design was based on many conditions that no longer exist. The Loew's theater chain alone had 150 theaters with a seating capacity between 3000 and 5000, with as many as three balconies. There are not many theaters of this size today. Moreover, the required distribution pattern is now quite different. Stadium seating now limits the vertical angle to 30° or less. As a result, the present theater loudspeaker can be designed with a wide horizontal distribution not possible with a low-frequency horn.

A flat-baffle vertical low-frequency array will produce an 8–10-dB increase in uniformity up to 1000 Hz at 45° compared to the Academy horn. This was demonstrated in 1969 at the Academy Theater. It can also extend an octave lower in frequency. The low-frequency cutoff at 50 Hz was a compromise between hearing the noise reduction equipment in the near subaudible frequencies (known as shutter bump) and obtaining a suitable level for low-frequency sound. The standardized theater loudspeakers were designed to cut off at 55 Hz to aid in reducing the noise contribution from these low-frequency noise reduction components.

The flat-baffle array reduces the need for an augmentation of so-called subwoofers backstage, since the array will do the same job to 25 Hz. In the early days 50 W was a big package of power, and using low-frequency horns seemed the only course to follow. The vertical array of four to six 15-in (380-mm) woofers will come very close to equaling the horn efficiency, with the advantage of wide uniform horizontal distribution over a larger frequency range.

What the industry now needs is loudspeaker design that tracks other changes and improvements. A new studio and theater standardization committee could accomplish this, and represent the present as well as the future.

THE AUTHOR

John K. Hilliard was born in Wyndmere, North Dakota, in 1901. He received a B.S. degree in physics at Hamlin University, St. Paul, Minnesota, in 1925 and did graduate work in electrical engineering at the University of Minnesota. He received an honorary doctorate in 1951.

Dr. Hilliard spent 14 years at MGM in the development of recording and reproducing film and tape equipment and the design of microphones and loudspeakers for theaters. He also worked for many years in high-intensity environmental sound equipment. From 1932 to 1960, Dr. Hilliard was with Altec Lansing as vice president of the advanced engineering department.

Dr. Hilliard is a fellow of the Acoustical Society of America, the Audio Engineering Society, and the Society of Motion Picture and Television Engineers. He has received the John H. Potts Award of the AES, and is a member of the American Physical Society, the Armed Forces Committee on Hearing, Bioacoustics and Biomechanics, Eta Kappa Nu, the Institute of Environmental Engineers, the Institute of Noise Control Engineers, and the National Council of Noise Consultants.

Dr. Hilliard was director of the LTV Western Research Center between 1960 and 1970. At the present time he is president of John Hilliard and Associates, acoustical and energy consultants.