Sound Recording with the Light Valve [1]

By DONALD MACKENZIE

SYNOPSIS: The light valve developed by Bell Telephone Laboratories is an electromagnetic shutter consisting of a loop of duralumin tape formed into a slit at right angles to a magnetic field. Sound currents from the microphone and amplifier flow in this loop causing it to open and close in accordance with the current variations.

The slit is focussed by a lens on the sound negative film. An incandescent ribbon filament is focussed on the light valve, and the light passed by the undisturbed slit appears on the film as a line at right angles to the direction of the film travel. As the valve aperture is modulated by sound currents, the film receives a varying exposure and a sound record of the variable density type is obtained.

For talking pictures such a sound film is made on a separate recording machine synchronized with the camera and is printed alongside the picture on the finished positive. The prints are displaced so that the sound is advanced over the corresponding picture. This is in order that the sound may be projected at a point of continuous film motion below the picture gate.

THE sound records I am about to describe are of the variable density type, and the method of making them is that developed by Bell Telephone Laboratories.

It is not difficult to specify the requirements of this type of sound film. So far as possible the exposure of the negative must be kept within the straight line portion of the Hurter and Driffield curve for the emulsion chosen, and the print must be timed with the same restriction. The development of the negative and of the print must result in a positive where the transmission of each element of length is proportional to the exposure of the corresponding element of the negative. The light modulator must be supplied with undistorted power from the recording microphone and amplifier. When the positive is projected, the striations of the sound track must be enabled to modulate the illumination of a photo-sensitive cell to retranslate the photographic effect into electrical current which shall be a fair copy of the microphone current generated by the original sound. From this point on the problem is the familiar one of sound re-enforcement, the film and cell having taken the places of the sound source and microphone.

Fig. 1 shows a photograph of the light valve, invented in 1922 by E. C. Wente of the Bell Telephone Laboratories. Essentially, it consists of a loop of duralumin tape suspended in a plane at right

[1] Presented before Society of Motion Picture Engineers at Lake Placid, New York, September 25, 1928.

angles to a magnetic field. The tape, 6 mils wide and 0.3 mil thick, is secured to windlasses A and A' and stretched tight by the spring held pulley B. At points C and C' insulated pincers confine the central portions of the tape between windlasses and pulley to form a slit 2 mils wide. Supporting this loop and adjusting devices is a slab of metal with central elevation D, which constitutes the armature of an electromagnet. The central portions of the loop are supported on insulating bridges to lie 3 mils above the face of D; here the sides of the loop are centered over a tapered slot, 8 mils wide by 256 mils long in this plane, opening to 204 mils by 256 mils at the outside face of the armature. Viewed against the light, the valve appears as a slit 2 mils by 256 mils.

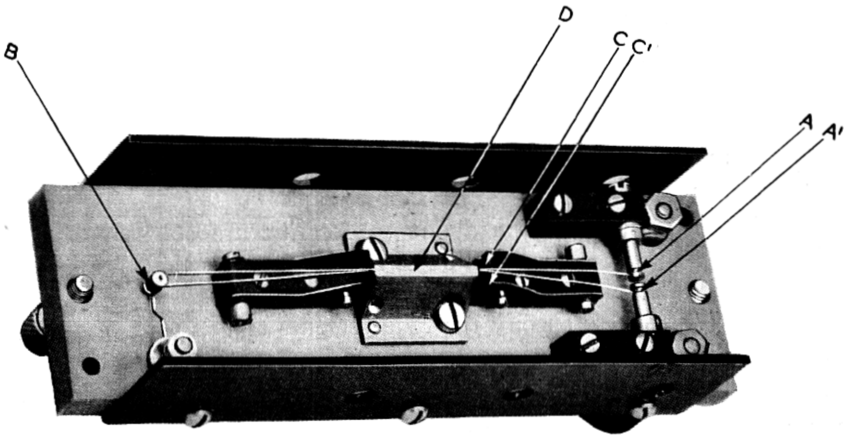

Fig. 1—The light valve.

The electromagnet core has a similar elevation opposing D across an air gap of 8 mils which closes to 7 mils when the magnet is energized from a 12 volt battery. A tapered slot in the magnet core begins 8 mils wide by 256 mils long and opens with the same taper as the slot in the armature. When the assembly of magnet and armature is complete, the valve constitutes a slit 2 mils by 256 mils, its sides lying in a plane at right angles to the lines of force and approximately centered in the air gap. The windlasses A and A', one of which is grounded, are connected to the output terminals of the recording amplifier. If the magnet is energized and the amplifier supplies a sine wave current from an oscillator, the duralumin loop opens and closes in accordance with the current alternations.

When one side of the wave opens the valve to 4 mils and the other side closes it completely, full modulation of the aperture is accomplished. The natural frequency of the valve is set by adjusting the tension applied by the pulley *B*; for reasons which involve many considerations the valve is tuned to 7,000 cycles per second. Under these circumstances about 10 milliwatts of A.C. power are required for full modulation at a frequency remote from resonance; about one one-hundredth of this power at the resonant frequency. The impedance of the valve with protecting fuse is about 12 ohms.

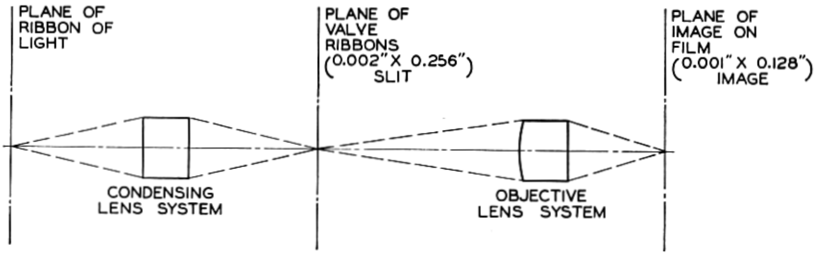

Fig. 2—Diagram of the optical system for studio recording.

If this appliance is interposed between a light source and a photographic film we have a camera shutter of unconventional design. Fig. 2 shows a diagram of the optical system for studio recording. At the left is a light source, a ribbon filament 18 ampere projection lamp, which is focussed on the plane of the valve. The light passed by the valve is then focussed with a 2 to 1 reduction on the photographic film at the right. A simple achromat is used to form the image of the filament at the valve plane, but a more complicated lens, designed to exacting specifications by Bausch and Lomb, is required for focussing the valve on the film. The undisturbed valve opening appears on the film as a line 1 mil by 128 mils, its length at right angles to the direction of film travel. The width of this line varies with the sound currents supplied to the valve, so that the film receives a varying exposure: light of fixed specific intensity through a varying slit.

Fig. 3 shows a studio recording machine with the door of the exposure chamber open. In this machine the film travels at 90 feet per minute, and the sound track is made at the edge away from the observer. The line of light, the image of the valve, overruns the perforations by 6 mils, extending toward the center of the film 122 mils inside the perforation line. The right-hand sprocket serves to draw film from the feed magazine above and to feed it to the take-up magazine below; this sprocket is driven from the motor shaft through a worm and worm-wheel. The left-hand sprocket engages 20 perforations and is driven through a mechanical filter from a worm and worm-wheel similar to that driving the feed sprocket. The mechanical filter enforces uniform angular velocity of the left-hand sprocket which carries the film past the line of exposure: the focussed image of the valve; balancing of the flywheel which forms part of this mechanical filter holds the angular velocity constant to one-tenth of one per cent, despite the imperfections of the driving gears.

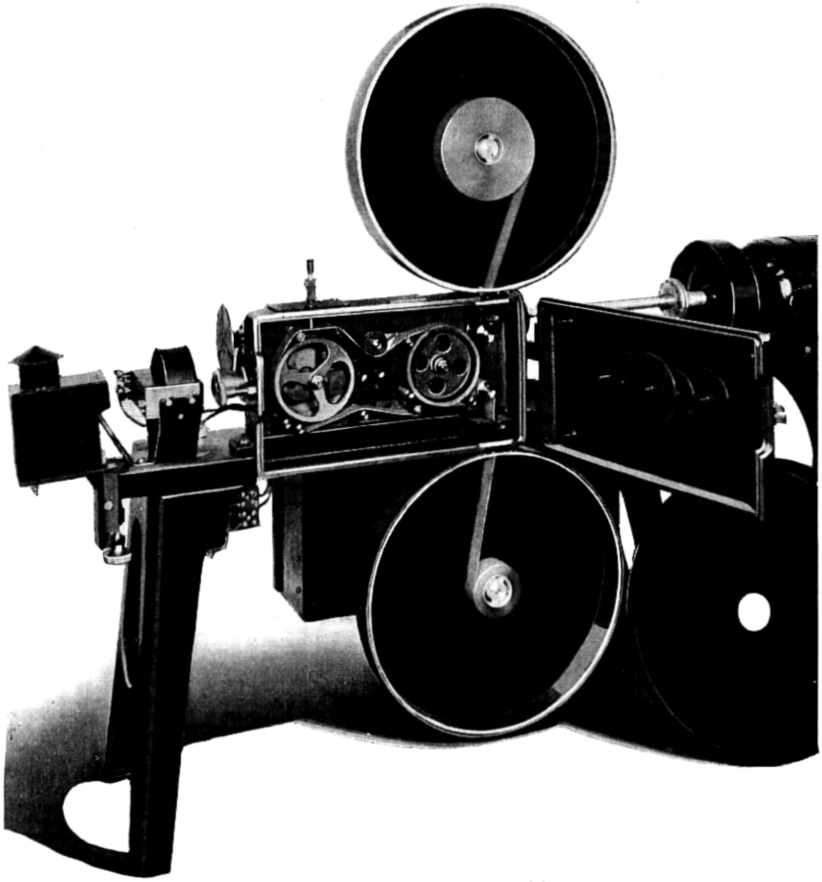

Fig. 3—Studio recording machine.

So far we have provided a means for driving the film and a means for modulating the light thereon, but we have not chosen the average illumination about which the modulation is to take place. The maximum exposure corresponds to the maximum opening of the valve and is therefore double the average.

Choose now the contrast to which the negative sound record is to be developed and draw the Hurter and Driffield curve for this contrast for the emulsion chosen for the negative sound record. The maximum exposure should correspond to the beginning of over-exposure, the average should be half this. The Hurter and Driffield curve will give the density of the over-exposure point for the chosen contrast and the density for half this exposure. Let the machine be run to expose film to light through the unmodulated valve for several values of the lamp current. Develop the film and measure the densities due to the various values of lamp current. Select, by interpolation if necessary, the lamp current which corresponds to half over-exposure. With this current in the lamp the machine is ready to make a sound record, since the focussing of the valve has already been done and manufacturing specifications insure that the line of illumination shall lie, within 3 minutes of arc, at right angles to the direction of film travel.

Consider at this point the procedure in the recording studio. Adding sound to the picture introduces no complication of technique other than to require sufficient rehearsing to make sure of satisfactory pick-up of the sound: microphone placement must be established and amplifiers adjusted to feed the light valve currents which just drive it to the edge of overload in the fortissimo passages of music or the loudest utterances of speakers.

In Fig. 3 the photograph shows a photoelectric cell mounted inside the left-hand sprocket, which carries the film past the line of exposure. Fresh film transmits some 4 per cent of the light falling on it, and modulation of this light during the record is appreciated by the cell inside the sprocket. This cell is connected to a preliminary amplifier mounted below the exposure chamber, and with suitable further amplification the operator may hear from the loud speaker the record as it is actually being shot on the film. Full modulation of the valve implies complete closing of the slit by one side of the wave of current; this modulation should not be exceeded or photographic overload will abound.

One or more cameras and one or more sound recording machines are driven by motors electrically synchronized from a common distributor. Speed control and synchronization of these motors are described in Mr. Stoller's paper. At the beginning of the day's work a check is made of the operation of the driving motors, and the tuning-and-spacing of the valves is verified.

Fig. 4 is a schematic diagram of the studio equipment for sound recording. Provision is made for combining if desired the contributions of several microphones on the set. This combination is under the control of the mixer operator in the monitoring room, viewing the set through a double window in the studio wall. The mixer controls also the gain of the amplifiers for the recording machines.

The diagram shows relays which permit the mixer to connect the horn circuit either directly to the recording amplifier or to one or the other of the monitoring photoelectric cells in the film recorders. The direct connection is used in preparing the sound pick-up in the studio: the program is rehearsed until satisfactory arrangement of microphones and of amplifier gain is effected. The electrical charac-

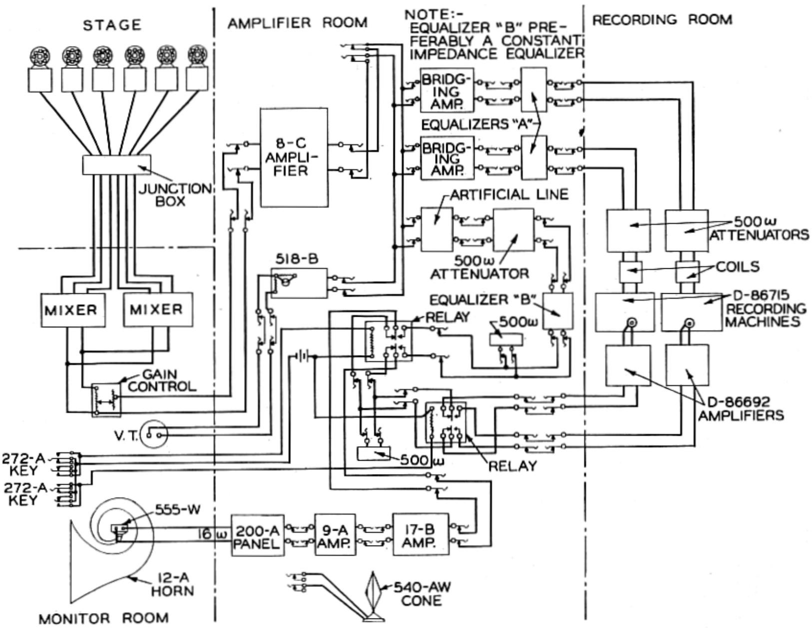

Fig. 4—Schematic diagram of the studio equipment for sound recording.

teristic of this direct monitoring circuit is so designed that the sound quality heard in the horns shall be the same as the quality to be expected in the reproduction of the positive print in the theater. Acoustic treatment of the walls of the monitoring room secures the reverberation characteristic of the theater, and the monitoring level is so adjusted that the mixer operator hears the same loudness that he would wish to hear from the theater horns. It is capitally important that the operator judge his pick-up on the basis of sound closely identical in loudness and quality with that to be heard later in theater reproduction.

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

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

In the choice of emulsion for the sound negative, the usual designation of speed may be disregarded, because it is desired to make the exposure of the unmodulated track many times the under-exposure of the emulsion used. The advantages of positive emulsion for the sound negative have come to be generally recognized; positive has been used by Bell Telephone Laboratories since 1924. The scale of Eastman positive film is about 20 to 1; we adjust the recording lamp current to give an illumination on the film for the unmodulated track of 10 times the under-exposure. After one lamp has been calibrated as described before it may be replaced when necessary by another in which the wattage in the ribbon filament is the same; the light emission is very closely correlated with the wattage. Where the unmodulated or average exposure is ten times the under-exposure minimum, 90 per cent modulation of the light can be permitted without running into under-exposure on the faint side of the wave. For sound currents reaching 100 per cent modulation of the light, 90 per cent of the wave is free from distortion; if the average light were halved, still 80 per cent would be free from distortion. There is therefore considerable latitude in the average exposure, and the negative is satisfactory if the transmission of the unmodulated track lies between fairly wide limits.

The choice of the negative sound gamma is determined by the practice of the laboratory in regard to picture development. It is usual to see on the screen pictures whose overall gamma considerably exceeds unity. On the sound track the overall gamma should equal unity, and the development of sound negatives should be uniform, though that of picture negatives is left to the judgment of the finisher.

Theoretically, it should be immaterial what combination of reciprocal values is chosen for the negative and positive sound gammas. Practically, we have to recognize the existence of ground noise in all records and take precaution to minimize it. No matter how excellently we reproduce the fortissimo passages, our record is unsatisfactory unless the ground noise is low enough for a wide volume range, that is, a wide range in level between fortissimo and pianissimo. Whether our negative sound record is made on negative or positive emulsion, there is always the danger that in reproduction we shall encounter variations in transmission from point to point due to local variations in the celluloid base, to local action of the developing agent, or to a developer excessively granular in action. The photoelectric cell is able to recognize variations of 1/10 of 1 per cent, whereas the eye ignores contrasts under 2 per cent. These local variations in transmission, continued to the positive print, constitute the ground noise.

The remedy is, in part, to choose a developer as little granular in its effect as possible. In part, to insist on machine development of the sound film with thoroughly agitated developer. Further, to carry the sound development to a high gamma; this obviates to a large extent flow marks of the developer, and goes a long way to escape local variations in the base by developing the negative striations to be conspicuous in comparison.

In 1924 we concluded that the optimum choice was positive emulsion developed to unit gamma for both sound negative and sound print. This is feasible for sound records separate from pictures, but a compromise must be made for the combination of sound and picture in a single positive print. Here the positive development required for a satisfactory picture is always to a gamma far above unity.

It is customary to develop picture negatives by inspection, having in mind the uniform positive development to be undergone by the prints from these negatives. The gamma of these positives need never exceed 1.8; the sound negative then should be developed to 0.55. In order not to disturb the practice of the film laboratory, we ask that the positive development be standardized and its gamma ascertained, the reciprocal of this gamma then arranged for in the standardized negative development. A negative gamma above 0.5, together with the precautions of careful handling, permits the realization of an adequate volume range.

It is beyond the scope of this paper to discuss the details of manipulation and of choice of developer, but I wish to acknowledge the cooperation of Mr. J. W. Coffman in the solution of such problems. The problem is the reduction of ground noise, and its seriousness is not to be diminished by choosing a different recording method.

In printing the sound negative, a uniform density for the print of the unmodulated track is desired. The volume of reproduced sound for a given reproducing light source, varies directly with the average transmission and the per cent modulation of this average. This average density should be on the straight line portion of the positive Hurter and Driffield curve, far enough to keep the denser negative portions from reaching the under-exposure region. For Eastman positive film a suitable transmission of the unmodulated portion of the sound print is 35 per cent, referred to air, for the usual values of positive gamma: 1.4 to 1.8. At this average transmission only the peaks of the recorded sound will encroach on the region of under-exposure. For the reciprocally developed negative track the region of under-exposure will have been reached by occasional peaks on the other side of the wave, and such photographic distortion as exists will be balanced between positive and negative.

Here we appropriately consider the photographic distortion as it occurs in variable density records. If the entire negative exposure has been confined to the under-exposure region of the emulsion chosen, a huskiness will result in the reproduction which can not be corrected by any known technique. But if the unmodulated negative transmission, for a gamma of 0.55, is about 16 per cent referred to air, 90 per cent of the wave will be clear of under-exposure, and experience shows that the ear detects no distortion. In telephonic terms, everything at a level 1 TU below full modulation will be free from distortion, and the peaks will be substantially perfect. The same may be said of the positive printed to an average transmission of 35 per cent, provided the overall gamma approximates unity.

It has been calculated that if the overall gamma departs from unity by 0.2 in either direction, a harmonic of 5 per cent amplitude of the fundamental will be introduced. Experimentation has shown that a 5 per cent harmonic is the least detectible. We state then the tolerance on the overall gamma for the sound track as 0.8 to 1.2. Variation of corresponding amount in the contrast of a picture print is intolerable; therefore greater latitude in contrast is permissible in the sound record than could be tolerated in the accompanying picture.

In printing these sound negatives in combination with pictures for projection in the theater, it is customary at the present time to print one negative, masking the space needed for the other, then run the positive again through the printer with the other negative, masking now the space already printed. In printing the picture negative, light changes are made as usual; for the sound negative the light is regulated to result in 35 per cent transmission of the unmodulated track after positive development. Provision of suitable masks in the camera has been made to show in the finder and expose on the film only the portion which will be available for picture projection.

In the theater projector, the sound gate is located 14.5 inches below the picture gate, in order to project the sound record at a point where the film is in continuous motion. Therefore in the printing it is arranged to print the sound negative displaced along the length of the positive enough to bring the sound 14.5 inches ahead

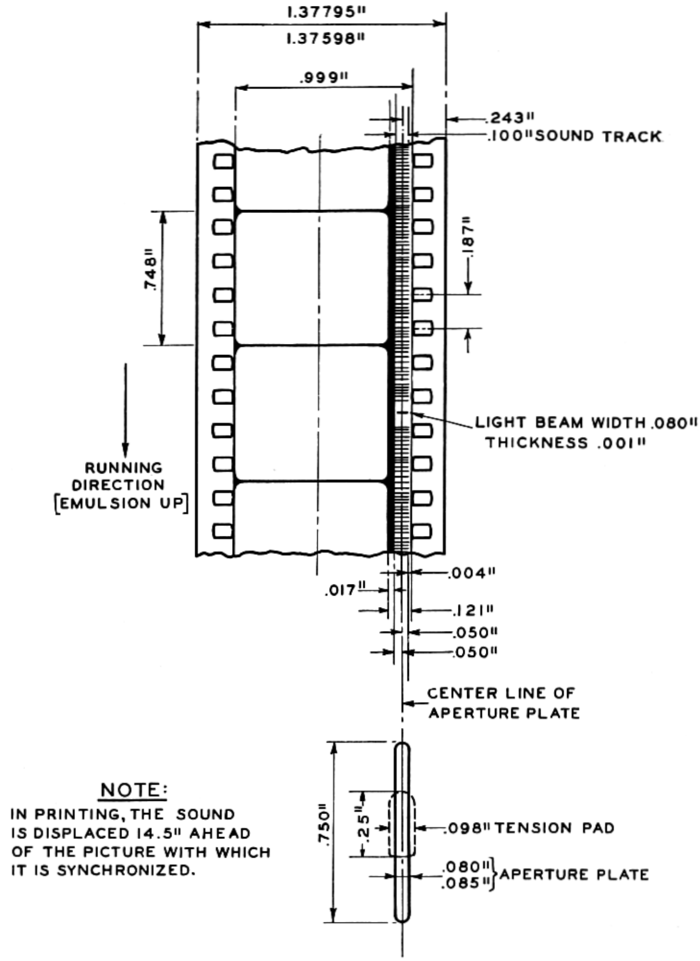

Fig. 5—Picture and sound track dimensions of synchronized sound film for standard 35 mm. positive stock.

of the corresponding frame. The printer apertures are chosen to give a dark no man's land 17 mils wide between picture and sound track; the latter at the outside is separated 4 mils from the inner perforation edge.

Fig. 5 exhibits the present practice for the finished positive. It will be seen that the sound track covers 100 mils clear, and is illuminated in the projector by a line of light 80 mils long, 1 mil wide, centered on the striations. This gives a margin of 10 mils at each end of the reproducing line, an allowance for lateral shifting of the film on the sprocket teeth.

In conclusion, let me estimate the quality of the sound record to be expected. Assume that the recording lamp current has been set to within 5 per cent of the theoretical optimum, the overall gamma held between 0.8 and 1.2, and the final average positive transmission is between 32 per cent and 38 per cent. Then the distortion of wave form due to photographic handling is so small that the ear can not distinguish the record from a theoretically perfect one. The frequency-amplitude characteristic of the reproduced sound remains to be stated.

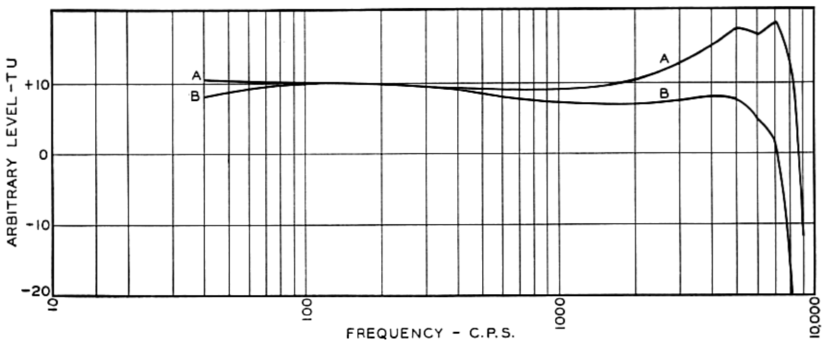

Fig. 6—Characteristic curves of sound recording.

Due to the fact that the element of illumination, both in recording and in reproducing, is 1 mil wide instead of infinitely narrow, the final print will not reproduce the higher frequencies as efficiently as the lower. For example, at the standard speed of 90 feet per minute, the line of illumination covers on the film an entire cycle length of the frequency of 18,000 cycles. This frequency is therefore extinguished completely. The drooping characteristic resulting from this effect, called the film transfer loss, may be largely offset by judicious choice of electrical characteristics and by taking advantage of the mechanical tuning of the light valve.

In Fig. 6 is shown in curve *A* the light modulation by the valve in recording for constant sound pressure of various frequencies at the transmitter; in curve *B* the overall characteristic of the reproduction in terms of electrical power delivered to the loud speaker for constant sound pressure at the transmitter in the studio. Experience shows that curve *B* is close enough to flat; the success of the record, as of the picture, depends on the director.