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(*TELEVISION PRINCIPLES — CHAPTER 1*)

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GENERAL FEATURES OF MODERN TELEVISION

(TELEVISION PRINCIPLES - CHAPTER I)

By C. E. Dean

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GENERAL FEATURES OF MODERN TELEVISION (TELEVISION PRINCIPLES - CHAPTER I)

INTRODUCTION

Purpose of Series of Reports

This report is the first of a series of systematic explanations which are planned to cover the subject of television. The scope of these reports is designed to enable readers who already have a good knowledge of broadcast receivers, to gain a knowledge of television, particularly in regard to receiving aspects. No preliminary acquaintance with television is assumed on the part of the reader.

In England the broadcasting of high-definition television programs has been in progress since November 1936. The station is located at Alexandra Palace in London, and now transmits for two or three hours a day. Some few thousand receivers have been sold, which are not tunable to other carrier frequencies. The quality of the received pictures is satisfactory.

What Television Is

As a precise definition we may quote Standard M9-111 of the Radio Manufacturers Association, as follows: "Television is the electrical transmission and reception of transient visual images". This definition may be seen to rule out the use of powerful telescopes, which of course make possible vision at considerable distances; the definition however may be considered to include the use of a modulated light beam as a carrier of the television impulses, since electrical methods are used for production of the signals at the transmitter and for the reproduction at the receiver.

Although the foregoing definition of television properly makes no reference to sound transmission, as a matter of practical utility, a sound channel will always accompany television broadcasting. This is a natural course because of the important increase in the interest afforded by the accompanying sound, and also because of the relatively simple equipment required for the inclusion of the sound feature.

Comparison with Sound Broadcasting

As a first step toward the understanding of television, we may well compare a modern television system with the well-known sound broadcasting system. In Figure 1 we show at the top the essential parts of a sound broadcasting system, and immediately below this the corresponding portions of a television system. The microphone, audio amplifier, and radio transmitter of the sound system will be

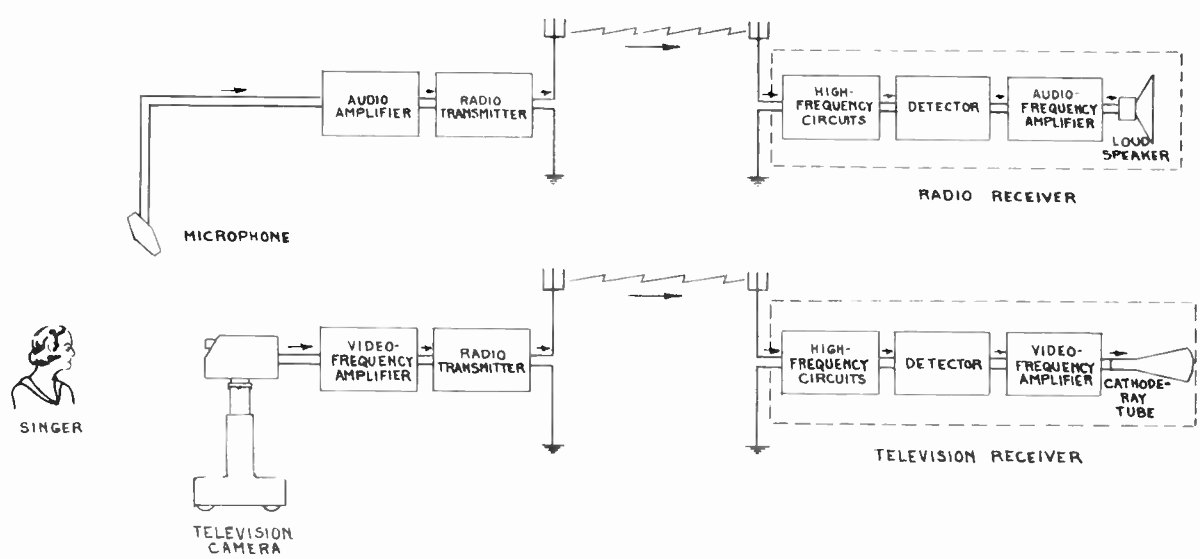

Fig. 1. Sound Radio System Compared With Television System.

seen and it is unnecessary to describe the functions of these parts. Also at the sound receiver there are the high-frequency circuits, the detector, the audio amplifier, and the loudspeaker, which together constitute the radio receiver.

The pickup device at a television studio is called a "camera" in accordance with motion-picture practice, although generally the parts and operation are entirely different from those in a motion-picture camera. The television camera produces electrical signals, and these go into the "Video-Frequency Amplifier" which is seen as the next element in the television system. Here the picture signals, or "video" signals are strengthened; thence they go to the radio transmitter and modulate it. This description of the electrical operations in the television studio and transmitter is of course greatly simplified, particularly in the omission of the elaborate scanning and synchronizing arrangements which are essential; these matters will be considered in subsequent reports.

At the television receiver there are high-frequency circuits corresponding to those in the radio receiver. These circuits may be merely radio-frequency amplifiers, in which case we have a tuned-radio-frequency television receiver. Or the high-frequency circuits may utilize the superheterodyne principle with the same significance of frequency changing as in broadcast receivers. It is expected that in the United States most television receivers, if not all, will be of the superheterodyne type.

The detector in a television receiver operates in the same fundamental manner as in a broadcast receiver and the video signals which it produces are amplified in a video-frequency amplifier which corresponds to the audio-frequency amplifier of the sound receiver. In place of the loudspeaker, some device must be used which will convert the varying amplitude of the video signals into corresponding variations of light; this device reconstitutes the original scene and thus makes the picture which the user sees.

The most common reproducing device is the cathode-ray tube. This may be called a "picture tube" on account of the fact that the desired picture is seen on the end of the tube. The action of the cathode-ray tube in reproducing a picture consists in the electron spot moving back and forth and up and down so as to cover the entire area of the picture, while the intensity of the spot is determined by the control grid of the tube. In this way each spot of the screen is made to have the proper brightness to reproduce the picture. It will be seen that the control grid in the cathode-ray tube controls the number of electrons in the beam in the same way that the control grid of an amplifier tube controls the plate current. This control-grid action is an essential part of the television reproduction. We mention this point because in oscilloscope practice there is usually no application of signal to a grid.

CHIEF PARTS OF TELEVISION SYSTEM

Pickup Device

The essential function of the television camera is to convert the light intensities of successive elements or points of the picture into proportional electrical currents. At the present time electronic means, with special types of vacuum tubes, are used for this purpose. Such tubes may be called "camera tubes" on account of their use in the television camera.

The most widely used camera tube has a mosaic plate on which an optical image of the scene is focused. The elements of this plate have photoelectric and secondary-emission characteristics. There are a great many of these elements, each insulated from the others and all held on a sheet of mica. On the back of this sheet of mica is a conducting metal coating, which is called the "signal plate". In operation the mosaic plate is scanned by a beam of electrons from a suitable "electron gun". The effect of this scanning is to cause varying potentials to be created on the signal plate as the scanning proceeds. These potentials are a measure of the changing brightness of the successive spots, and constitute the video signals which must be transmitted thru the television system to the cathode-ray tube of the receiver. The signal level produced by the camera tube is about one millivolt across a load of 10,000 ohms.

Camera tubes of the type just described have been given the trade-marked designation of "Iconoscopes" by the RCA group, and this term is often seen in television literature. In England, the Marconi-E.M.I. group similarly uses the term "Emitron".

The Video Amplifier

On account of the many points into which the scene must be divided for high-definition transmission, and also on account of the number of times each second with which a complete scene must be reproduced, the range of frequencies produced by the television camera and its associated circuits extends to a very high value, such as two or three megacycles. The range also goes down to zero frequency at the lower end, since the direct-current component conveys the information as to the average brightness of the scene.

The amplification of this very wide band of frequencies constitutes a severe requirement on the video amplifier. It has been found that a modified form of resistance coupling will accommodate all of the necessary frequency range except the lowest frequency components; special arrangements are used for taking care of this very low-frequency portion of the range. With the latest types of tubes, gains of 15 or 20 decibels per stage are obtained.

The video amplifier at the transmitter consists of a number of stages, and the first ones of these are located in the camera itself. This amplification in the camera raises the energy level of the video signals so that they are less subject to interference in transmission thru the flexible cable which connects the movable camera to the fixed equipment.

There is also a video amplifier in the receiver, and this usually has only one stage. It delivers the control voltage to the reproducing picture tube.

Radio Transmitter

Fundamentally the radio transmitter in a television system performs the same function as in a sound broadcasting system. The essential purpose is to produce a powerful high-frequency radio wave having such variation in amplitude, that is such modulation, as to convey the desired signals.

Two reasons have operated to cause the carrier frequencies used in television radio systems to be considerably higher than those previously common with sound broadcasting systems. One of these reasons is the wide band of video frequencies which have to be transmitted. A moment's reflection, or examination of appropriate data, will lead one to the conclusion that radio systems in the communication art usually operate with carrier frequencies several times as great as the highest component of the signals to be transmitted. This permits the use of tuned circuits as the frequency-selecting means rather than involved types of filters. The other reason for the choice of higher carrier frequencies was the fact that the lower frequencies were already occupied more or less by other radio services. The Federal Communications Commission has now adopted 6 megacycles as the standard width of a television band, and has set up a group of channels on this basis, which will become effective in October 1938. For example, the lowest-frequency one of the new bands extends from 44 to 50 megacycles.

All these television carrier frequencies lie in what is generally called the "ultra-high-frequency" band which is characterized by, first, the absence of the sky wave, and second, the limitation of the service range to approximately the horizon as seen from the transmitting antenna. Unfortunately the interference range extends considerably beyond the horizon. It would of course be fortunate if television stations had coverage similar to that of sound broadcasting stations. However the technical necessity for using the ultra-high frequencies renders this impossible. There is something of a compensation in the likelihood that cities several hundred miles apart can use the same carrier frequencies for television without objectionable interference.

In Table I there are listed all the ultra-high-frequency television licenses granted as of February 1938 by the Federal Communications Commission except those for powers less than one kilowatt. All of these assignments are for operation in the region of 42 to 56 megacycles or in the region of 60 to 86 megacycles. All of these are for experimental operation. The powers given are

TABLE I. ULTRA-HIGH-FREQUENCY TELEVISION LICENSES FOR ONE KILOWATT OR MORE

Licensee and Transmitter Location	Call Letters	Power in KW Visual	Power in KW Aural
Columbia Broadcasting System, Inc., Chrysler Building, New York, N. Y.	W2XAX (Construction Permit granted for 7.5 kw)	0.5	
Don Lee Broadcasting System, Los Angeles, California.	W6XAO (Construction Permit only)	1	
Farnsworth Television Incorporated of Pa., Springfield, Pa.	W3XPF (Construction Permit only)	4	1
National Broadcasting Co., Inc., Empire State Building, New York, N.Y.	W2XBS	12	15
Philco Radio & Television Corporation Philadelphia, Pa.	W3XE	10	10
Radio Pictures, Inc., Long Island City, N.Y.	W2XDR	1	0.5
RCA Manufacturing Co., Inc., Camden, New Jersey	W3XEP	30	30

* * * * * * * * * * * *

the licensed values and may be greater than yet used.

A new assignment of frequencies from 44 to 108 megacycles has been made by the Federal Communications Commission, providing for the needs of television, government services, and aviation, to become effective in October 1938. These assignments are as follows:

Frequency Range	Service
44-50 mc.	First Television Band
50-56 mc.	Second Television Band
56-60 mc.	Amateur
60-66 mc.	Government
66-72 mc.	Third Television Band
72-78 mc.	Aviation and Government
78-84 mc.	Fourth Television Band
84-90 mc.	Fifth Television Band
90-96 mc.	Aviation
96-102 mc.	Sixth Television Band
102-108 mc.	Seventh Television Band

In addition to the foregoing assignments, the Commission has also made assignments for various services from 156 to 294 megacycles, including twelve television channels, each of 6-megacycle width. The practical value of these television assignments above 150 megacycles remains to be determined in the future.

Station W2XBS is now operating with a picture carrier of 46.5 megacycles and an audio carrier of 49.75 megacycles. Station W3XE is operating with a video carrier of 50 megacycles and an audio carrier of 54 megacycles.

Superheterodyne and Tuned-Radio-Frequency Receivers

Television receivers of the tuned-radio-frequency type require several stages of carrier-frequency amplification. It has been found impractical to make these with variable tuning; therefore these receivers are adapted for use only where a single television wavelength is to be received. Such is the case in England, where the London transmitter is the only station, and a number of such tuned-radio-frequency receivers have been sold. A service adjustment of the tuning for alignment upon the one channel is the only variation provided.

For the United States it is contemplated that more than one station will be available in some cities, so that tuning facilities must be provided for the choice of stations. Another consideration is that it is very desirable for a given model of receiver to be usable in or near any city having one or more stations. Therefore American receivers are expected to accommodate more than one, and probably all of the seven television channels below 108 megacycles listed on page 6. The use of the superheterodyne circuit makes this practicable. A majority of the English receivers to date have been superheterodynes, but have provided only vernier tuning for one station frequency.

It may be observed that the seven television channels allocated by the Federal Communications Commission and listed above on page 6, do not constitute a single continuous spectrum; there are gaps, which are assigned to amateur operations, aviation, and government services. The existence of these gaps, and the adoption of push-button tuning for broadcast receivers, make it likely that it will be found practicable to design television receivers with a push button for each of the assigned channels. Should continuous tuning be used, there are special circuits which might be used to disable both the picture and the sound reproduction until the receiver is properly tuned.

The choice of stations, which it is expected will be provided in American receivers, also makes desirable the feature of automatic volume control, which has not been incorporated in English receivers. The need for this feature arises from the different field strengths of the various stations to be received. There is little fading at the ultra-high frequencies, such as encountered at lower frequencies, because of the absence of the sky wave. However, sometimes highways and airways are so located that traffic on them affects the received television field strength, and in these cases fading will occur according to the motion of traffic.

The ordinary sound receiver has automatic volume control which operates to produce an approximately constant level of the carrier component; change of the percentage modulation does not alter the gain of the receiver. In a television receiver the conditions are different in that some indication of the average background brightness must be transmitted, and it is general practice to use the amplitude of the carrier component for this purpose. One expedient is to have an ordinary automatic-volume-control system in the sound portion of the television receiver and use the control voltage from this to determine the gain in both the sound and vision carrier amplifiers. Another expedient, applicable to push-button television receivers in the absence of fading, is to have no automatic volume control, but provide a volume-adjusting screw for each push button; these screws are for the service man to adjust when installing the receiver. Other possibilities as to automatic volume control depend on the polarity of the video modulation, and will be discussed in later reports.

Intermediate-Frequency Amplifier

The very wide band of video frequencies to be accommodated in a television receiver makes it essential to employ a much higher intermediate frequency than used with sound receivers. Values of intermediate frequency from about 4 megacycles to 15 megacycles have been used.

The band width which these intermediate-frequency amplifiers must transmit is relatively much greater than in the usual broadcast receiver, despite the use of a much higher intermediate frequency. In the television receiver special steps must be taken to accommodate this band width. These measures generally take the form of damping resistors across the primary and secondary of the intermediate-frequency transformers. These of course lower the gain; on this account about three intermediate stages are required, with four transformers. There are promising developments of tubes with high mutual conductance which may assist in securing the necessary gain in the intermediate and also the video amplifiers of television systems.

Reproducing Device

The output of the last intermediate stage of the television receiver is applied to a detector, which is ordinarily of the diode type, from which the detected video signals go to the video amplifier of the receiver. After amplification, the video signals go to the reproducing device which converts them into optical form for viewing.

Most television receivers employ the cathode-ray tube as a reproducing device. Tubes of large size have been made, screen diameters of 12 inches being fairly common. The deep-green screen color which was formerly about the only color obtainable for picture tubes has given way to more pleasing shades of a yellowish-green tinge and to "black-and-white" tubes of attractive appearance. The black-and-white tubes actually have considerable blue and other colors, but give a picture which the layman would describe as "black and white".

SCANNING

Necessity for Scanning

A very simple picture could be transmitted by a group of multiple circuits, there being one circuit for each part of the picture. In Figure 2 we show such a system for the transmission of a picture having only four parts. At the moment indicated, two of the parts are dark and the other two are light. As time goes on, the four parts vary their brightness in any manner, and the system reproduces all these effects at the receiving end. It will be seen that a photo-sensitive cell is provided to be operated by the light from each of the four parts of the scene. An individual circuit for each of these cells connects with the corresponding lamp of the reproducing apparatus, so that the variations are reproduced properly. It will be realized of course that this is a schematic representation, and that various additional apparatus would be required for practical operation.

The multiple-circuit system for television, however, is in fact totally impracticable on account of the very great number of picture points required for good definition. Thousands of wires or radio channels would be required to transmit even a poor television picture by this means. Recourse is therefore had to a system whereby successive points of the scene can be transmitted in order over one circuit. In Figure 3 the same simple television scene of only four parts is shown being transmitted by the use of such a process. It will be seen that a commutator is provided so that the photocells are connected in turn to the line at the transmitter, and that the lamps are similarly connected in turn to the line at the receiver. It is necessary of course that the two commutators be maintained in synchronism, that is in step with each other, so that the proper lamp will always be in circuit for each photo-sensitive cell. By rotating the commutators at moderate speed and having lamps of appreciable thermal capacity, the intermittent nature of the reproducing process may be brought within the persistence-of-vision characteristic of the eye, and a steady re-created scene like the original will be observed.

The arrangement of Figure 3 may be considered as a crude scanning system.

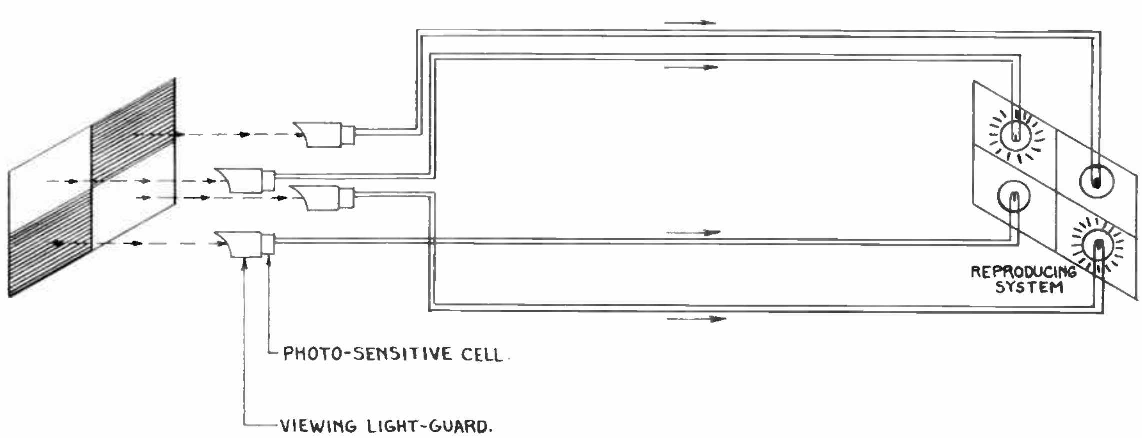

Fig. 2. Multi-Channel Transmission of Very Simple Changing Picture.

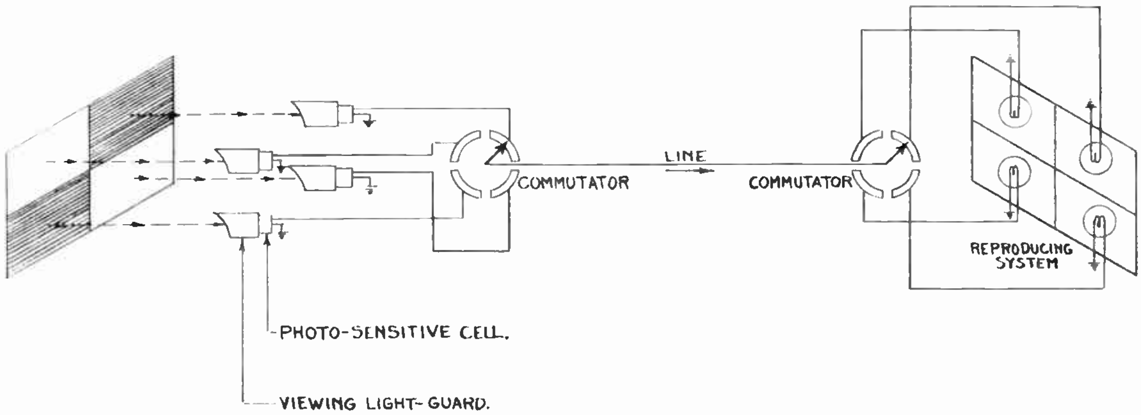

Fig. 3. Transmission of Very Simple Television Image By Time Division of One Circuit.

It is of course impracticable for present-day television use because of the large number of photo-sensitive cells which would be required. However, the arrangement shown at the receiver in Figure 3 was actually used in demonstrations by the Bell Telephone System in 1927. A large number of neon lamps arranged in a continuous folded tube and an elaborate commutator were employed. This general arrangement has also been demonstrated by Baird in England.

In modern television transmission an elaborate system of picture analysis and synthesis, that is point-by-point transmission, is used. The scene is scanned horizontally from left to right. That is, the entire television system is engaged at one moment in transmitting the intensity of the light at the upper left-hand corner of the scene. The scanning spot then proceeds horizontally to the right, and the television system transmits continuously the illumination corresponding to the various points along this line. At the end of this first line, a quick return to the left side is made, and a line slightly below the first one is scanned. In this way the process continues line by line until the entire scene has been traversed. It will be seen that the process is similar to reading print on a page, where the eye travels from left to right and reads one line after another until the page is finished.

It is well to note that the scanning of each line is a smooth, continuous process, not intermittent as it would be if the line consisted of definite individual points. We may say therefore that, strictly speaking, the scene is transmitted by being divided into horizontal lines, each of which is sent as a steady process. It is often advantageous to consider television transmission as a point-by-point process, but in this case it should be kept in mind that the points along one line are merely the portions of the line and that they are transmitted as a continuous, not an intermittent, process.

The following definitions from the standards of the Radio Manufacturers Association are of interest:

Number	Wording
M9-112	A Frame is a single complete picture.
M9-113	Scanning is the process of analyzing successively, according to a predetermined method, the light values of picture elements constituting the total picture area.
M9-114	A Scanning Line is a single continuous narrow strip which is determined by the process of scanning.

Number	Wording
M9-115	Frame Frequency is the number of times per second the picture area is completely scanned.

As a summary on the essential nature of scanning we may quote the following sentence from page 48 of Wilson's "Television Engineering": "The implication is that every object point at the transmitter yields its brightness value in turn to a photo-sensitive device, while at the receiver the apparent brightness at every point of a field of view is modified in turn to develop a picture, in contradistinction to the idea of having a separate transmission channel for conveying the brightness-value of every object point simultaneously to the receiving screen."

The reader may ask why the scanning process is carried out only in one direction along the lines, that is why the first line is not scanned from left to right, the second from right to left, and so forth. There are good reasons why this method is not used. The worst shortcoming of such scanning in both directions is that slight irregularities in the speed of the scanning spot cause corresponding portions of adjacent lines to be seriously out of register and thus greatly impair the definition of the reproduced image. Another fault of such bi-directional scanning is the double coverage at the ends of the lines where the scanning spot retraces the course it has followed immediately before.

Interlaced Scanning

The description of scanning in a modern television system which is given in the preceding section is simplified by the omission of the feature of interlacing, which we will now describe.

The successive lines which were scanned in the description in the preceding section should be thought of as slightly separated, so that one line does not lie against the line immediately above it. The interlacing process consists in going back again for a second scanning, at which time the scanning spot takes these intervals between the lines which were scanned previously.

The principle of interlacing is easily understood if the reader considers a simple experiment with a coin, a piece of paper, and a pencil. If the paper is placed over the coin, and horizontal lines starting at the top are drawn, slightly separated, the features of the coin will be partly revealed. The pencil may then be carried again to the top of the coin, and an additional set of horizontal lines be drawn between those of the first set. In Figure 4 we show diagrammatically the result of such a process.

The following standard definitions of the Radio Manufacturers Association point out the difference between plain, or "progressive", scanning and interlaced scanning:

Number	Wording
M9-112	A Frame is a single complete picture.
M9-115	Frame Frequency is the number of times per second the picture area is completely scanned.
M9-117	Progressive Scanning is that in which scanning lines trace one dimension substantially parallel to a side of the frame and in which successively traced lines are adjacent.

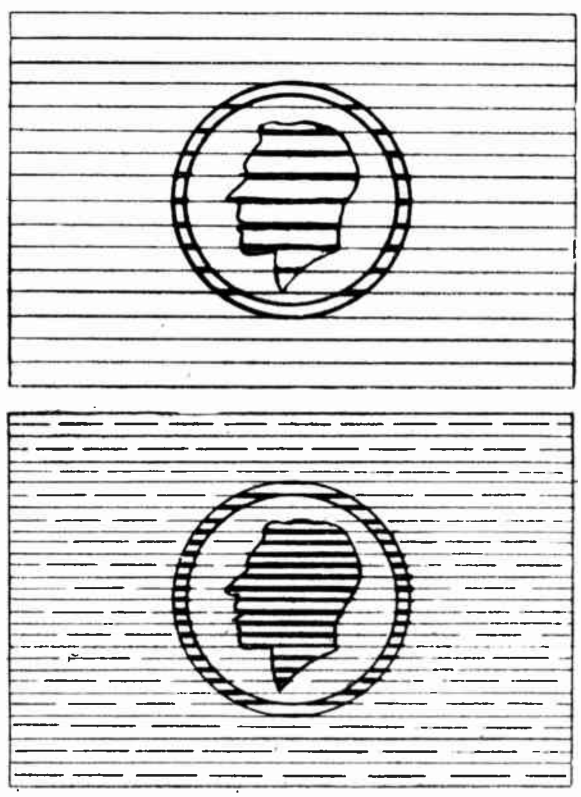

Fig. 4. Explanation of Interlacing With Paper, Coin and Pencil.

Number	Wording
M9-118	Interlaced Scanning is that in which successively scanned lines are spaced an integral number of line widths, and in which adjacent lines are scanned during successive cycles of the field frequency scanning.
M9-119	Field Frequency is the number of times per second the frame area is fractionally scanned in interlaced scanning.

The purpose of the interlacing process is not to improve the definition of the picture; this could be accomplished by increasing the number of scanning lines with simple scanning. The reason that interlacing is employed is to reduce an objectionable effect called "flicker" which would otherwise be experienced. This effect is described in a later section of this report.

Scanning by Electronic Means

In Figure 5(A) we show the usual camera tube, which is scanned electronically. The scanning is accomplished by the electron beam sweeping over the mosaic plate under the control of the horizontal and vertical sets of scanning coils which are shown.

The deflection of a beam of electrons by means of a magnetic field may be explained by the well-known rule of motor theory where a wire carrying a current in a magnetic field experiences a force perpendicular to both the direction of the wire and the direction of the field. The beam of electrons in the present case is electrically similar to a corresponding flow of electrons along a wire and the beam experiences the deflecting force in the same way that an actual wire would.

For the horizontal scanning of the beam there are provided two windings, and from the discussion in the preceding paragraph it will be seen that these windings must be located above or below the neck of the tube. In practice one winding is above and the other below. Similarly for the vertical scanning, two coils are provided, one on each side of the neck of the tube. The instantaneous magnetic field is of course proportional to the instantaneous current. In this way the desired scanning action can be obtained by the passage of suitable current thru the scanning coils.

In Figure 5(B) we show a picture tube in which the scanning is accomplished by an electric field acting upon the electron beam. Pairs of deflecting plates are provided for scanning in the two component directions, in exactly the same manner as in the usual laboratory oscilloscope.

In Figure 5(C) we show a picture tube in which magnetic scanning for both the components is used. The action here is of course the same as in the camera tube of Figure 5(A). It is entirely possible with a picture tube to use magnetic scanning for one component and electrostatic scanning for the other.

Saw-Tooth Wave Form

With magnetic scanning it is necessary that the scanning current increase steadily so that the spot will travel uniformly from left to right. When the right edge is reached, the control grid of the cathode-ray tube receives a bias beyond cutoff, and the spot is extinguished. While the spot is extinguished the scanning current rapidly changes to a value corresponding to the beginning of a scanning line. The cutoff bias on the tube is then removed, the spot comes on again, and the scanning of the next line proceeds. Similarly with electrostatic deflection, the voltage must increase steadily as the point proceeds from left to right, and at the end of the line the voltage should quickly change to the value for the beginning of a scanning line. In this case also the spot is extinguished while the rapid change of voltage occurs.

This gradual change of value of scanning current or voltage, with a rapid return to the original condition, corresponds to a special wave form which is known as the "saw-tooth" wave form from its similarity to the teeth of a saw. In Figure 6 we show such a wave form. The essential characteristic of a saw-tooth wave form is that ideally the wave consists of only two straight lines. These differ in length, so that the two portions of the cycle, that is the increasing portion and the decreasing portion, are of unequal duration. In particular the saw tooth is

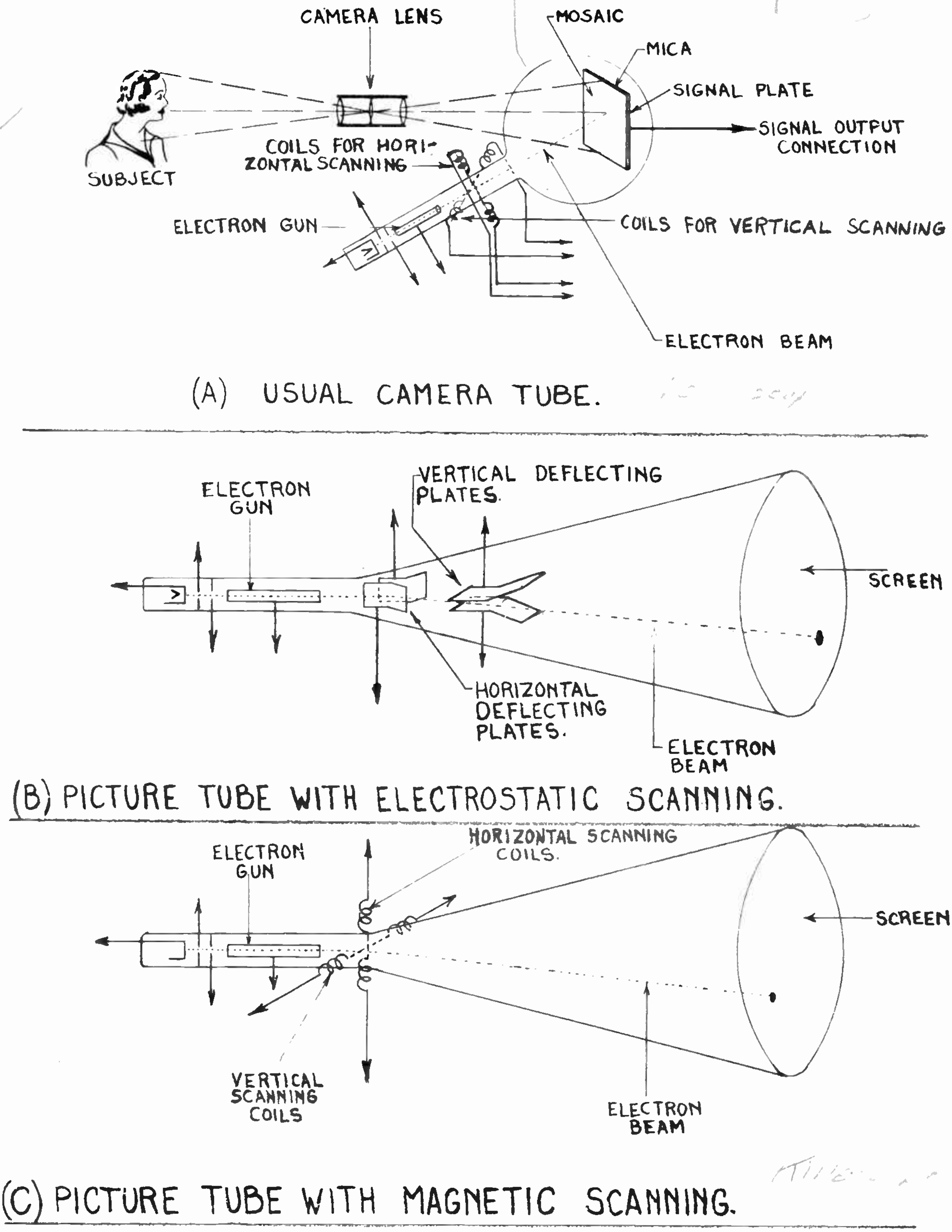

Fig. 5. Electronic Scanning Arrangements.

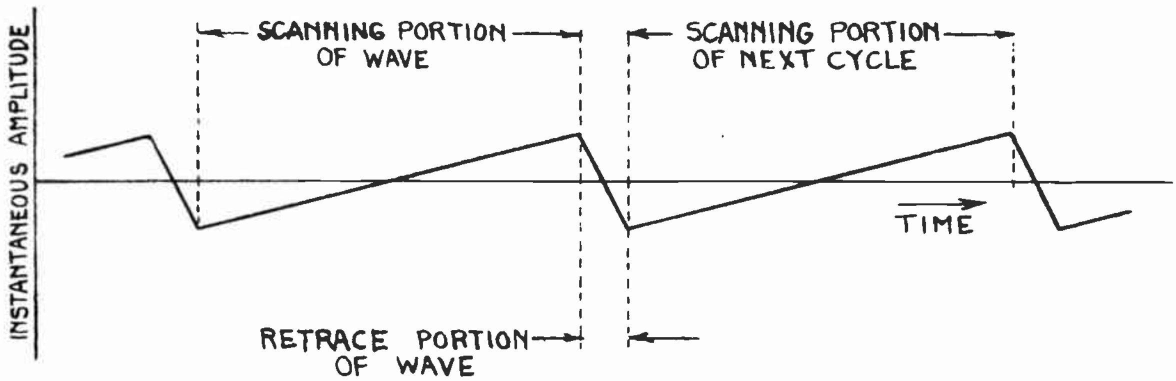

Fig. 6. Saw-Tooth Wave Form.

usually plotted, as in Figure 6, so as to show the increasing portion of long duration and the decreasing portion of short duration. Special circuits are required to produce currents or voltages having this wave form. If amplifiers are used, they must have wide frequency characteristics in order not to impair this wave form. It is desired that the straight-line portion, which uses up most of the period of the cycle, be as straight as possible, that is have a high degree of linearity. As a matter of fact, however, there is a practical limit to the degree of linearity which can be obtained.

The return portion of the saw-tooth wave form is made as short as possible to reduce the amount of lost time. In practice this consumes about 15% of the line cycle for the line retrace, and 10% or somewhat less of the vertical cycle for the vertical retrace.

TRANSMISSION REQUIREMENTS

Range of Video Frequencies

A little reflection will quickly lead one to the conclusion that very high video frequencies are required in television transmission. For example if the picture is to be divided into 400 horizontal lines, and each line is considered to have 500 points, the entire picture consists of the product of these two numbers, or 200,000 points. It is necessary to reproduce the entire picture at a frequency comparable to motion-picture practice, and in fact in the United States, the use of 60-cycle power makes it certain that a frequency of 30 frames per second will be used. The 200,000 points and the 30 times per second that this image is reproduced, give a figure of 6,000,000 points per second. As a preliminary assumption, it may be said that one cycle will reproduce two points, giving a range of video frequencies extending to 3,000,000 cycles per second, or 3 megacycles.

It is desirable that a substantial fraction of this 3-megacycle range be transmitted by the circuits. The significance of this wide band may be missed at first; the idea is that the video amplifier must transmit all frequencies from zero up to this value as the upper limit. This includes all of the audio range, plus the usual range of long-wave radio signals, plus the usual broadcast range (ending at 1600 kilocycles), and in addition frequencies somewhat higher than this. Obviously such a requirement on the video channels, and the corresponding band-width requirement on radio-frequency and intermediate-frequency amplifiers, is very severe, and special designs must be used to obtain satisfactory results. We indicate these special features very briefly in the corresponding sections above, and will deal with them at length in subsequent reports.

Phase Requirements

The very wide frequency band is not the only requirement which is characteristic of a high-definition television system. An additional property which is necessary is a uniform time of transmission for the various frequency components. On account of the fact that this is a quantity which is of little interest in sound broadcasting, we give several paragraphs here discussing the subject.

It is well known that a fundamental frequency and a particular harmonic will give a certain wave form when the initial phases of the two frequencies are equal, but in general will give a different wave form for other initial relations of the phases of the two component frequencies. This is illustrated in Figure 7; it can be seen that in Figure 7(A) a fundamental and third harmonic, both going thru zero simultaneously and in the same direction, give an approach to a square-wave condition. In Figure 7(B) the two frequencies again pass thru zero simultaneously, but are now going in opposite directions; this is seen to give a high amplitude, and high voltages of this type may break down insulation in severe cases. It is seen therefore that the wave form of a wave consisting of certain frequency components depends on the phase relations among the components. For this reason, changes in phase relations in the video signal during transmission cause alterations in the succession of the various shades of light in

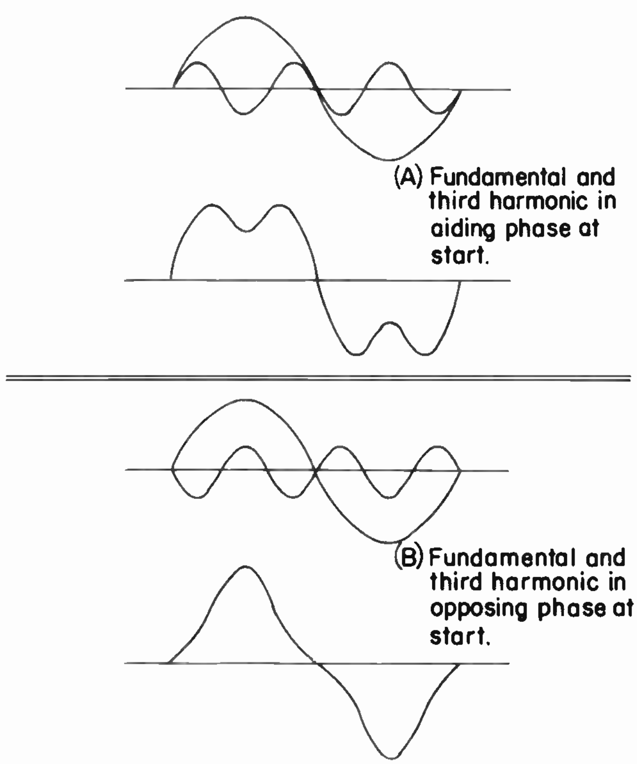

Fig. 7. Dependence of Wave Form on Phases of Components

the reproduced scanning lines, and thereby distort the picture.

The human ear has little or no appreciation of the phase relations of the components of a complex sound; change of phase only is generally not perceptible to a listener. The only qualification is in the case of very loud sounds, which may be exceptions. As an example of this general principle, the fundamental and third harmonic with various phases and wave forms, described in the preceding paragraph, sound alike to the ear at all low and medium amplitudes.

This independence of phase relations, which is a technical assistance in sound transmission, does not apply in the transmission of still pictures and television. The received wave form determines the shades along the reproduced lines, whence change of wave form affects the picture. Care is necessary in these optical transmissions to preserve the actual wave form.

A certain amount of time is of course required for the transmission of a signal of a given frequency thru various equipment and over wire and radio connections. An original complex wave form, made up of various frequencies, will be reproduced accurately if all frequency components require the same length of time for their passage thru the system. The requirement for ideal transmission in this regard may thus be stated as follows: The time of transmission thru the system shall be independent of frequency. Failure to meet this criterion is sometimes given the descriptive name of "velocity distortion", meaning that various frequencies have proceeded at different velocities thru the system. However, the usual term in television discussions is "phase distortion".

The ideal requirement of constant time of transmission for various frequencies is often stated in terms of phase, and an explanation of this is required. A given time of transmission represents more phase difference at a high frequency than at a low frequency. As an example, a 1/10-microsecond time of transmission at a frequency of 1 megacycle is 1/10 of a period or 36 degrees of phase change, but at 100 kilocycles is only 1/100 of a period, or

3.6 degrees change of phase. In terms of phase, the criterion for complete absence of phase distortion is that the transmission phase angle for the various frequencies shall be proportional to the frequency.

The picture faults observed with imperfect phase relations depend on whether the discrepancies are chiefly for the low video frequencies, or for the high video frequencies, or what other particular relations may exist. In general phase distortion will cause sharp edges in the original picture to be lost. Under some circumstances a light spot in the view may be accompanied by a succession of bright and dark shadows. A dark point in the view may have a similar train of shadows. Other errors in phase conditions may produce bas-relief effects.

In actual television systems it is impossible to attain the ideal condition of uniform time of transmission, and the question naturally arises as to how much departure from the ideal is permissible. Practical television experience going back for some years has led to a figure of about 1/6 of a microsecond as the permissible tolerance in terms of time for television systems having about 400 lines and 25 frames. These scanning specifications are closely representative of present English practice, which is of course high-definition television. In the United States 441 lines and 30 frames will undoubtedly be used.

A recent preliminary theoretical study of allowable phase tolerance has led to the conclusion that the permissible time distortion is greater for the lower video frequencies. There was obtained the criterion that for very good reception the error in the phase of the various frequencies should not exceed 1/10 radian over the major part of the video range; however near the cutoff frequency, of say three megacycles, where the amount of the phase error ordinarily increases greatly, the tolerance is also much greater. This figure of 1/10 radian is the positive or negative departure at any frequency from the mean straight line through the origin in a plot of transmission angle as a function of frequency. In terms of time, the 1/10-radian criterion is 1/60 microsecond at 1 megacycle and 1/6 microsecond at 100 kilocycles.

CHARACTERISTICS RELATED TO HUMAN EYE

Illusion of Continuous Motion

Motion-picture experience dating from many years back, indicates that if successive pictures are projected on a screen, as in motion pictures, with a frequency of 16 per second, or even at lower frequencies than this, the observer will obtain the illusion of continuous motion. That is, the progress of moving persons and objects in the scene will appear to be smooth and continuous rather than jerky. Figure 8 shows some modern motion-picture film.

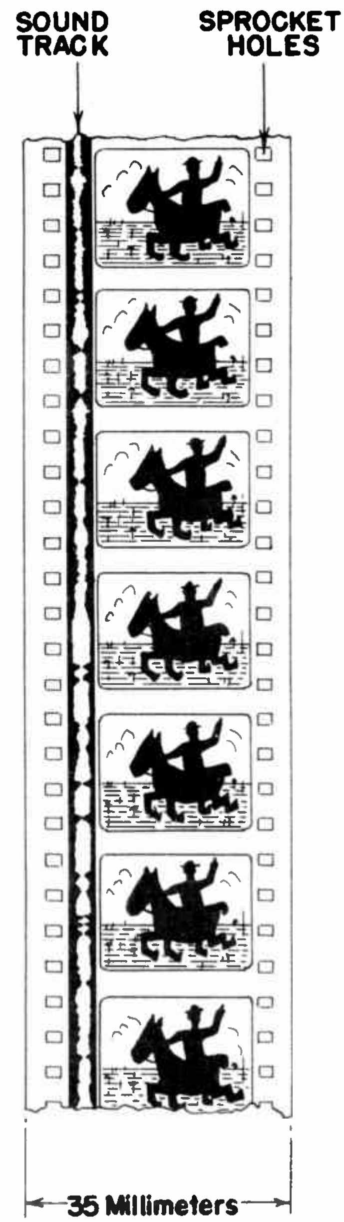

Fig. 8. Motion-Picture Film.

Special experiments made in England on this subject have shown that for slowly changing close-up views, a frequency of only 3 times per second is sufficient to give the impression of continuous motion; for rapidly moving subjects a rate of 10 per second was required. In these tests suitable steps were taken to prevent error due to flicker, which is another effect. The subject of flicker is discussed in later sections of this report. At the present point it is desirable to consider the characteristic of the human eye known as "persistence of vision".

Persistence of Vision

If one looks steadily at an ordinary neon sign operating on a 60-cycle power supply, the red color appears to be continuously present; there is no suggestion of the actual intermittent character which the light possesses. As a matter of fact the light goes out and comes on many times each second. The apparently continuous appearance of such a neon sign is due to a characteristic of the human eye known as the "persistence of vision". Another example of persistence of vision is the continuous ring of light seen whenever an electric bulb is rotated rapidly in a circle.

The characteristic of persistence of vision makes possible the enjoyment of both motion pictures and television. Were it not for this characteristic, the observer in a motion-picture theater would be conscious of the many intervals during which the screen is totally black. In television the instantaneous appearance of the cathode-ray screen depends on the persistence, or phosphorescent, characteristic of the screen material. After a spot is illuminated by the cathode-ray beam, it glows with gradually decreasing intensity while many subsequent lines are being reproduced. If the observer had no persistence of vision he would be conscious of the fact that the line being scanned was bright, with the lines above, already scanned, decreasing gradually in intensity toward the top of the picture. As a definite figure, we may mention that Phosphor #3 of the RCA Radiotron Division, used in the #1800 and #1801 picture tubes, falls to 8% of its initial intensity in the field period of 1/60 of a second. This appears to be a reasonable compromise between desired maintenance of intensity between scannings and avoidance of lag in the reproduction of rapidly moving objects.

Flicker

If the frequency with which light issues from a lamp is not sufficient to give the impression of steady light, a rapid fluctuation in the intensity will be seen, and this phenomenon is known by the descriptive term of "flicker". Similarly if a surface is illuminated with an intermittent light, flicker may be observed. The possibility of flicker in motion pictures and television arises from the intermittent illumination which is generally characteristic of these arts.

In some large cities lights are operated on 25-cycle power, and these lights will be seen to flicker if observed out of the corner of the eye, that is if observed in such a way that the light is in the edge of the field of vision of the eye. Since an incandescent lamp operating on 25-cycle power produces 50 flashes of light per second, we can conclude that a 50-cycle flicker frequency is perceptible in the edge of the field of vision of the eye, but not in the center of the field of vision. The fact that an observer always looks directly at a motion-picture screen or a television receiver assists in meeting the requirement for absence of flicker, since the eye is less sensitive to flicker in the central portion of its field of view.

In addition to the frequency of the illumination, and the part of the retina used for the observation, one other factor determines the amount of flicker. This is the intensity of the light; flicker is more severe for the higher intensities of illumination.

Correction of Flicker in Motion Pictures

In accordance with the characteristics of flicker in the preceding section, it is possible to reduce the flicker by means of cutting off the light from the screen momentarily during the time when otherwise a given frame would be continuously shown. That is, after a new frame has come into place, it is shown for a short time, then the light is cut off, and then the same frame is shown again. At the end of this time the light is again cut off and a new frame brought into place. The shutter, which cuts off the light rotates once per frame, or 24 times per second, and it has one "working blade" and one "flicker blade". We show details of a typical projector and shutter in Figure 9.

The reduction of flicker by the use of a flicker blade on the shutter is accomplished primarily by the increase in the frequency of screen illumination. Some decrease of flicker also results from the decrease of illumination of the screen. However, this decrease of illumination is of itself not desirable, since tests have shown that in general at the present time, an increase of screen illumination would be welcomed by the audience; the difficulty about increasing the illumination is that suitable projectors are not available. Arcs taking up to 150 amperes are already used as light source to obtain as much light as possible.

Present motion-picture practice is characterized by projection at the rate of 24 frames per second; with each frame thrown on the screen twice by the two openings in the shutter, there is a total of 48 projections per second. This gives satisfactorily low flicker with as much illumination of the screen as is available.

Prior to the introduction of sound in movies, which began in 1926, motion pictures were projected at a nominal rate of 16 frames per second, but actually at rates often considerably higher. However it was sometimes desirable to project pictures at approximately the nominal rate of 16 per second, and under these circumstances the flicker obtained with a two-blade shutter was noticeable, there being only about 32 total projections of a picture on the screen per second. To alleviate this condition, three-blade shutters were being adopted during the last years of the silent-picture era. Such shutters of course gave a flicker frequency of 48 or more per second.

Correction of Flicker in Television

It is mentioned above on page 16 that an instantaneous view of the screen of a television receiver would show a horizontal band which is brightest at the bottom and is moving down the screen. This is a band rather than a single spot because of the phosphorescent character of the screen material, which causes it to glow for some time after the electron beam has passed on. The intensity of the band which would be seen at a given instant is greatest along the bottom edge of the band and declines upward, because the vertical scanning is from the top toward the bottom. We may say therefore that the reproduction of the television picture in interlaced American practice consists in such a band traveling from the top of the screen to the bottom each sixtieth of a second. This is sufficiently rapid to make flicker unobjectionable. If simple scanning were used, such a traveling band would traverse the picture only 30 times per second, and flicker would be noticeable. We may summarize this by stating that interlaced scanning is used to remove flicker without the

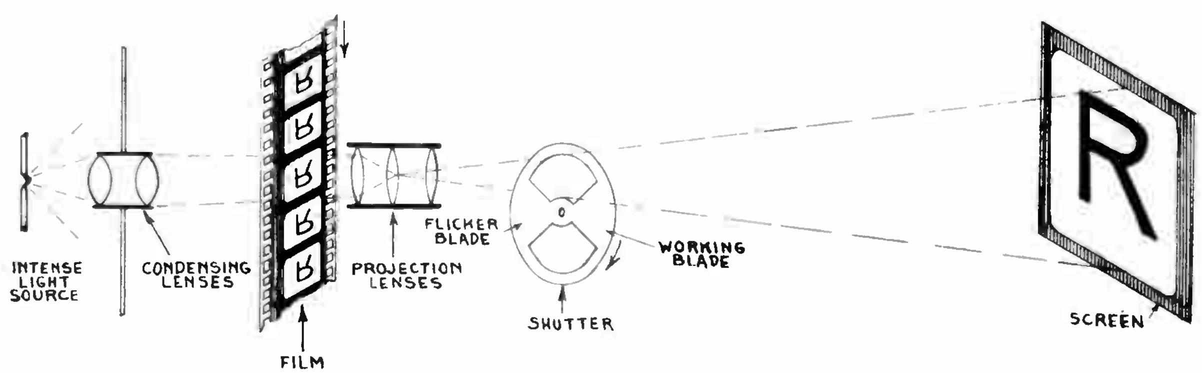

Fig. 9. Essentials of Motion-Picture Projection.

increase of bandwidth which simple scanning at a higher frame frequency would entail. The phosphorescent character of the screen assists in the reduction of flicker, but is less important than the interlacing.

The use of 60-cycle power in the United States has an important influence on the choice of television standards, as is pointed out in the following section. This power frequency naturally leads to the choice of 60 partial scans, or fields, per second, and 30 complete scans, or frames. It is seen therefore that one frame consists of two fields; a field may be said to be half a frame. In British literature the half scanning is called a "frame", and the complete scanning is called the "entire picture" or some similar term.

INFLUENCE OF POWER-SUPPLY FREQUENCY

Relation of Frame Frequency to Power Frequency

All modern television systems have a frame frequency of half the power frequency in the particular country. In the United States where 60-cycle power is generally found, television receivers operate at 30 frames per second. Similarly in Europe where 50 cycles is the standard alternating-current frequency, television receivers operate at 25 frames per second. The use of a frame frequency equal to half the power frequency has important advantages, one of which is that the presence of hum in the video channel causes stationary rather than moving shadow bands in the picture. If another frequency were used, these bands would in general move up or down across the picture and appear prominent and objectionable.

The desirability of this relation between frame and power frequencies may be expressed in other terms if we consider the hum filtering in a television receiver; when the imperfections on the screen due to the hum are stationary, a larger amount of hum can be tolerated and a considerable saving in filter costs thus be realized.

The reader may desire an explanation of the production of interference by hum. The simplest type of interference to explain is the horizontal shadow-bands. For this explanation let us consider a scene in which the top, center, and bottom are black and the intervening portions gradually shading into white; along any horizontal line the shade is constant. The video output from this scene, being scanned at a field frequency of 60 per second, is a series of half sine waves, looking like the output of an unfiltered full-wave rectifier. Obviously if hum is introduced in the receiver, it will cause such a pattern to be seen, and if the field frequency of the scanning differs from the power-supply frequency, horizontal bands will move up or down across the scene.

The value of 30 frames and 60 fields per second for the United States is seen to satisfy the three requirements as follows: (1) frame frequency of 30 per second is ample to give satisfactory illusion of continuity of motion; (2) field frequency of 60 per second is sufficiently high to remove flicker; and (3) frame frequency of 30 per second is equal to half the power frequency so as to give stationary rather than moving patterns resulting from hum.

REFERENCES

There is considerable literature on television, but the majority of it is chiefly or entirely devoted to mechanical apparatus rather than to electronic types. Another drawback for the present purpose is that most of the material is elementary and popular in character. The following references have been chosen as the most useful general treatments for engineering purposes in the English language:

"TELEVISION RECEPTION" by Manfred Von Ardenne, translated by O. S. Puckle of A. C. Cossor, Ltd., London; published by Chapman and Hall, Ltd., London; sold in the United States at about $3. It has 121 pages. Written in German by Von Ardenne in 1934; English translation published in 1936. Devoted to electronic methods.

"TELEVISION: COLLECTED ADDRESSES AND PAPERS ON THE FUTURE OF THE NEW ART AND ITS RECENT TECHNICAL DEVELOPMENTS", reprints of television papers by RCA personnel; two volumes appearing in July 1936 and October 1937 respectively; published by the RCA Institutes Technical Press, 75 Varick

Street, New York City. Each of these volumes has over 400 pages. About 50 papers are reprinted in the two volumes.

"TELEVISION ENGINEERING", written in England by J. C. Wilson now of the Bayside Laboratory of the Hazeltine Service Corporation, a volume of 492 pages, published in 1937 by Sir Isaac Pitman and Sons, Ltd., London, at 30 shillings; sold in the United States at $10. The book gives an advanced discussion of both mechanical and electronic apparatus, and includes many drawings, equations, tables, and references to the literature. This volume is almost essential for engineers and research personnel seriously interested in television.

The following portions of the Wilson text will be of interest in connection with the present report: history, page 1; the eye, 13; camera tube, 376 and 380; interlacing, 100 and 350; phase distortion, 199; and flicker, 23.

"TELEVISION RECEPTION TECHNIQUE" by Paul D. Tyers, published in London by Sir Isaac Pitman and Sons, Ltd., in 1937 at 12 shillings 6 pence, a volume of 144 pages. This book gives a moderately advanced treatment of electronic methods of reception.

Probably the best magazine now issued in English on television is the British "TELEVISION AND SHORT-WAVE WORLD", published by Bernard Jones Publications, Ltd., 38, Chancery Lane, London, W.C. 2, at 13 shillings 6 pence per year. This magazine gives prompt and relatively complete accounts of new developments.

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