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ALTERNATIVE SYNCHRONIZING AND RECEIVING METHODS
(TELEVISION PRINCIPLES - CHAPTER 8)

C. E. Dean
 Editor

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ALTERNATIVE SYNCHRONIZING AND RECEIVING METHODS
(TELEVISION PRINCIPLES - CHAPTER 8)

INTRODUCTION

Before proceeding with a detailed consideration of the portions of the television system which is now of greatest interest, it is well to give a brief description of the more important alternative forms of synchronizing signals and receiving apparatus.

In the first section of the present chapter we give one paragraph each about several developments, relating to modulation, scanning, and other subjects, which are not further considered. The subsequent sections take up alternative synchronizing signals in more detail, followed by various topics of present-day interest related to mechano-optical receivers.

BRIEF DESCRIPTIONS OF
CERTAIN DEVELOPMENTS

Beyond the scope of the present discussions there lie many interesting sidelines of television development which from an economic and practical viewpoint it is not profitable to discuss in detail. In the progressive evolution of a satisfactory commercial system in any branch of technology there are bound to be produced ingenious schemes and devices which, by the application of engineering skill and financial resources, can be pushed into what may be termed a "demonstratable condition". But this degree of success is not sufficient to insure commercial employment: there must be something more, some happy combination of best elements by virtue of which one class of system stands out above the competing arrangements.

Velocity Modulation

Of those schemes and devices which do not lie in line with present commercial development we may notice first

velocity modulation, in which, instead of altering the instantaneous intensity of a steadily moving scanning spot on the receiver screen, the intensity of the spot is kept constant but its velocity in the line of travel is altered by the modulation. In this the spot skips quickly over dark parts of the picture and goes slowly over lighter parts. Synchronizing is implicit in the modulation waveform in this type of system instead of being an explicit function as in the present standard commercial systems.

Change Modulation

A scheme, in which signals are transmitted corresponding with the changes only in the picture content, has been proposed and is called "change modulation". This is in line with the information-transmission principle that any steadily transmitted sinusoid or complex wave built of sinusoids (as, for example, a stationary television picture signal) contains zero information and that therefore the channel width and time of transmission of a television system should not be wasted upon steady-state conditions but should be utilized only for transmitting real information; i.e., changes in the picture. Such a system could probably be made to work; the picture would first be built up at the receiver at the commencement of a transmission and thereafter only changes in it would produce a modulation waveform in the channel.

Incommensurate Scanning

In a system of scanning which may be called "incommensurate scanning", the ratio of line and frame periodicities is some irrational number, such as a multiple of $\sqrt{2}$, so that a given scanning track is never precisely repeated. The line structure of the image (if it could

be slowed down) would appear to creep up or down the raster forever, giving the illusion, at the proper speed, of an invisible line structure.

Cross Scanning

The term "cross scanning" designates a proposal for diminishing the effective line structure of the image by scanning it first in a series of parallel lines from side to side, and then in lines vertically, the whole process being repeated within the period of retentivity of the eye. Unfortunately, at the moment there is a fatal objection to cross scanning in that the synchronizing tolerances would become impracticably close. With orthodox scanning, if the phase at which the line oscillator trips advances or retreats slightly there is no noticeable effect because the image merely moves as a whole slightly to the left or right; but with cross scanning the picture would suddenly become completely scrambled like printing seen thru a block of Iceland spar.

Slice Scanning

Finally, there is the possibility of abolishing the line structure of the image at a single blow, by not scanning it in lines; such a proposal has been made, and the method may be generically called "slice scanning". In this, a narrow streak of evenly modulated luminosity traverses the image area at right angles to its length, the angle of traversal being oriented progressively round the 360 degrees of a full cycle within the period of retentivity. The streak is long enough to reach the margins of the picture at both ends of the streak.

Stereoscopic Reproduction

Three-dimensional or stereoscopic reproduction has been achieved experimentally, but is not, from an entertainment point of view, worth the extra bandwidth involved in the transmission of the necessary double information.

NON-STANDARD SYNCHRONIZING WAVEFORMS

In addition to the now standardized method of transmitting synchronizing signals in the form of pulses lying

on the blacker-than-black or infra-black side of the video waveform, there have been proposed and put into experimental practice certain other methods of conveying synchronizing information from the transmitter to the receiver. The most important of these are examined in this section, and their performance compared, from a theoretical point of view, with that obtained with the general system which is standard in the United States, England, and Germany.

Four-Channel Method

First of all, there is the four-channel method. This is illustrated in Figure 1. A picture carrier P is modulated with a band of frequencies comprising the components of the picture signal alone; this band is shown asymmetrically with respect to the carrier in the diagram to indicate vestigial-sideband transmission, which is also called "sesqui-sideband" transmission. The concomitant sound is modulated upon a sound carrier S, and both sidebands as usual are radiated. A third carrier X is inserted either between the picture and sound radio-frequency bands, or on the far side of the sound band, and this carrier is modulated with 60-cycle and with 13,230-cycle sinusoids, which appear in the radio-frequency spectrum as side frequencies AA and BB or A'A' and B'B'.

At the receiver the P, S, and X bands are separated from one another by suitable filters, and the two sinusoids after demodulation are separated from each other and used for synchronizing the field and line oscillators. In the case of the field sync signal, greater accuracy of timing can be obtained, without increasing the total bandwidth occupied by the transmission, by modulating carrier X with sharp-edged 60-cycle pulses including harmonics up to about 10,000 cycles. In the case of the line-frequency signal, the addition of harmonics to sharpen the waveform is not equally practical on account of broadening of the frequency band.

Where plenty of frequency bandwidth is available, it has been experimentally practised to make the X carrier a sub-carrier modulated upon the sound

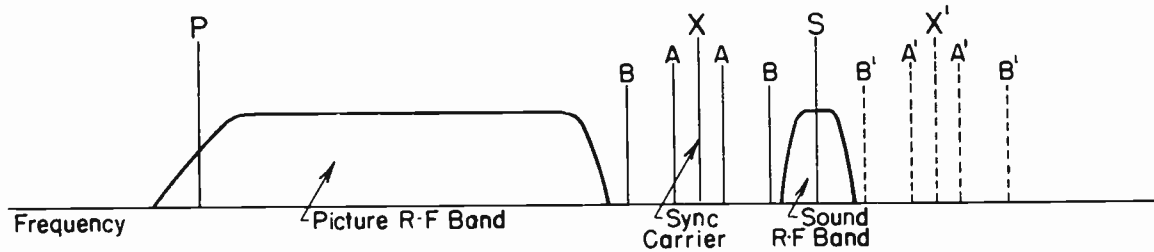


Fig. 1. Four-Channel Method, Having Picture, Sound, Line-Scanning and Field-Scanning Channels.

channel. In this case there appear in Figure 1 both the frequencies X and X' and also the sidebands surrounding them. The synchronizing signals can be demodulated along with the sound, after which a filtering and a second demodulation will recover the original synchronizing frequencies.

The fact that the four signals - picture, sound, and the line and field synchronizing signals - are sent over separated portions of the frequency spectrum gives this arrangement the name "four-channel method".

It is worth while examining for a moment the relative advantages and disadvantages of this kind of synchronizing system. In it the timing information is not transmitted as part of the video waveform distinguished by amplitude difference, but is transmitted in one or two separate frequency regions. This leaves the whole of the useful modulation range of the picture carrier available for the picture signal itself. A list of the advantages and disadvantages is given in convenient form in Table I. On the whole, it appears from a consideration of the theoretical arguments for and against, and

TABLE I

Advantages and Disadvantages of Four-Channel System as Compared with Amplitude-Demarcation System

Advantages

The whole of the useful video modulation amplitude range is left available for picture signal, thus increasing service area for a given transmitter power.

Continuous synchronizing information is supplied, independent of the nature of the picture; the sync-separating means at the receiver, being frequency-selective, is less likely to be influenced by video components of interference than amplitude-separated sync.

Disadvantages

The useful video modulation range is the linear portion, and this leaves at least one curved portion unused. In amplitude-demarcation synchronization, the curved portion is usefully employed.

The absolute frequency band required is extended, not so much on account of the 13,230 + 13,230 cycles extra bandwidth as on account of the extra guard bands between P, X, and S bands.

The timing information is not precise, as it depends upon the phase of a sinusoid (at any rate as regards the line frequency) instead of an edge.

from the fact that the present amplitude-demarcation system has been field-tested and works excellently from a commercial point of view up to distances corresponding with the maximum obtainable from an ultra-high-frequency broadcast system anyway, that the four-channel system would be less effective in most countries at the present time.

There is a modification of the four-channel system, illustrated in Figure 2, in which use is made of the fact that fairly good sound quality may be obtained using only the frequency range between 100 or 150 cycles per second and about 8000 or 10,000 cycles per second. This leaves room in the sound-modulation frequency band to insert a 60-cycle sinusoid below the utilized range, and a 13,230-cycle sinusoid (or even a set of pulses) above the utilized range, these waves being filtered out at the receiver and used for synchronizing.

In Figure 2, the video band is transmitted in a sesqui-sideband manner on the carrier P, and the sound carrier S is modulated not only with the sound range of frequencies as shown but with a 60-cycle frequency, the side frequencies of which appear at the points marked A, and with a 13,230-cycle frequency, the side frequencies of which appear similarly at the points marked B.

The synchronizing frequencies in this system are, of course, demodulated with the sound, and have to be separated from the sound components by frequency discrimination afterwards.

Transmission of Full Scanning Wave

A system of rather different type is illustrated in Figure 3. In order to avoid the necessity of transmitting precisely timed pulses corresponding with the termination of each line and field, it is feasible to transmit a complete scanning wave of saw-tooth form as a modulation upon a suitable carrier, and to use this at the receiver, after demodulation and amplification, for producing traversal synchronous with that at the transmitter. This method seems very attractive from several points of view, and is worth examining a little more closely.

The video band is transmitted as before, modulated in a sesqui-sideband manner upon a carrier P, and the accompanying sound is transmitted as a double sideband upon a carrier S. An additional carrier frequency, marked T in the diagram, is modulated with a lower-frequency band f and a higher-frequency band l. These bands respectively contain the frequency components of a field scanning wave and a line scanning wave of saw-tooth form up to a highest component which is predetermined in each case for a certain maximum residual distortion of the wave.

As shown in the diagram, sesqui-sideband transmission is chosen in order to reduce the total frequency bandwidth necessary for a single complete television channel.

At the receiver, the carrier T and its sideband, containing the scanning modulation f and l, are isolated and

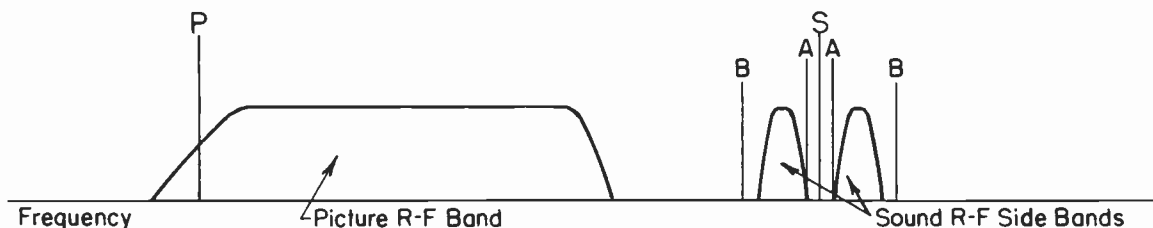


Fig. 2. Utilization of Lower and Upper Portions of Sound Frequency Range for Sync Channels.

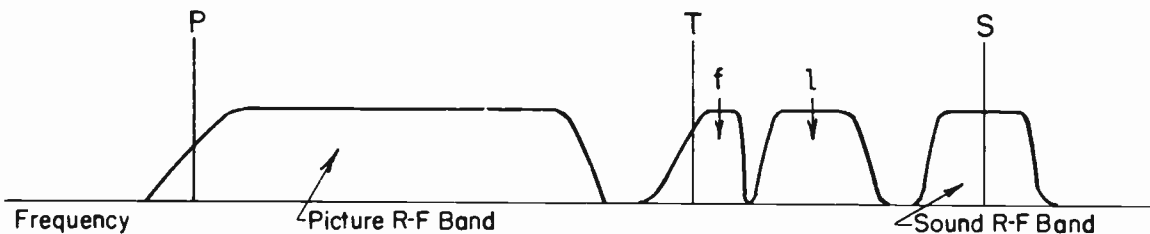


Fig. 3. Transmission of Saw-Tooth Scanning Waves as Vestigial-Sideband Modulation on an Auxiliary Carrier.

detected, and the vertical and horizontal scanning waves are separated from each other by mutually exclusive filters. The line-frequency scanning wave, after suitable amplification, is used to control directly the deflection of the picture-tube cathode-ray beam in the horizontal direction, and the field-frequency wave is similarly used to control the deflection in the vertical direction.

This method of transmission obviates the use of scanning oscillators and the usual synchronizing-pulse separating circuits. Also the receiver can operate on various numbers of lines and traversal frequencies. However, there are certain disadvantages. For instance, a burst of static, which normally affects only the video waveform and causes but slight disturbance of a scanning oscillator, will produce very severe picture distortion because it will affect the instantaneous position of the spot in both vertical and horizontal directions. Moreover, variations of signal strength (e.g. due to passing vehicles or airplanes) which normally have no effect on the size of the picture, will produce a marked effect with this system; even when automatic volume control is provided, this change of picture size can adversely affect the entertainment value of the image.

A slightly modified arrangement has been developed, in which instead of a saw-tooth scanning wave, a triangular wave is used. The waveform in this case is an isosceles triangle; this has the property that the higher-frequency components play a less important part than

with the saw-tooth form, since the steep slope of the saw-tooth retrace is absent. This use of a triangular wave constitutes bi-directional scanning, that is the retrace is lengthened and used for picture reproduction; successive lines of a field are scanned in opposite directions. The method suffers the same fundamental disadvantage as cross scanning, that unless the synchronization is perfect (and this includes the equivalent of a receiving system devoid of phase distortion), the picture will become scrambled by the oppositely-directed displacements of adjacent scanning lines.

RELATIVE EFFICIENCIES OF ELECTRONIC AND OPTICAL REPRODUCING SYSTEMS

In this section there are discussed the fundamental properties of picture-reproducing systems of three basic kinds. These are illustrated in Figures 4, 5, and 6, and may be described as follows:

I. Plain Mechano-Optical. Figure 4 shows an ordinary straightforward mechano-optical scanning system in which a spot of light from a modulated source is traversed rapidly and repetitively over a normal projection screen, for example by means of a mirror-polyhedron scanner. The picture is built up or integrated subjectively by means of the retentivity of the eye, often called the "persistence of vision".

II. Commutating Distributor. Figure 5 shows a system in which the image is built up on a mosaic of small light

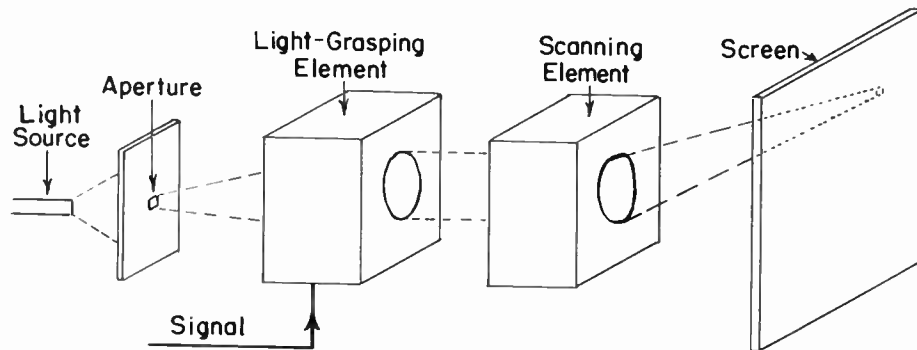


Fig. 4. Elements of Plain Mechano-Optical Reproducing System.

sources, arranged in rows and columns and commutated in proper scanning sequence, so that each lamp is connected in turn to the signal circuit.

III. Phosphorescent Screen. Figure 6 shows a luminescent-screen scanning system in which an electron beam is swept over a screen of phosphorescent material possessing the property of light lag or afterglow, so that the luminosity of each point persists after the beam has passed over it.

Brightness in the Three Systems

According to Talbot's law, the apparent brightness of a field, the illumination of which is discontinuous but cyclically repetitive, is equal to the actual brightness (when illuminated) multiplied by the period of illumination and divided by the total period of repetition. In other words, the actual brightness is averaged or spread over the whole scanning cycle, provided the repetition rate is high enough to prevent flicker.

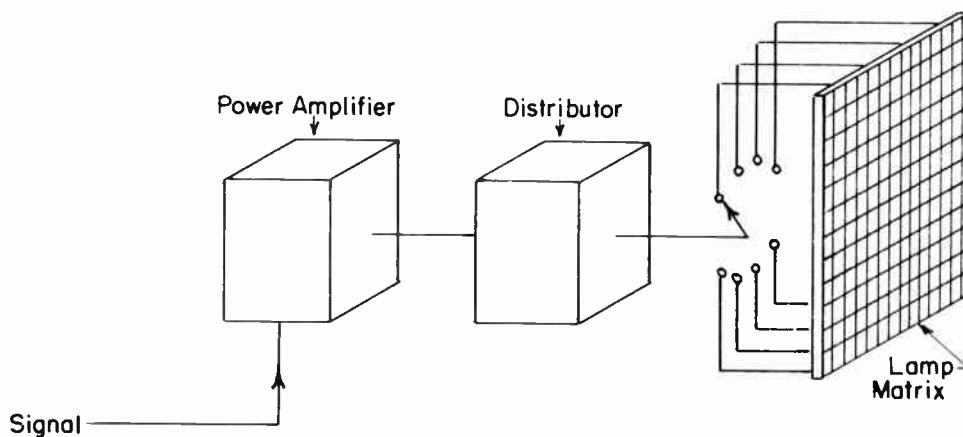


Fig. 5. Elements of Reproducing System with Commutating Distributor.

An application of Talbot's law to one point of the screen in Figure 4 leads to the result that the visual brightness level is equal to the peak instantaneous brightness divided by the fraction of the frame period during which the point is illuminated. This fraction is the reciprocal of the number of picture points, which latter figure is about 200,000. From this it is evident that the visual image brightness is very much less than the peak instantaneous brightness of the spot. In fact, the visual brightness may be quite low while the peak brightness is comparable with that of an incandescent tungsten source.

In the case of Figure 5, as soon as the commutator touches the segment devoted to a particular lamp (for example, a small gas-discharge lamp or electron-beam-fluorescence lamp), this lamp will light up with the full brilliance of which it is capable, assuming that the corresponding point of the image is full white. In the absence of any special provision it would extinguish as soon as the commutator passed off that segment. However, it is comparatively simple to arrange a time-constant circuit which has a quick charge and a slow discharge, so that, once having reached incandescence, the lamp continues to glow with exponentially decreasing brightness throughout the otherwise inert portion of the scanning cycle. A substantial increase

in image brightness is obtainable by this method. The circuit with the double time constant is located in the grid circuit of the tube whose anode supplies the lamp; a large number of such circuits and tubes are of course required.

By making use of a more complex type of electrical network on the input to the tube feeding each lamp, the instantaneous brightness can be held up to a value which is very little lower than the peak.

This type of system is therefore capable of giving incomparably brighter pictures than the simple mechanically scanned screen, a fact which has been experimentally demonstrated.

With the third type of system, the usual cathode-ray picture tube, represented in Figure 6, the brightness does not rise instantly when the front edge of the scanning spot touches a point of the screen, but rather the rise follows a curve which for certain practical purposes may be regarded as an exponential. The slope of the rise curve at the start is inversely proportional to the length of afterglow, so that if the lag is shorter the peak instantaneous brightness is relatively greater, and vice versa. The visual brightness level is therefore the same for a given material with different degrees of afterglow, (if such different

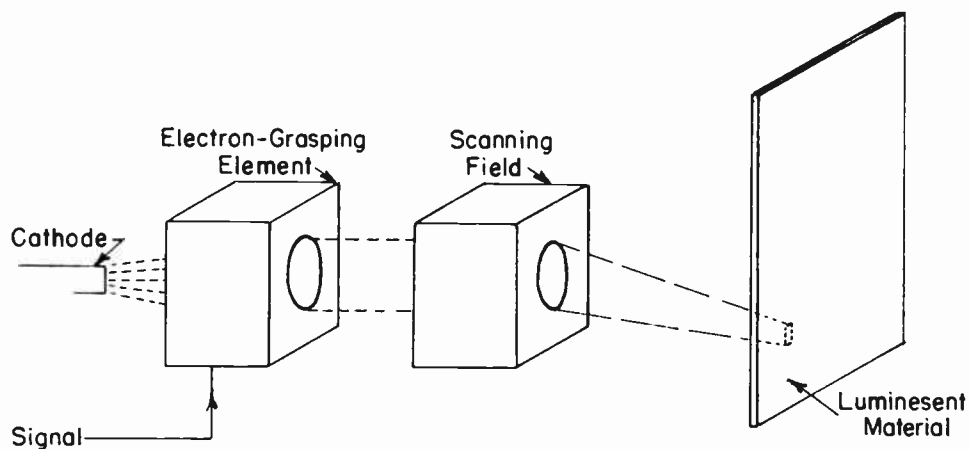


Fig. 6. Elements of Reproducing System with Electron Beam and Phosphorescent Screen.

degrees could be secured), provided that the repetition rate of activation is great enough to avoid flicker.

Owing to the comparatively high energy efficiency of phosphors as opposed to, for instance, incandescent light sources, the visual brightness level of a cathode-ray television image may be quite large compared with what might be expected from the analogous optical case, where relatively enormous dissipation of energy is required to achieve satisfactory brightness.

A point which must be borne in mind in assessing the relative merits of optical and cathode-ray methods is that phosphors in general exhibit non-linearity. This manifests itself in the phenomenon of saturation, which is of interest with projection tubes.

Phosphors differ much more markedly in energy efficiency than do incandescent light sources, and this factor may make a difference of an order or more in the final result.

The systems of Figures 5 and 6 have this in common, that as the light is actually emitted from the screen itself, and is not projected thru the screen or on to a screen as in Figure 4, they are much less directional as regards angle of observation. Unless special precautions are taken with a projection system of the type shown in Figure 4, the viewing angle is limited (even with the best ground glass screens) to about 20 degrees or 25 degrees from the normal and this severely limits the number of observers who can view the image at one time. This is not the case with cathode-ray-tube images, where the angle is limited only by the optical distortion introduced in viewing a picture on a flat or curved surface from an oblique vantage point.

Operation of System with Mirror Drum and Interlace Disk

Figure 7 shows a scanning system in which both the line and field scanings are accomplished with a mirror drum (whose successive mirrors are properly canted) and in which a disk with suitable slots is provided to give the feature of

interlacing. The mirrors on the drum are canted progressively with respect to the axis of the drum so as to scan successively in one revolution all the lines of one field. The interlace disk, in the particular case illustrated in Figure 7, has two arcuate slots cut in it, and the mirror drum is geared to revolve at twice the speed of the disk, so that on one revolution the drum traces all the lines of one field, and on the next revolution traces all the lines of the other field, of the complete frame. The change from one field to the next is accomplished by an elevation or lowering of the used part of the fixed slot by the interlace disk. This change raises or lowers the light on each mirror of the drum, so that the spot on the screen is altered in height by one line width.

Broadly, the principle of a system of this kind is that the degree of interlacing, that is the interlace number, gives the number of slots which are necessary in the interlace disk, and also gives the necessary gear ratio between the drum and the disk; the drum must make this many complete revolutions for each revolution of the disk.

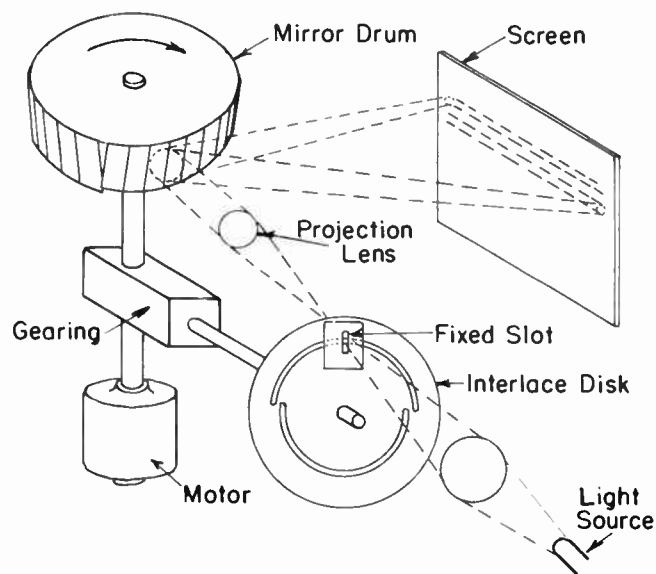


Fig. 7. Interlaced Scanner with Canted Mirrors and Slotted Disk.

From this description it may be seen that this type of system is suitable for even-line interlacing, that is interlacing in systems where the total number of lines in each frame is an even number. To accommodate odd-line interlacing, the mirror drum is constructed with all mirrors parallel to the axis, and the field scanning function is transferred to a suitable different disk or additional mirror drum.

Light from the projector lens is spread out to cover two adjacent mirrors, so as to obtain even illumination from end to end of each scanning strip. In a practical design the lenses have a rectangular shape so as to cover the mirrors without waste. The distance between the projector lens and the drum is considered short compared with the optical distance between the drum and the screen.

Experience and optical analysis with systems of this kind indicate that the brightness is greater with higher orders of interlacing. There is, however, a limitation in this direction in that the eye is unable to integrate properly a number of successive high-order interlaces; this has led to the choice of double interlacing in the standards for high-definition television in various countries.

Brightness Increase by Multiple-Point Reproduction

Owing to the limitations of optical systems, where the onus of increased efficiency is thrown upon increased speed of a rotary element, an altogether different mode of attack has been developed. This consists in not having merely a single scanning spot (equal in size to a picture element) operative at one time, but several spots in the form of a continuous streak of the image which is then traversed over the screen lengthwise in the usual way. This streak may be a substantial portion of one line.

If the whole of the image streak were modulated to the same instantaneous brightness throughout, it would obviously have the effect of enormously reducing the definition of the image, - in fact it would merely be an oversize scanning spot. This difficulty is overcome by

modulating the streak differently along its length, the light-and-shade distribution of the modulation moving down the streak or "traveling" at just the same speed as that of traversal but in the opposite direction, so that the modulation appears stationary while the streak moves. The action is like a caterpillar-tractor tread, in which a substantial portion of the belt is making an impression on the ground. The tractor moves uniformly forward, but the working portion of the belt is stationary. The image brightness is then increased in proportion to the number of picture elements contained in the length of the streak.

One example of a system embodying this principle is shown in Figure 8, in which a mirror drum (for simplicity) plays the part of the scanning device, and a quartz parallelepiped situated between crossed polarizing devices serves the purpose of light modulator.

The mode of functioning of the arrangement is as follows. Light from the source, which may be an ordinary incandescent lamp, is polarized by passage thru some light-polarizing medium and then is concentrated upon a linear translucent bar of quartz. This bar is provided

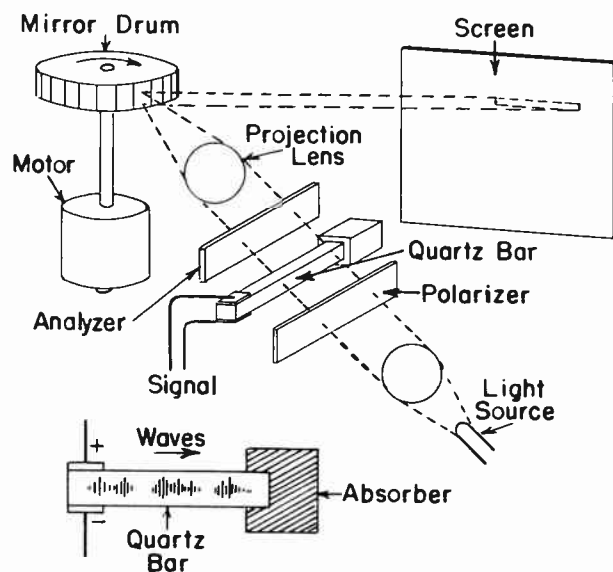


Fig. 8. Multiple-Point Reproduction Obtained by Traveling Modulation in Quartz Bar.

with electrical means at one end for producing in it a mechanical-stress wave and is also provided with a buffer at the other end adjusted to absorb the waves arriving there. Under the influence of these waves the quartz regionally alters its birefringent properties and therefore regionally alters the quality of the polarized light passing thru it. In this way plane-polarized light becomes locally elliptically polarized. Those portions of the light beam which have become elliptically polarized are able to produce a transmitted component at the crossed analyzer, which was originally set for total extinction of the beam.

An image of the quartz bar is cast upon the screen by the projector lens, via one mirror of the drum, and this image appears lighted in its various parts in accordance with the modulation of the electrical signal producing the stress waves. Since the stress waves travel down the bar to the end with a constant velocity dependent only upon the material of the bar and its temperature, this velocity can be exactly counterbalanced by the scanning velocity produced by the rotation of the drum. The waves of light and shade upon the screen will appear to stand still, but the streak of image will move to traverse the whole screen in the usual manner.

The velocity of propagation of stress waves in quartz is inconveniently high for television scanning purposes with the usual numbers of lines. In consequence of this the same principle has been employed in a modification shown in Figure 9. Here a small quartz crystal serves to start a train of pressure waves in a liquid of suitable density, and these waves travel down a cell of the liquid to the other end of the vessel where they are absorbed.

Because such waves in a liquid cannot produce birefringence, some other mode of "indication" must be used. One is ready to hand. The wavelength in the liquid is made very short (for example, by modulating the television signal upon a 10-megacycle carrier which in turn is impressed upon the quartz crystal) so that closely packed pressure striations are obtained. These cause corresponding

changes of refractive index in the liquid, and produce interference fringes in the plane of an apertured diaphragm upon which the light rays passing thru the cell are converged. The formation of these interference fringes lessens the intensity of the light in the central zone (which coincides with the narrow aperture in the diaphragm), and so modulates the light passing thru the aperture. An image of the cell is reconstructed by the projector lens P in the plane of the viewing screen. The letters A, B, C, and D, in the cell and on the screen show the simultaneous reproduction of a number of points. Point A is the last to be received over the signal circuit, point B earlier, and so forth.

Using kerosene as the liquid, the waves travel the length of a 4-centimeter cell in about 30 microseconds; the wavelength at 10 megacycles is of the order of 0.13 millimeter, giving a diffraction angle of about $1/230$ radian. This, although small, is sufficient to give a satisfactory depth of modulation.

The characteristics of this type of modulation are further given in the description of the ultra-sonic light valve below on pages 183-184.

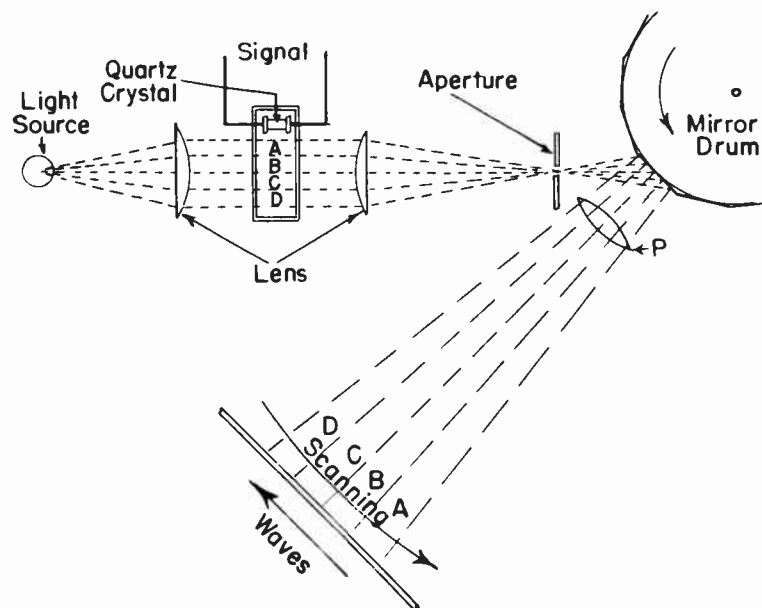


Fig. 9. Multiple-Point Reproduction Obtained by Traveling Modulation in Cell of Liquid.

RAY OPTICS OF OTHER
SCANNING DEVICES

There are several types of mechanical scanning devices other than the drum and interlace disk described previously which have been used for high-definition television. Some of these are illustrated in Figures 10 thru 13.

Two-Drum Scanner

In Figure 10 is shown a common type of scanner consisting of a pair of mirror drums, one of which revolves at a high speed to take care of the line scanning while the other rotates more slowly and functions to space out the lines transversely so as to provide the vertical scanning. In the figure, drum A is the fast element and drum B the slow one. It will be seen that a double loss of light is incurred, in that the output flux from the projector lens P must be spread to cover two mirrors of the high-speed drum, and the sweeping beams from each of these mirrors must cover two mirrors of the low-speed drum in order to achieve even illumination on the screen. This arrangement can be used in high-definition receivers for the double-interlace transmissions now generally adopted. It can be designed for odd-line interlacing, or for even-line.

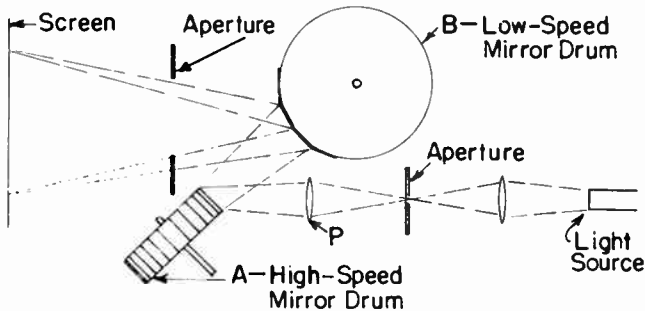


Fig. 10. Scanner with Individual Drums for Line and Field Components.

Mirror Wreath

The device illustrated in Figure 11 is an inversion of the usual mirror-drum scanner in which the mirrors of the drum are facing inward, and are stationary. A small relatively inertialess mirror is rotated in the center of this wreath, and light from a source falls

upon the rotary mirror (which is usually double-sided), whence it is reflected to a mirror of the wreath and back again to the rotary mirror where it undergoes a final reflection (and deflection) before proceeding to the screen. With this arrangement, final adjustments of the cant of the individual mirrors of the wreath can be effected while the scanning operation is in progress; moreover, since there are no centrifugal forces acting upon the mirrors the method of mounting may be relatively light and inexpensive. Since the rotary element is so small, the synchronizing torque is correspondingly slight, which is an advantage in receiver design.

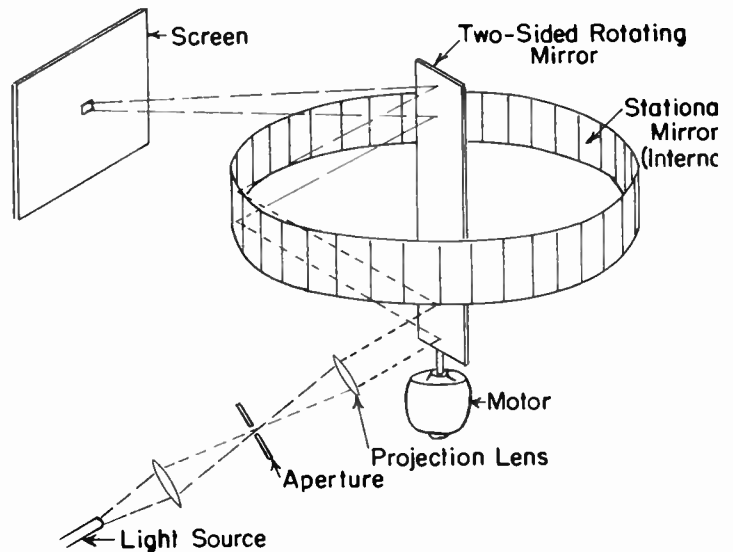


Fig. 11. Scanner with Stationary Mirror Wreath and Central Rotating Mirror.

Drum and Fixed Mirrors

Owing to certain optical difficulties with the mirror wreath, a modification of the kind shown in Figure 12 is often used, in which, instead of a simple two-sided reflector and nearly complete circle of relatively canted mirrors, a small drum (commonly a nonegon of faceted glass) cooperates with a small number of fixed mirrors which are not relatively canted. This device, employing the same trick of double reflection from the facets of the moving element, is of utility as a high-speed scanner for mechano-optical high-definition receivers, and is usually used in combination with a slowly rotating drum to supply the vertical component of scanning.

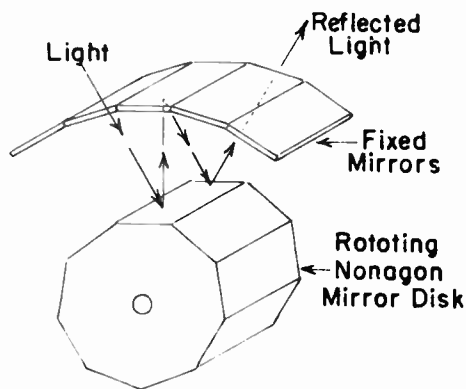


Fig. 12. Scanner with Mirror Drum and Small Number of Fixed Mirrors.

Split-Focus Method

In Figure 13 is shown a film scanner utilizing what is sometimes called the "split-focus" principle. A light source is focused in one dimension only by means of a cylindrical lens L_1 , the light being concentrated on the optical elements of a rotary disk. These elements are in the form of narrow slices of cylindrical lens, the curvature of each being at right angles to that of the first lens L_1 . The focal length of these slices is such that they are able to image the light source in one dimension in the plane of the film; it will be seen that one of these slices is the only lens in the system which converges light in the horizontal plane.

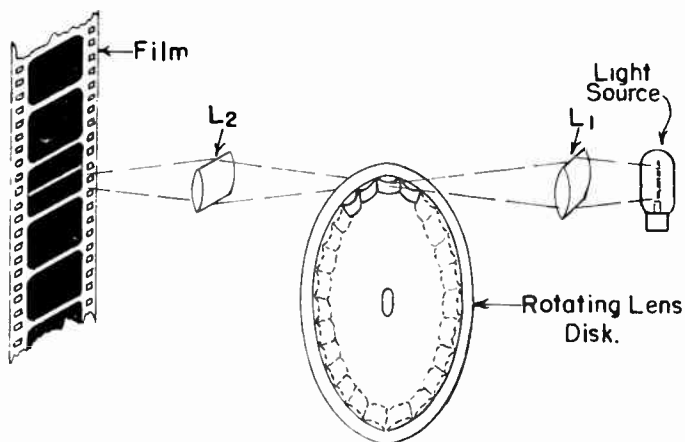


Fig. 13. Film Scanner Using Split-Focus Principle.

A second cylindrical lens L_2 , similar to L_1 and similarly oriented, receives the light passing thru the disk and focuses it in one dimension also upon the film. The net effect of the entire system as regards focusing is the same as though the usual spherical lenses had been used in the disk, but the light grasp of the system (that is, the total flux passed by it to the film) can be increased.

Such an optical system can be arranged to scan a screen by adding a vertical-deflecting element.

LIGHT VALVES

A necessary concomitant of mechano-optical receivers is some means for modulating the intensity of the light source, or else means for altering the light flux passed from the light source thru the rest of the optical system.

Formerly, for low-definition systems, it was possible directly to modulate the light source itself, for example in the form of a modulated arc or a gas-discharge tube to which the current feed is under the control of the signal. These methods, however, are of no use for high-definition television because of the inherent lag in response of such directly modulatable devices.

The Kerr Cell

One of the most practical forms of light valve for use in high-definition systems comprises the Kerr cell. This consists of a pair of plates, or of a multiplicity of interlaced plates, immersed in a medium which has the property of becoming birefringent under the influence of electric stress. Such media are carbon disulphide, nitrobenzene, and meta-nitrotoluene.

Referring to Figure 14, this shows the optical state of affairs when a pair of plates immersed in such a medium is subjected to an increasing potential difference. Let us suppose that initially, with no potential difference across the plates, a beam of plane-polarized light is passed between them. This can be thought of as proceeding outward toward

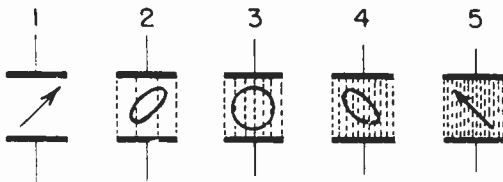


Fig. 14. Alteration of State of Polarization in Kerr Cell at Increasing Voltages.

the reader thru the paper, with the vector representing the sense of polarization lying in the direction of the arrow.

With a small amount of electric stress between the plates (the direction of the potential difference is immaterial), the light becomes elliptically polarized as indicated in the second diagram. With further stress the ellipse broadens out into a circle as in the third diagram, and then with still further stress begins to collapse into an ellipse of transposed major and minor axes as in the fourth diagram. The final stage arrives when, at a certain voltage, the light becomes plane-polarized again in a direction at right angles to its initial sense of polarization (fifth diagram).

These changes may be used to provide light control in accordance with impressed signal voltages by providing a second polarizing device, located after the cell in the direction of propagation of the light, so arranged that no light is passed by it when the cell is unstressed. That is, the planes of polarization of light passed by the first polarizer and of light passed by the second polarizer (termed an "analyzer") are at right angles. In this way, when the voltage across the cell reaches that value for which the ellipse collapses to a straight line again, all the light issuing from the polarizer will be passed by the analyzer.

A diagrammatic layout for such a Kerr light valve and a plot of its light transmission for various voltages are given in Figure 15. This arrangement can never be more than 50 percent efficient because half the light is lost at the first polarizing device. After the light

flux reaches a maximum (that is, after the state of affairs represented by the fifth diagram of Figure 14 has been reached), the light issuing from the cell becomes elliptically polarized again with increasing potential difference; in consequence, the light flux passed by the system falls. There are recurrent maxima and minima of light flux with increasing voltage, which become increasingly close together at the higher voltages.

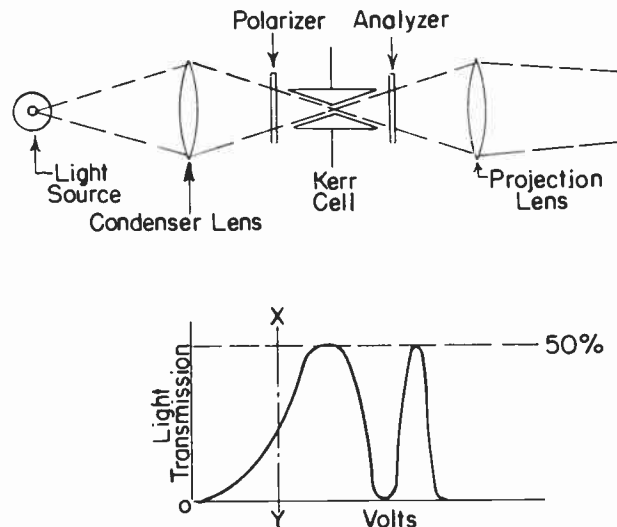


Fig. 15. General Arrangement and Characteristic Curve of Kerr-Cell Light Valve.

High-Efficiency Kerr Cell

There is a method of improving the efficiency of the Kerr-cell light valve which consists in utilizing both the ordinary and extraordinary rays developed in the polarizing device. This is sometimes called the double-image Kerr cell, and employs the principle of the circular polariscope.

Figure 16 shows the layout of such a Kerr-cell light valve. Light from a source *S* is condensed by a lens *L*₁ and passes thru a rhomb of Iceland spar (that is, calcite) designated *C*₁. Unlike an ordinary polarizing device, such as a Nicol prism or a piece of polaroid screen, a block of calcite has the property of passing both the ordinary and the extraordinary rays developed within it, there being a small angular divergence between the two beams. Each of the beams contains

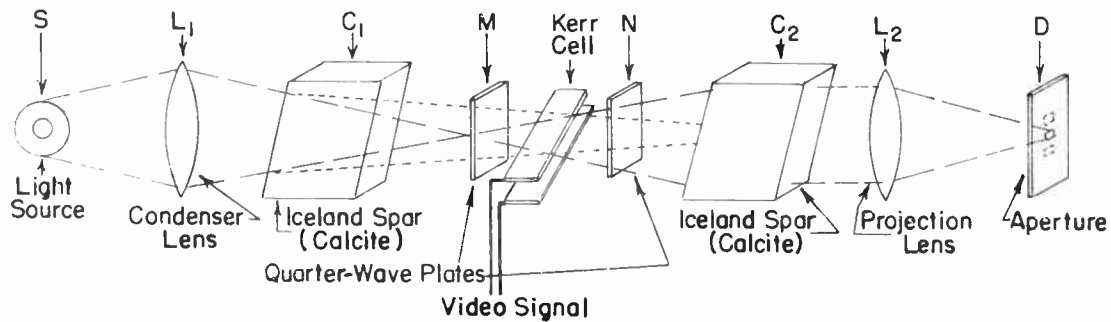


Fig. 16. Use of Calcite Blocks to Furnish Both Ordinary and Extraordinary Polarized Rays in High-Efficiency Kerr Cell.

half the light originally caught by the condenser L_1 . Both rays pass thru the Kerr cell and fall upon another block of calcite C_2 which is so oriented that the ordinary ray from the first block is extraordinarily refracted, while the extraordinary ray is ordinarily refracted. This results in a still further divergence of the two rays, and they can be focused by means of a second lens L_2 upon a diaphragm D into twin images of the original light source, separated by a small distance, and lying one on each side of a central aperture in the diaphragm.

On applying to the cell a voltage corresponding with the first maximum of the curve of Figure 15, the planes of polarization of the two emergent rays are effectively interchanged, so that, when they meet the surface of the calcite block C_2 they will be converged instead of further diverged. Provided the optical thickness of the calcite blocks is the same, this convergence results in exact superposition of the images at the aperture in the diaphragm D , and the full light flux is passed by the system.

It is important to notice that the two beams do not move inward until they coalesce in the center. What happens is that each splits into two again, one member of each pair coinciding with the aperture and growing in strength, as the voltage is raised, and the other member of each pair correspondingly weakening.

Owing to the fact that the angle of polarization of a light ray must initially be at forty-five degrees to the

direction of the electric field in order to exhibit the Kerr effect, the cell plates in the simple double-image system just described have to be placed relatively far apart as indicated by the full lines in Figure 17. However a modification is possible to overcome this difficulty, which would otherwise lead to inefficiency in the sense that a very much larger signal voltage would have to be applied to the cell.

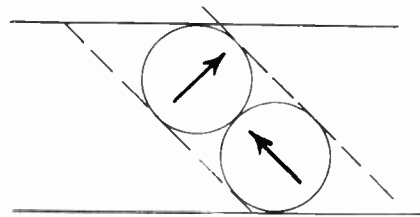


Fig. 17. Rotation of Kerr Cell and Reduction of Spacing by Introduction of Quarter-Wave Plates.

This modification may be simply explained with reference to the curve of Figure 18 and the layout diagram of Figure 16. Suppose that a pair of quartz plates

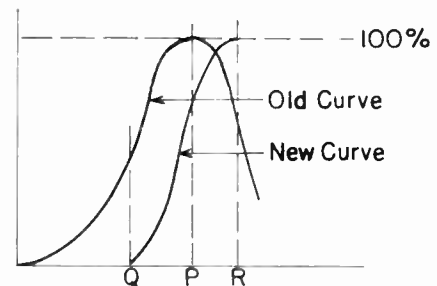


Fig. 18. Increase of Steepness of Kerr-Cell Curve by Provision of Bias Voltage and Additional Quarter-Wave Plate.

M and N are introduced into the system, one on each side of the Kerr cell, and that these plates (termed "quarter-wave plates") are just sufficiently thick to introduce a relative retardation of a quarter of a wavelength of yellow light between the ordinary and extraordinary components of each beam. Then the light in each beam passing thru the cell will be circularly polarized, and the electrodes of the cell may be placed as shown by the dotted lines in Figure 17. The second quarter-wave plate prepares the light again for entry into the calcite block C₂.

In addition to this, if an initial bias of voltage P in Figure 18 is applied to the cell, and an additional quarter-wave plate (not shown in Figure 16) is introduced into the system between M and N on either side of the Kerr cell, then the equivalent bias point is at Q and the working characteristic becomes the lower curve between the limits Q and R. This is considerably steeper, and therefore more economical of modulation volts, than the initial portion of the original curve up to P.

Ultra-Sonic Light Valve

There is a different type of solution to the problem of producing an efficient light valve for high-definition television, the nature of which has already been indicated on pages 177 and 178 but which can now be explained in more detail.

This, as is partly implied by its name, "ultra-sonic light valve", utilizes the diffraction effects of ultra-sonic waves in optical media for producing a variation in luminous flux passed; the effects are in accordance with the amplitude of an electric oscillation generating the waves.

The layout using such a valve is indicated in Figure 19, in which the source is conveniently a bright, narrow, luminous streak such as an incandescent filament. Light from this source is collimated between two lenses, the second of which forms an image in the plane of a diaphragm having a narrow slit in it.

The collimated light between the two lenses passes thru a cell containing an optical medium, usually a liquid such as water, kerosene or paraffin oil. At one end of this cell is a quartz crystal, adapted to be excited in mechanical vibration by an applied electrical oscillation at its natural frequency; at the other end is a pad of absorbent material to dissipate incident ultra-sonic waves without reflection. The quartz crystal is excited by an oscillating voltage at about 10 megacycles, and the ultra-sonic pressure waves of this frequency pass along the cell to the opposite end, where their energy is dissipated.

In general, pressure in a liquid is accompanied by change in density, and this in turn by an alteration of refractive index. Thus the ultra-sonic waves passing thru the liquid give the effect of alteration of the refractive index in striae transverse of the cell. These move along the cell with the velocity of propagation, and the distance apart is equal to the wavelength, both quantities depending on the density and elasticity

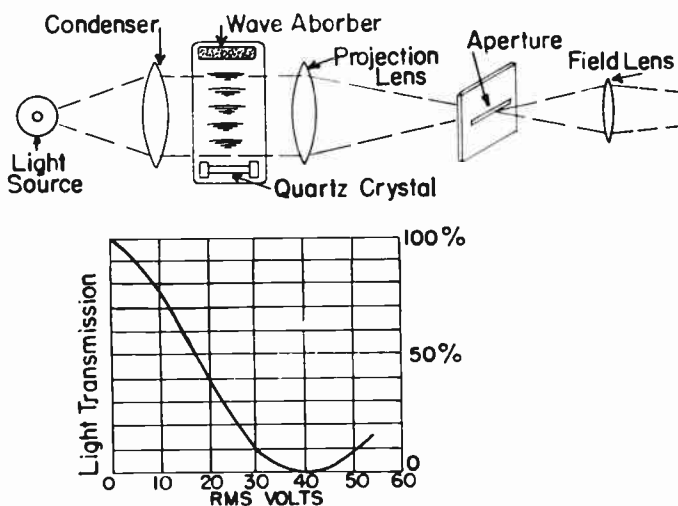


Fig. 19. Ultra-Sonic Light Valve and Characteristic Curve.

of the liquid. If these striae are close enough together, the cell will exhibit diffraction phenomena of the same general kind as are obtained with a coarse grating; the central bright band in the image of the light source on the diaphragm will become dimmer, and a diffraction pattern of lateral bright bands will spring up.

For oscillation at the typical frequency of 10 megacycles, the wavelength in suitable liquids is 200 or 300 times the wavelength of yellow light. Nevertheless this spacing of the striae is sufficiently small to produce a marked diffraction effect. The amount of the effect depends upon the thickness of the cell in the direction of the light, the amplitude of the vibration and the number of waves effective in the length of the cell.

The form of the characteristic (that is, light flux in the central band against applied volts) is shown in Figure 19, computed theoretically. In practice the shape of the characteristic obtained agrees very well with this although the operating voltages required for full extinction may be somewhat higher.

THE SCOPHONY SYSTEM

The Scophony receivers use several of the principles described in the preceding sections. For the scanning mechanism two drums are used after the manner of Figure 10, but including the split-focus light-grasping principle of Figure 13. In combination with this, the ultra-sonic light valve, adapted for multiple-point reproduction so as to gain the necessary luminous efficiency to make a high-definition mechanical system workable, is employed.

The high-speed scanning element is made in the form of a cut-glass polyhedron with metallized facets, the diameter of the polyhedron being very small (about 1.2 centimeters) in order to achieve very high rotational speed and ease of synchronizing. The polyhedron is driven by an asynchronous motor up to the speed of 30,375 revolutions per minute, which is necessary with a 20-face shape and the British standards of 405 lines and 25 frames. It is maintained at this speed

by a synchronous motor fed with synchronizing signals suitably amplified from the vision receiver. The power to drive the low-speed scanner (a 12-mirror polyhedron of about 12 inches diameter) is obtained by amplifying the field synchronizing pulse obtained from the vision radio receiver.

PROJECTION TELEVISION IN COLOR

A schematic layout of a color projection system is given in Figure 20. This makes use of the type of optical system shown in Figure 7. This development is a 6-interlace 120-line system for each of three primary colors.

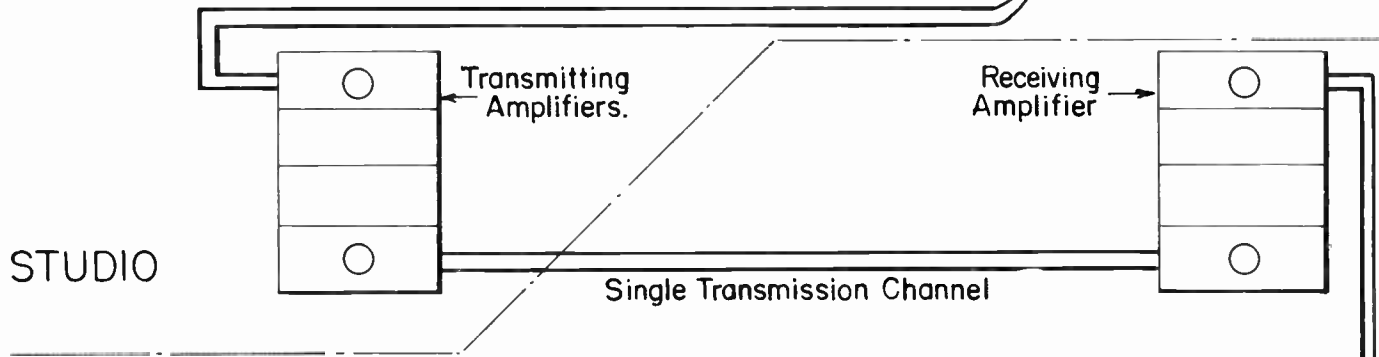
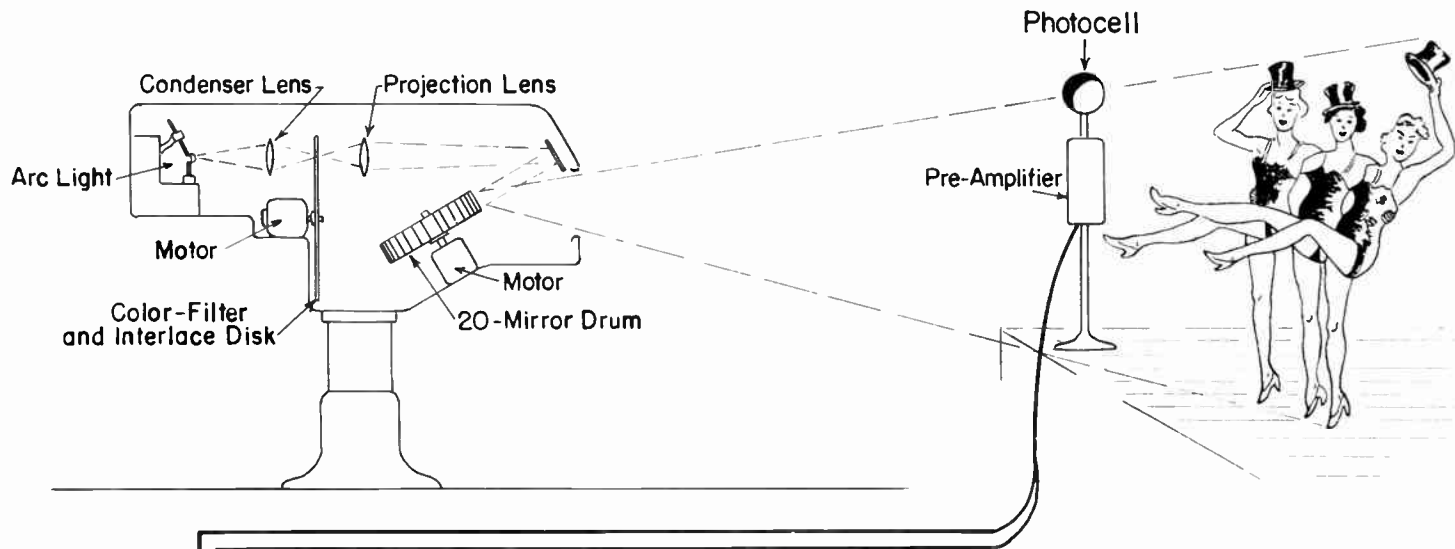
In the upper section of Figure 20 is shown a studio scanner of the flying-spot type, using a small arc lamp and separate synchronous motors to drive the scanning drum and interlace disk. For simplification it is well to assume at first that the interlacing is progressive, and on this basis the disk is of the type shown in Figure 21, where the layout of the slots can be seen. It may be noted that there are six arcuate slots for red, six for blue, and six for green. The transition from each slot to the next changes the effective position of the scanning aperture vertically by one line width. In this way the 6-interlace scanning for each color is accomplished.

There are twenty mirrors on the drum, each mirror properly canted with respect to the axis of the drum; since the drum rotates six times during the scanning for one color, the total number of lines is 120 for each color.

Each of the three sets of slots is covered with a color filter, one passing red light only, one blue, and one green. By this means the field area of the subject is scanned first of all by a flying spot of red light which executes 120 lines, then similarly by a spot of blue light, and finally by a spot of green light.

The scannings of the three colors are, as a matter of fact, not exactly in coincident lines; it is found advantageous, taking the position of a line of one color as a reference, to have

Color Flying-Spot Scanner.



THEATRE

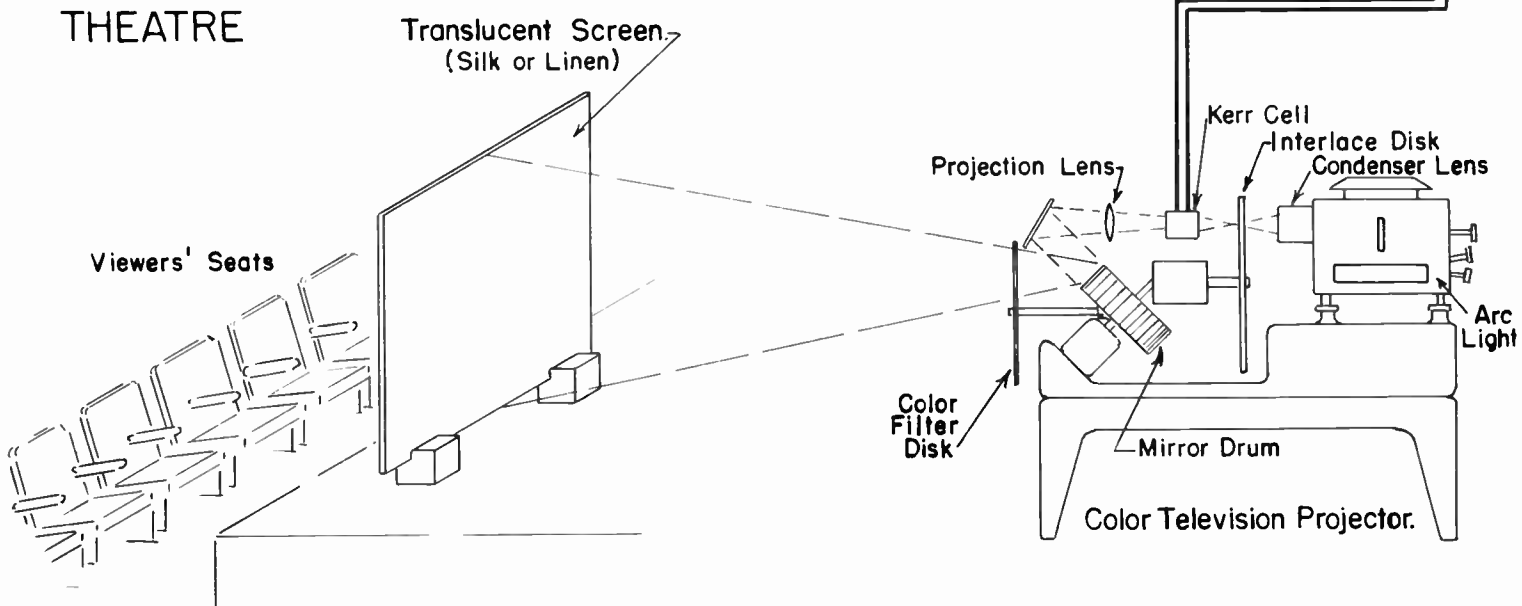


Fig. 20. General Arrangement of System for Colored Projected Television.

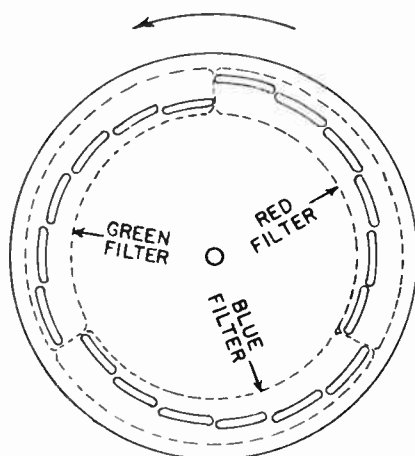


Fig. 21. Interlace Disk for Color Television Assuming Progressive Interlacing.

the line of one other color higher by one-third of a line width and the line of the remaining color lower by the same amount. This mutual staggering of the individual color scanings serves to increase the definition of the picture compared with a straight 120-line 6-interlace scan, without impairing the quality of the color reproduction.

For the remainder of the system, referring again to Figure 20, light diffused from the scene falls upon several large photocells, of which one is shown in the diagram. The output from these photocells, after suitable amplification, is transmitted either by wire or radio to the theatre in which the projector is installed.

The color projector consists of a disk and drum arrangement, similar in principal to the transmitting scanner. A large air-cooled flame arc is used in conjunction with a Kerr-cell light valve. The slots of the disk, while geometrically similar to those at the transmitter, are not covered with color filters because of the intense heat in the light beam from the arc. A second tri-color sector disk is used to intercept the scanning beam immediately after it has left the drum where, owing to the light losses in the

scanning action, the problem of heat is less severe.

The pictures are projected upon the back surface of a translucent screen of artificial silk or tracing linen; these materials, owing to the lenticular (that is, lens-like) action of the fibers, are found to give a broader directional distribution than ground glass or opal glass.

In Figure 21 the interlace disk is shown in a simplified form, namely for progressive interlacing, in order to facilitate the initial explanation. With this type of interlacing the lines of the second field fall just below those of the first field, those of the third just below those of the second, and so forth. High-order interlacing of this kind has the limitation that it tends to produce a phenomenon known as "crawling" when the eye, in following some upward or downward movement of an object in the image, chases the interlace sequence. Dark lines appear in the image under these circumstances, and the effective definition yielded by the system is reduced. However, this effect can be mitigated by means of a non-sequential interlace pattern. To achieve this irregular sequence, the six slots of the disk for each color are disposed at appropriate radial distances from the center of the disk, as shown in Figure 22.

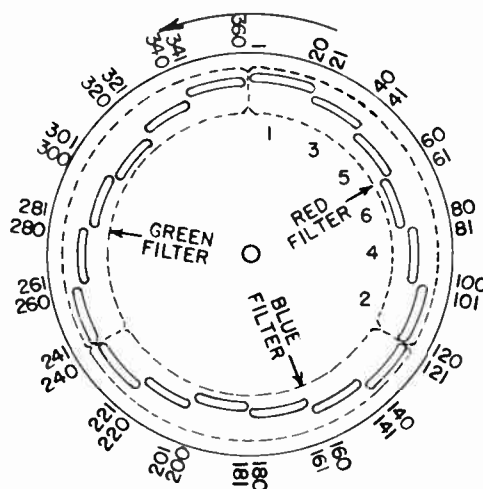


Fig. 22. Interlace Disk for Color Television with Non-Sequential Interlacing.

The operation of the non-sequential interlacing is shown in another way in Figure 23, which represents the upper lines of the scene. From the fact that a total of 360 lines are scanned in one revolution of the disk, it will be seen that one line is scanned for each degree of rotation of the disk. In Figure 23 the lines are designated by the degree positions of the disk, starting with #1 at the beginning of a red scanning; this method of numbering is therefore in the order of successive scanning as a function of time throughout the complete three-color cycle. The first line is red and is shown at the top in Figure 23 as #1. The mirror for line #2 is canted enough to throw this line down sufficiently to accommodate the intervening five lines of the remaining interlaces. The next line, #3, is similarly projected with room for the lines of the later interlaces, or fields. This continues downward beyond the portion of the screen represented in Figure 23, while the first slot is operating, until line #20, which the particular mirror throws near the bottom of the screen, has been projected. This first slot of the disk has the largest radius of the six, that is, this slot is nearest the edge of the disk. In the chosen order of non-sequential interlacing, the second slot is third from the

edge, whence line #21 is the third one after starting with #1 in Figure 23. For the same reason line #22 is third going down from #2. The third slot, giving lines #41 thru #60, is fifth from the edge of the disk, whence each of these lines is two line widths below the corresponding line of the preceding slot. It may be seen that the remaining interlaces of the red scanning are completed with lines #61 thru #120.

After this the blue scanning is done with lines #121-240, each of these being one-third of a line lower than the corresponding red line in order to improve the definition, as already explained. Finally the green scanning is done with lines #241-360, again with each line one-third lower than the corresponding blue line.

CONCLUSION

The discussion of the mechanical systems in the present chapter has been included so that the reader will be familiar with some of the developments in the art which preceded the adoption of the present electronic system. The requirements for a 441-line high-definition television system are difficult to meet with mechanical scanning. There may of course be considerable use of some mechanical arrangements in the future; at present the most promising possibilities of this sort appear to be in film scanning at the transmitter and in large-screen receivers using some means, such as in the Scophony receiver, to increase the brightness over that of a straight optical system.

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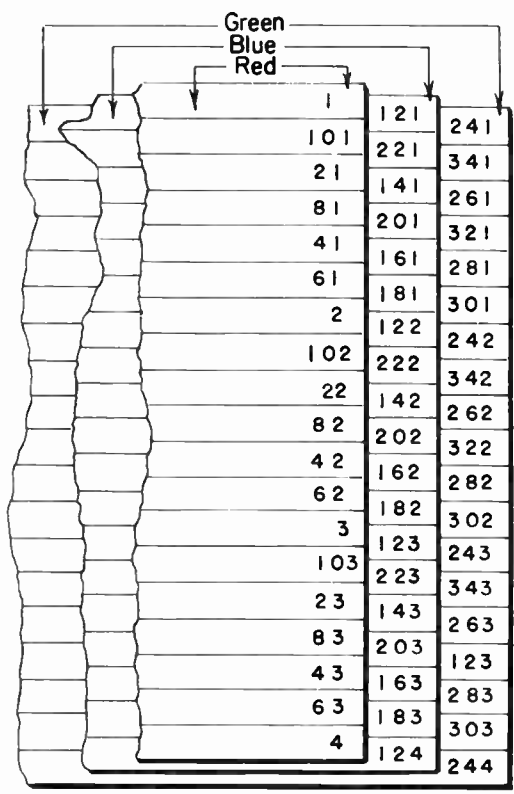


Fig. 23. Diagram Showing Succession of Scanning Lines in Upper Portion of Screen with Non-Sequential Interlacing in Color Television

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