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RECENT PROGRESS IN TELEVISION TECHNIQUE

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Delivered before the Radio Club of America, Pupin Hall, Columbia University, September 14, 1939

INTRODUCTION

A paper on "recent progress" in television must take into account the fact that the whole modern history of television is a period which may properly be called "recent." The first completely electronic system (employing a cathode-ray camera tube and a cathode-ray picture tube) was assembled barely ten years ago. Three years ago images of 343 lines were the rule; today 441 lines is the standard. Barely eight months ago, the Radio Manufacturers Association completed its list of television transmission standards. Four and one-half months ago, a public television program service was inaugurated. Barely ten weeks ago the new Orthicon Camera was announced and within the past month the new camera has been tested experimentally on the air.

It is safe to say that when the first 441-line television images were shown, in 1937, they presented only 35 per cent of the ultimate quality of which a 441-line image is capable. At present a fair guess is that the quality, under the best conditions, is about 75 per cent of the ultimate. It is the purpose of this paper to discuss the improvement from the initial 35 per cent level to the 75 per cent level of the present, and to do some guessing about the remaining 25 per cent.

Fig. 1—Comparison of original image and televised reproduction.

It is informative to compare a television image with a photograph of the subject taken under the same conditions (Fig. 1). At the left is Miss Betty Goodwin in the NBC studio. At the right, the televised reproduction of a nearly identical pose. There are noticeable differences of course, especially in the detail around the eyes, and in the fabric of the dress (the later due to poor shading at the edges). In general, however, this is a fair comparison between object and image in the modern television system.

It is an axiom in television engineering that a picutre of a pretty girl makes a very poor test chart. The imagination of the viewer is only too willing to fill in the gaps left by the transmission system, and it is hard to be critical of phase response, for example, when confronted by 60 db of female pulchritude. So we must revert to the less inspiring standard test chart now used on the NBC transmissions (Fig. 2).

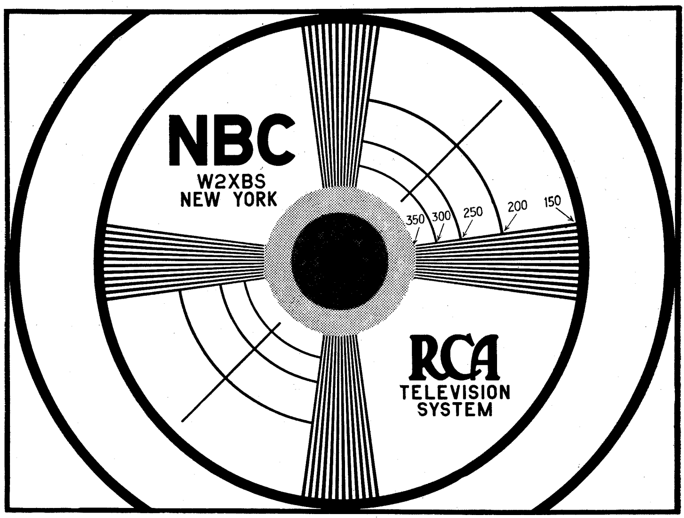

Fig. 2—Standard test chart used in NBC transmissions.

Since this pattern illustrates image qualities to be described later, it is worthwhile to examine it in detail. The outer circle fixes the width of the pattern, while the inner one fixes the height. The ratio of the diameters of these two circles is 4-to-3, which is in agreement with the standard aspect ratio set up in the R.M.A. Standards. The three shaded circles in the center of the pattern indicate three degrees of photographic tone, roughly speaking black, dark gray and light gray. All three of these tones must be properly reproduced in the received image when the system is in proper operation.

The wedges of converging lines which extend radially from the center of the pattern are used to evaluate the degree of detail resolved by the system. If only the outer portions of the wedges are resolved, the detail resolution is poor. If they are resolved to the center, the performance is good. The quarter circles mark regions of the wedges. At the center the width of each black and white line is 1-350th of the picture height. This is known as a resolution of 350 lines. Similarly resolutions of 300, 250, 200 and 150 lines are marked. (The figures have been added for clearness. They do not appear in the pattern as broadcast by the NBC). The wedges which extend up and down reveal the detail along each scanning line, the horizontal detail, while the wedges which extend from left to right reveal the detail across the line structure, i.e. the vertical detail. It is usual to find that the left-to-right wedges are correctly reproduced, because the signal reproducing them consists of low frequency components. The up-and-down wedges are reproduced by high frequency components, which are more readily attenuated in the transmission process.

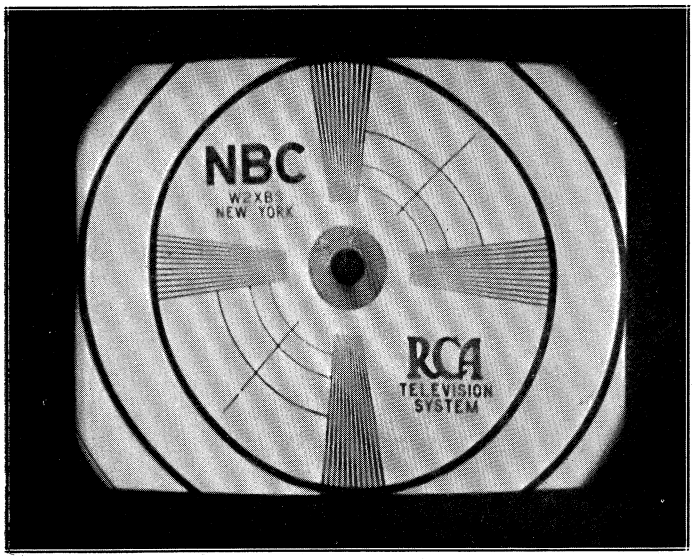

Fig. 3—Televised reproduction of test chart, photographed from monitor picture tube.

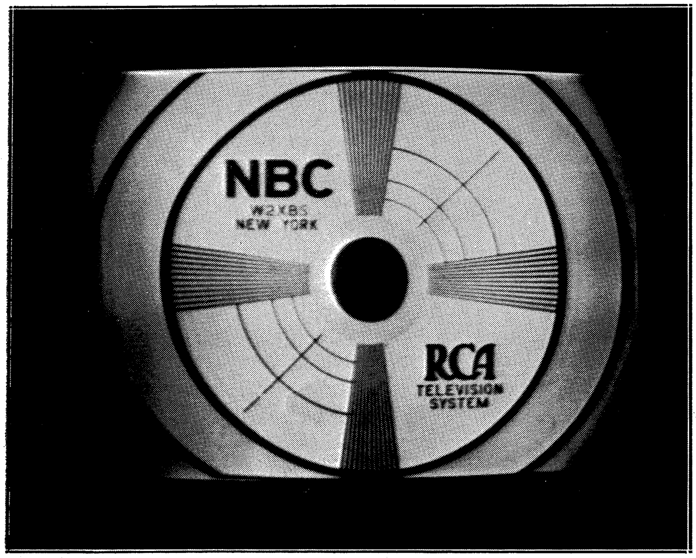

Fig. 4—Image received on typical amateur-built receiver with 1-millivolt r-f signal.

The circular shape of the pattern outline is a great help in determining the correct height of the pattern, relative to its width, as well as revealing non-linearity in the scanning motions.

Now that we have the pattern well in mind, let us view a televised reproduction of it. Figure 3 represents a very excellent reproduction in the present state of the art. The pattern was taken from the face of a monitor picture tube in the NBC studios. It will be noted that the detail wedges are completely resolved, horizontally, indicating excellent high frequency response, and that the wedges are very nearly completely resolved in the vertical direction. The photographic tone values are excellently reproduced. Virtually the only defect in the pattern is a slight irregularity of the geometrical outline, due to imperfect adjustment of the scanning circuits. This is a matter which can be remedied readily, however.

Having seen the image in its nearly-perfect form before it leaves the transmitter, we can now go to an image photographed from a typical receiver. The image shown (Fig. 4) is taken from an amateur receiver described in the September, 1939 issue of *Electronics*. The performance indicated is not the best obtainable, nor by any means the worst. Note that the detail of the up-and-down wedges has been lost above the 300-line mark (due to inadequate frequency response above 3.0 megacycles displayed by the receiver, and partially also to the size of the scanning spot in the nine-inch picture tube on which it was photographed). The tonal values are not clearly demarked, due to too low a setting of the brightness control. The geometrical proportions are not bad, somewhat better than those of the Figure 3. The geometrical distortions are readily adjusted, if the scanning circuits have been properly designed in the first place and if sufficient patience is used in adjusting them.

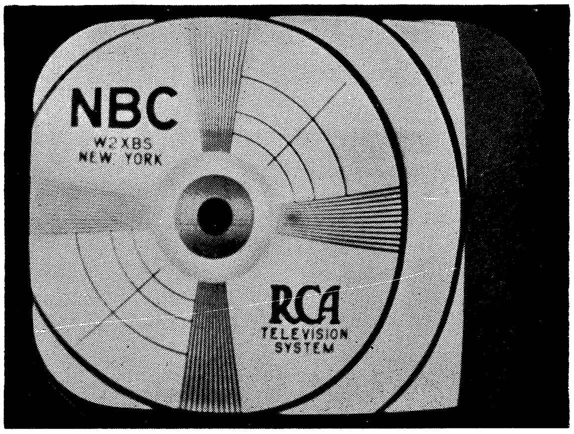

Fig. 5—Incorrect positioning due to excessive d-c component in horizontal scanning system.

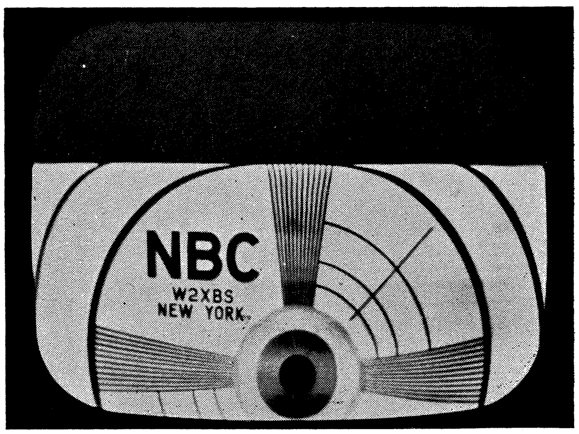

Fig. 6—Incorrect positioning due to excessive d-c component in vertical scanning circuit.

Now, having seen the pattern as reproduced in more or less proper fashion, it is instructive to examine a few of the almost infinite number of ways in which the pattern may be reproduced in improper fashion. The following examples of image defects were photographed at RCA in Camden for the booklet "Practical Television." A simple error of position is shown in Fig. 5, correctable by turning the horizontal centering control of the receiver. The same defect in the vertical direction is shown in Fig. 6. Too small a scanning current or voltage in the horizontal direction produces the too narrow picture shown in Fig. 7. Too little a scanning current or voltage in the vertical direction appears in Fig. 8. All these are readily corrected by adjusting knobs provided for the purpose. The next Figures illustrate apparatus failure in the receiver. When

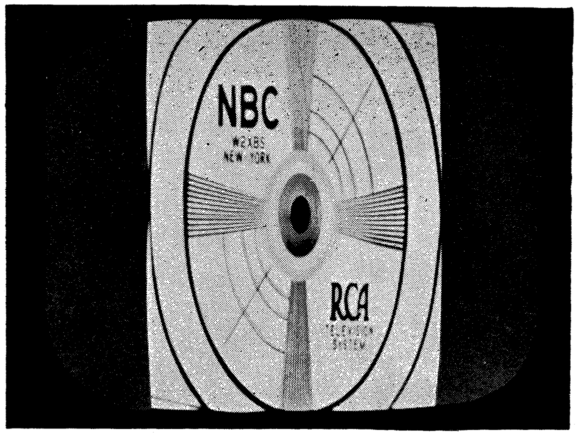

Fig. 7—Incorrect aspect ratio resulting from insufficient horizontal scanning amplitude.

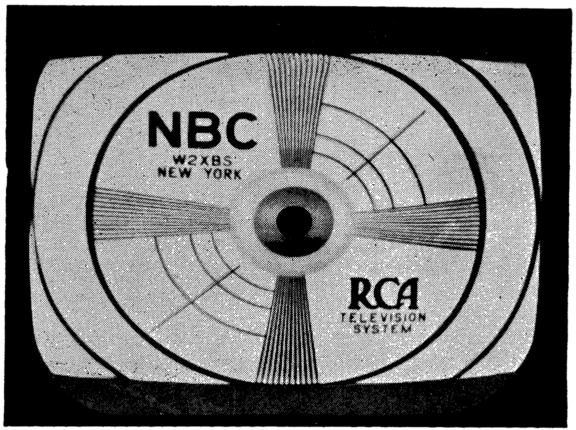

Fig. 8—Incorrect aspect ratio resulting from insufficient vertical scanning amplitude.

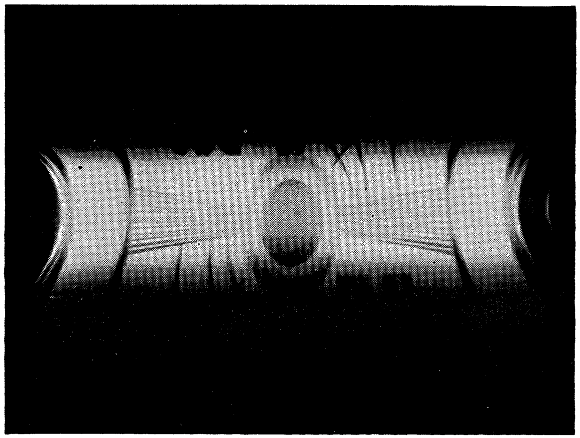

Fig. 9—Variation in horizontal scanning amplitude and change in brightness from top to bottom of picture due to excessive ripple in the second-anode voltage, such as would occur when the filter capacitors fail. This pattern remains stationary only if the 60-c.p.s. power systems at transmitter and receiver are synchronized.

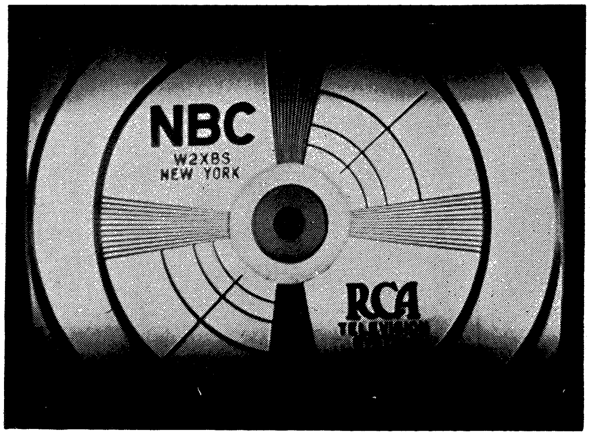

Fig. 10—60-c.p.s. hum in the video signal circuit.

Fig. 11—Hum (60-c.p.s.) in the horizontal deflection circuit or horizontal synchronizing circuit, or both.

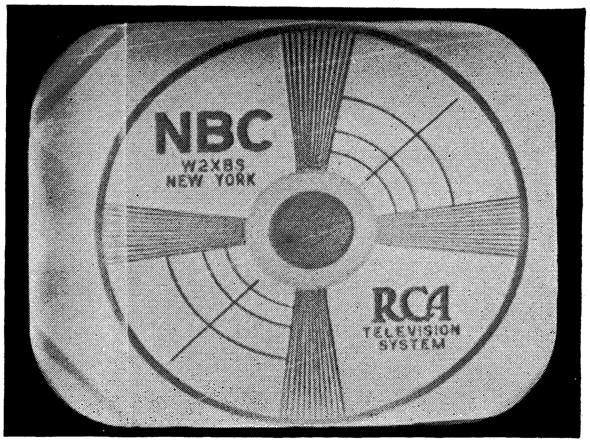

Fig. 12—Nonlinearity of horizontal scanning due to failure of the damping rectifier circuit.

the high voltage filter condensers fail, the result shown in Fig. 9 occurs. Hum in the video amplifier shows up as shown in Fig. 10. Hum in the horizontal deflecting circuit shows up as in Fig. 11. The failure of the damping rectifier tube (used with magnetic scanning in some receivers) introduces a serious non-linearity in the horizontal direction (Fig. 12). Figure 13 shows the effect of too much signal (contrast control too high).

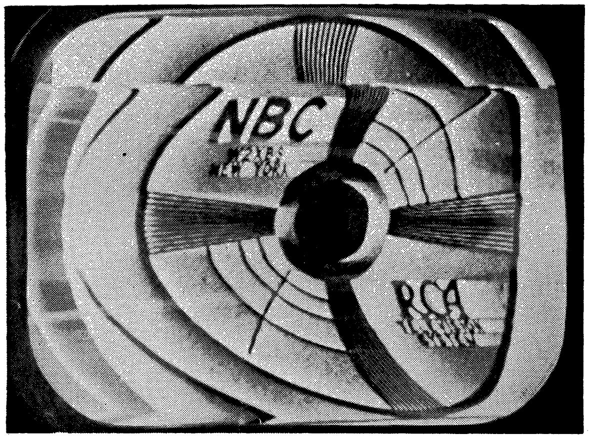

Fig. 13—Tearing, phase distortion, and tone reversals resulting from excessive signal strength and too high a setting of the contrast control.

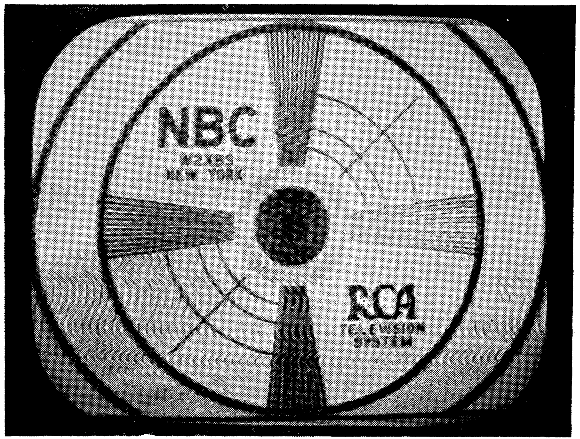

Fig. 14—Stippled effect due to excessive interference from diathermy apparatus. The herringbone pattern results from frequency modulation of the diathermy interference.

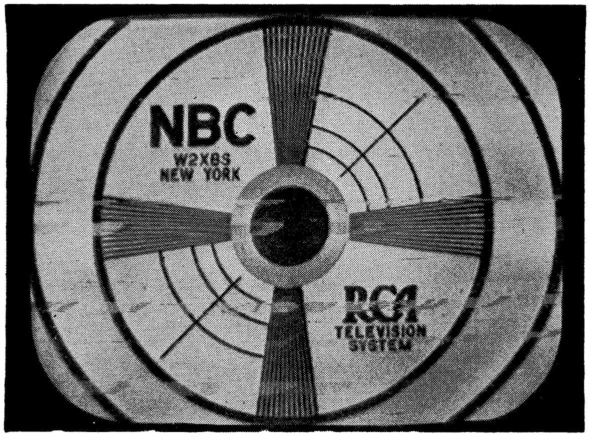

Fig. 15—Tearing of lines due to loss of horizontal synchronization during excessive interference from an automobile ignition system.

The next Figures illustrate difficulties due to interference, which are perhaps the worst enemy of good television reception. Figure 14 shows the effect of diathermy interference. This is a not-too-serious case since it does not completely obliterate the picture, but it is typical. The herring bone pattern indicates frequency modulation of the diathermy oscillator. The separation between the lines of the interference pattern is a measure of the frequency separation between the television carrier wave and the diathermy carrier wave; in this case it is nearly a megacycle. This is television's curse, and it must be abated before the ultimate effectiveness of the television system can be reached. The effect of auto ignition is shown in Fig. 15. The impulse-type interference affects the synchronizing of the image and accounts for the displaced lines. Figure 16 shows the effect of interference from a radio frequency carrier emitted by a continuous wave station. This type of interference may occur either at the r-f frequencies or at i-f frequencies. Since the picture i-f frequency of a television receiver extends from about 8.50 to 12.75 Mc within which a great many powerful stations are located, it is important to trap out such interfering signals before they enter the i-f amplifier. This type of interference has not been publicised as widely as diathermy and

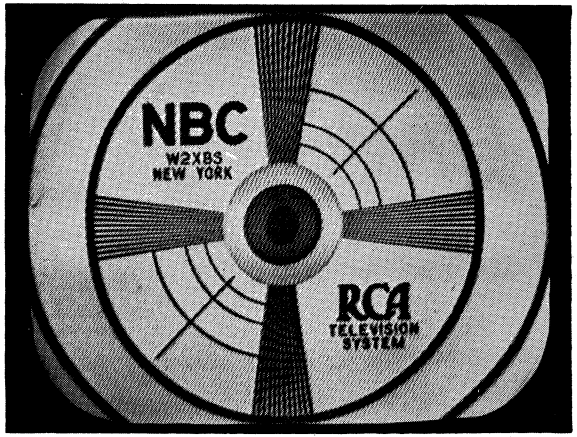

Fig. 16—Regular interference pattern resulting from beat notes with a stable r-f or i-f carrier signal. Modulation of the interfering signal by audio frequencies shows up as a series of rapidly shifting horizontal dark bands.

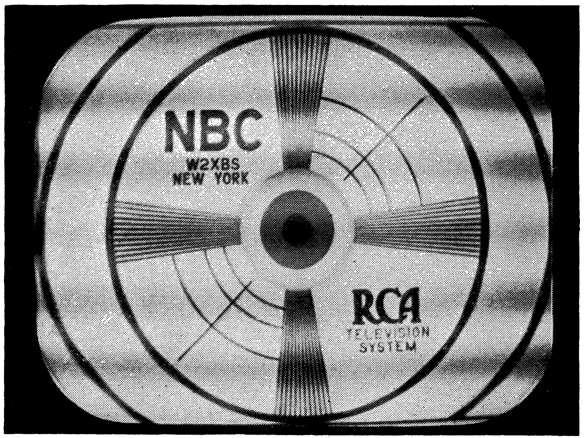

Fig. 17—Interference from audio frequencies in the signal circuit. May arise from cross-talk anywhere in transmission or reception system, but usually from inadequate trapping of sound intermediate frequencies at 8.25 or 14.25 Mc.

ignition, but it is just as troublesome unless eliminated by proper circuit design. Sound modulation which has eluded the trap circuits and found its way into the video signal produces the effect shown in Fig. 17. Note that these interference lines are horizontal whereas those produced by carrier interference are vertical. The rule is that any demodulation frequency below 13,230 cps produces vertical lines, frequencies above 13,230 produce vertical lines (this is due to the fact that the line scanning frequency is 13,230 cps).

Finally, the most fundamental form of interference of all, circuit noise, is shown in Fig. 18. Whenever the signal level at the receiver input terminals falls below, say, 50 microvolts, this random interference is apt to be prominent. Circuit noise may be reduced (by employing low values of coupling impedance and low values of plate current in the amplifier tubes) but it is hard to reduce it much below an equivalent of 50 microvolts at the antenna terminals. This picture shows a signal-to-noise ratio of roughly 1-to-1. A ratio of 5-to-1 is bearable to look at, but a ratio of 20-to-1 is necessary before all traces of noise can be said to be eliminated from the pattern. Hence the rule that television signals should have a strength of 1000 microvolts or more for best reception. It should be pointed out in passing that "noise" is not the proper descriptive term for this type of interference, because noise is an audible quantity, whereas this type of interfering signal cannot be heard. A better name for this random interference is, in the author's opinion, the term "mask." It is apparent that the television signal has many hazards in its path from studio to audience. A great part of recent television progress consisted in reducing these hazards and in safeguarding the signal from them.

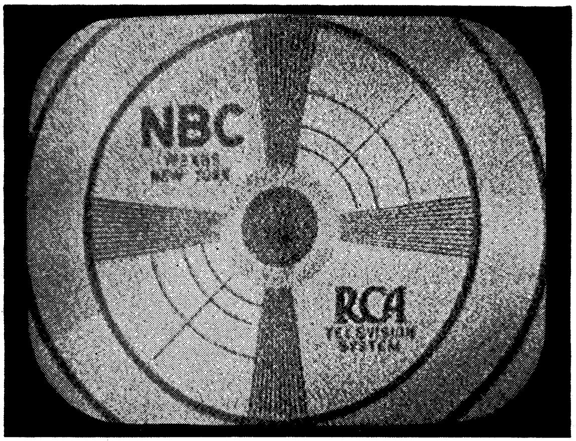

Fig. 18—Interference caused by tube and circuit masking voltages (thermal agitation and shot-effect noise) usually associated with a weak signal and most clearly visible in the absence of other interferences.

Now let us turn to some specific techniques which have resulted in improvement of television transmissions. The progress has occurred on so wide a front that it is hopeless to review it adequately in a single paper. Furthermore, an understanding of many of the recent achievements depends on a detailed knowledge of specialized circuit functions, which at present is restricted to a small number of engineers actively engaged in television development. So it is necessary to limit our discussion to a general subject which is of outstanding importance and which at the same time does not require specialized circuit knowledge. That subject is the photographic quality of television images.

By photographic quality of television images is meant the quality of the reproduced image judged from the photographic standpoint. What, for example, distinguishes the photographic quality of a good movie? First it must have photographic detail adequate to the subject, that is the picture must be in focus and free from grain. Second it must display contrast and tone gradation adequate to the subject matter. In photographic parlance the picture must be exposed and developed to the proper value of gamma, and the exposure should be situated on the straight portion of the gamma curve. Thirdly the picture must be free from extraneous lights and shadows, that is, there must be no light streaks, fogging, uneven developing, water spots, etc., evident in the finished product. In the fourth place, the picture must be properly exposed, i.e., not too dark or too bright, so that the background of the picture is in the proper context relative to the subject matter, and so that adequate contrast and range can be obtained. With these factors under control: detail, contrast, gradation, average brightness and extraneous light, a good photograph may be produced.

In television an exactly analagous situation arises. The same factors exist and must be under control if a satisfactory television image is to be reproduced. Most important, it is quite possible by the application of photographic principles, to improve the quality of television images without resorting to a change in the basic transmission standards. Hence we can expect further improvements, within the framework of the 441-line standard, to consist largely in the application of photographic concepts to their electrical analogs in television circuits.

In particular we shall discuss these photographic categories in three groups (1) the detail of the image; (2) the transmission of average brightness; (3) the transmission of tonal contrasts and gradations from black to white.

Picture Structure and Photographic Detail

When we view an object directly, we are apt to assume that the scene before us is continuous, and that any structure displayed by the scene must be inherent in the scene itself. But this is far from the truth. The human eye discovers detail by means of cones in the fovea of the retina, which are tiny light sensitive particles, each individual and separate. The retina of the eye thereby divides the scene into tiny elements, and imparts a structure to everything we see. The structure is not directly visible to us, but its effect is very evident when we attempt to read a page of fine type from too great a distance. The structure of the letters as focused on the retina may then be finer than the structure of retina itself, and the letters are then not separately resolved.

So it is with reproduced pictures. All reproduced pictures have a structure of some sort or other. The most obvious case is the printed half-tone engraving, shown in Fig. 19. The structure of the picture in the upper left is not immediately obvious, but when it is enlarged three diameters, the halftone dots become evident. Each dot is a basic item of information in the picture. Essentially the problem of television is the dissecting of a picture into such dot-like elements, and sending information on the position and brightness of each picture element from transmitter to receiver, quickly enough to allow the motion of the scene to be taken into account.

The question then arises as to the maximum number of dots (or picture elements) required to make a television image realistic enough to hold the attention of the eye over long periods. Experience has shown that not less than 100,000 elements, preferably more, are required. The inexpensive television receivers of today, employing five inch cathode ray tubes, just barely scrape under the wire in this respect. The better receivers are able to produce pictures having 150,000 dots, and the ultimate of which the 441-line standard is capable with the present channel widths is in the neighborhood of 250,000.

What does a picture containing 250,000 dots look like? The most easily understood answer to this question is that it looks like a standard motion picture, almost but not quite. Good motion picture film, properly exposed, processed, and projected for general theatre release has about 500,000 effective picture elements. A 441-line television image cannot reproduce a scene quite as well as can 35-mm film, but it can come very close to it. There may be owners of television sets who contest this statement. But when the full utilization is made of the 441-line standard, it is the author's opinion that there will be very little to choose between a motion picture and a properly televised reproduction of it.

Fig. 19—Picture-element structure of a half-tone engraving. (*After C. E. Burnett.*)

Beyond this, however, there is very little likelihood that a 441-line image can go. The detail limit is fixed inexorably by the channel of frequencies available for the transmission of the picture signal.

It is instructive to examine some of the implications of picture detail in relation to conditions under which the picture is viewed. This question is bound up in the ability of the eye to distinguish between the structural elements of the picture. A quantitative measure of this ability, shown in Fig. 20, is the acuity of the eye. Suppose the two dots on the screen are two half-tone dots in a printed reproduction of a scene, and suppose that the distance between the dots is s inches. Then the screen is moved further and further from the eye until the two dots appear to merge into a single dot. This is the limiting distance, d at which the structure of the retina becomes coarser than the

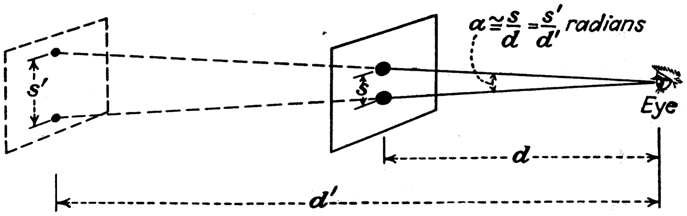

Fig. 20—Fundamental relationship of viewing distance to visual acuity angle.

image of the two dots focussed upon it. Then let us measure the angle α subtended by the dots. The angle is found to be about one minute of arc of the average normal eye. This angle is the fixed quantity so far as the eye is concerned. If we move the screen out to a distance d', the dots must be separated by a correspondingly larger distance s', so that the angle α remains equal to one minute. Otherwise the details are not resolved separately. The application of this principle is shown in Fig. 21. Here the elements to be separated are picture elements on

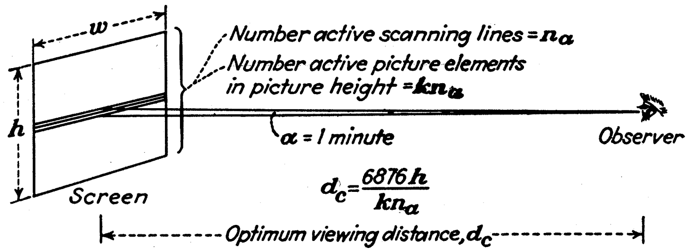

Fig. 21—Application of acuity angle to scanning pattern.

two scanning lines, separated by another scanning line. If the screen is moved back until the two elements appear to merge into one (until the angle is just one minute) then the viewing distance is found to be about 23 times the picture height. Hence the limiting distance, beyond which the detail of a television image is lost, is about 23 times the picture height, or roughly 180 inches for a picture 8 inches high. The moral is, sit no further than 15 feet from a television picture 8 inches high if you expect to get all there is in the picture.

The minimum viewing distance is not so easy to define, since it depends upon how much of the picture structure can be tolerated by the viewer before the structure itself obscures the content of the scene. Most people prefer to sit at the distance where they can just begin to see the lines separately, which ordinarily occurs at a distance of about 4 to 6 times the picture height. Some people enjoy the picture as close as twice times the picture height, but few observers wish to view it closer than this. A viewing distance of 5 times the picture height is a good compromise, and this ratio agrees well with that obtaining in the preferred seats at motion picture theatres.

It should be noted that the *absolute size* of the picture is of little importance compared with the *ratio of the picture size to the viewing distance.* Large pictures, while desirable from a psychological point of view, are not necessary except for large audiences.

The significant advance in television engineering, so far as the reproduction of photographic detail is concerned, is the adoption of the so-called vestigial sideband method of transmission. This advance has increased the useful picture detail nearly 70 per cent, without increasing the channel limits in the ether spectrum. Before going into the details of the vestigial sideband method, however, it is necessary to trace the connection between photographic detail and the video signal required to reproduce it.

The scanning process is illustrated in detail in Fig. 22. The picture elements along a single line of the image are simple squares of black and white. The signal which results from the scanning of such a line ideally has the shape shown just below, that is, it is a square wave. The square wave can be transmitted only if the frequencies in the video signal include many harmonics of the fundamental frequency. If the video signal is restricted so that it includes only the fundamental, as is the case in the most detailed portions of the image, then the square wave cannot be transmitted. Rather, a simple sine wave of the same frequency is transmitted, as shown at the bottom of the diagram. When this signal is used to reproduce the image at the receiver, the black and white dots along the line are not clearly demarked, as in the original, but have a blurred outline. Nevertheless the detail *is* reproduced, in distorted form. Figure 23 shows the degree to which the square wave may be approached if more and more harmonics are included in the video signal. If five hormonics are included, the result is a fairly good approximation of the square wave, much better than that of the sine wave fundamental. If 21 harmonics are included the approach to the square wave is correspondingly better.

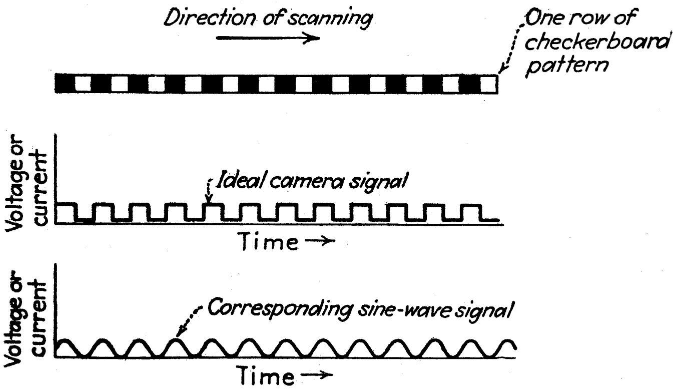

Fig. 22—The square wave as a result of scanning a "checkerboard" image. If a large number of harmonics can be transmitted, the signal waveform approaches the ideal square wave. This can occur only if the squares are large relative to the area of the scanning pattern. If the squares are the size of picture elements, then only the fundamental frequency can be transmitted (lower curve) and the sharp demarcation of the squares is lost in the reproduction.

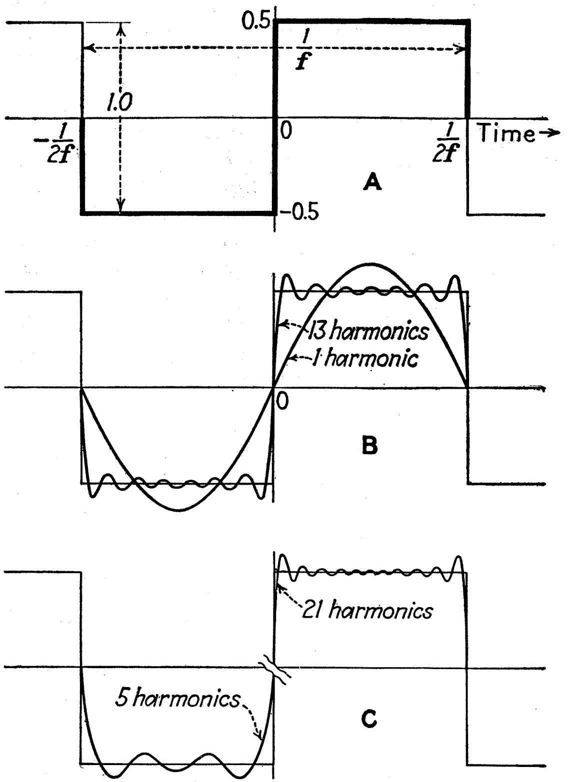

Fig. 23—The square wave. A, the basic wave; B, wave computed using one harmonic and 13 harmonics; C, same for 5 harmonics (lower portion) and 21 harmonics (upper portion).

To obtain a sharp contrast between black and white, the edge of each square must be sharp, and this is possible only if a very great many harmonics are present. In other words, the presence of a very wide band of video frequencies not only allows the depiction of the fine detail in the image but it also permits the depiction of sharp edges on more extended portions of the image. Both effects are of importance in reproducing a satisfactory image.

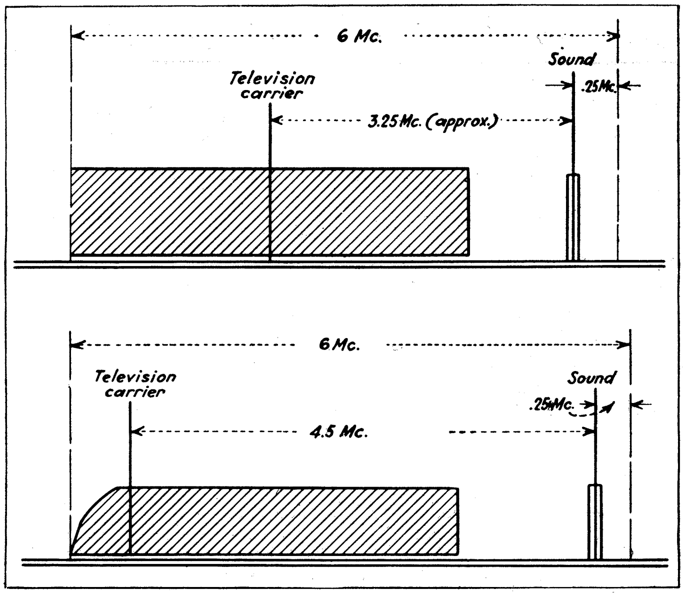

Fig. 24—Comparison of double-sideband and vestigial-sideband transmission.

We can arrive at the numerical values of frequency in the video signal by the following reasoning. Assume first that there are 240,000 picture elements in the picture. These elements are arranged along roughly 400 active lines (the remaining 41 of the 441 lines are blanked out between the successive pictures). Along each line, then, there are 240,000/400 = 600 picture elements. As the scanning beam moves from left to right along each line it must reproduce a maximum of 600 picture elements. Now the time it takes the scanning spot to travel across the picture is roughly 1/15,000th of a second (for a 441 line picture, 30 pictures per second, with 15 per cent of the scanning time devoted to retrace (right to left) scanning motion.) Hence we have 600 picture elements in 1/15,000th of a second, or 9,000,000 million picture elements per second. On the average half of these picture elements will be positive (darker than the average brightness) and half negative (brighter than the average) so there will be 4,500,000 bright elements and 4,500,000 dark elements. The video signal can produce one dark and one bright element with a single cycle. Hence the maximum frequency in the video signal is 4.5 million cps. or 4.5 megacycles. Thus 240,000 picture elements per picture can be laid down by a 4.5 Mc. signal which is the limit allowed by the present channels. At present the highest video frequency used in commercial practice is closer to 4 Mc. hence the number of picture elements is proportionately reduced, to about 210,000 picture elements. The 4-Mc. bandwidth is possible, within the 6 Mc. channel assigned by the FCC, only by the use of the vestigial sideband system. The older double sideband system was limited to 2.5 Mc. corresponding to about 130,000 elements per picture.

The comparison between vestigial sideband and the older double sideband transmission channels is shown in Fig. 24. Above is the older method with two sidebands dividing the available channel width between them. In the newer system, below, one sideband occupies nearly all the space formerly given to the two sidebands, and only a small portion of the remaining sideband is transmitted. The result is a 60 to 70 per cent increase in the available sideband width, and a corresponding increase in the picture detail.

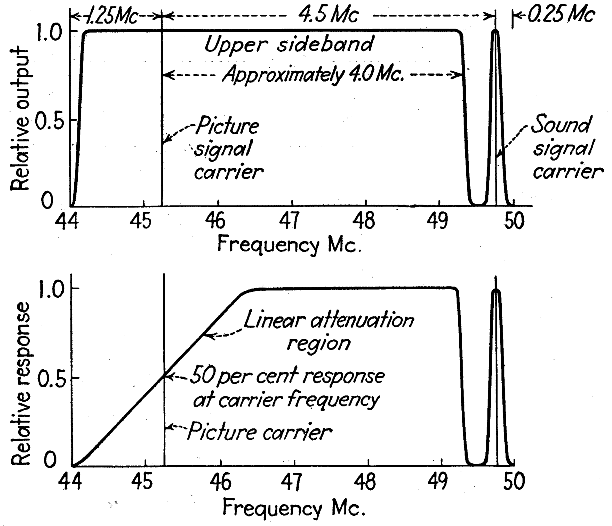

Fig. 25—The vestigial sideband television channel standardized by the R.M.A. Television Committee and now used as the basis of transmissions in the United States. The upper diagram is the transmitter output curve, the lower the receiver response curve which equalizes the percentage modulation of sideband components near the carrier to that of components far removed.

Figure 25 shows the corresponding transmitter and receiver characteristics for the vestigial sideband method. The transmitter transmits all sideband components equally inside the pass region, but attenuates sharply outside this region. The receiver characteristics is so placed that the picture carrier falls at the edge of the pass band, at the 50 per cent response level. This arrangement restores the full modulation of the outer sideband components, and equalizes the double sideband nature of those components near the carrier.

The most striking aspect of the vestigial sideband method is the rapidity with which it was adopted and put into practice. A year ago, the system was a suggestion only. In February of this year the R.M.A. Television Committee, after some argument, voted it as the standard method of transmission. Two months later it was put in operation in a public television program service, both receivers and transmitters having been hastily altered to accomodate the change. Today, four and one half months later, the system is established as eminently successful.

The Transmission of Average Brightness

At first glance it might appear that when the detail of an image has been transmitted adequately the job is finished. But this is not so. Of almost equal importance is the overall brightness of the picture. If the picture is dark, that is, shown with a low background brightness, it is possible to convey the impression of moonlight, for example, whereas if the same scene is shown with a high average brightness, the impression changes to one of sunlight. The detail of the scene in both cases is the same, but the change in the average brightness has produced two entirely different contexts. Such changes in brightness are constantly employed by the sense of sight in interpreting the scenes it sees. Furthermore such changes in brightness occur often in the ordinary routine of a visual performance. The television system must take account of these brightness changes and it must transmit them to the receiver in such a manner that they add to the realism of the reproduction.

Electrically, the problem is related to the a-c and d-c components of the video signal. The detail of the scene is conveyed by the a-c component of the video signal, whereas the average background is conveyed by the d-c component of the signal. The meaning of these terms is shown in Fig. 26. Here we have the video signal plotted as a current (or voltage) against time. We confine our attention to the "camera signal" that is that portion of the signal existing below the black level. The a-c component consists of the variations which comprise the waveform. The d-c component is the average value of these variations, measured from the black level. The solid line shows a given signal and its d-c component. The dotted line shows the same detail (the same waveform) but with an added d-c component. The picture produced by the dotted line has the same detail as that produced by the solid line (since the waveform is the same), but the brightness produced by the dotted line is approximately twice as great as that produced by the solid line. Obviously, then, to transmit the d-c component faithfully, it is necessary that the relationship between the black level and the average of the signal be preserved.

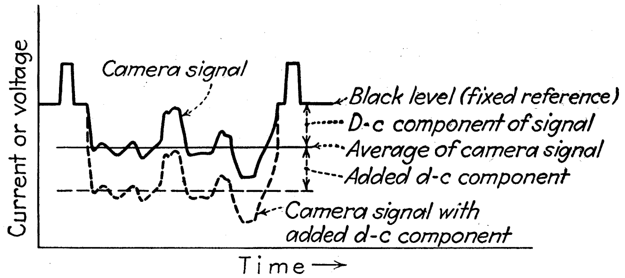

Fig. 26—The d-c component of the video signal. The waveform retains its shape, but is displaced upward or downward as the picture becomes darker or brighter, respectively.

In the transmitter, this d-c signal may be transmitted by the use of conductive coupling between the modulating video amplifier and the modulated r-f amplifier, as shown in Fig. 27. The result is a modulated carrier whose maximum level, and the black level, remain fixed, while the average of the video signal below the black level may take any position demanded by the average brightness of the scene being transmitted.

So long as the signal remains in the form of a modulated carrier, the relationship between the signal average and the black level will remain fixed, and the d-c component is thereby preserved. But when the carrier is demodulated, the black level becomes a part of the d-c current in the second detector output circuit. Thereafter d-c amplification of some sort is necessary, if the relationship between black and average is to be preserved. Unfortunately d-c amplification at this point is rather inconvenient since it is usual to couple the following video amplifier through a capacitor which eliminates the d-c component and substitutes an arbitrary bias voltage in its place.

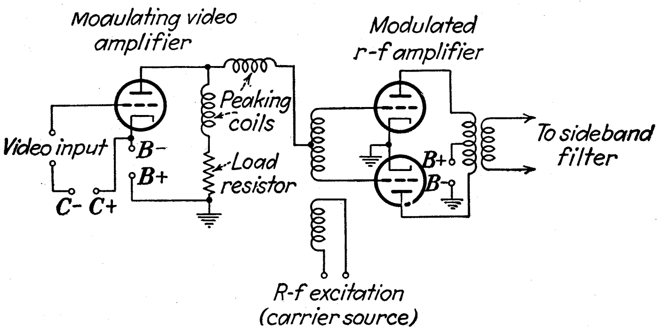

Fig. 27—Method of conductive coupling between modulating video amplifier and modulated r-f amplifier. The plate of the video amplifier operates at the bias potential of the r-f amplifier, hence the cathode of the video amplifier must be maintained at a high negative potential.

To avoid this difficulty it is usual to rectify the video signal in a diode whose load circuit has a large enough time constant to develop a d-c voltage equal to the peak value of the signal. The peak value of the signal, we remember, has been fixed at the transmitter, and hence constitutes a reference level in the signal against which the average of the video signal may be measured. The peak-level d-c output of the rectifier is used as a portion of the bias voltage in the picture tube grid circuit. Then the total d-c voltage in this circuit includes the d-c component which acts to fix the average brightness of the scene. The rectifier used for restoring the d-c component may be a separate diode, or it may be simply the grid and cathode of the video amplifier tube, which is so biassed that the grid draws current and hence acts as a diode element. By means of this d-c restoring technique it is quite possible to produce changes in overall brightness which may extend throughout the limits imposed by the saturation of the circuits and of the picture-tube screen.

When properly used, the d-c restoring system adds greatly to the enjoyment of the programs. But when improperly used, it may actually be a detriment. It is incumbent on the engineers at the transmitter to send out a d-c component which actually represents the desired average brightness of the scene. Furthermore, the operator of the receiver must adjust the controls of his receiver so as to put the d-c component on the proper portion of the picture tube characteristic. The rule is fairly simple: The brightness control should always be set at a position just below the point at which the retrace lines become visible. This insures that the black level at the receiver is in point of fact black, not blacker than black. In the second place the contrast control should be set so that the three degrees of shade appear separate and distinct, not merged together. After adjustment of the contrast control, it may be necessary to readjust the brightness control to the previously mentioned level (just below the point where the retrace lines become visible). When this is done, the average brightness of the receiver picture is at the level intended at the transmitter, and the program will then be received with maximum fidelity. If these rules are disregarded, the detail of the darker portions of the picture may be lost (if the brightness control is set too low, the contrast control too high), or the highlight detail may be lost if the opposite conditions exist. This procedure has not been fully explained in the instruction booklets of commercial receivers, most of which instruct the operator to set these controls "Until the most pleasing effect is obtained." The operator should, of course, be permitted to please himself, but he should also be instructed concerning the adjustment of the controls which gives a maximum of fidelity. It is important that the virtues of proper operation of television receivers be emphasized from the start rather than as an after thought, as has occurred in sound radio practice.

Contrast and Tonal Range in Television Transmission

We now come to the third group of photographic qualities of a television image, that is, the contrast and the range of tones or shades which can be accomodated in the system. This is the latest of the three divisions to receive the attention of television engineers, and it is as yet very imperfectly developed. In fact, in my opinion the remaining 25 per cent between the present quality of 441-line images and the ultimate is to be achieved principally by understanding and applying the principles of tone rendition.

The whole problem of tone rendition may be stated fairly simply. In the scene to be transmitted there is a range of brightness from the darkest parts of the picture to the brightest parts, and there are intermediate shades between the limits of the range. When the scene is viewed directly by a person in the studio the range of brightnesses produces an effect which is best described by the term "contrast." Quantitatively the term is brightness contrast, and it refers to the ratio of the highest brightness to the lowest brightness in the scene.

In television the problem resolves itself to providing a sufficient dynamic range in the system so that high brightness contrasts may be shown. Then if low contrast is demanded by the subject, only a restricted part of the available dynamic range need be used. The problem of tone rendition and contrast thus involves every item of equipment in the television system.

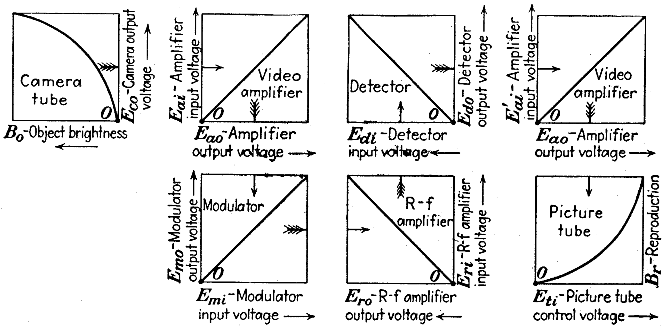

Fig. 28—Transfer characteristics of successive transducers in the television system.

An elementary statement of this problem is given in Fig. 28. Here we have the relationships between input and output of seven different items of equipment: the camera, the video amplifier, the modulator, the r-f amplifier, the detector, another video amplifier and the picture tube. These items of equipment have been arranged in the usual sequence through which the signal passes, as indicated by the arrows. The output of one device is made equal to the input of the succeeding device, the scales of all the curves are in the same units, and a common origin has been selected for each. By following the arrows we can trace the connection between the object brightness (the brightnesses of the scene in the studio) to the image brightness (the corresponding brightness in the received image). The camera tube characteristic is non-linear, to agree with the usual form of the characteristic displayed by the iconoscope (the orthicon, on the other hand, has a linear characteristic). The input output curves of the amplifiers, modulator and detector have been shown as linear, for simplicity, although in practice such linearity may not be achieved. The characteristic of the picture tube is not linear, since in point of fact the relationship between control grid voltage and screen brightness of such tubes is not linear, but displays the anti-saturation characteristic shown. Note that the non-linearity of the picture tube characteristic tends to compensate for the curvature of the camera tube characteristic, hence the overall relationship, the so-called overall brightness transfer curve, is approximately a straight line. Thus, changes in the transmitted scene are directly proportional to the corresponding changes in brightness in the received picture.

Offhand it might appear that this is the desirable condition for faithful rendition of the tones in the scene. But this is not true. The important thing, so far as the perception of light by the observer is concerned, is not the brightness of the various parts of the scene but the logarithm of the brightness. This is in accordance with the Weber-Fechner law, an approximation which states that the sensation of light is proportional to the logarithm of the brightness producing that sensation. Hence we find that a great many different relationships between object brightness in the studio and image brightness in the receiver will satisfy the condition of proper rendition of tonal values. Some idea of the variety of curves which will satisfy this condition is shown in Fig. 29. These curves are all of the form:

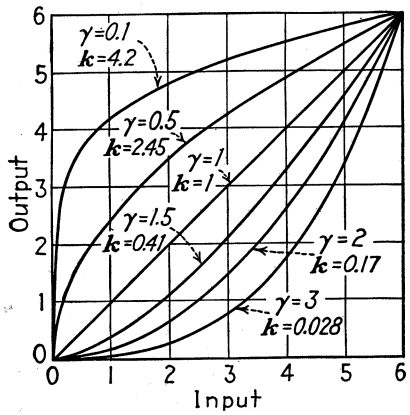

Fig. 29—Various logarithmic transfer characteristics plotted for various values of gamma, with the proportionality constants chosen to give a total range of 0 to 6 in output and input.

$$\text{output} = k\,(\text{input})^{\gamma}$$

When γ (gamma) is equal to unity, the curve is straight. When it is less than unity the curvature is of the "saturation" type. When it is greater than unity the curve is of the "anti-saturation" type. Any curve in the group satisfies the condition for the proper rendition of tones, because when plotted in logarithmic form, they all produce straight lines. Thus

$$\log(\text{output}) = \gamma \log(\text{input}) + \log k$$

which is the equation of straight line. This set of curves explains why so much non-linearity may be tolerated in a television system without producing pictures of obviously bad quality. But the type of non-linearity actually used has a great effect on the apparent contrast of the reproduced image. If the gamma characterizing the non-linearity is greater than one, the reproduced contrast is enhanced, whereas if the gamma is less than unity the reproduced contrast is reduced. Obviously then non-linearity has its engineering uses in a television system. At present there is much discussion among television engineers whether it is proper to introduce non-linearity into a television system for the purpose of enhancing or reducing contrast. It is the author's opinion that anything is proper which produces a desired result with engineering economy. Actually at present, the broadcasters are attempting to make their transmissions linear, and relying on the inherent anti-saturation characteristic of the picture tube to improve the contrast. In the future, however, I believe that controllable non-linearity will be used to obtain artistic effects and to compensate for limitations in the transmission system.

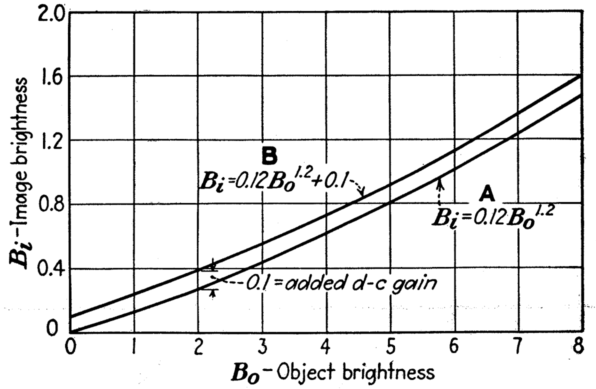

Fig. 30A—Effect of added d-c gain on the over-all brightness-transfer characteristic: A, original curve in which zero object brightness coincides with zero image brightness; B, same with 0.1 added d-c component.

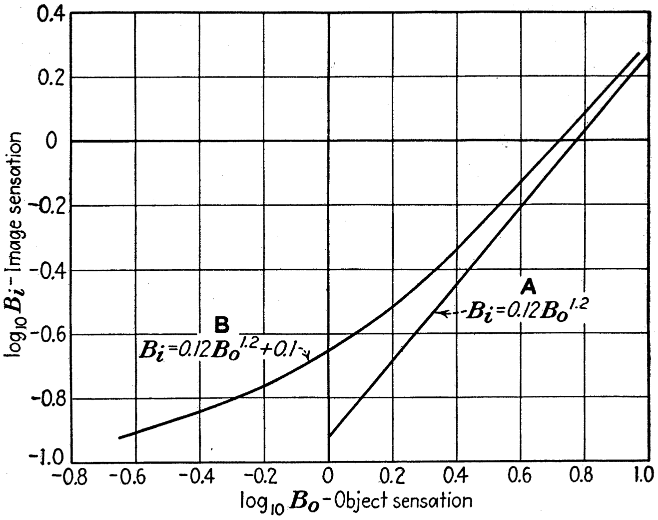

Fig. 30B—Transfer characteristics of Fig. 30A, plotted in logarithmic coordinates. The original curve A shows a constant slope, whereas the curve B with added d-c gain gives more contrast in the high lights than in the shadows.

The study of the brightness transfer characteristic of a television system reveals some very interesting effects when the d-c amplification of the system is varied relative to the a-c amplification. In photography this distinction is not ordinarily made, since both the average brightness and the variations from the average are treated alike in photographic processes. But in television the distinction is very real. Every time the operator of a television receiver adjusts the brightness control he changes the d-c level (hence the d-c amplification) without changing the a-c amplification. What effect does this have on the picture reproduction? For a partial answer to this question we may consider Fig. 30. At the top is a typical non-linear transfer characteristic relating the object brightness to the image brightness. Suppose we add to the d-c gain, that is displace the curve upward as shown. Then let us look at the logarithmic plots of these two cases. The first is a straight line implying a linear relation between object sensation (what the mind sees in the studio) and image sensation (what the mind sees at the receiver). The second, with the added d-c component is not linear at all. Rather, a given change in object sensation at low levels produces a much smaller change in image sensation than does an equal change at higher levels. In other words the highlight contrast is emphasized relative to the shadow contrast. This is an effect which may have its uses in the television transmissions of the future. Figure 31 shows the effect produced by increasing the a-c gain while maintaining the d-c gain constant. A is the original transfer characteristic. In C the curve has been twisted about the amplifier bias level, by the effect of the a-c gain. The corresponding logarithmic curve to C is shown at the right. It is not linear, and its shape is such as to produce a higher contrast in the shadows than in the highlights, just the reverse of that shown in Fig. 30. Curve B shows the effect of changing both the a-c gain and the d-c gain together. The logarithmic curve in this case is a straight line displaced from curve A, which treats both the highlights and shadows alike. It is clear, therefore, that unless special effects are desired, both the a-c and d-c gain of the system should be varied together. This requirement is not met unless the operators both at the transmitter and at the receiver take care to do so.

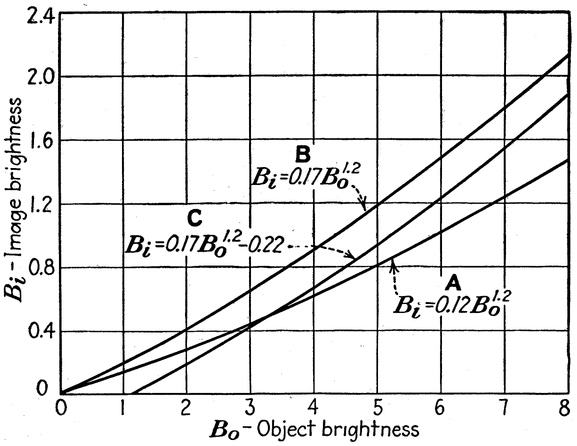

Fig. 31A—Effect of added a-c gain on over-all brightness-transfer characteristic: A, original curve; B, curve with a-c and d-c gain equal (zero object brightness still coincides with zero image brightness); C, curve with a-c gain only, revolved about the point (3.3, 0.5). The latter curve shift produces the same effect as a reduction in d-c gain.

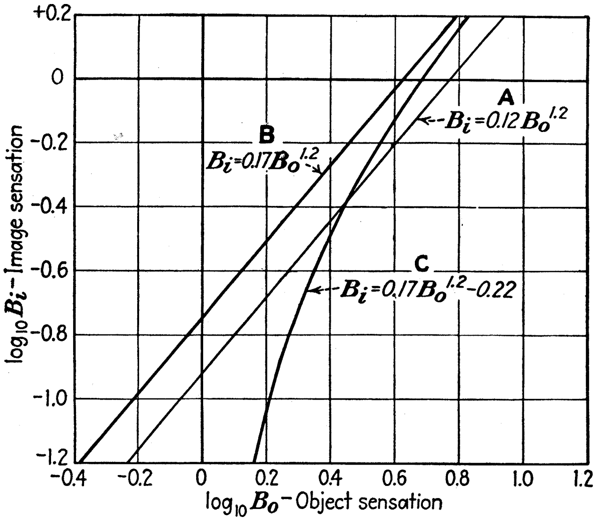

Fig. 31B—Logarithmic plots of the curves in Fig. 31A. The curve B, representing a change in a-c and d-c gain, is simply displaced from the original curve, producing a brighter picture of the same uniform contrast. The curve C, with excess a-c gain, produces higher contrast in the shadows than in the high lights, just the reverse of the effect shown in Fig. 30B.

It should be remarked in passing that this approach is only a partial analysis since the eye does not follow the Weber-Fechner law too accurately, and since the changes in d-c and a-c gain have not been particularized, but in general the effects noted are valid. Study of such photographic concepts as these will add very greatly to the apparent realism of the reproduction of television images.

Improvements in Apparatus

The final attainment of the ultimate quality possible from a 441-line image rests not only in understanding the fundamental processes at work but also in improving apparatus. The Orthicon camera is a very great forward step of this kind. This new camera has a gamma of unity, has a flatness of background illumination (that is, freedom from shading defects) which is substantially perfect, and in addition it has the potentialities of greatly increased sensitivity relative to the iconoscope.

Still another improvement well worth noting is the remarkable improvement in the color sensitivity of pick-up cameras. Not many years ago, iconoscope cameras were so sensitive to infra red light that the black lapels of a dinner jacket often televised gray because of the large amount of infra red reflected from them. Now the color response of iconoscopes is almost exactly the same as that of a good panchromatic photographic film. For proof of this statement notice Fig. 32. At the left is a photograph of the Agfa color chart, taken with panchromatic film. At the right is a televised reproduction of the chart. The sensitivity at the far red and far blue regions is not quite so good in the camera as in the film, but otherwise the two are remarkably alike in response. It is thus very true to say that the iconoscope camera is capable of producing as good a black and white picture from a colored subject as is film used in movie production today.

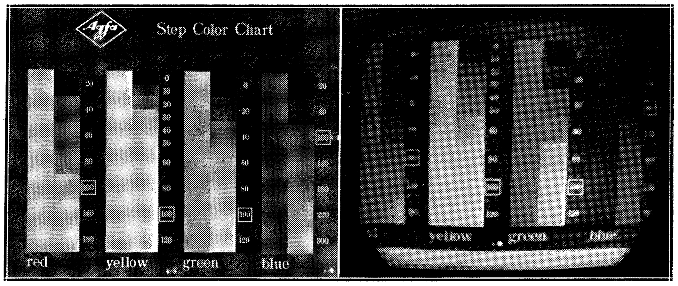

Fig. 32—Comparison of original and televised reproduction of color test chart, taken with silver-sensitised iconoscope.

In conclusion I wish to draw attention to three outstanding improvements in television technique which it has not been possible to discuss in detail. One is the achievement of Nils Lindenblad of R.C.A. Communications in his "Indian Club" antenna which is now atop the Empire State Building. This antenna makes it possible to radiate all the sideband of the transmitted signal without attenuation (in fact it has ether space for several television transmitters operating simultaneously on adjacent channels). A second achievement is the picture projection equipment recently demonstrated in New York by the Baird firm of England. This apparatus is capable of producing a 9- by 12- foot picture of quality fully the equal of that possible with a conventional picture tube, and with sufficient brightness to avoid eyestrain (although not as bright as a movie projection). This is not a gadget for the home, as yet, because the second anode voltage used is 50,000 volts at several hundred microamperes. Finally, attention should be drawn to the outstanding work being done at Schenectady by the General Electric Engineers on their new television transmitter. This transmitter, will deliver a peak power (tips of the sync pulses) of 40 kilowatts (corresponding to a carrier power of 10 kilowatts) or about four times as high as any one has been able to do thus far. One of the secrets of this high power is a new transmitting tube. The anode shell of this tube is bent back upon itself, so that its length is greatly shortened without reducing the surface available for cooling. Hence the tube retains a high power rating with low interelectrode capacitances. The G. E. station is remarkable also for its successful use of low-level single-sideband modulation, and for the fact that the signal is modulated at the studio, and thereafter not demodulated but carried through all successive steps as a modulated carrier wave. When this transmitter is completed and demonstrated to the engineering world, it may have a decided effect on the designs of the future. Fig. 33 is one of the finest photographs of a television image ever taken in this country. It was taken by Bill Haussler of NBC (who has taken more television pictures than anybody else in the world) from the monitor screen, (from a model, not from a photograph). The picture has truly remarkable detail, contrast, tonal gradation, and I think you will agree—the subject is worthwhile.

The author wishes to express his appreciation for the cooperation of the NBC engineering staff, to Major Lenox Lohr, President of the NBC for permission to use some of the illustrations from his forthcoming book "Television Broadcasting," to the McGraw-Hill Book Company for permission to use illustrations from the author's forthcoming book "Principles of Television Engineering" and to Mr. & Mrs. Keith Henney for their help in preparing some of the slides illustrating photographic quantities.

Fig. 33—Televised image of excellent photographic (and pictorial) quality.

From the laboratories of the pioneer . . . . .

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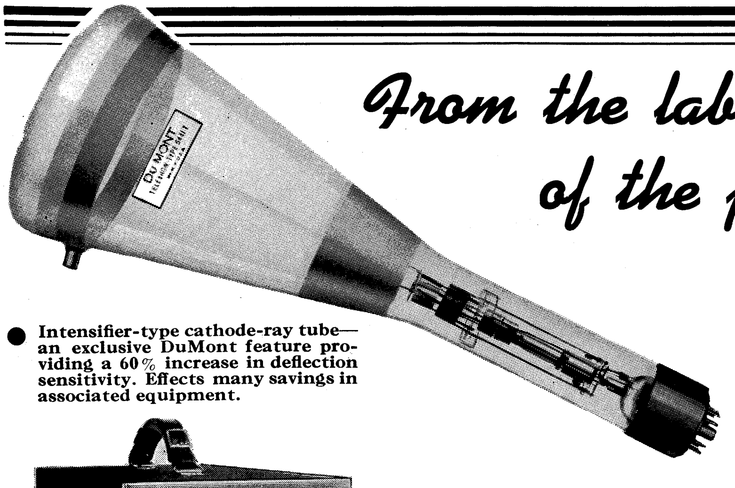
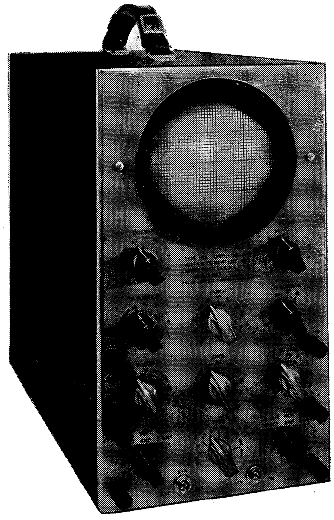
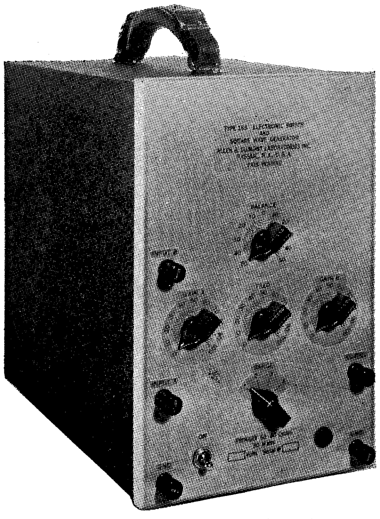


- Intensifier-type cathode-ray tube—an exclusive DuMont feature providing a 60% increase in deflection sensitivity. Effects many savings in associated equipment.



- Popular DuMont service-type cathode-ray oscillograph, providing maximum usefulness at a within-reach price of the average serviceman.



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TUBES AND OSCILLOGRAPHS

DuMont cathode-ray tubes are now available in many types and sizes. These tubes incorporate several exclusive features, such as the DuMont intensifier electrode. The DuMont 14-inch Teletron is the largest television image tube in regular production today. DuMont cathode-ray oscillographs are also available, ranging from inexpensive service instruments to the finest laboratory types, meeting every purpose.

PRACTICAL TELEVISION

The DuMont television receiver was the first commercial cathode-ray television receiver to be made generally available in the U.S. Today DuMont offers several popular types of television receivers—table and console models, either direct-view or reflected-image type, with all-wave radio receivers. DuMont also designs and manufactures complete television transmitting equipment, including synchronizing-signal generators, cameras, film-pickup equipment, and monitoring equipment.

SPECIAL APPARATUS

Over the entire world, DuMont special as well as standard cathode-ray equipment is now at work. Used by governments, many industries, in laboratories and production, and in research activities, DuMont equipment is opening up many new fields and possibilities.

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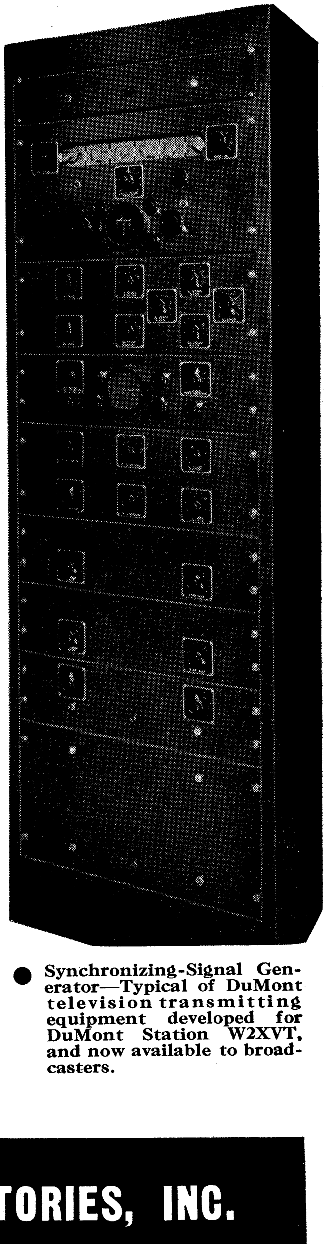

- Synchronizing-Signal Generator—Typical of DuMont television transmitting equipment developed for DuMont Station W2XVT, and now available to broadcasters.

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