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Technological Boundaries of Television

VOLUME 2 Simulated TV Displays of Different Size & Sharpness

TECHNOLOGICAL BOUNDARIES
OF TELEVISION
VOL II
SIMULATED TELEVISION DISPLAYS
OF DIFFERENT SIZE & SHARPNESS

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PICTURES BY

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INTRODUCTION

It is impossible to convey in words the impression that a wider screen or a greater number of scan lines is likely to produce on viewers of television. Picture demonstrations of such changes are required. The Eastman Kodak Company has kindly contributed to filling this need by providing the illustrations in this volume. These pictures were produced by a scanning system that can modify photographs in a variety of ways. Specific changes in format, number of scan lines per picture height, luminance contrast, modulation transfer function, chromaticity reproduction, noise, and in various other physical characteristics can be introduced.

This equipment is normally used in basic studies of the relation between the physical characteristics of the images and the subjective reactions[1-3] of the persons who view the images. One of the findings, which is applicable to television as well as to photography, is that the subjective attribute known as image sharpness is predictable from the modulation transfer function (MTF), noise spectrum, and contrast of the image, the viewing distance, and the MTF of the observer's vision.[4] A simpler criterion[5] involving only the image MTF, the viewing distance, and the visual MTF is, however, more commonly used and is very satisfactory when the noise is low and the contrast is normal. In the Appendix of this volume, modulation transfer data and image sharpness values are given for the imaging systems illustrated here.

In the application of this scanning equipment to the simulation of television images, certain problems were encountered which initially were thought could be overcome. In the course of the work it was found, however, that some radical redesign of the equipment would be needed to achieve simulation in all details. The pictures produced achieved nevertheless almost all the effects sought. Items which were not effectively simulated include scan-line profiles of the type that are generally seen on television receivers, certain edge effects often present in television, interlace errors, ghosts, and high resolution (1100 scan lines) with color. The latter problem occurred largely because of the loss of resolution in certain additional stages required to make color simulations in a format suitable for producing many copies.

The details of the equipment and the data on the simulations that follow are given in the Appendix of this volume.

Figure 1 shows four simulated television black-and-white displays which differ from each other in sharpness. They are identified by the number of scan lines per picture. The scan line profiles are of the type that blend, and the lines are not visible. Image noise (snow) was purposely kept very low. The number of scan lines varies from 525 to 1100. One picture corresponds to the 625 lines used in Europe.

The reader can judge for himself how significant is the difference in sharpness as he compares each picture with the others. He should judge the sharpness of the picture as though he were looking at a television program. And, as indicated in the instructions given on the page opposite the pictures, he should judge only the foreground detail; the background is out of focus.

In the Appendix it is explained that the perception of sharpness generally decreases with age. Trial presentations of this set of four pictures to a number of persons clearly showed the effect of age, although some of the older persons proved to be very sensitive to the differences in sharpness.

Table 2 in the Appendix shows calculated values of sharpness for each of the four systems illustrated by these pictures and, for comparison, gives the sharpness values for several well-known film systems marketed by the Eastman Kodak Company. It also expresses the sharpness results on a category scale by means of the terms "excellent," "very good," "good," "fair," and "poor."

The physical characteristics of the four television systems illustrated in Fig. 1 were specified by the late Eric Leyton of RCA. They are described in Fig. 1A and Table 1 of the Appendix.

Figures 2a and 2b were prepared to give some indication of the impact of a wide screen, 2½ x 5 feet, in a home compared with today's large television screen having a 25-inch diagonal.

Displays of such large size are beginning to be available by projecting the pictures produced by a specially designed television tube (price $2,000 to $2,500). The ideal flat screen display with 1100 lines or more is not available, but may be expected in the future -- perhaps some ten years from now.

Figure 3 is shown to indicate the potential of a large screen for the presentation of sport. If the reader can look at that picture from a distance of twelve inches or so, and imagine the scene in action instead of still, he may be able to sense the extent to which he could have the feeling of being in the scene rather than looking in from the outside.

The number of lines for this picture is the NTSC number of 525. For such large screens at short viewing distances the number should be 1100; the difference would be very noticeable at such distances. It is of interest to note, however, that the resolution with 525 lines produces an acceptable picture.

Figure 4 is similar in purpose to Fig. 3 except that it compares directly a 1100-line large screen with a current 525-line 25-inch diagonal screen. The size of the men is the same in both the pictures shown.

Figure 5 shows the effect of the number of lines on the display of text. These two pictures show clearly that an 8½ x 11 inch page of ordinary type cannot be satisfactorily displayed with 525 lines. 1100 lines appears to be very satisfactory.

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2. Theory and Methods of Scaling, W. S. Torgerson, John Wiley & Sons, Inc., New York, N.Y. 1958.

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SIMULATION OF TELEVISION IMAGES

View the images in Fig. 1 at a distance chosen from this table. It applies to a television screen with a 25-inch diagonal.

TV Viewing Distance	Page Viewing Distance
4 feet	11 inches
6	16.5
8	22
10	27.5

USE ONLY THE FOREGROUND OF THE PICTURES FOR JUDGING IMAGE SHARPNESS

Fig. 1. (Adjoining page.) Simulations of 15x20-inch television images (25-inch diagonal). The modulation transfer functions (MTFs), other physical characteristics, and calculated sharpness values for the systems simulated are given in the Appendix. Sharpness is a subjective quantity that depends on the MTF of the image, the viewing distance, and the MTF of the observer's vision. The visual MTF varies from person to person and generally depends on the person's age.

525 lines, TV Monitor

625 lines, Monitor

525 lines, Home TV

1100 lines, Monitor

Fig. 1

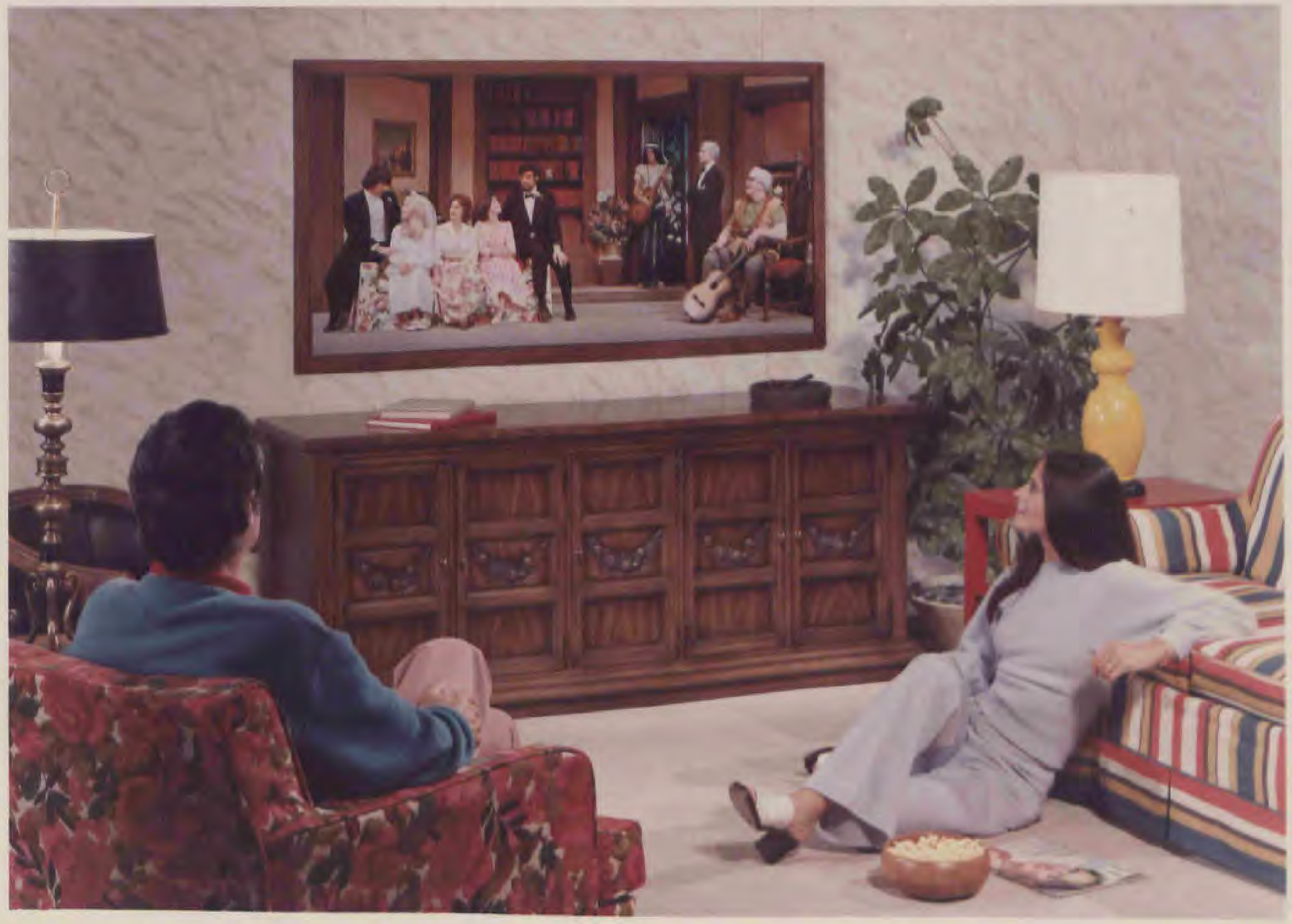


Fig. 2a. Viewing TV in the home. Potential effect of a wide screen (2.5 x 5 ft).
1100 lines

Fig. 2b. Viewing TV in the home. Present day 15 x 20 inch screen.
525 lines

2.5 x 5 ft. screen

525 lines

Fig. 3 Overview of baseball field.

TV Viewing Distance	Page Viewing Distance
6 feet	11 inches
7	12.5
8	14.5
9	16
10	18

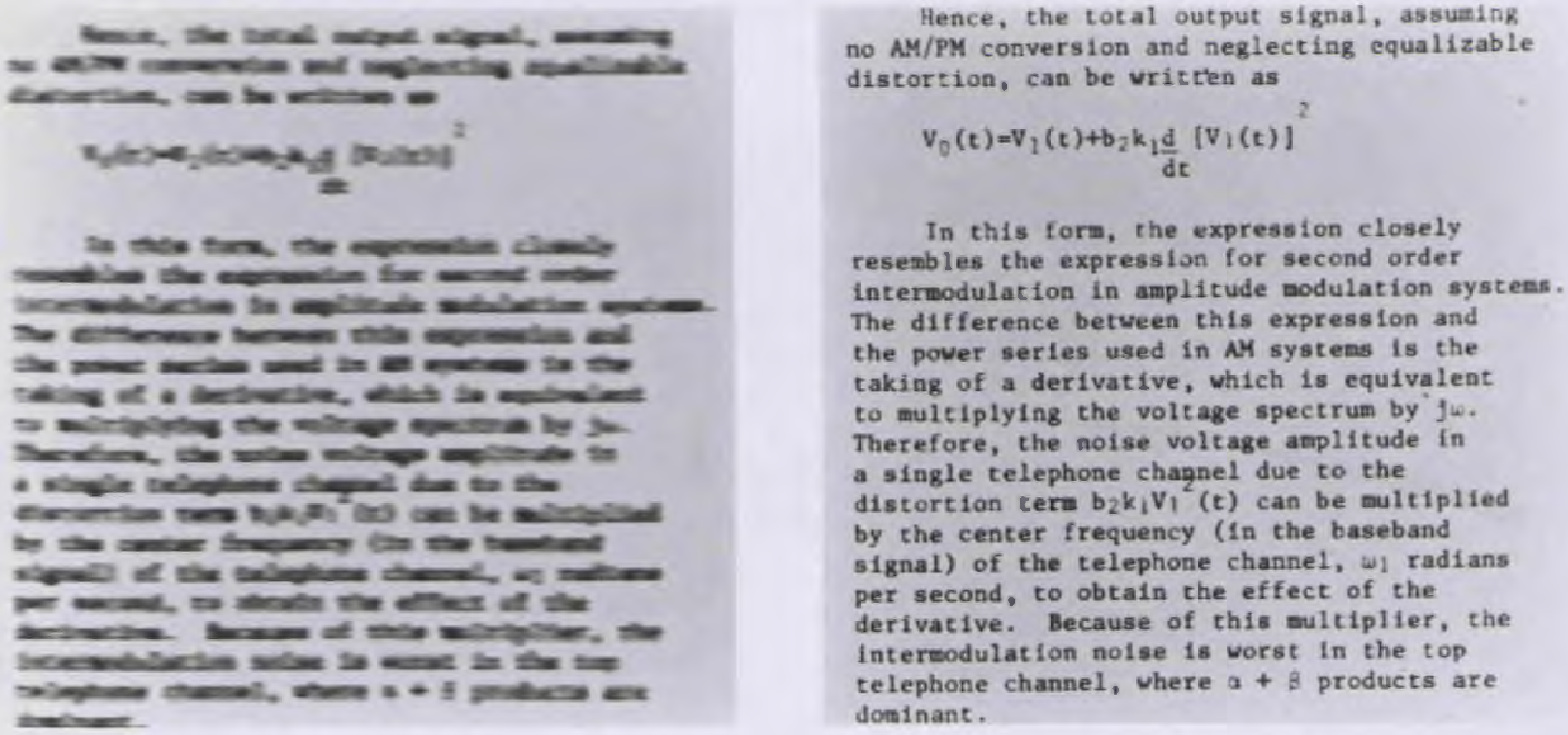
2.5 x 5 ft. screen

1100 lines

15 x 20 inch screen

525 lines

Fig. 4. Wide screen vs normal display of baseball game.



525 lines **1100 lines**

Fig. 5. Simulated TV display of text. These 24 lines of text* occupy one third of the screen height. An 8.5 x 11-inch page of text of this size would occupy seven-tenth of the screen height. 525 scan lines per screen height corresponds to 4 lines per capital letter height; 1100 scan lines per screen height corresponds to 8.5 lines per capital letter height.

*** Written by typewriter (letter height: 0.1 inch)**

APPENDIX

Image Sharpness and Modulation Transfer Functions

Image sharpness is an important component of image quality. Increasing the number of scan lines in a television image, for the purpose of improving the sharpness, involves a costly increase in the frequency bandwidth of the system. Such a change would not be worthwhile unless the improvement in sharpness and quality were substantial and readily apparent to most viewers.

It is of interest, therefore, to determine as accurately as possible the magnitude of the gain in sharpness that could be achieved by means of certain increases in the number of scan lines per picture. The pictures in the main body of this volume provide direct demonstrations, without sharpness numbers, of the consequences of such changes. This Appendix provides sharpness numbers and descriptive categories of sharpness that have been determined from the physical characteristics of the imaging systems considered. Three different viewing distances were assumed for the sharpness calculations.

It was necessary to take account of the fact that the number of scan lines per picture is, by itself, not a satisfactory indicator of sharpness. At the normal viewing distances, the human eye gives greater weight to the intermediate spatial frequencies in a television image than to the frequencies lying at or near the upper limit of resolution set by the number of scan lines. The subjective perception of sharpness is related to the brightness gradient across the edges in a picture. Each edge contains a wide range of frequencies, including low frequencies. Reducing the contrast (modulation) at any frequency within the visual range of frequencies lowers the sharpness. For this reason, the modulation transfer function (MTF) of the image is more appropriate than the number of scan lines per picture as the basis for calculating image sharpness.

The MTF can be defined as the response of the system to an input consisting of sine-wave light patterns of constant amplitude with different spatial frequencies. The ratio of the output amplitude to the input amplitude at any given frequency is the modulation transfer factor at that frequency, assuming that the gamma or low-frequency contrast of the system has been adjusted to unity.

The relation between image sharpness and the modulation transfer function has been studied intensively for more than a decade. Psychological scaling procedures[1-3] were used in which a number of observers made subjective evaluations of the sharpness of photographs having measured MTFs that varied widely in magnitude, shape, and extent. Excellent correlations were found to exist between the subjective ratings and the predictions of sharpness obtained by integrating the product of the MTF of the image and the MTF of the observer's vision, the frequency scales of the image MTF and the visual MTF being related in accordance with the viewing distance. This criterion[5] applies when the image noise is low and image gamma is normal. The effect of changes in noise and gamma can be taken into account by means of a more elaborate criterion.[4] Because psychological scaling of images is a slow and laborious process, image sharpness values are now usually obtained by measuring the MTF and applying one of these criteria. This procedure was used here. Because the noise was low and the gamma held constant, the simpler of the two criteria was applied.

The MTFs for the systems considered in this volume were provided by the late Eric Leyton of the RCA Research Center at Princeton, N. J. These MTFs are plotted in Fig. 1A of this Appendix. The uppermost graph, labeled 525-line Home TV Receiver, gives the data for present-day television images displayed on a receiver that is assumed to be somewhat out of adjustment, as is typical of an average home receiver. The Y function MTF applies to the luminance component of the image, which is the pertinent MTF for sharpness calculations. The I and Q functions apply to the color information. The graph labeled 525-line Station Monitor represents present-day television with a high-quality monitor receiver in good adjustment. The graph for the 625-line Station Monitor represents approximately a system which is available in Europe. The graph labeled 1100-line Station Monitor represents a system that is not available, but it presumably could be built on the basis of current knowledge and technology.

The MTF for average human vision for a viewing distance of five picture heights is shown as the solid curve in the graph at the bottom of Fig. 1A. Because the visual MTF varies from person to person and tends to depend on age, a range of visual MTFs is indicated by the dotted lines.

An exaggerated form of crispening is sometimes used in television, and it could have been introduced in the specifications for the 525-line systems as a means of increasing their sharpness relative to that of the other systems. This change would be indicated by an MTF that rises above 1.00 at some intermediate frequencies. It would provide an undesirable type of compensation for the relatively low resolution of the 525-line systems. The subjective effect has long been known to be unpleasant. Furthermore, this kind of crispening could also be specified for the 625 and 1100-line systems, which would nullify any advantages obtained for the 525-line systems. The MTF for a camera lens gradually slopes downward and lies below the MTF for a TV system at the low and middle frequencies. Compensation of the MTF of the lens or any other component MTF by means of electronic enhancement in a TV system is a favorable kind of crispening when it brings the system MTF to values not greater than 1.00. The MTFs for the television systems specified here can be thought of as having the favorable rather than the unfavorable kind of crispening.

Various other physical characteristics of the 525, 625, and 1100-line systems were also specified by Mr. Leyton. They are given in Table 1. The specifications for the 525-line Home TV Receiver were not included in the data submitted by Mr. Leyton, but were developed later during telephone conversations with him.

Table 2 gives the calculated sharpness values obtained by applying the sharpness criterion[5] to the television MTF data of Fig. 1A and to the MTF data for several familiar film systems marketed by the Eastman Kodak Company. Sharpness is expressed on a 0 to 100 scale. A just noticeable difference (JND) on this scale is slightly greater than one unit. A sharpness of 100 has the significance that it would be obtained for an image with an MTF of 1.00 at all spatial frequencies lying within the frequency range of the eye. Such an image would appear to be as sharp as the original subject.

Table 2 also gives categorical ratings of sharpness in terms of "excellent," "very good," "good," "fair," "poor," and "very poor." The categories were established by asking many observers with normal vision to express their opinion about images for which the sharpness numbers had been determined.

As Table 2 shows, the four television systems differ significantly in sharpness at the short and medium viewing distances. At the longer viewing distance, they become

MODULATION TRANSFER DATA

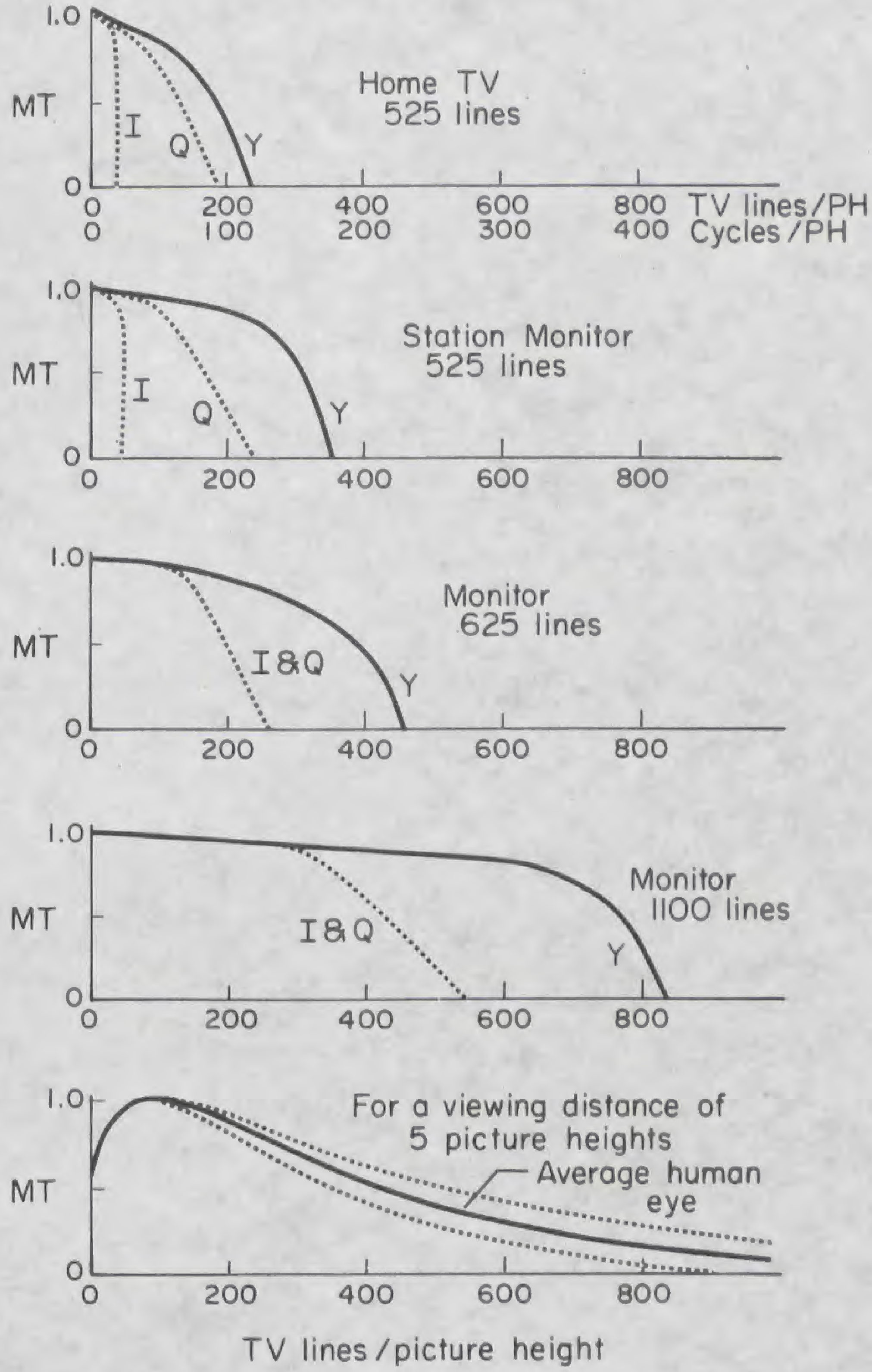


Figure 1A

Table 1

Characteristics	525 Lines M/NTSC System	625 Lines 6,6,6 System	1100 Lines 6,11,20 System
Channel Width	6 MHz	8 MHz	24 MHz
Video-Audio Carrier Spacing	4.5 MHz	6.5 MHz	22 MHz
Nominal Video Bandwidth	4.2 MHz	6 MHz	20 MHz
Frame Rate	30 Hz	30 Mz	30 Hz
Frame Duration	33.333 ms	33.333 ms	33.333 ms
Number of Lines	525	625	1125
Line Duration	63.5 µs	53.333 µs	29.6 µs
Number of Active Lines	483	581	1045
Duration of Active Portion of Each Line	52 µs	43.73	24.3 µs
Max. Video Cycles Per Line	208	262.4	486
Vertical Resolution (0.7 Kell Factor)	338	406	731
Horizontal Resolution (TV lines per picture height)	312	393.6	729

(Data from Eric M. Leyton, RCA Research Center, Princeton, N.J.)

Table 2

Imaging System	Image Sharpness at Three Viewing Distances		
	D = 2.5H	D = 5H	D = 10H
Television			
525-line Home TV Receiver	61(Poor)	77(Fair)	90(Very Good)
525-line Station Monitor	69(Poor)	84(Good)	94(Very Good)
625-line Station Monitor	73(Fair)	87(Good)	96(Excellent)
1100-line Station Monitor	88(Very Good)	95(Excellent)	99(Excellent)
Film and Optical Projector			
Super 8 Motion Pictures	66(Poor)	80(Good)	90(Very Good
16mm Motion Pictures	82(Good)	90(Very Good)	96(Excellent)
35mm Motion Pictures	91(Very Good)	97(Excellent)	99(Excellent)
35mm Slides	95(Excellent)	99(Excellent)	100(Excellent)

Note: The viewing distances, D, are expressed as 2.5, 5, and 10 times the picture height, H. If the television images are 15 x 20 inches, for example, their viewing distances would be about 3, 6, and 12 feet. If the film images are 3 x 4 feet, their viewing distances would be 7.5, 15, and 30 feet. The film used for these calculations was Kodak Kodachrome II Film (ASA Speed = 25). The film was assumed to be used in the camera, reversal processed, and then (without being printed on a duplicating film or used in a TV system) projected directly on a white reflecting screen.

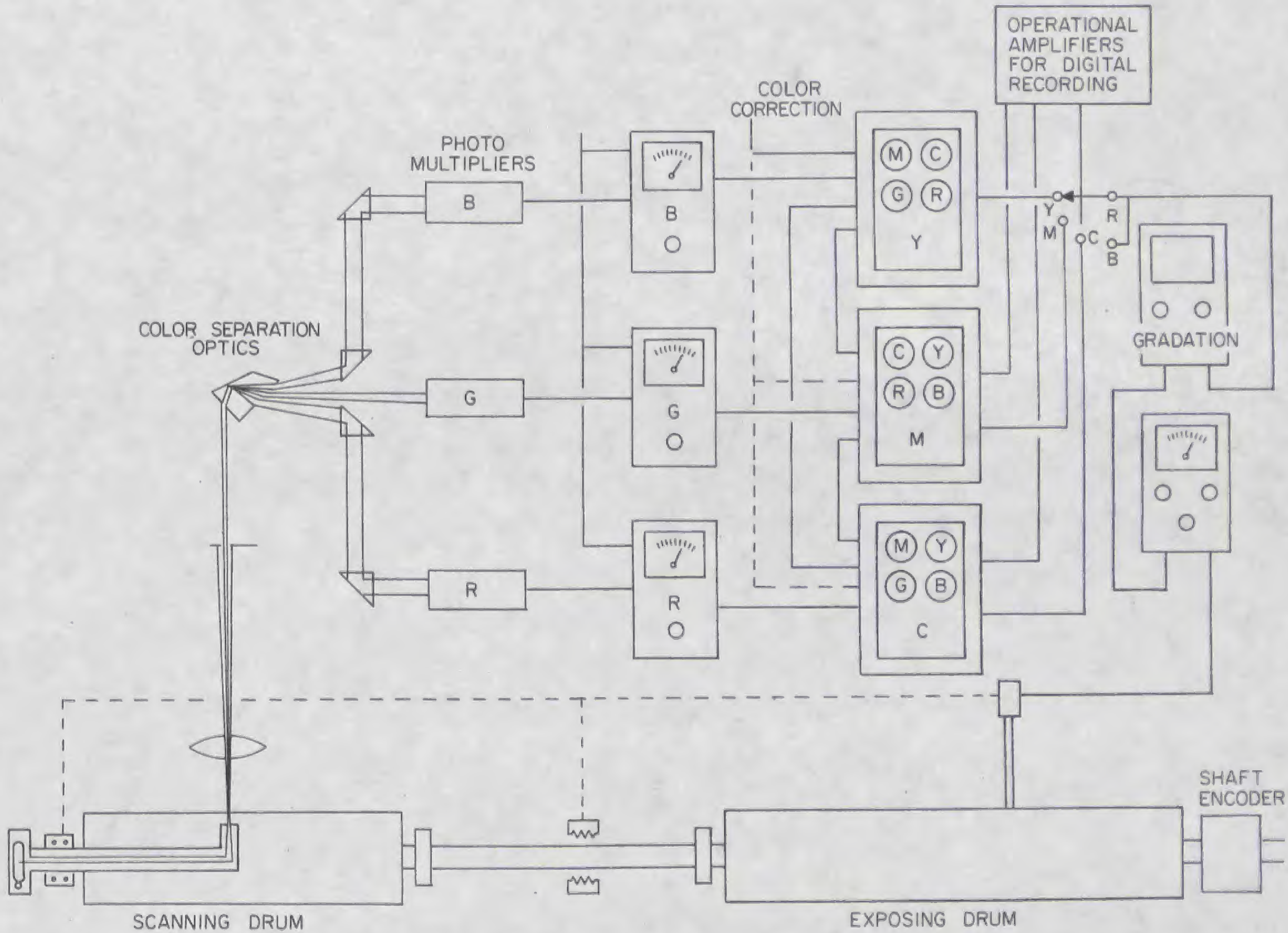
almost alike subjectively. The human eye is the limiting component at the long viewing distances.

Equipment Used to Produce the Simulations

The photographs in this volume were produced with the aid of a graphic arts scanner-printer: the K.S. Paul Color Scanner. This instrument, which is shown schematically in Fig. 2A, is a mechanical-optical scanner with associated electronics designed for use in the production of color corrected separation negatives or positives.

The instrument scans a transparency positioned on the clear scanning drum with an effective circular aperture diameter of 38 μm or (0.0015 inches). The scanning is accomplished by simultaneous rotation of the reading (scanning) and exposing drums and the translation in unison of the reading and exposing optics. The drums are interconnected by a lead screw. A carriage containing both sets of optics is connected to this lead screw through a set of nut jaws which traverse the lead screw as the drums rotate. Lead screws providing 1000, 500, and 250 lines to the inch are available.

The light transmitted by the transparency is divided by color separation optics into blue, green, and red components which modulate a 100 kHz carrier imposed upon each photomultiplier. The modulated photomultiplier signals go to their respective input units where they are amplified, logged and rectified. Both positive and negative D. C.



OPERATIONAL AMPLIFIERS FOR DIGITAL RECORDING
COLOR CORRECTION
PHOTO MULTIPLIERS
B
B
M C G R
Y
Y R M C B
G
G
C Y R B
M
GRADATION
COLOR SEPARATION OPTICS
R
R
M Y G B
C
SHAFT ENCODER
SCANNING DRUM
EXPOSING DRUM

Figure 2A

voltage signals are used for color correction. The D.C. voltage from the color correction units are scaled by operational amplifiers to match the voltage levels required by an analog to digital converter and sequencer which digitizes the voltage levels to 256 digital values representing densities. The digitized data is formatted by a small general purpose computer and recorded on magnetic tape for modification by a larger computer. The modified data is then played back and recorded on film as a separation negative or positive.

The heights of the transparencies scanned were chosen so that the required number of scan lines were included to simulate the vertical resolution of the 525-line, 625-line, and 1100-line television systems. The horizontal resolution was simulated by operating on the recorded picture information along the scan line by transforming to the Y, I, and Q space and introducing the modulation transfer characteristics of the Y, I, and Q channels, transferring back to R, G, and B space, and making separation positives that were register printed onto Kodak Ektacolor negative material at the size desired for the prints in the report. The black and white positives were made from the green signal and printed onto Kodak Commercial film at the size desired.

Acknowledgment

Mr. S. J. Campanaro took the original photographs used as the basis for Figures 1 through 4. The modifications of the photographs were made by Mr. R. S. Mickelson, Mr. N. R. Nail, Mr. N. H. Glaser, and Mr. E. T. Murphy.

References

See the references given in the INTRODUCTION.

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