U.S. Department of the Interior

U.S. Geological Survey

Image Production Equipment and Procedures

by

Joseph S. Duval

Open-File Report 82-534
1982

Image Production Equipment and Procedures

by

Joseph S. Duval

INTRODUCTION

The USGS Denver image-production equipment consists of three Optronics[1] film writing machines. The first of these machines to be acquired is capable of writing on or digitizing from black and white film and digitizing from color film. The second machine acquired is designed to write on color film and the third is capable of writing on either color or black and white film. These machines are used to convert digital data into black and white or color images. Any type of data that can be put into the format required by the machines can be used. The purpose of this report is to describe the operating principles of the machines, characteristics of the film used, and quality control considerations. For descriptive purposes the machines will be designated as the old black and white (BW) machine, the old color machine (CO), and the high speed color (HSCO) or high speed black and white (HSBW) machine.

OPERATING PRINCIPLES

The Optronics film writing machines are raster plotting devices which use photographic film or paper as a plotting medium although paper is seldom used at the USGS Denver facility. The photographic material is mounted on a cylindrical drum which rotates at a fixed number of revolutions per second. A raster line of data is written on the film during a revolution of the film drum and the raster line position is changed by moving a light focusing mechanism along a rod which is parallel to the axis of rotation of the film drum.

The data to be displayed in an image form are expected to consist of measurements of some parameter from points or areas that are contiguous in an x-y coordinate system. These data are ordered as successive rows of measurements and data that are adjacent on sequential rows are assumed to be contiguous in space. If the original data do not meet these requirements, artificial data points must be inserted to obtain a geometrically correct image. Each data point represents a picture element (pixel) and each row (raster line) is called a scanline. Pixels are square and can be selected to have side dimensions of 25, 50, 100, or 200 microns. Figure 1 illustrates the layout of a data set.

Before the data can be written on film they must be rescaled into the range of integer values from 0 to 255 which corresponds to the range of values that can be represented by an 8-bit binary number. The choice of the data range is related to the fact that the use an 8-bit binary number permits maximum efficiency for data storage on 9-track magnetic tapes. Other factors such as the properties of photographic materials and the ability of the human eye to discriminate shades of colors are also important. Each logical record on a tape corresponds to a scanline of data. Because the data are to be written on film with a variable film density , the data values will be designated as density numbers (DN's) for the purposes of this paper.

Exposure of the film is accomplished using an appropriate light source. The light sources for the color machines are gaseous glow tubes which produce a light flux directly proportional to the voltage applied to the tube. The light sources for the black and white machines are light emitting diodes (LED's) which also produce a light flux directly proportional to the voltage applied to them. Because of their small size the LED's are mounted on the carriage that moves the light focusing mechanism which assures a constant light intensity along the axis of the film drum if the DN value is constant. The glow tubes are large compared to the LED's and are mounted in fixed positions at one end of the machines. Because the glow tubes are in fixed positions, the light from them must be collimated and focused to produce a beam of light parallel to the axis of the film drum. The beam of light is reflected by a beam splitting mirror on the focusing mechanism such that part of the light passes through the lens onto the film. The remaining light shines on a light detector which measures the intensity of the light. This detector is part of a feedback loop designed to keep the light intensity for a given DN value constant along the length of the film drum.

The film exposure is controlled by controlling the voltage applied to the light sources and the length of time that the voltage is kept constant. In the case of the black and white machines the exposure time is constant and approximately equal to 10 microseconds. The exposure time of the color machines is dependent upon the rotation speed of the film drum and the ratio of exposure times at different drum speeds is equal to the ratio of the speeds. The relationship between the DN's and the voltages applied to the light sources is determined by an anti-logarithmic amplifier and the equation governing the relationship is of the form:

(1) $$V = A e^{-N} + B$$

where V is the voltage, N is the DN value, A is a scaling factor, and B is a zero level adjustment normally equal to zero.

FILM CHARACTERISTICS

Black and white film

Black and white film normally consists of a film base (usually a cellulose ester - commonly triacetate or acetate-butryrate (Jacobson and others, 1978)) with one or more emulsions made of silver halide crystals suspended in gelatin. The BW and HSBW machines use a 10 inch by 10 inch sheet of Kodak 2476 black and white film which has three emulsion layers designed to extend the sensitivity of the film over a greater range of light intensity than a single emulsion would provide. The choice of film type was governed by the fact that the LED's emit red light, and the film size is the maximum size that can be used, although the film drums can be modified to accept other sizes. The emulsions are sensitive to red light and exposure to light produces a latent image of the light source. Development chemicals are used to make the image visible. See Jacobson and others (1978) for complete details on the development process.

The effects of the film exposure and development can be quantified by comparing the relationship between the intensity of light incident on the developed film and the intensity of the light transmitted through the film. One such relationship is called the opacity and is calculated as the ratio of the incident light to the transmitted light. Because the response of the human eye to light is approximately logarithmic (Jacobson and others, 1978), the film density (D) defined as the logarithm of the opacity is a more appropriate parameter to use.

The film exposure is another useful parameter and is calculated as the exposure time multiplied by the light intensity (flux). A characteristic curve for the film can be defined as the relationship between exposure and film density. Because a characterstic curve of film density versus exposure increases rapidly and approaches an asymptotic value, a more convenient curve for film characteristics is the density versus the logarithm of the exposure. These curves are commonly called DlogE curves. Figure 2 presents a curve of density versus DN for a film exposed using the HSBW. This curve is equivalent to a DlogE curve because the light intensity used was proportional to the antilogarithm of the DN.

The minimum film density achievable is determined by the light transmission properties of the film base. The maximum film density is a function of the development chemicals and developing time. The maximum film density increases as the developing time increases; however, the minimum film density also increases as the developing time increases. Usually developer chemical activity must be modified to achieve desired results for minimum and maximum film densities with reasonable development times.

Color reversal film

Color reversal film has a film base similar to film bases used for black and white film. The color film, however, has three emulsion layers each of which is designed to be sensitive to a different part of the visible light spectrum. The CO and HSCO machines use an 8 inch by 10 inch sheet of Kodak SO-278 film. The size choice was governed by the fact that 10 inch by 10 inch sheets increased the cost significantly and 8 inch by 10 inch sheets are large enough to meet most of our needs. The choice of film type was based upon a desire to operate the machines at the highest possible drum speed, and because increasing the drum speed decreases the film exposure, the available film with the greatest sensitivity to light was chosen. Other film types with greater light sensitivity are now available in sheet format. Figure 3 presents a schematic representation of color film. The yellow filter layer shown is needed to prevent blue light from exposing the red and green sensitive emulsions.

The development of color film is complicated and the reader is referred to Jacobson and others (1978) for complete details. For our purposes we only need to know that the film is first processed in a black and white developer which develops the latent images in the emulsions and determines the maximum film density of the developed film. Contrary to the effects on black and white film, longer developing times result in lower values for the maximum film density. Lower film densities mean greater light transmission and the overall result is that the image appears brighter and colors become more pastel. Using longer black and white development times is called "push processing" the film. One stop push processing (ideally) results in a 0.3 decrease in the maximum film density and two stops (ideally) causes a 0.6 decrease for color reversal film using E6 processing. In practice, one stop push processing is done by using twice the normal development time in the first developer and two stops uses three times the normal time. The definition of normal processing is based upon test developing strips of film provided by a film manufacturer. These strips contain neutral density step wedges for which the ideal film densities are known as a result of measurements on a calibration strip. The film processor adjusts the process chemistry to match the ideal film densities within acceptable limits (in most cases the limits are 0.09 above or below the ideal value).

Because we are using a color film, the measurement of film densities is done using appropriate filters to restrict the light to the red, green, and blue parts of the spectrum. An additional filter which is a nonselective neutral filter is also used and is called a visual filter. By design neutral colors are produced when the film densities measured with each of the four filters are approximately the same. Figure 4 presents the film densities measured using the red, green, and blue filters to measure red, green, and blue images, respectively. The visual film density was measured on a grey (neutral color) image. Figure 5 presents the visual film density measured on grey images which were processed normal, push one stop, and push two stops. The straighter portions of the curves in Figure 5 are approximately parallel which means that push processing to two stops does not significantly degrade the response function of the film. Push processing can affect the granularity of the film; however, examination with 10X magnification of films processed normal, push one stop, and push two stops did not show any visually significant differences.

QUALITY CONTROL CONSIDERATIONS

Black and white film

Quality control for black and white film consists of two separate parts -- control of the film processing and control of the image production machines. Film processing is controlled using grey step wedges produced by exposure of the film with a calibrated light source. Identifiable points in the step wedge are required to have film densities within 0.09 of fixed values. Whenever these requirements are not met, the chemistry must be modified. The control procedures used are given in detail by Eastman Kodak Company (1973). These step wedges are also put on test films used to examine the performance of the machines to provide a measure of the quality of the film processing which is separate from the normal process control done by the technician operating the film processing equipment. An average characteristic curve for the step wedge was defined by processing a number of films with the calibrated step wedge. This average curve was then taken as the standard against which a calibrated step wedge could be compared as an independent check on the process control. Table 1 lists values of a goodness of fit parameter calculated as the sum of the squares of the deviations from the standard curve divided by the number of measurements. Values greater than 0.01 indicate a problem with the processing.

Control of the image production machines begins with an examination of the focus of the image. Because of their physical properties the LED's can be turned on and off in a time interval (approximately 10 microseconds) that is short compared to the time needed for a point on the film drum to rotate more than a few microns. As a result each pixel of a properly focused black and white image can be seen as a distinct square when appropriately magnified. If the pixels are distinct and have sharp edges under 10 power magnification, the focus is correct. Figure 6 shows a properly focused image with a magnification of approximately ten. Other problems such as dust or fibers on the pixel collimation slits can cause distortions in the pixel shapes and may cause the user to think that the focus is incorrect.

Proper exposure is tested by comparing a characteristic curve to a standard curve established as the mean of a number of curves judged to be acceptable. A goodness of fit parameter is calculated as the sum of the squares of the deviations from the standard curve divided by the number of density measurements. Table 2 presents some results of these measurements for both the BW and HSBW machines. Values greater than 0.01 indicate that the exposure is not correct.

Color film

Quality control for color film also involves the film processing and the image production equipment. Because the film is processed at a commercial facility, we can only monitor the processing. This is done in the same way it is done for the black and white film. Step wedges are put on the color film using the calibrated light source. We can then calculate an average curve for the film densities of the step wedge using a number of films processed in a short period of time (one month) and compare additional curves to the average curve. When doing this type of comparison, it is imperative that all of the film be from the same manufacturing batch. Table 3 presents some results of measurements comparing the step wedges for one stop push processing of the film. Values greater than 0.01 indicate a problem with the film processing.

The focus of the color images is more difficult to adjust than the focus of the black and white images because distinct pixels cannot be distinguished except where adjacent pixels are significantly different in color or shade. The lack of distinct pixels is caused by the fact that the glow tubes cannot change intensity levels as rapidly as the LED's. The color image production machines can be checked for proper focus by examining places on the image where the exposure changes from minimum to maximum and back to minimum. The boundary between the light and dark pixels should be relatively sharp and under 10 power magnification should not appear fuzzy.

Proper exposure of color film involves not only intensity but also color balance. If the film densitometer being used is designed to provide what is denoted as Status A densitometry, color balance can be defined as being satisfied if the red, green, blue, and visual film densities are equal (Jacobson and others, 1978). Any deviation from that condition can be easily measured. A goodness of fit parameter can, however, be misleading because the maximum film densities of the red, green, and blue measurements can differ significantly. This difference may be related to the basic design of the film as well as to the manufacturing process. Another factor to be considered is the fact that experience has shown that most observers cannot distinguish moderate (0.3-0.5) changes in film density for values greater than 2.0. For these reasons graphs of the deviation from the ideal are used to judge the adequacy of te color balance. Figure 7 presents example curves for testing color balance. Ideally all three curves should follow the dashed lines that represent a "perfectly" neutral color (the ideal values are equal to zero and the curves have been offset for clarity). If one of the curves is above the line, light intensity of that color is too high relative to the other colors. Conversely, values below the dashed line indicate that the light intensity is too low relative to the other colors. Within limits the intensity of the light for each color filter can be adjusted and a fault light blinks if the limits are exceeded. We are currently using the criteria that the color balance is adequate is all of the film density curves are within 0.1 of the ideal value. The limit of 0.1 is based upon the limits used at the commercial film processing laboratory and the results to date have been subjectively judged to be satisfactory. Given the machine configurations and the film type and processing being used, I have found that above a DN of about 150 the curves are not critical because the film density produced by the conditions of exposure and processing is such that the colors are too dark to be discriminated. Checks on intensity levels are done in the same way the black and white checks are done using visual film density measured on grey step wedges. This procedure is adequate provided the color balance is good. Table 4 presents the results of these intensity checks for both the CO and HSCO machines. Values greater than 0.01 indicate a problem with the overall intensity of the exposure.

SUMMARY AND CONCLUSIONS

One important property of an image processing laboratory should be an ability to reliably reproduce images from digital data with predictable results. An essential element in this ability is a quality control program designed to test both the image writing machines and the film processing. Film processing can be monitored by using a calibrated light source to put step wedges on test film as described above. The performance of the machines can be checked using color or neutral color step wedges as described above. Used properly these quality control procedures are adequate to test and maintain an image processing laboratory. The control limits given in this paper are based upon the subjective judgement that film products produced within those limits do not exhibit any visual differences that significantly affect the usefulness of the products.

REFERENCES

Eastman Kodak Company, 1973, Process monitoring of Kodak black & white films: New York, 36 p.

Jacobson, R.E., Ray, S.F., Attridge, G.G., and Axford, N.R., 1978, The manual of photography: London, Focal Press, 628 p.

FIGURE CAPTIONS

Figure 1. Schematic diagram of data set used for image production.

Figure 2. Visual film density versus the input DN for a black and white film.

Figure 3. Schematic diagram of the essential elements of a color film.

Figure 4. Film densities measure on a colored film. Red, green, and blue densities were measured using red, green, and blue filters on red, green, and blue images, respectively. The visual film density was measured on a grey image.

Figure 5. Visual film density measured on grey images for films processed normal, push one stop, and push two stops.

Figure 6. Properly focused black and white image magnified approximately ten times.

Figure 7. Curves used to test the color balance of the color machine.

Table 1. Typical values of the goodness-of-fit parameter calculated as a measure of the quality of the film processing of black and white film.

DATE	GOODNESS-OF-FIT VALUE
01/25/82	.0013
02/01/82	.0006
02/09/82	.0002
02/16/82	.0130
02/22/82	.0026
03/01/82	.0004
03/09/82	.0010
03/15/82	.0020
03/22/82	.0004

Table 2. Typical values of the goodness-of-fit parameter calculated as a measure of the quality of the exposure of black and white film by the BW and HSBW film writing machines.

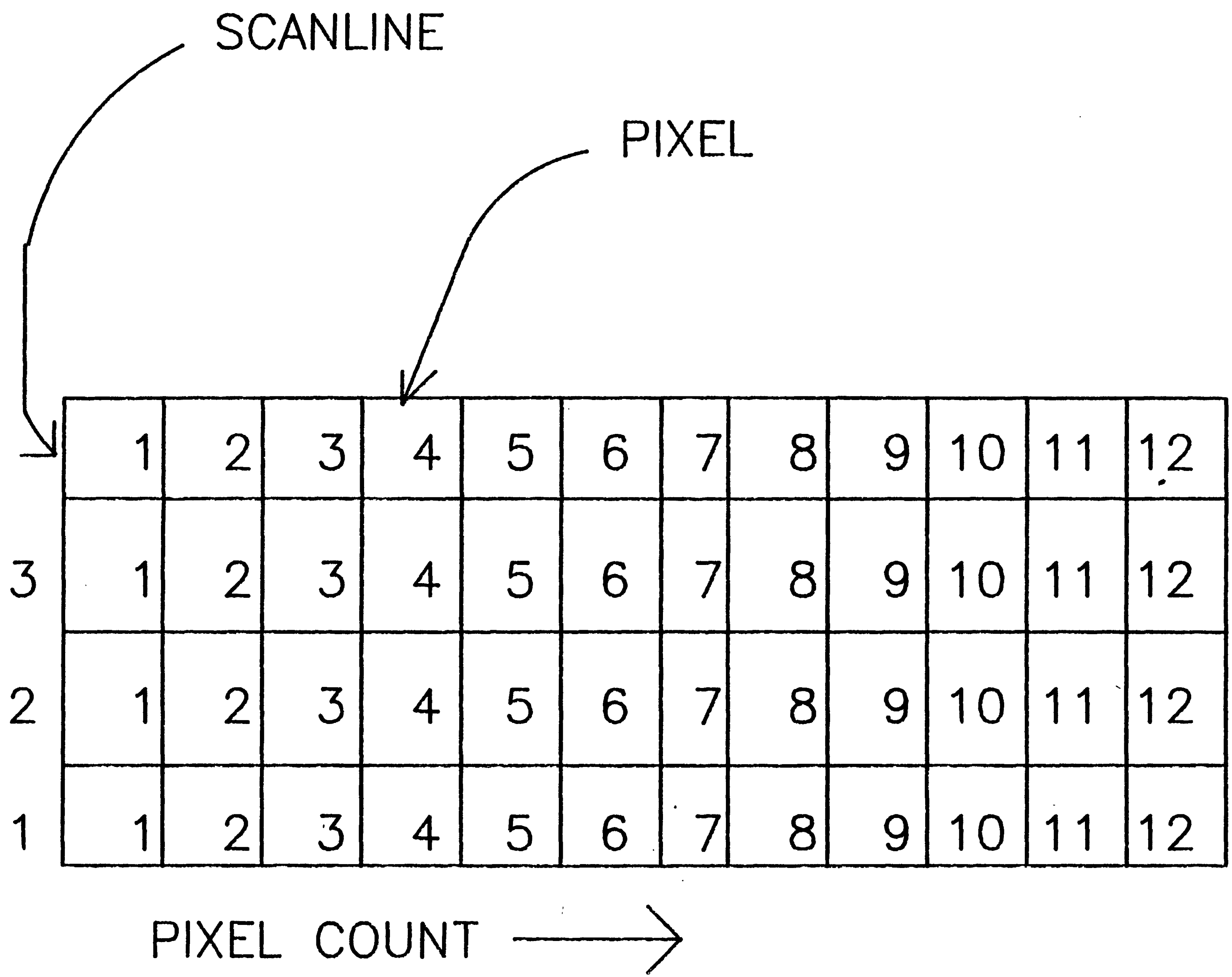
DATE	BW MACHINE	HSBW MACHINE
01/25/81	.0013	.0013
02/01/82	.0019	.0027
02/09/82	.0002	.0030
02/16/82	.0071	.0217
02/22/82	.0077	.0227
03/01/82	.0020	.0258
03/09/82	.0012	.0240
03/15/82	.0062	.0752
03/22/82	.0093	.0146

Table 3. Typical values of the goodness-of-fit parameter calculated as a measure of the quality of the film processing of color film with push one stop processing.

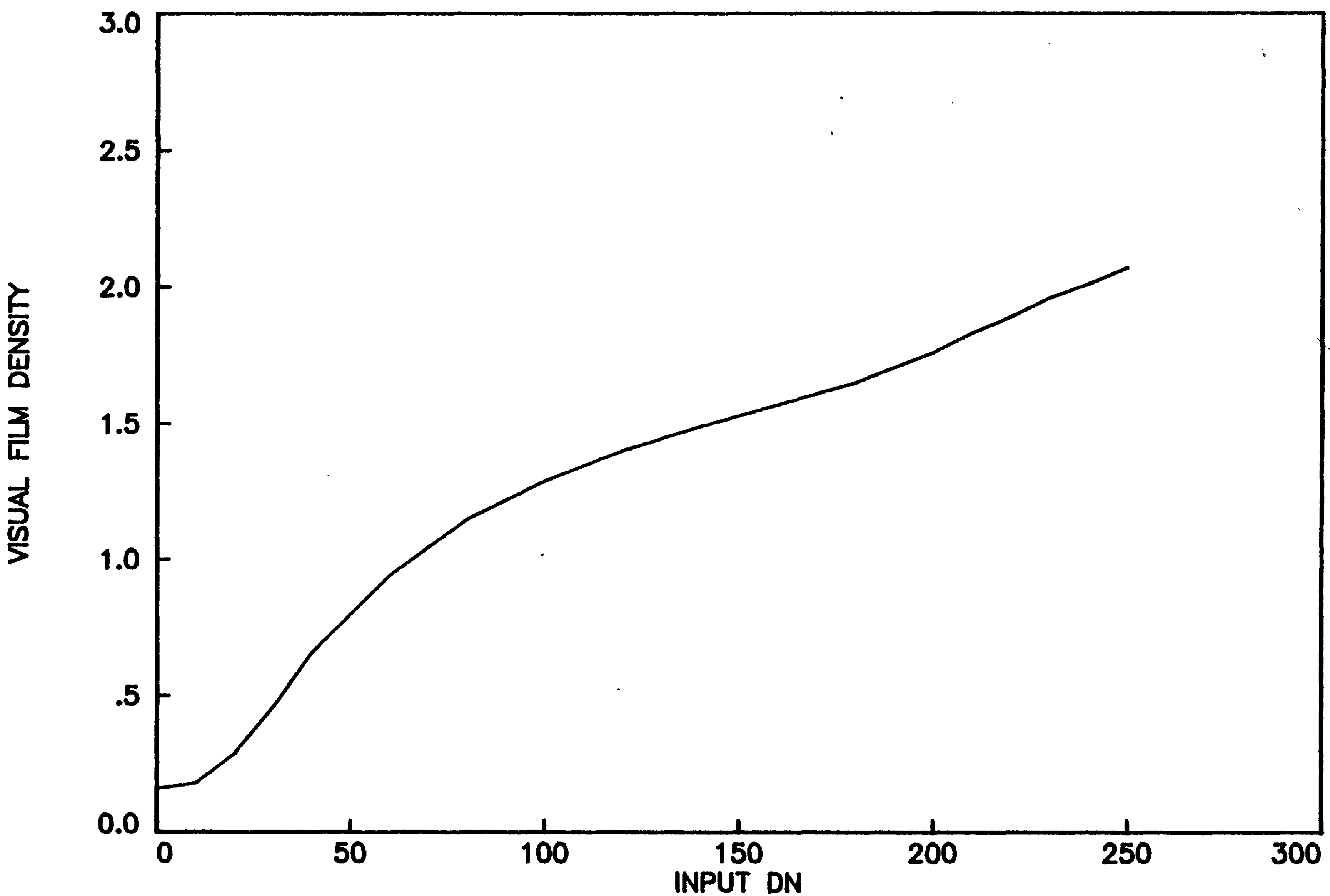
DATE	RED	GREEN	BLUE
11/09/81	.0003	.0001	.00007
11/10/81	.0013	.00008	.0001
11/12/81	.0004	.00007	.00006
11/23/81	.0004	.0007	.0004
12/07/81	.0026	.0017	.0034
12/29/81	.0009	.0008	.0032
01/18/82	.0046	.0040	.0024
01/25/82	.0082	.0073	.0032
02/01/82	.0025	.0028	.0003
02/08/82	.0002	.0005	.0005
02/15/82	.0034	.0032	.0010
02/22/82	.0003	.0004	.0016

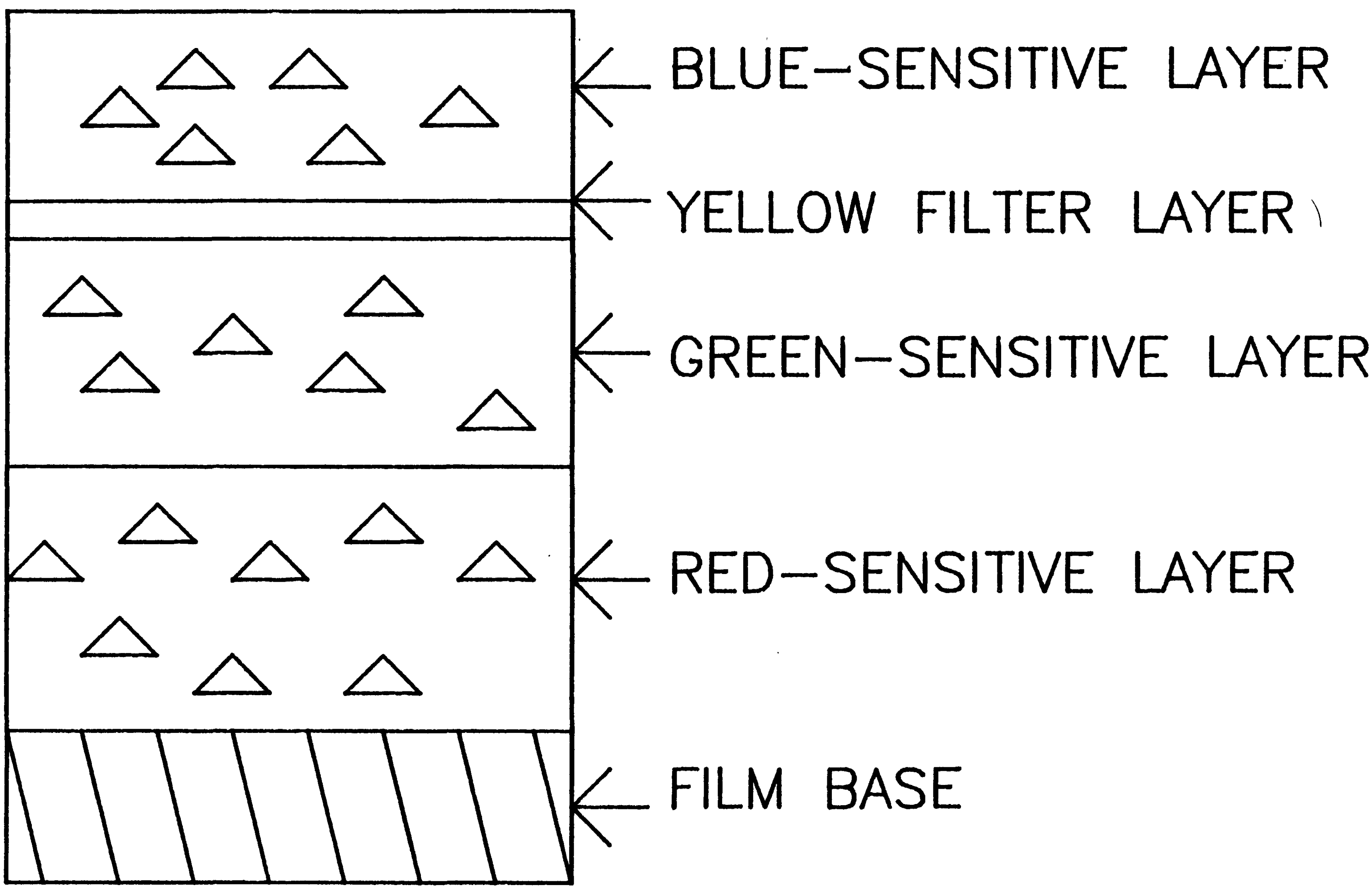
Table 4. Typical values of the goodness-of-fit parameter calculated as a measure of the quality of film exposure by the color film writing machines.

DATE	CO MACHINE	HSCO MACHINE
11/23/81	.0010	.0010
12/07/81	.0003	.00009
12/21/81	.0006	.0021
02/01/82	.0014	.0030
02/08/82	.0017	.0022
02/16/82	.0005	.0037
02/22/82	.0041	.0283

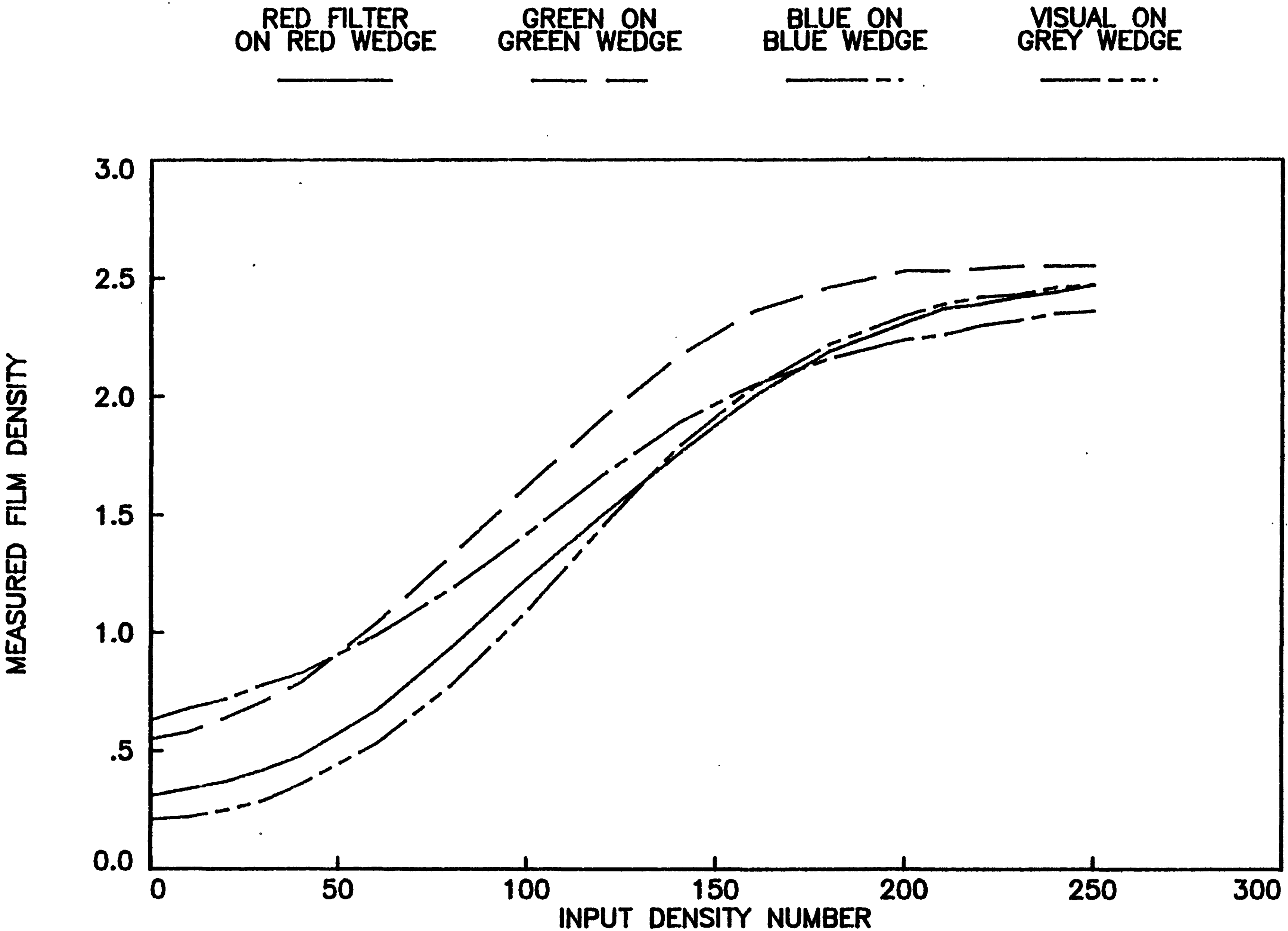

SCANLINE
PIXEL
1 2 3 4 5 6 7 8 9 10 11 12
3 1 2 3 4 5 6 7 8 9 10 11 12
2 1 2 3 4 5 6 7 8 9 10 11 12
1 1 2 3 4 5 6 7 8 9 10 11 12
PIXEL COUNT

VISUAL FILM DENSITY OF BLACK & WHITE FILM
PRODUCED USING HSBW

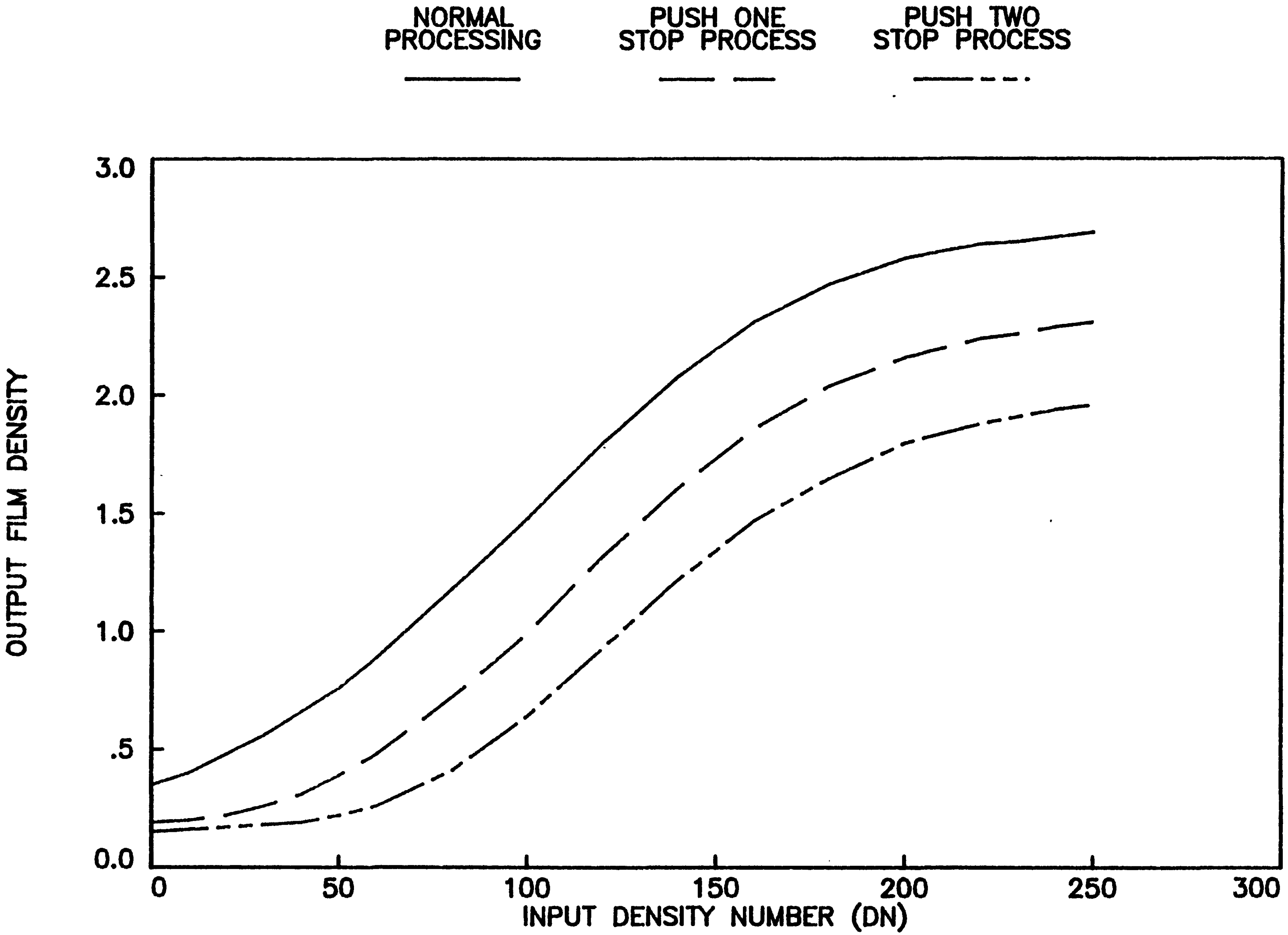


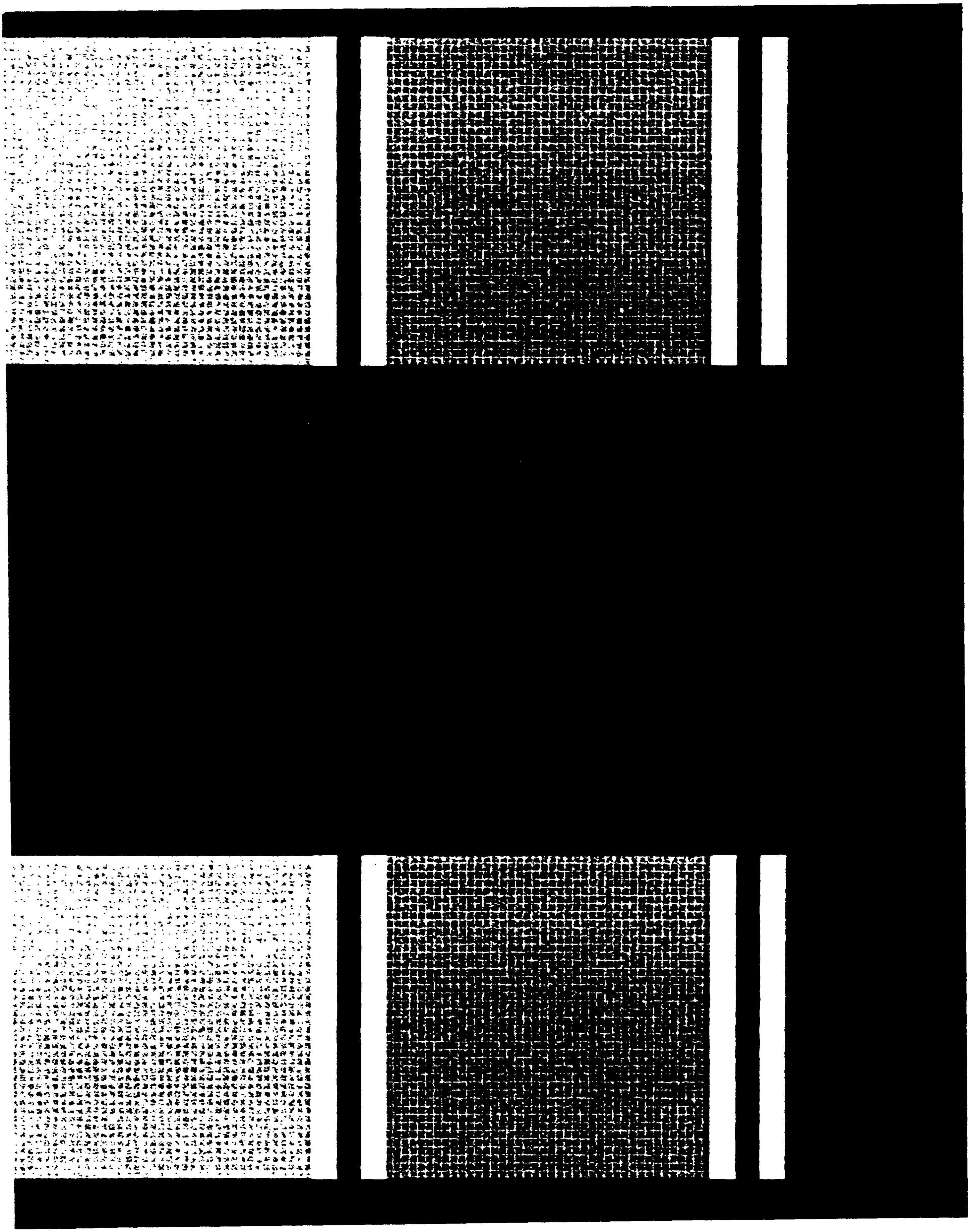

BLUE-SENSITIVE LAYER
YELLOW FILTER LAYER
GREEN-SENSITIVE LAYER
RED-SENSITIVE LAYER
FILM BASE

CHARACTERISTIC CURVES OF RED, GREEN, BLUE, AND VISUAL FILM DENSITIES ON COLOR WEDGES



EFFECTS OF FILM PROCESSING ON VISUAL FILM DENSITIES MEASURED ON GREY WEDGES





CURVES USED TO JUDGE COLOR BALANCE OF A COLOR FILM WRITING MACHINE