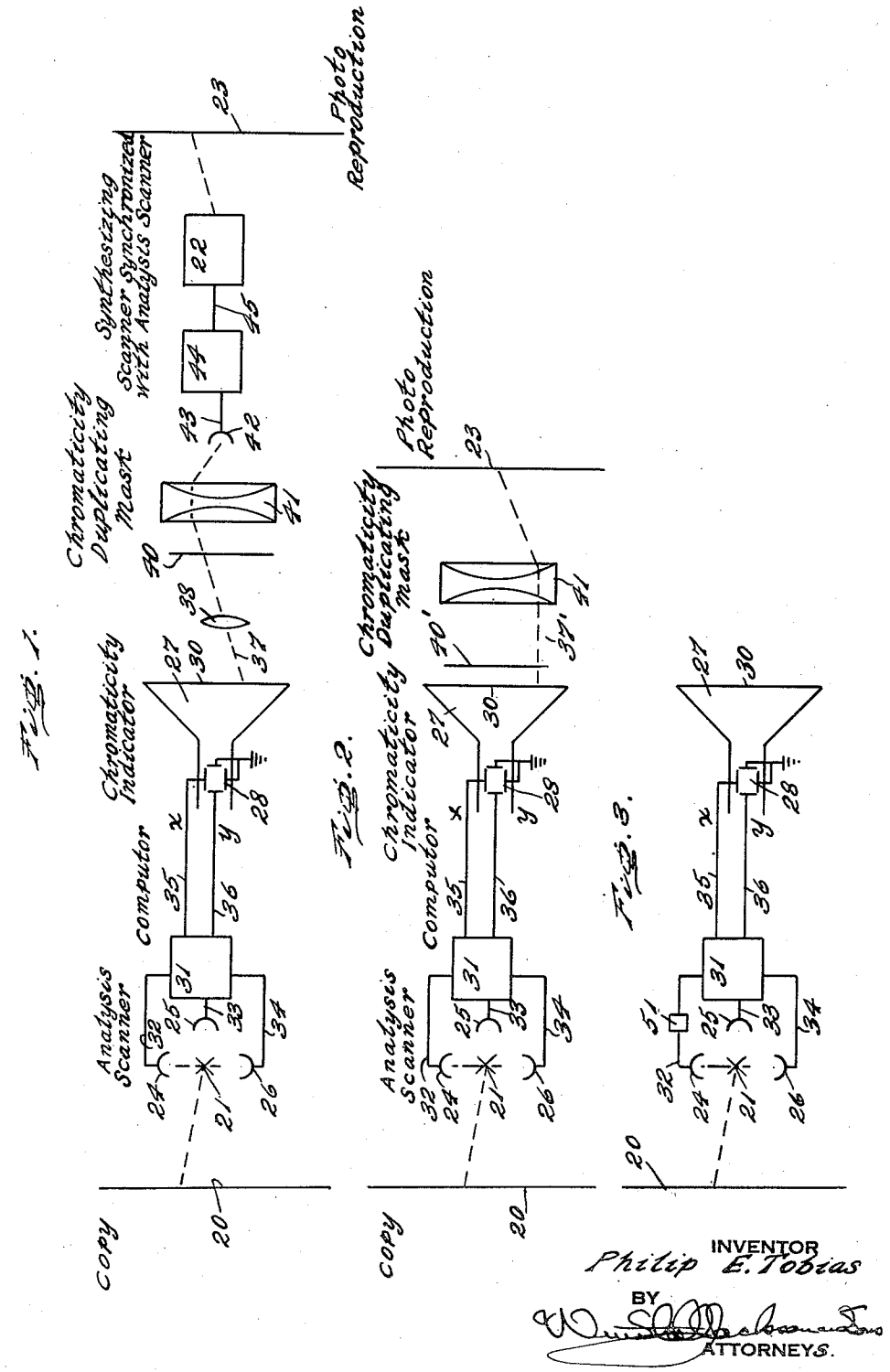
June 14, 1955 P. E. TOBIAS 2,710,889

COLOR REPRODUCTION

Filed Jan. 21, 1953 5 Sheets-Sheet 1



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COLOR REPRODUCTION

Filed Jan. 21, 1953 5 Sheets-Sheet 2

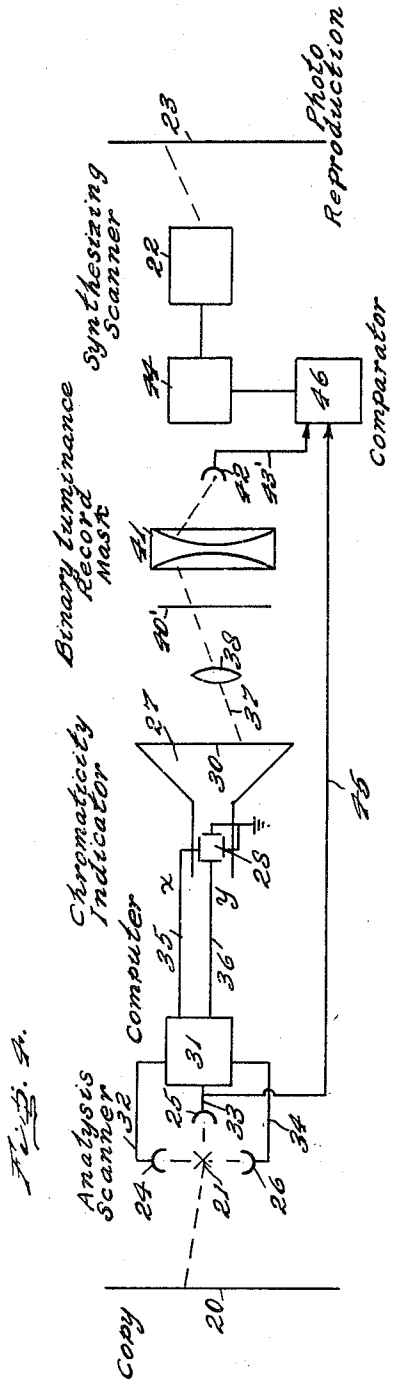

Fig. 4.

INVENTOR
Philip E. Tobias
BY
ATTORNEYS.

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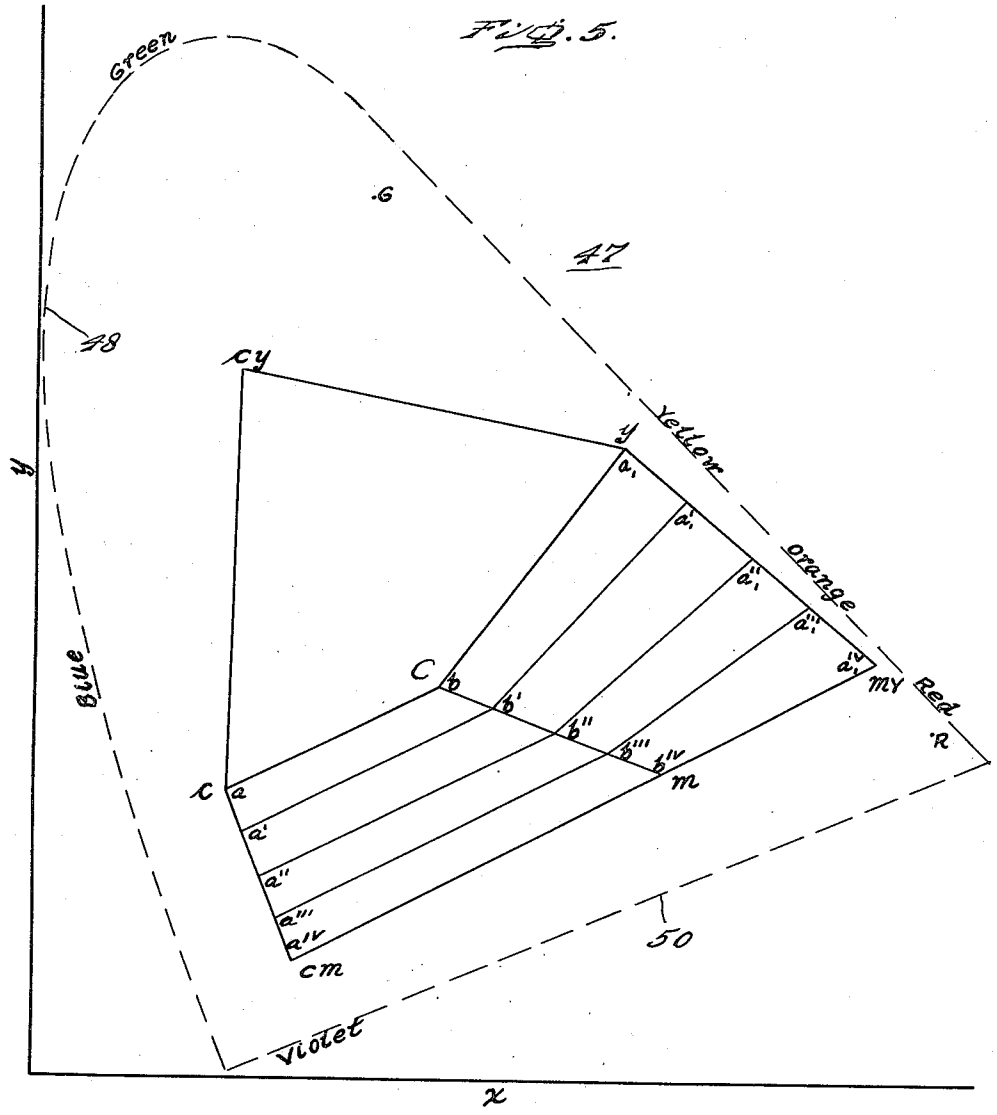
Fig. 5.



INVENTOR
Philip E. Tobias
BY
ATTORNEYS.

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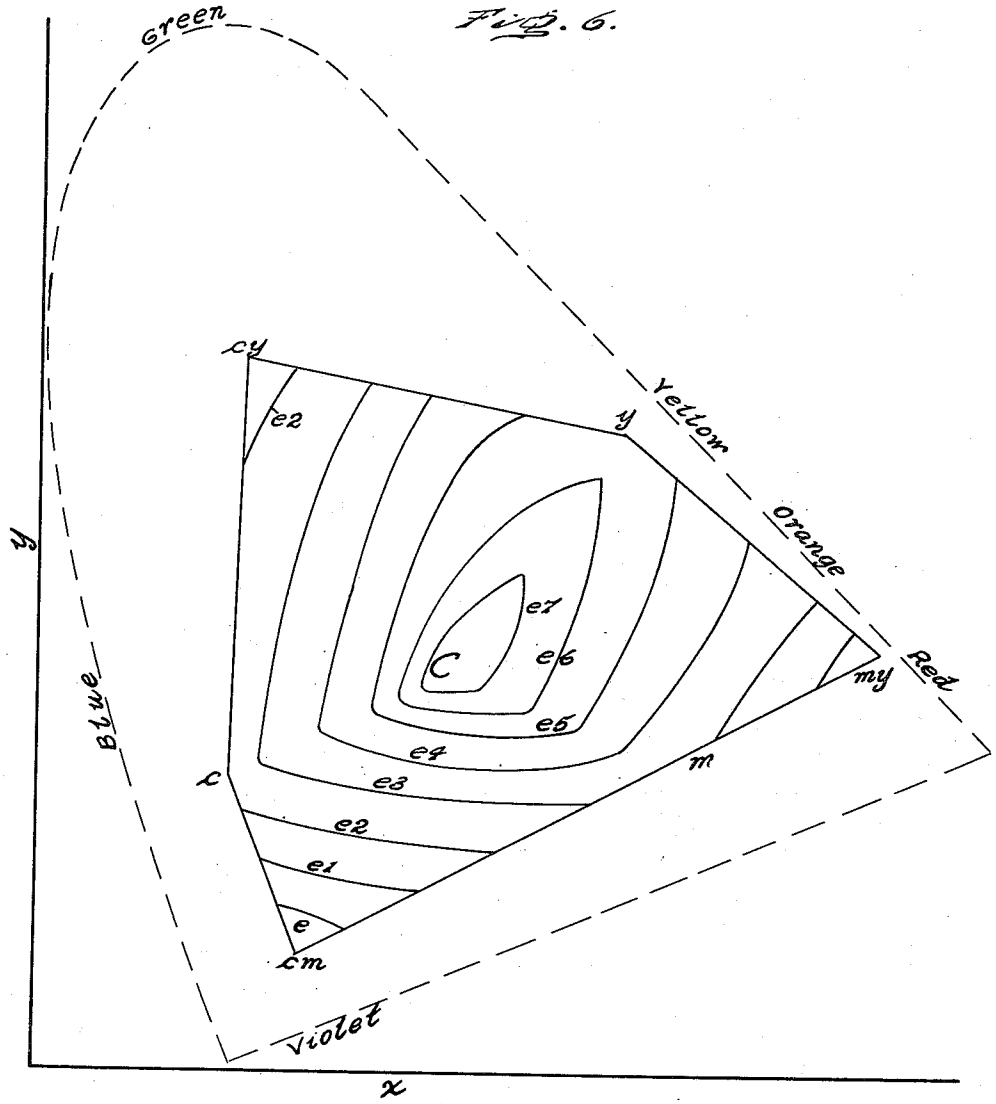
Fig. 6.



INVENTOR
Philip E. Tobias.
BY
ATTORNEYS.

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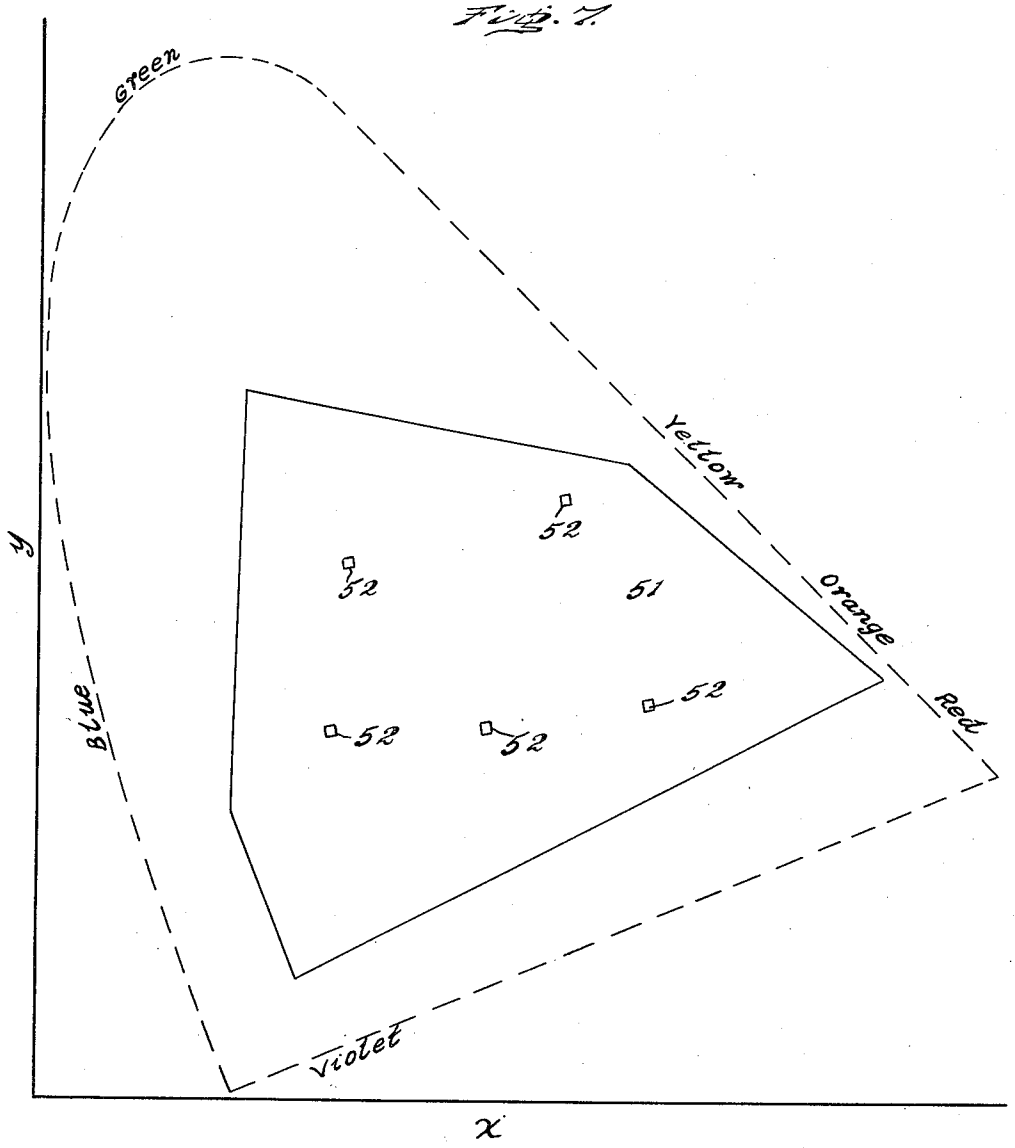
Fig. 7.



Philip E. Tobias INVENTOR

BY

ATTORNEYS.

United States Patent Office 2,710,889 Patented June 14, 1955

2,710,889

COLOR REPRODUCTION

Philip E. Tobias, Upper Darby, Pa., assignor to Edward Stern & Company, Incorporated, Philadelphia, Pa., a corporation of Pennsylvania

Application January 21, 1953, Serial No. 332,258

26 Claims. (Cl. 178—5.2)

The subject matter of any patent granted on this application may be used by or for the United States Government for governmental purposes without the payment of any royalty to the inventor or his assignee.

The present invention relates to color reproduction, especially by means of printing plates.

A purpose of the invention is to obtain greater fidelity in color reproduction by printing plates.

A further purpose is to reduce the cost of making high quality color reproductions, and particuluarly to minimize or wholly eliminate the cost of making corrections on color saparation negatives, positives or plates.

A further purpose is to predetermine a printing density for each printing ink involved in reproducing colored copy having local areas of a particular chromaticity, the printing density being predetermined by an optical density of a mask as it transmits a beam of incident light.

A further purpose is to automatically adjust the color reproduction by a set of color separation plates in accordance with the luminance (brightness) of the colored copy at each point thereon.

A further purpose is to match the colored copy in hue and saturation with binary mixtures of colored printing inks and to duplicate the brightness of the colored copy by adding black or a combination of colored inks which produce black.

A further purpose is to scan colored copy, measure the chromaticity of the copy at the point scanned, desirably by measuring the ratio of reflectance of one color such as red to the total reflectance, and by measuring the ratio of the reflectance of another color such as green to the total reflectance, to control the position of an electron beam suitably in a kinescope according to the rectilinear coordinates of the chromaticity of the copy at the different points scanned and thereby generating a light beam from the impingement of the electron beam on a phosphor on the face plate at a point corresponding to the chromaticity, to pass the light beam through a transparent mask which modulates in a predetermined manner the intensity of the light beam passing through the mask in accordance with the position of impingement of the light beam on the mask, and to expose photosensitive material to a light beam to produce a printing density which varies with the quantity of light passing through the mask.

A further purpose is to vary the printing density on the photosensitive material by generating on electric current responsive to the light passing through the masks, scanning the photosensitive material by a light beam in synchronism with the scanning of the copy and modulating the latter light beam in accordance with the magnitude of the electric current to vary the exposure of the photosensitive material.

A further purpose is to form the mask for the color printing plates with varying optical densities in different active areas, with the optical density in any active area corresponding to the chromaticities given by the rectilinear co-ordinates on the mask and with isooptical-density lines on the mask corresponding to a particular amount

of the ink to be printed by the plate in binary combination with other colored inks having adjoining chromaticities in all possible combinations.

A further purpose is to determine the printing density of a black printing plate by a mask which varies in optical density over its active area, and which has for each point, determined by the chromaticity co-ordinates an optical density which corresponds to the luminance of the binary combination of printing inks which produced that chromaticity.

A further purpose is to compare the actual luminance of a particular point on the copy with the luminance of the binary mixture of inks which gave that chromaticity in determining the ultimate printing density of the black printing plate.

A further purpose is to provide for automatic printing of chromaticities which are a predetermined function of the chromaticities on the copy, or of any given chromaticity on the copy, thus permitting overall modification of the color of the copy, or of selected colors on the copy.

A further purpose is to modify the gain on one of the input channels from a color selective optical pickup, or on all of such channels, so that the chromaticities indicated are artificially constrained to fall within the gamut of the printing inks.

A further purpose is to provide arbitrarily assigned printing densities on color separation plates for colors on the copy which are beyond the chromaticity gamut of the printing inks used.

A further purpose is to accomplish the variation in optical densities of the mask within the gamut of chromaticity capabilities of the particular printing inks, and also desirably to assign arbitrary or preselected optical densities for each printing ink color for chromaticities outside the range of capabilities of the particular colored printing inks.

A further purpose is to employ a mask which has opaque areas between areas allowing light transmission, so as to selectively exclude from reproduction all but certain chosen chromaticities.

Further purposes appear in the specification and in the claims.

In the drawings I have chosen to illustrate a few only of the numerous embodiments in which my invention may appear, selecting the forms shown from the standpoints of convenience in illustration, satisfactory operation and clear demonstration of the principles involved.

Figure 1 is a conventional diagram of a color reproduction device in accordance with the present invention, arranged to accomplish color separation and preparation of color printing plates.

Figure 2 is a conventional diagram of a device similar to Figure 1 showing a variation, in that the light from the kinescope passes directly to the photosensitive material.

Figure 3 is a fragmentary view corresponding to Figure 1, showing a variation in the gain of one of the pickup channels.

Figure 4 is a diagrammatic illustration of mechanism in accordance with the invention for producing a black printing plate.

Figure 5 is a diagram of a chromaticity duplicating mask for one of the color plates, in this case the magenta printer.

Figure 6 is a diagram of a mask for the black printer.

Figure 7 is a diagram of a chromaticity duplicating mask which selects colors.

Describing in illustration but not in limitation and referring to the drawings:

One may define the attributes of a color in terms of its red, green and blue reflectances.

If the spectral response of each of the receptors used to measure these reflectances is matched to the eye response of a "standard observer," these red, green and blue reflectances will uniquely define the appearance of a color to this standard observer. A match is obtained between two colors when the red, green and blue reflectances (usually referred to as tristimulus values) of the two colors are respectively equal.

From the tristimulus values it is possible to obtain three other co-ordinates which are significant. The ratio of the red reflectance to the total (red+green+blue), and that of the green reflectance to the total, which are designated x and y respectively, establish two variables which define the chromaticity co-ordinates of a color and are capable of being plotted on rectilinear co-ordinates. The chromaticity co-ordinates are functions of the hue and saturation of the color.

There remains a third independent variable, since the color has an attributable of luminance, commonly called brightness, which can be imparted by adding black to a pigment which produces the color or by altering the level of illumination. The luminance may be measured for example by the absolute value of the green reflectance.

Thus it is seen that the establishment of the chromaticity co-ordinates and the luminance completely specify a color. This coincides with the manner in which an observer instinctively arranges colors and also with the results of process color printing.

In color printing using three or four process colors (with permissible addition of other colors, in order to obtain the purity and improve the reproductibility of a certain important color of the work), it is common practice to make color separation negatives which are records of the red reflectance, the green reflectance and the blue reflectance respectively. The negatives approximately define the amount of the printing inks (cyan, magenta and yellow respectively) which nominally reflect wave lengths except the particular color used in making the separation (red, green and blue respectively) and therefore reflect the red, green and blue respectively in approximation to the original copy. These processes using complementary printing inks are well known as subtractive printing processes.

When the dots on a particular location of the three printing plates are printed in the ultimate reproduction, they apply at that point a predetermined amount of the cyan, magenta and yellow inks which absorb from white light the colors not desired, and reflect a colored light which approximates the original. The inks themselves in this process are approximately transparent so that colors of the same approximate order of appearance are obtained from dots of different inks which are superimposed as from dots which are side by side.

If no additional processing of the plates were accomplished, however, the colors of the reproduction would only slightly resemble the original colored copy. These deficiencies result partly from the defects in the color separation filters, from the fact that the inks deviate from ideality in their reflectances, from the fact that the behavior of superimposed dots in printing is different from that of dots arranged side by side, from the fact that in the printing process distortions are obtained in the tonal scale, from the light absorption into the paper on which the reproduction is made and because of the color-wise contribution of the paper on which the reproduction is printed. It has accordingly become standard practice to correct for these deviations from ideality to make the reproduction look like the original colored copy.

It will be evident that the method of correction will depend upon the particular printing process, and that the correction will have the effect of changing the printing density on a particular color plate in a particular area. In those processes in which printing density is established by the size of the dots in a particular area it will be evident that correction must take the form of varying dot sizes.

The most generally used method of color correction is by a color correction artist who relies upon his experience or refers to a color chart which covers all printed tone combinations of the four process colors, magenta, yellow, cyan and black, showing the necessary printing densities of each plate to establish the particular color. The separations, whether as plates or as separation negatives or positives, are corrected either by dyeing or etching to the correct optical density or printing density as the case may be to give a printed result which will reproduce the original. This is a very laborious and expensive process, as it requires much time by a highly skilled operator and may require making several provings. In the end the result commonly leaves much to be desired from the standpoint of fidelity. In common practice as much as 80% of the cost of making color plates is spent on the color correction of the plates.

A second method of accomplishing correction consists in masking, that is, the addition or removal of density to one separation negative as a function of the densities of the other two at a particular point. This may be accomplished by a number of different processes, but the result is often lacking in high fidelity, requiring further hand correction to produce accurate results, and these corrective processes are themselves difficult to use.

A third method of correction employs a scanning system and then corrects by the masking effect as previously mentioned. This is subject to the same difficulties and inaccuracies as the second method mentioned.

A fourth method, which is still in the developmental stage, uses an electronic scanning device and predicts the printing operation by application of Neugebauer equations, which express the tristimulus result in terms of dot areas of magenta, yellow, cyan and black printing plates, and in terms of the tristimulus values of the individual colored inks and their solid combinations. The procedure is to scan the original to obtain a linear transformation of the tristimulus values at a particular point on the copy, and then by a feedback arrangement, determine the printing densities of the colored printing plates and the black printing plate which would give identical results. This system is complicated by errors resulting from a theoretical prediction which cannot define all of the complex variables which affect the physical process of printing. Thus errors through distortion in the tonal scale, dot spread, penetration of light into the paper, the intereffects of surprinting half tone dots of different colors and the break-up of the structure by the paper cannot properly be predicted. In addition, due to the feed-back type of circuit, difficulty is had under conditions where the density of the original colored copy exceeds that obtainable from the printing inks or where a color in the original is beyond the gamut of the printing inks.

In accordance with the present invention, the difficulties of these prior art processes are largely eliminated. A faithful reproduction of the color of the copy is obtained, and the necessity of subsequent color correction is largely eliminated. Thus a major factor in the expense of making color reproductions is no longer present, and any deviation in quality which has heretofore been experienced due to the skill of the operator is entirely avoided.

In the present process the chromaticity and luminance of a particular point on the colored copy is matched with an actual printed result which is obtained by printing mixtures of the process color inks. For example any deviations in accuracy of reproduction due to departures from ideality of standard printing inks or of the paper, any effects due to surprinting of dots, effects due to tone distortion at the ends of the scale, necessary variations in the color of the process inks actually used as compared to the standard, and the like, are simply eliminated and do not affect the process. The results obtained are as high in quality as can be secured by the most capable

color correction artist, with the advantage of eliminating cost of hand color correction and producing a photographic quality which is not possible in hand correction of intricate subject matter.

Likewise the invention is applicable to give high quality results where speed is a factor, as in reproduction of maps and other similar subject matter.

At any particular point on the colored copy, the ratio of the red light reflected to the total light reflected and the ratio of the green light reflected to the total reflected establishes the trichromatic coefficients generally referred to as chromaticity. These trichromatic coefficients are determined by filter-photocell combinations which are equivalent to the distribution functions of the C. I. E. standard observer. The chromaticity defines the dominant wavelength and degree of saturation of the color, but does not establish its luminance or brightness.

In a three color printing ink system, of the character of magenta, yellow and cyan, all proportions of the printing inks taken two at a time such as magenta and yellow, yellow and cyan and magenta and cyan, define the entire chromaticity gamut of the system. The addition of the third ink to a binary mixture causes graying, and does not alter the chromaticity gamut available from the binary mixtures.

It will thus be evident that graying or variation in luminance of the pigment can be obtained either by adding black to the binary mixture, or by adding the equivalent of black, that is, magenta, yellow and cyan in the required proportions to produce black. As a corollary it will be evident that the binary mixtures which produce different chromaticities vary in their luminance. It will of course be evident that where a black printing plate is used, the black should be as devoid of hue as possible.

If now we assume a point on colored copy which is to be matched on the reproduction, it is obvious that such a match can be accomplished as to chromaticity by a binary mixture of colored printing inks, but that in order to duplicate luminance or brightness it is necessary to add black or an equivalent of black in order to reduce luminance to the desired extent.

The trichromatic coefficients of the point of the copy plotted according to rectilinear coordinates define the dominant wavelength and the saturation of the copy, and likewise the similar trichromatic coefficients of the reproduction define the dominant wavelength and saturation obtained from the printing inks. A perfect match of chromaticity results when the x and y values of the binary mixture of printing inks which print the reproduction are the same as the x and y values which uniquely identify the chromaticity of the point on the copy.

If therefore we make a press print on the nature to be used in the printing process, using all possible tonal combinations of magenta and yellow, yellow and cyan and magenta and cyan, each one of these tonal combinations will have x and y values measuring chromaticity which uniquely identifies the particular mixture. Likewise a given value of x and y on the copy will be matched by these emprically determined densities of magenta, cyan and yellow in binary mixtures. It will thus be seen that at any one point in the chromaticity coordinate system, the density of at least one colored ink must equal zero. The amount of black required to gray the reproduction to give it a luminance corresponding to the copy will then complete the color match.

It should be noted that when only three colored printing inks are involved, each one affects an area on the mask adjoining both others and the binary combinations include all combinations taken two at a time. Where, however, one introduces a fourth, fifth, etc. color of ink to increase the gamut of chromaticities available from the printing inks, one will, in general, only make binary combinations of each ink with those which on the chromaticity chart or the mask adjoin it on either side, and not with the color or colors which are remote.

In accordance with the present invention, the empirically determined relationships between the x and y values and the printing densities of the color separation plates are utilized. The colored copy is scanned so that at any instant a given point only is subject to analysis. The chromaticity and the luminance of this point is measured, and these chromaticity and luminance values thus determined are used to establish the particular printing densities of the binary mixture of color printing inks which gives that chromaticity, and also to establish the printing density of black to accomplish the required graying.

Considering now the embodiment of the invention shown in Figure 1, colored copy **20** such as a photograph, painting, map, advertisement or the like is subject to the view of an analysis scanner **21** which in the preferred embodiment scans in synchronism with the scanning by a synthesizing scanner **22** projecting a light beam to photosensitive material **23**. Depending on the character of the process, the material **23** may become a color separation negative or positive, or an actual photo-sensitive color printing plate. It will of course be understood that depending on whether or not the particular process contemplates granulation or breaking up of the surface into dots, the photosensitive reproduction **23** may be screened or unscreened. Of course where the photosensitive material **23** is an intermediate step in accomplishing reproduction, screening may take place at a later stage before the ultimate printing plate is produced.

The analysis scanner may be of any conventional type, whether electronic or mechanical, and no detail of the same is considered to be critical in the present invention. For example, electronic scanners used in facsimile type transmission are suitable, as well as flying spot scanners and rotating mirror scanners. Likewise the scanner may be strictly of mechanical type, for example of the well known character in which a drum carries both the copy **20** and the reproduction **23** and manipulates them through identical paths in reference to similarly placed light beams as well known in the art.

While the invention is considered to find its widest application in connection with the reproduction of opaque colored copy, and reference has been made herein to reflectance of the copy, it will be understood that the invention is also applicable to reproduction of transparencies, in which case the light given off by the copy may be transmitted light, and it will be understood that when reference is made herein to reflectance from the copy it is intended to include the possibility that the copy may transmit light in addition to reflectance or instead of reflectance.

At a position at which light given off by the copy can be received, a group of photosensitive pickups **24**, **25** and **26** are located, each of which is selective in its response to a particular one of the analysis light colors. Normally these will be phototubes provided with filters or dichroic mirrors, the filter-phototube combination giving the desired spectral sensitivity. Permissibly a combination of dichroic mirrors and filters may be employed, using one pickup for one light color and another pickup for another. The particular pickups **24**, **25** and **26** should have spectral responses as close as possible to the tristimulus distribution functions or linear transformations thereof, for example **24** responding to red (x), **25** to green (y) and **26** to blue (z). Suitable tristimulus colors are set forth in Arthur C. Hardy, Handbook of Colorimetry (Technical Press 1936, Massachusetts Institute of Technology), 8. As a convenient way of positioning, the pickups as shown are disposed 90° apart around the crossed mirrors which accomplish the beam splitting.

A kinescope tube or cathode ray oscilloscope **27** is employed, having the usual electron gun with a deflection system **28** which causes the electron beam to position on a face plate **30** having a suitable phosphor. The phosphor will preferably be of the short persistence type,

where a high scanning rate is to be used at the analysis scanner. The deflection system **28** is subjected to control on the horizontal and vertical coordinates by a computer **31** which receives an electric voltage responsive to the pickup of one tristimulus color from photopickup **24** through channel **32**, receives an electric voltage responsive to another tristimulus color from photopickup **25** through channel **33** and receives an electric voltage responsive to the other tristimulus color through channel **34**. The computer produces an output voltage controlling either the horizontal or vertical coordinates of the electron beam through channel **35**, and produces another output voltage controlling the other coordinate of the electron beam through channel **36**.

It is important that the voltage through channel **35** corresponds to the chromaticity coefficient x, that is, it should conform to the expression:

$$x=\frac{V_r}{V_r+V_g+V_b}$$

where V_r is the voltage in channel **32**, V_g is the voltage in channel **33** and V_b is the voltage in channel **34**. Likewise the voltage in channel **36** varies in accordance with the chromaticity coefficient y according to the expression:

$$y=\frac{V_g}{V_r+V_g+V_b}$$

The relationship between the ratios indicated by x and y and the deflection of the beam may be one of identity, proportionality or other function as desired.

The computor **31** may be a computer as well known in the art which directly takes in three variables and produces responses according to the ratio of each of two variables to the sum of three variables. In a preferred embodiment, however, the computer **31** will be a logarithmic amplifier well known in the art.

In this case it is proposed to use the sum of log V_r, log V_g and log V_b vectorially disposed at 120° to each other. Here the resultant is a function of the chromaticities and is independent of the absolute values of V_r, V_g and V_b. The horizontal component of the resultant proposed is:

$$\log V_r-\frac{\log V_g+\log V_b}{2}$$

and the vertical component is:

$$\sqrt{\frac{3}{2}}(\log V_g-\log V_b)$$

It will be understood that any one of the available commercial logarithmic amplifiers can be used as a computer for the present purposes.

It will thus be seen that the analysis scanner analyzes the copy by scanning different points and the pickup system responds to the tristimulus values of any point on the colored copy, and the computer then causes the electron beam to reach a point on the face plate which indicates the chromaticity of the copy at this point. The electron beam striking the phosphor creates a light beam **37** which passes from the kinescope, and is employed to optically determine the printing density required at the corresponding point on the reproduction. It will be understood that the light beam **37** as it leaves the face plate is invariable in intensity, but that its position corresponds to the chromaticity of that point on the copy.

In the preferred embodiment the density determining light beam **37** passes through a projector lens **38**, then through a chromaticity duplicating mask **40**, and next through a condenser lens **41** to photopickup **42**, suitably a phototube. The photopickup **42** is connected through channel **43** to the input of amplifier **44** which through channel **45** modulates the intensity of the light beam emanating from synthesizing scanner **22**. The device is, however, applicable to direct photographic exposure of the photo sensitive surface **23** by the light beam **37**. In this case the mask **40'** (of course with its control areas differently located to suit the different beam position) is juxtaposed in front of the face plate, the beam **37'** passing through condenser lens **41** directly to the photo sensitive material **23**, which in this case is manipulated to agree with the manipulation of the colored copy **20**, as by a mechanical scanning device.

The lenses **38** and **41** are desirably of the type employed in flying spot television scanners.

The density of the mask **40** varies over the active area of the mask as later explained in more detail, in order to modulate the light beam **37** in accordance with the optical density of the mask, so that the light reaching the photopickup **42** from the beam **37** is determined by the x and y chromaticity coefficients of the colored copy at the given point. This density of the mask therefore directly controls the intensity of the exposure of the photo sensitive material **23**, and the printing density of the reproduction.

It will be understood that a separate binary chromaticity duplicating mask will be used for each of the colored printing inks which is to be used in reproduction, but that the same pickup from the copy will be employed in making each of these color separations.

A separate mechanism is employed in producing the black printing plate, in accordance with Figure 4.

The form of Figure 4 may conveniently correspond to that of Figure 1 for making the color plates except for some modification as explained below. It will be understood that the mechanism of Figure 4 can simply be modified by suitable switching to make it conform to that of Figure 1 and vice versa, or separate kinescopes can be used connected respectively in parallel to the channels **35** and **36** of Figure 1.

The function of the mechanism of Figure 4 is to make a comparison between the reflectance of the copy at a given point and the reflectance of the binary mixture of printing inks which produce the corresponding chromaticity. For this purpose a lead **45** connected to the output of photopickup **25** (conveniently the green pick-up is chosen) is fed into a comparator **46**, and the output **43'** of the photopickup **42** is fed into the same comparator in opposition to the output through lead **45**. In this case a binary luminance record mask **40'** corresponding to the green reflectance of the binary mixture of printing inks which produced the chromaticity is used to modulate the light from the kinescope.

The comparator is of any suitable character, as well known in the art, which makes a computation in which the output equals:

$$1-\frac{V_g}{V_g'}$$

where V_g is the output from pickup **25** and V_g' is the output from photopickup **42**.

The color mask of the type employed at **40** in making the colored plates will suitably be of the general type shown in Figure 5. The x and y coordinates shown conform to the chromaticity coordinates, although obviously if the lens reverses position they will be obverse of the normal position. As shown there are areas of the coordinates as at **47** which have no physical embodiment, and all the physical embodiments of the magenta printing plate as shown in Figure 5 will lie within the limits of the chromaticity curve **48** of the spectrally pure colors and the purple curve **50**.

However, the printing inks available do not provide a gamut covering the entire chromaticity range, and all of the chromaticities which can be actually produced by the particular typical printing inks lie in the polygon cyan (c), cyan plus yellow (cy), yellow (y), magenta plus yellow (my), magenta (m), cyan plus magenta (cm) and cyan (c).

If additional colored inks are introduced such as that indicated by points G or R, the area of the gamut of the

inks can be increased. Binary mixtures then will be defined as m and RR and y, y and G, G and c and c and m. Thus, chromaticity duplicating masks can be used for reproducing any printing color if all of the inks are combined in binary mixtures as explained. If the number of colors is more than three, the binary mixtures of each color include the two colors which have adjacent chromaticities. For example, use of green in general would result in mixtures of green and cyan and green and yellow, but not with mixtures of green and magenta. Each point within the polygon has a characteristic optical density, that is, the proportion of the light beam 37 which is transmitted by the mask, and there is a characteristic relationship of each x and y coordinate position within this range which determines the chromaticity. The mask for printing a particular color, in this case magenta, will include a number and preferably an infinite number of isooptical-density lines which respectively correspond to different quantities of the particular ink being printed (in this case magenta) with all other binary combinations of the other inks. Thus, the line aba_1 is an isooptical-density line for 0% magenta and the line a^{IV} b^{IV} $a_1{}^{IV}$ is an isooptical-density line for 100% magenta, while the intervening similar lines are isooptical-density lines for intermediate quantities of magenta, with varying quantities of cyan or yellow as the case may be.

The manner of making the mask for color plate printing will vary with the particular application to be made of the process. Without limitation to any particular manufacturing technique, one way of making the mask is to scan printed copy which initially has 100% magenta and all possible binary combinations with yellow and cyan, thus obtaining a trace on the kinescope which corresponds to the isooptical-density line for 100% magenta, and to expose optically sensitive material for the mask to the beams from this trace, thus obtaining the outline of the trace on the mask. The same repeated for each other percentage of magenta with each other percentage of the other inks will give the trace for the isooptical-density line for each other content of magenta. The isooptical-density lines can then be dyed to the desired density, either by hand application of dye, or by accomplishing the photography through neutral density filters.

Note that the line of isooptical-density for 0% of the particular colored ink being printed will go through C which represents white light and through the points corresponding to the two other pure inks being printed. Thus in the case of the yellow printing mask this line will follow the course cCm for 0% yellow whereas cyymy corresponds to 100% yellow. Likewise for the cyan printing plate, the 0% cyan line will follow the course yCm for 0% and cyccm for 100% cyan.

Figure 6 shows the mask for the black printer which has the polygon as already described. Included are isooptical-density lines e, e_1, etc. which are determined experimentally. Each spot has an optical density corresponding to the luminance of the corresponding binary mixture of printing inks which gives that chromaticity. This mask is produced by individually determining the required optical densities and producing the mask photographically by means of varying exposures or by dyeing the masks to the required densities.

If desired the invention can be employed to create artificially a difference between the color of the copy at a particular point and the color reproduced. This can be done arbitrarily to redden, green or blue the reproduction by providing densities within the range of the polygon on Figure 5 which are deliberately displaced with respect to those called for by the x and y coordinates. In this case there will in some instances be a slight departure either in all colors or in certain colors from the x and y coordinate positions, whereas in other instances one or more individual colors may be markedly changed to alter the color in the reproduction for special effects. Thus all reds on the colored copy can be rendered as purple on the reproduction by simply modifying the optical densities of the chromaticity duplicating masks to the required extent at the desired regions.

This principle is applicable also to the reproduction of chromaticities which fall outside of the polygon in Figure 5. Such colors are beyond the gamut of the standard printing inks and cannot be reproduced accurately. This condition occurs for example when pure color G is to be matched, which is in a range of saturation beyond the limits of mixtures of the inks C and Y. There is then a choice presented of matching the hue but not the luminance, of matching the luminance but not the hue or of compromising to any desired degree on both luminance and hue. Depending upon the nature of the copy it will be preferable to adopt one or the other of these expedients. This is readily accomplished by providing at the desired point outside of the polygon on each of the chromaticity duplicating masks and also on the binary luminance record mask, densities which control the particular chromaticity and luminance to be obtained in reproducing that point on the copy.

The flexibility with which such compromise can be applied in scanning the copy at points outside the chromaticity gamut of the printing inks is one of the great advantages of this invention, as obviously various masks making this compromise in varying ways can be employed for different requirements of reproduction.

In some instances it is desirable to obtain a uniform modification of chromaticity coordinates of the copy to points within the polygon. This is accomplished as shown in Figure 3 by modifying the gain in one or more of the channels **32**, **33** and **34** as by inserting any desired voltage control **51** in one or more of such channels. It will of course be evident that the voltage may be modified by series or parallel impedance, regulation of control grid voltage, or any other well known method, and **51** may be considered by way of example only as a series resistance.

Another procedure for which the invention can be utilized is to discriminate among colors which are quite similar. Thus, in map reproduction, lines may be drawn of various colors which it may be practically impossible to separate photographically. Even similar colors will have different chromaticity. In this case it is merely necessary to employ a chromaticity duplicating mask as in Figure 7, which has all of the area **51** opaqued except those areas at **52** corresponding to x and y values which it is desired to reproduce, and at the desired points the mask will conform to the practice explained previously. No color which does not have a chromaticity falling within one of the areas of transparency **53** will be reproduced. Thus it is possible to obtain a separation among the various lines in linear colored copy.

The invention is also applicable to two-color pseudo-process, in which case, of course, chromaticity duplicating masks will be used only for the colored printing inks which are being employed.

The invention is also applicable to reproduction of textile design colors, wall paper colors and other color matching or reproduction which does not necessarily correspond to usual three-color process work.

In view of my invention and disclosure, variations and modifications to meet individual whim or particular need will doubtless become evident to others skilled in the art, to obtain all or part of the benefits of my invention without copying the process and apparatus shown, and I, therefore, claim all such insofar as they fall within the reasonable spirit and scope of my claims.

Having thus described my invention, what I claim as new and desire to secure by Letters Patent is:

1. In mechanism for color reproduction, means for scanning colored copy by a light beam, means for measuring the chromaticity of the copy at individual points of scanning, a kinescope, means for deflecting the position of the electron beam in the kinescope in response

to the chromaticity coordinates of the copy at the point of scanning and thereby generating a light beam having a position determined by a chromaticity of the point scanned, a mask varying in optical density over its area in a predetermined manner, means for passing the light beam from the kinescope through the mask at a particular area corresponding to the chromaticity and means for exposing photosensitive material to light at scanning positions corresponding to the scanning of the copy in accordance with the magnitude of the light transmitted through the mask.

2. In mechanism for color reproduction, means for scanning colored copy by a light beam, means for measuring the chromaticities of the copy at individual points of scanning, a kinescope, means for deflecting the position of the electron beam in the kinescope in response to the chromaticity coordinates of the copy at the point of scanning and thereby generating a light beam having a position determined by the chromaticity of the points scanned, a mask varying in optical density over its area in a predetermined manner, means for passing the light beam from the kinescope through the mask at a particular area corresponding to the chromaticity, photoelectric means for producing an electric current responsive to the beam of light passing through the mask, photosensitive material, means for scanning the photosensitive material by a light beam in synchronism with the scanning of the copy, and means for modulating the latter light beam in accordance with the magnitude of the current to vary the exposure of the photosensitive material in accordance with the chromaticity.

3. In mechanism for color reproduction, means for scanning colored copy by a light beam, means for measuring the ratios of reflectances of at least two tri-stimulus colors of the copy to total reflectance at individual points of scanning, a kinescope, means for deflecting the position of the electron beam in the kinescope in response to the relationship between the functions of the ratios and thereby generating a light beam having a position determined by the relationship of the functions at a particular point scanned, a mask varying in optical density over its area in a predetermined manner, means for passing the light beam from the kinescope through the mask at a particular area corresponding to the chromaticity, photoelectric means for producing an electric current responsive to the beam of light passing through the mask, photosensitive material, means for scanning the photosensitive material by a light beam in synchronism with the scanning of the copy and means for modulating the latter light beam in accordance with the magnitude of the current to vary the exposure of the photosensitive material in accordance with the chromaticity.

4. In mechanism for photo-reproduction, means for scanning colored copy by a light beam, means for measuring the chromaticity of the copy at individual points of scanning, a kinescope, means for deflecting the position of the electron beam in the kinescope in response to the chromaticity coordinates of the copy at the point of scanning and thereby generating a light beam having a position determined by the chromaticity of the point scanned, a mask varying in optical density over its area in a predetermined manner, the optical densities at particular active areas on the mask corresponding to rectilinear chromaticity coordinates and the mask having isooptical density lines each corresponding to a particular content of one printing ink in binary combination with all other printing inks of adjoining chromaticities in a set in all possible quantities, means for passing the light beam from the kinescope through the mask at a particular area regulated by the chromaticity and means for exposing photosensitive material to produce printing densities responsive to the light transmitted through the mask.

5. In mechanism for photo-reproduction, means for scanning colored copy by a light beam, means for measuring the chromaticity of the copy at individual points of scanning, a kinescope, means for deflecting the position of the electron beam in the kinescope in response to the chromaticity coordinates of the copy at the point of scanning and thereby generating a light beam having a position determined by the chromaticity of the point scanned, a mask varying in optical density over its area in a predetermined manner, the optical densities at particularly active areas on the mask corresponding to rectilinear chromaticity coordinates and the mask having isooptical density lines each corresponding to a particular content of one printing ink in binary combination with all other printing inks of adjoining chromaticities in a set in all possible quantities, means for passing the light beam from the kinescope through the mask at a particular area regulated by the chromaticity, photoelectric means for producing electric current responsive to the beam of light passing through the mask, photosensitive material, means for scanning the photosensitive material by a light beam in synchronism with the scanning of the copy and means for modulating the latter light beam in accordance with the magnitude of the current to vary the exposure of the photosensitive material in accordance with the chromaticity.

6. In mechanism for color reproduction, means for scanning colored copy by a light beam, means for measuring the chromaticity of the copy at individual points of scanning, a kinescope, means for deflecting the position of the electron beam in the kinescope in response to the chromaticity coordinates of the copy at the point of scanning and thereby generating a light beam having a position determined by the chromaticity of the point scanned, a set of masks each corresponding to a printing ink color other than black, each varying in optical density over its area in a predetermined manner individual to the printing densities required for the particular color of printing ink, means for passing the light beams from the kinescope through the masks at a particular area corresponding to the chromaticity, means for scanning photosensitive materials by light in synchronism with the scanning of the copy while the light beam from the kinescope is passing through the different masks, and means for modulating the light which contacts the photosensitive material in accordance with the light beam transmitted through the different masks.

7. In mechanism for color reproduction, means for scanning colored copy by a light beam, means for measuring the chromaticity of the copy at individual points of scanning, a kinescope, means for deflecting the position of the electron beam in the kinescope in response to the chromaticity coordinates of the copy at the point of scanning and thereby generating a light beam having a position determined by the chromaticity of the point scanned, a set of masks each corresponding to a printing ink color other than black, each varying in optical density over its area in a predetermined manner individual to the printing densities required for the particular color of printing ink, means for passing the light beams from the kinescope through the masks at a particular area corresponding to the chromaticity, photoelectric means for producing electric current responsive to the beam of light passing through the particular mask, a set of photosensitive materials, means for scanning each of the different photosensitive materials by a light beam in synchronism with the scanning of the copy, and means for modulating the latter light beam in accordance with the magnitude of the current produced using each of the different masks to vary the exposure of the photosensitive material in accordance with the chromaticity.

8. In mechanism for color reproduction, means for scanning colored copy by a light beam, means for measuring the chromaticity of the copy at individual points of scanning, a kinescope, means for deflecting the position of the electron beam in the kinescope in response to the chromaticity coordinates at the copy at the point

of scanning and thereby developing a light beam having a position determined by the chromaticity of the point scanned, a set of masks each individual to a different color of printing ink other than black, each varying in optical density over its active area, each active area on the mask corresponding to different rectilinear chromaticity coordinates and each mask having iso-optical density lines each corresponding to a particular content of one colored printing ink in binary combination with all other printing inks having adjoining chromaticities in all possible combinations, means for passing the light beam from the kinescope through the particular mask at a particular area corresponding to the chromaticity, photoelectric means for producing an electric current responsive to the beam of light passing through the mask, a set of photosensitive materials, means for scanning each of the photosensitive materials by a light beam in synchronism with the scanning of the copy, using a different mask for scanning each photosensitive material, and means for modulating the latter light beam in accordance with the magnitude of the current to vary the exposure of each photosensitive material in accordance with the chromaticity.

9. In mechanism for color reproduction, means for scanning colored copy by a light beam, means for measuring the chromaticity of the copy at individual points of scanning, a kinescope, means for deflecting the position of the electron beam in the kinescope in response to the chromaticity coordinates of the copy at the point of scanning and thereby generating a light beam having a position determined by the chromaticity of the point scanned, a set of masks, one for each color of printing ink than black, each varying in optical density over its area in a predetermined manner characteristic of the particular color of printing ink, means for passing the light beam from the kinescope through the mask at a particular area corresponding to the chromaticity, a set of photosensitive materials, means for scanning the photosensitive materials with light in synchronism with the scanning of the copy, means for modulating the light scanning each photosensitive material in accordance with the light transmitted through a mask for a particular color of printing ink other than black, means for comparing reflectance of the copy at each of the points scanned with reflectance of a binary combination of the printing inks having the same chromaticity, further photosensitive material for making a black printing plate, means for scanning the further photosensitive material in synchronism with the scanning of the copy, and means for modulating the exposure of the further photosensitive material in accordance with the relationship of the reflectances.

10. In mechanism for color reproduction, means for scanning copy by a first light beam, means for measuring the chromaticity of the copy at individual points of scanning, a color printing kinescope, means for deflecting the position of the electron beam in the color printing kinescope in response to the chromaticity coordinates of the copy at the point of scanning and thereby generating a second light beam having a position determined by the chromaticity of the points scanned, a set of masks, one for each printing ink color other than black, each varying in optical density over its area, each having active areas corresponding to rectilinear chromaticity coordinates and each having isooptical-density lines corresponding to a particular content of one color of printing ink other than black in binary combination with other colors of printing ink having adjoining chromaticities in all possible combinations, means for passing the second light beam from the color printing kinescope through the particular mask at a predetermined area corresponding to the chromaticity, photoelectric means for producing an electric current responsive to the second beam of light passing through each particular mask, a set of photosensitive materials, one to be exposed for making the printing plates for each color of printing ink other than black, means for scanning each photosensitive material by a third light beam in synchronism with the scanning of the copy while using the mask for the particular color of printing ink, means for modulating the third light beam in accordance with the magnitude of the current to vary the exposure of the photosensitive material in accordance with the chromaticity, a black printing kinescope, means for deflecting the position of the electron beam in the black printing kinescope in response to the chromaticity coordinates of the copy at the point of scanning and thereby generating a fourth light beam having a position determined by the chromaticity of the points scanned, a black printing mask varying in optical density over its area, having active areas corresponding to the rectilinear chromaticity coordinates, whose optical densities correspond with the reflectance of binary combinations of printing inks of adjoining chromaticities having the chromaticity corresponding to the rectilinear coordinates, means for passing the fourth light beam from the black printing kinescope through the black printing mask, means for generating a further current responsive to the light of the fourth beam passing through the black printing mask, means for comparing the further current with a current responsive to the reflectance of the copy at the particular point of scanning, further photosensitive material, means for scanning the further photosensitive material with a fifth light beam in synchronism with the scanning of the copy and means for modulating the fifth light beam in accordance with the comparison of the currents.

11. In mechanism for color reproduction, means for scanning colored copy by a light beam, means for measuring the chromaticity of the copy at individual points of scanning, a kinescope, means for deflecting the position of the electron beam in the kinescope in response to the chromaticity coordinates of the copy at the point of scanning and thereby generating a light beam having a position determined by the chromaticity of the point scanned, a mask having optical density areas corresponding to rectilinear chromaticity coordinates within the gamut of a set of printing inks and rectilinear chromaticity coordinates outside of that gamut, the mask having within the gamut, optical densities corresponding to chromaticities within the gamut and having outside the gamut optical densities which produce chromaticities within the gamut, whereby a compromise is effected in showing chromaticities outside the gamut of the printing inks, means for passing the light beam from the kinescope through the mask at a particular area corresponding to the chromaticity, photosensitive material, means for scanning the photosensitive material by a light beam in synchronism with the scanning of the copy and means for modulating the latter light beam in response to the light which passes through the mask.

12. In mechanism for color reproduction, means for scanning colored copy by a light beam, means for measuring the chromaticity of the copy at individual points of scanning, a kinescope, means for deflecting the position of the electron beam in the kinescope in response to the chromaticity coordinates of the copy at the point of scanning and thereby generating a light beam having a position determined by the chromaticity of the point scanned, a mask varying in optical density over its active area in a predetermined manner and establishing optical densities which definitely depart from those which produce chromaticities corresponding to those on the colored copy, means for passing the light beam from the kinescope through the mask at a particular area corresponding to the chromaticity and means for reproducing on photosensitive material the variations in the intensity of the light beam passing through the mask.

13. In mechanism for color reproduction, means for scanning colored copy with a light beam, means for measuring the chromaticity of the copy at individual points of scanning, means for varying the indication of the chro-

maticity thus measured, a kinescope, means for deflecting the position of the electron beam in the kinescope in response to the varied chromaticity measurements and thereby generating a light beam having a position determined by the modified chromaticity of the point scanned, a mask varying in optical density over its active area in a predetermined manner, means for passing the light beam from the kinescope through the mask at a particular area corresponding to the modified chromaticity, and means for reproducing on photosensitive material the variations in the light transmitted through the mask.

14. A chromaticity record mask for use in mechanism according to claim 1, having varying optical density in different active areas, each active point corresponding to different rectilinear chromaticity coordinates, and having an optical density value individual to the particular chromaticity at each rectilinear coordinate position.

15. A chromaticity record mask for use in mechaism according to claim 1, having varying optical density in different active areas, each active point corresponding to different rectilinear chromaticity coordinates, the mask having a plurality of isooptical-density lines each corresponding to a particular content of one colored printing ink other than black in binary combination with other colored printing inks having adjoining chromaticities in all possible combinations.

16. A color reproduction mask for use in mechanism according to claim 1, having active areas of individual optical densities, points on the mask being arranged in sequence according to chromaticity variations on rectilinear coordinates.

17. A set of color reproduction masks for use in mechanism according to claim 6 each having individual optical densities arranged in accordance with chromaticity according to rectilinear coordinates, and each having optical density values at different chromaticities which correspond to the densities of printing of different colored inks of a set.

18. A color separation mask for use in mechanism according to claim 1, having variations in optical density arranged in accordance with variations in functions of x and y trichromatic coordinates.

19. A chromaticity record mask for use in mechanism according to claim 1, having varying optical densities in different active areas, in which different active points correspond to different rectilinear chromaticity coordinates, having isooptical-density lines each corresponding to a particular content of one colored printing ink other than black in binary combination with other colored inks of adjoining chromaticities in all possible combinations, including active points over a range within the chromaticity gamut of a set of inks.

20. A chromaticity record mask for use in mechanism according to claim 1, having varying optical densities in different active areas, in which different active points correspond to different rectilinear chromaticity coordinates, having isooptical-density lines each corresponding to a particular content of one colored printing ink other than black in bineary combination with other colored inks of adjoining chromaticities in all possible combinations, including active points within the chromaticity gamut of a set of printing inks and active points outside the chromaticity gamut of the set of printing inks which have optical densities producing chromaticities corresponding to chromaticities within such gamut.

21. A chromaticity duplicating mask for use in mechanism according to claim 1, having varying optical densities in different areas, having isooptical-density lines each corresponding to a particular content of one colored printing ink other than black in binary combination with other inks of adjoining chromaticities in all possible combinations, various points on the mask having optical densities which correspond to a function of the chromaticity on rectilinear coordinates but are different from the chromaticity.

22. A set of color duplicating masks for use in mechanism according to claim 6 each for a different color of printing ink other than black, each having varying optical densities at different points, each having optical densities at rectilinear coordinate points which are a function of chromaticity, each having isooptical-density lines on each mask, corresponding to particular contents of different colored printing inks in binary combination with other colored printing inks of adjoining chromaticities other than black in all possible quantities.

23. A binary luminance record mask for use in mechanism according to claim 9 having varying optical densities in different areas, any particular active point on the mask corresponding to different rectilinear chromaticity coordinates, the mask having at any chromaticity coordinates an optical density corresponding to the reflectance of a binary combination of colored printing inks which produce that chromaticity.

24. A binary luminance record mask for use in mechanism according to claim 9 having varying optical densities in different areas, any particular active point on the mask corresponding to different rectilinear chromaticity coordinates, the mask having at any chromaticity coordinates an optical density corresponding to the reflectance of a binary combination of colored printing inks which produce that chromaticity, and the mask having lines of iso-optical density extending thereover.

25. A set of color reproduction masks for use in mechanism according to claim 9 each having varying optical densities in different areas, each having active points corresponding to rectilinear chromaticity coordinates, a plurality of the masks in the set being chromaticity duplicating masks each of which has iso-optical density lines corresponding to a particular content of a different colored printing ink other than black in binary combination with colored inks of adjoining chromaticities in all possible combinations and one of the masks being a binary luminance record mask having at each set of chromaticity coordinates a density corresponding to the reflectance of the binary mixture of printing inks which produces that chromaticity.

26. A color separation mask for use in mechanism according to claim 1, having variations in optical density arranged in accordance with variations in chromaticity and having opaque areas between areas at which variations in density appear.

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