

June 16, 1942.

V. C. HALL

2,286,730

ELECTRIC CIRCUITS FOR COLOR CORRECTION

Filed May 14, 1941

5 Sheets-Sheet 1

FIG. 1.

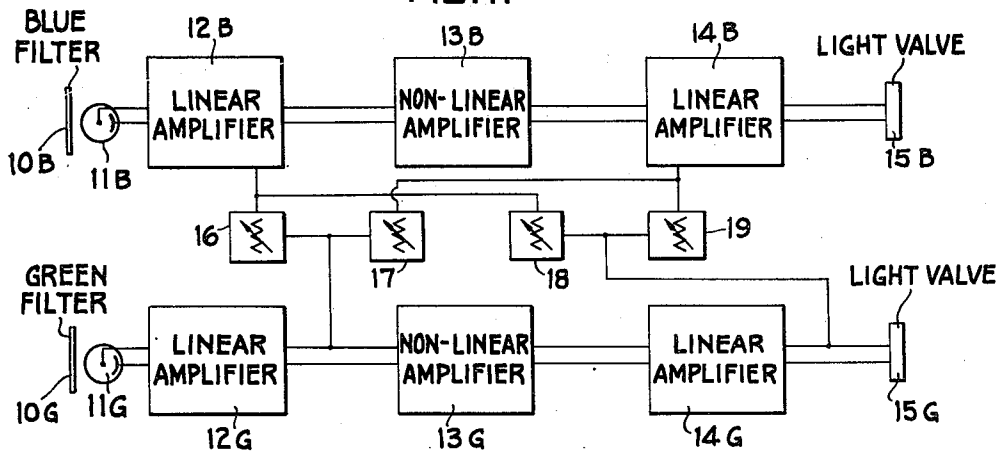
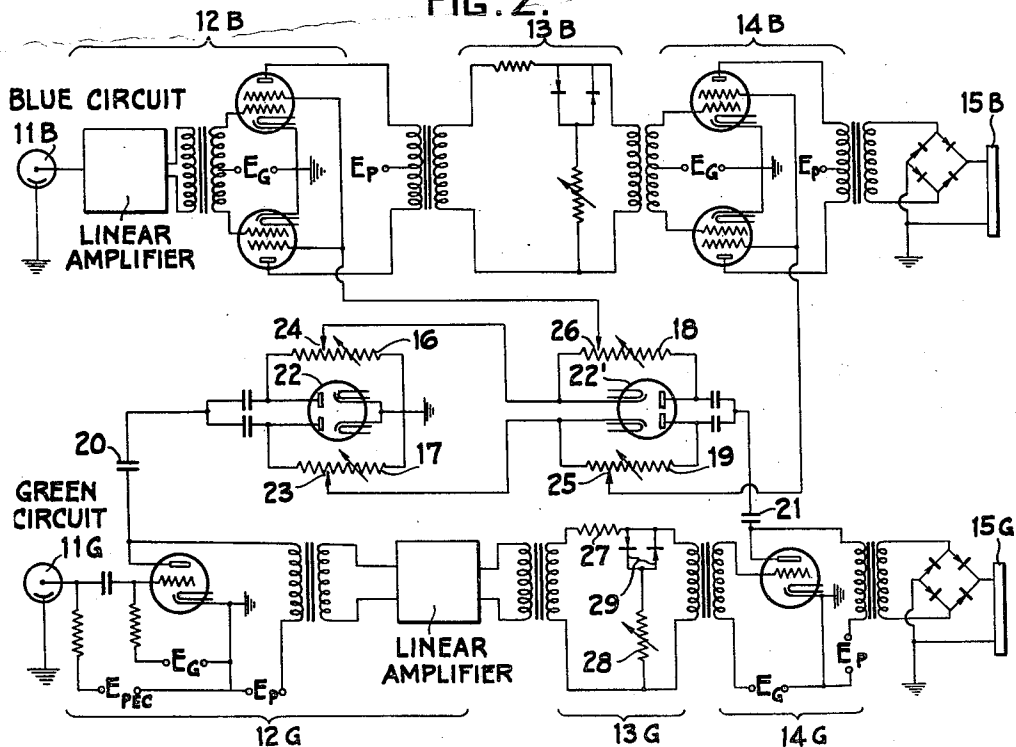


FIG. 2.



VINCENT C. HALL
INVENTOR

BY *Walter M. Pomeroy*
ATTORNEY

June 16, 1942.

V. C. HALL

2,286,730

ELECTRIC CIRCUITS FOR COLOR CORRECTION

Filed May 14, 1941

5 Sheets-Sheet 2

FIG. 3.

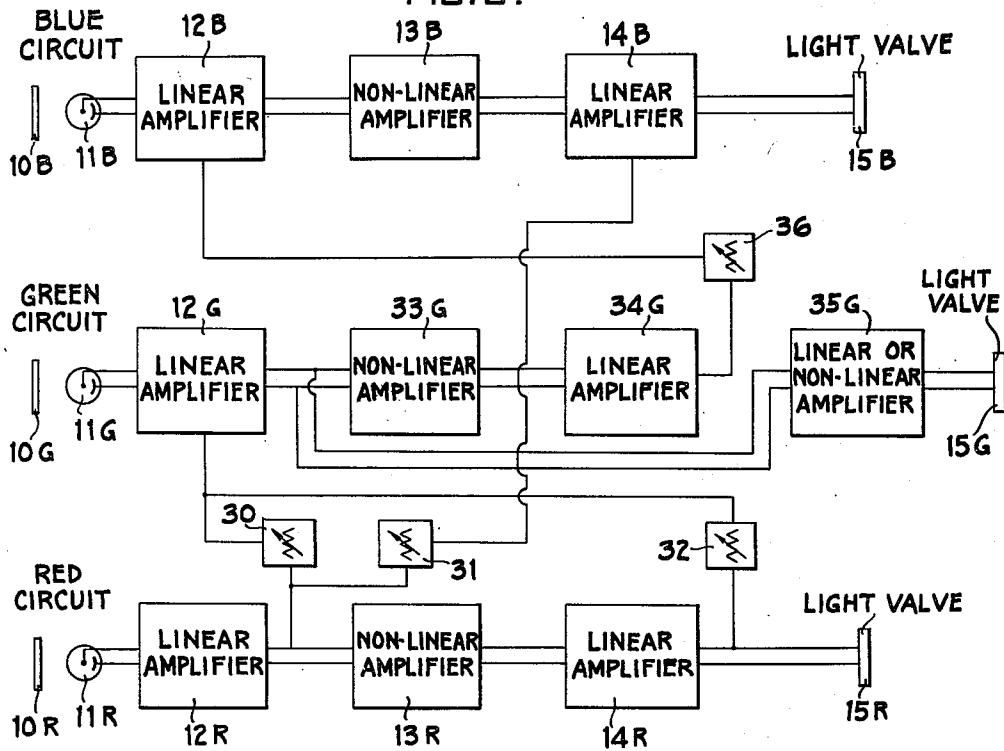
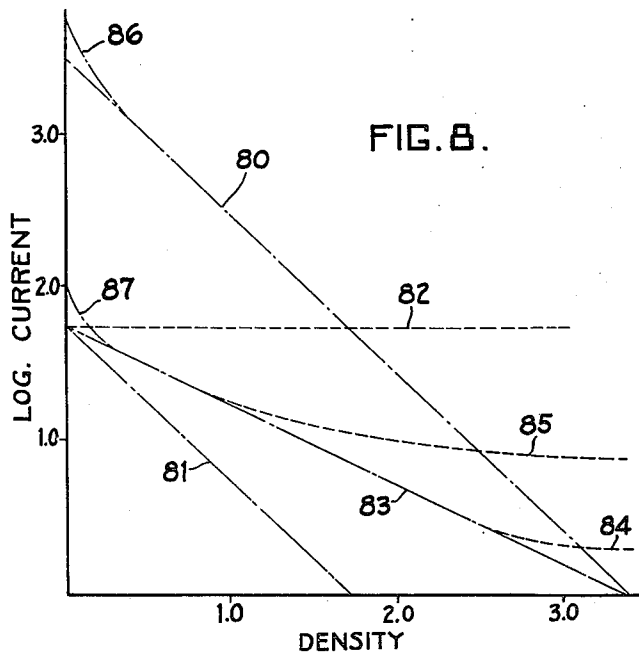


FIG. 8.



VINCENT C. HALL
INVENTOR

BY *W. W. P. P. P.*
ATTORNEY

June 16, 1942.

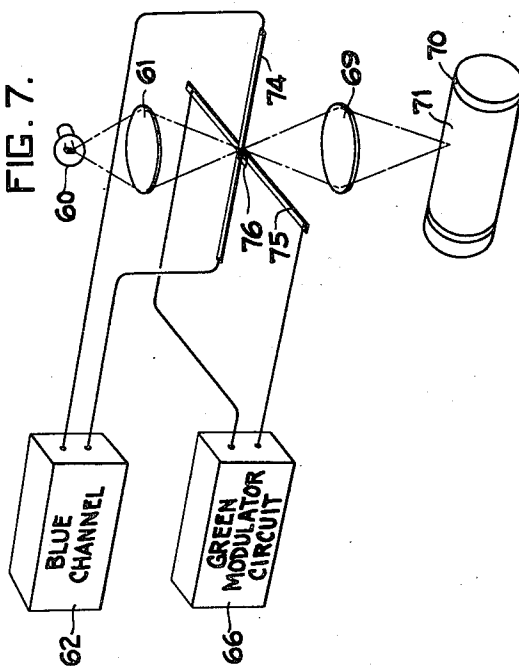
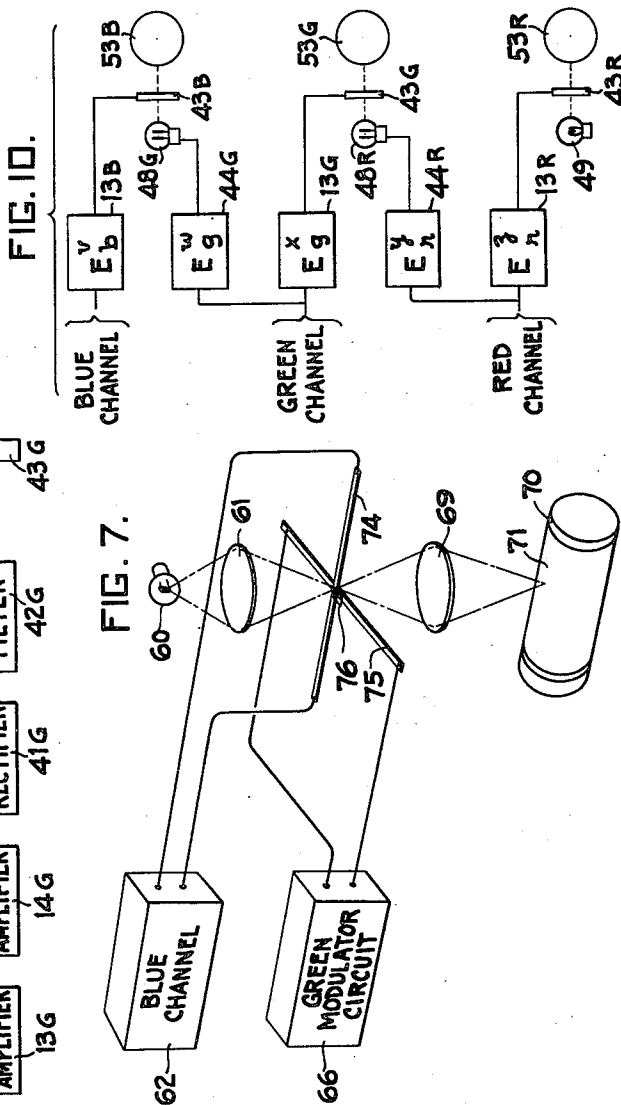
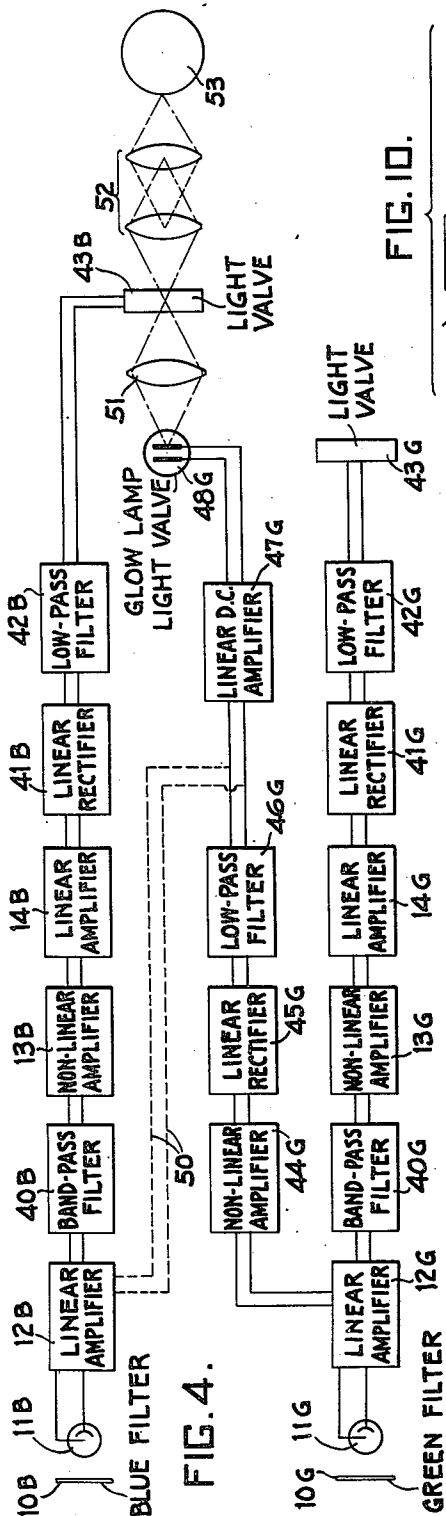
V. C. HALL

2,286,730

ELECTRIC CIRCUITS FOR COLOR CORRECTION

Filed May 14, 1941

5 Sheets-Sheet 3



VINCENT C. HALL
INVENTOR

BY *William P. ...*

ATTORNEY

June 16, 1942.

V. C. HALL

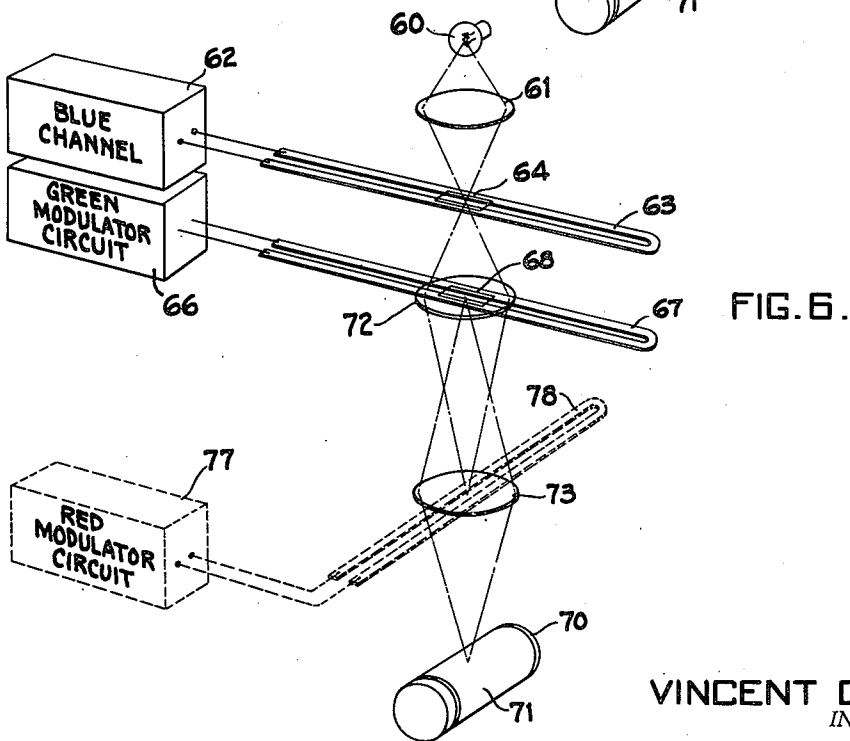
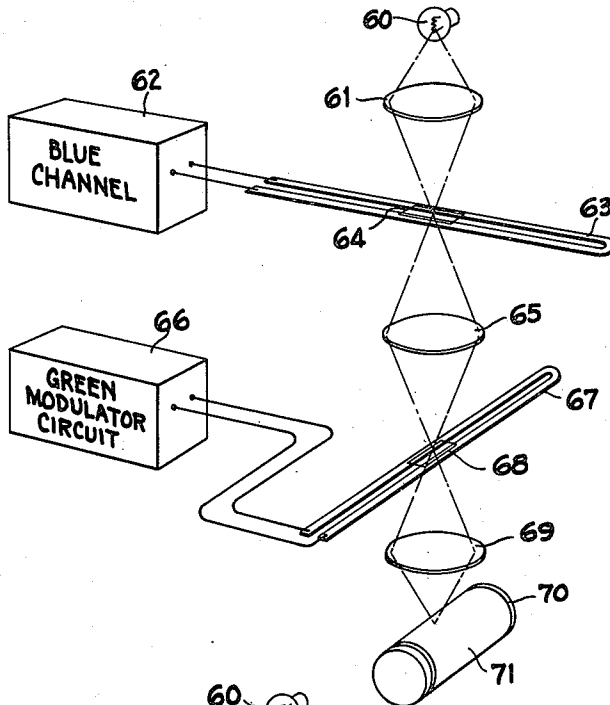
2,286,730

ELECTRIC CIRCUITS FOR COLOR CORRECTION

Filed May 14, 1941

5 Sheets-Sheet 4

FIG. 5.



VINCENT C. HALL
INVENTOR

BY *Wm. M. Pinnis*

ATTORNEY

June 16, 1942.

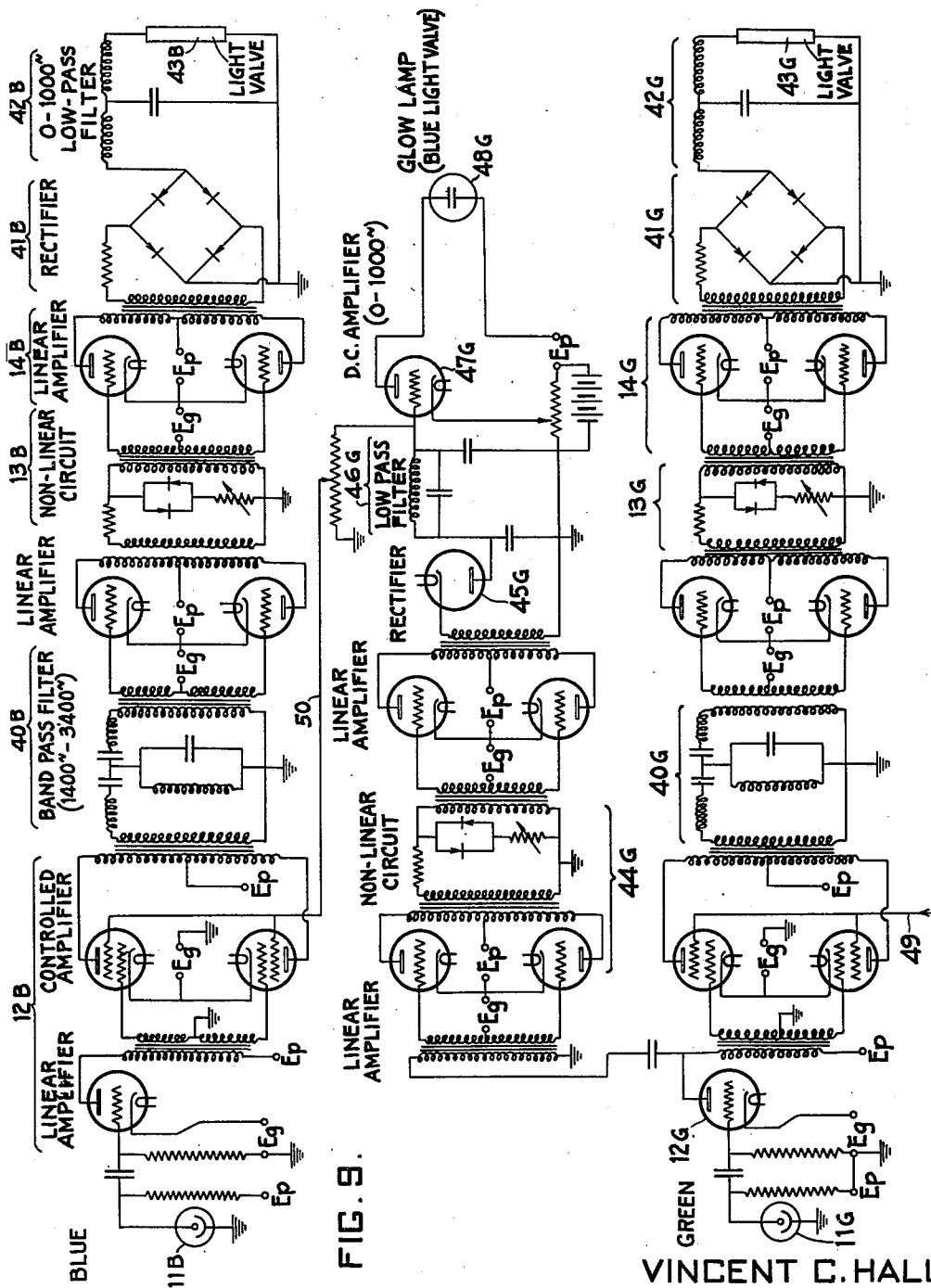
V. C. HALL

2,286,730

ELECTRIC CIRCUITS FOR COLOR CORRECTION

Filed May 14, 1941

5 Sheets-Sheet 5



VINCENT C. HALL
INVENTOR

INVENTOR

BY *Newton M. Pernes*

ATTORNEY

UNITED STATES PATENT OFFICE

2,286,730

ELECTRIC CIRCUIT FOR COLOR
CORRECTION

Vincent C. Hall, Rochester, N. Y., assignor to
Eastman Kodak Company, Rochester, N. Y., a
corporation of New Jersey

Application May 14, 1941, Serial No. 393,418

19 Claims. (Cl. 178-5.2)

This invention relates to electro-optical systems for the reproduction of multi-colored originals. It relates particularly to a method and means for introducing color correction in such systems.

In a copending application, Serial Number 120,964, filed January 16, 1937, now Patent 2,253,086, A. Murray and R. S. Morse describe the broad idea of introducing the color correction in electro-optical systems of this type. In U. S. Patent 2,231,669, I have described the application of this broad idea to the problem of correcting errors which occur in the duplication of mono-pack color transparencies. The present invention may be applied to the specific idea of that patent as well as to the system broadly disclosed by Murray and Morse. It may also be applied to the transmission of colored pictures by wire or television.

The present application is a continuation in part of my application Serial Number 234,422, filed October 11, 1938, now Patent 2,249,522.

It is an object of the present invention to give improved color correction and better control over the amount and type of color correction than hitherto available.

It is the object of this continuation in part to provide improvements of these types even to a much higher degree than obtainable with the arrangement described in my parent application.

The type of electro-optical systems to which the invention belongs usually include some scanning device and a beam-splitter together with color filters, for example, the three primary colors, for scanning the original in plurality of colors. Each of the colored scanning beams is directed to a photoelectric cell which together with its amplifying circuit and a light valve forms an electric channel carrying an electric energy in accordance with the intensity of the corresponding scanning beam. The analogous systems in television or sending pictures by wire are obvious from the following description and will not be separately considered. The light valve which may be of the ribbon type or a glow lamp controls the printing of a color separation negative corresponding to the color falling on the photoelectric cell or any type of light controlling devices such as used in reproduction of pictures sent by television. According to the Murray and Morse application above mentioned, color correction is introduced by modifying the energy in one of the channels in accordance with the corresponding energy in another of the channels. The less preferable systems wherein color separa-

tion negatives are first made and the color channels are controlled by scanning these negatives simultaneously and synchronously may also benefit by the present invention.

5 According to the present invention the outputs of the channels are further modified in one or both of two ways. First, the output is made proportional to some power other than unity of the input by including a non-linear amplifier in the channel. Secondly, the modification of the energy in one channel may be in accordance with a non-linear power function of the energy in one of the other channels.

More specifically, one or more of the channels include a non-linear amplifier having an output to input transmission function between the .25 and unit power, i. e. between the fourth root and linear. By modulating the output of the photoelectric cell in another channel in accordance with the output of this non-linear amplifier, a degree of modulation proportional to the transmission function of the non-linear amplifier is obtained. On the other hand, the energy in a circuit having only linear amplifiers may be used to modify the output of this non-linear amplifier and hence the degree of modification in this channel which contains the non-linear amplifier will be proportional to a power between 4 and 1 of the energy in the other channel.

30 My parent application Serial Number 234,422 referred to above, related to this broad idea of modifying the energy or signal in one color channel by a non-linear (the specific example being an exponential) function of the signal in another of the channels. The particular example given in that application employed "electrical modification," i. e. modification of the signal while it is in the form of electrical energy. In any electro-optical color reproduction system the signals are first set up as light energy variations in the scanning beams reflected or transmitted by the original color picture (or color separation negatives). The light energy variations are converted by the photoelectric cells to electrical energy variations and then are reconverted by the light valves (this term includes glow lamps, ribbon valves operating on light beams, etc.) to light energy variations.

The present continuation-in-part relates to an improvement of the species disclosed in the parent application and has for its main object improved color modification.

The specific objects of the improvement are of two classes, namely to obtain closer conformity with the ideal type of modification predicted by

mathematical theories or found by mathematical analysis of perfect reproductions and secondly to extend the range of reproducibility of this conforming modification.

A mathematical comparison of electro-optical and photographic systems of color reproduction aids in understanding the reasons for the broad invention and in differentiating the various forms thereof. As an example of electro-optical systems, the case where the original is scanned directly (no uncorrected negatives being made) and where color corrected negatives are exposed by controlled light valves, is analysed in comparison with purely photographic systems of making color separation negatives, the following features being analogous. The "reflectivity" or "transmission" of the original to red, green and blue is the same in both cases. The "exposure" of the photographic negative and the "exposure" of the photoelectric cell are the same and are directly proportional to the original "reflectivity" or "transmission." In the electrical case the signal is proportional to the exposure of the cell and any number of linear amplifiers in the circuit merely changes the proportionality factor. In the photographic case, on the other hand, the negative density is not linearly proportional to the exposure but follows a characteristic curve, part of which involves a logarithmic relationship between density and exposure i. e. a linear relationship between density and log exposure. The slope of this characteristic curve is the contrast of the negative relative to the original and the value of this slope for the linear portion thereof is called "gamma."

Even when there is no color correction, the gamma of each color component must be controlled and balanced against that of the other colors.

Furthermore color correction of the masking type when performed photographically involves the superposition in register (masking) of a high or normal contrast color separation negative and a low contrast positive corresponding to a different color. In fact in every type of color correction of practical importance, it is desirable and necessary to be able to control the gamma (contrast) and/or similar features.

The present invention provides in electro-optical systems a control similar to, but in many ways better than, the control of gamma or contrast in a purely photographic system of color correction.

Mathematically masking consists of the addition of densities one of which is the density of a positive and the other of a negative. This is equivalent to the subtraction of quantities which are logarithmically or exponentially proportional to exposures (i. e. to original reflectivities or original transmissions). It is also equivalent to the division of quantities linearly proportional to exposures, etc. When a negative and a positive are thus placed together in masking register the contrast or gamma of the combination is equal to the difference of the individual contrasts (or gammas).

When an attempt is made to simulate masking with an electro-optical system, the degree of correction obtained for all values of the two signals involved will be correct only when the above discussed mathematical relationship holds i. e. when the modification is equivalent to the subtraction of quantities exponentially proportional to exposures. It should be understood that simple modulation involving the multiplication of one

signal (linearly proportional to exposure) by a quantity negatively linearly proportional to another signal would not simulate masking. Basically the "masking" type of correction is the preferred one, but slight improvements thereon (e. g. to correct for the toe and shoulder of the characteristic curve of the original or for the toe and shoulder of the curve of the negative materials being exposed; or for disproportionate losses in signal transmission, especially in television; or for any of the other factors not peculiar to color reproduction but present even in black and white systems and/or for correcting for those lesser errors present even in purely additive processes of color reproduction), may be combined with pure masking to give more accurate and pleasing color reproduction. The present invention permits the practical realization of such combinations which were not possible with simple electro-optical systems or with photographic systems.

The specific embodiment of this continuation-in-part gives the subtraction of quantities exponentially proportional to exposures over a range greater than that obtained with the specific arrangement of the parent application and furthermore even the small variations from pure subtraction of quantities exponentially proportional to exposures are such as to aid in the correction of the minor errors listed above. This specific embodiment (the continuation-in-part) consists of optical modulation using two light valves in cooperative optical tandem, i. e. two valves operating simultaneously on the same light beam, the valves being controlled by the energy from different color channels. The optical tandem arrangement may be two ribbon-type valves in series with respect to the light beam, it may be a glow lamp whose output is modified by a ribbon-type valve or other variable aperture or it may be a ribbon valve with two or more independently operated ribbons in the same magnetic field as described in application Number 417,540, filed Nov. 11, 1941, by John Streiffert and myself. By way of precise definition, it is pointed out that the three valves making the black printer in Fig. 5 of U. S. 2,183,524, Yule, are not in "cooperative optical tandem" since they operate alternately not simultaneously on the light beam as is necessary to the present invention.

Furthermore each of the valves of this tandem pair may separately consist of two valves in tandem to give increased range as described in my copending application Serial Number 378,781 filed Feb. 13, 1941.

Light valves in optical tandem are not per se new, but the advantages of the present invention are due to the combination of this feature with the non-linear amplifier invention of my parent application. These specific advantages became apparent to me only after careful investigation of all modification of the broad invention including that specifically disclosed in the parent application. The following mathematical analysis indicates that the present embodiment and that of the parent application are theoretically identical and hence the reason why the present embodiment is so superior could not be predicted and cannot even now be explained mathematically.

The color components of an original are in general the primary colors—red, green, and blue, corresponding respectively to the blue-green (cyan), magenta, and yellow printers. When

the original or an image thereof is scanned, the resulting signal corresponds to the points of the original "in scanning succession." Since yellow printing inks are usually satisfactory, most color correction processes of the masking type involve reduction of the yellow by an amount proportional to either or both of the other colors. By way of example, the correction of the blue (yellow printer) signal by the green (magenta printer) signal is here described. Aside from the various minor errors discussed separately, electro-optical correction must be in the direction which simulates masking.

In purely photographic masking

$$D'_b = D_b + D_{(pos)_g} = D_b - C_1 D_g + C_2 = \log C \frac{R_b K}{R_g L}$$

$$T'_b = \frac{R_b L}{C_2 R_g K}$$

where all C's are constants, D_b and D_g are the densities of the blue and green negatives uncorrected, $D_{(pos)_g}$ is the density of the positive mask made from the uncorrected green negative, D'_b is the density and T'_b the transmission of the corrected blue negative, R_b and R_g are the reflectivities or transmissions of the original to blue and green respectively and K and L are the gammas to which the negative and mask are respectively developed relatively to the original.

In the arrangement taught in my parent application, the basic equation, without regard to the variation due to circuit factors and the form of the light valve response, is:

$$E'_b = E_b M (C_4 - E_g^N)$$

where E'_b is the corrected blue signal, E_b and E_g are the uncorrected blue and green signals and M and N are the exponential coefficients of the non linear amplifiers. The signal E'_b passing through a light valve controls the exposure of a corrected blue negative whose density is therefore:

$$D'_b = P \log (C_5 E_b M [C_4 - E_g^N])$$

where P is the gamma to which this negative is developed.

Similarly with light valves in optical tandem, the basic equation is

$$D'_b = P \log (C_5 E_b M [C_4 - E_g^N])$$

which is identical to the one for purely electrical correction.

However it has been found practically that either system gives results which simulate masking over a wide range of energies (i. e. greater than 30 to 1 and up to 1000 to 1 and more, which corresponds to a range of densities up to 0 to 3 and even greater.) Obtaining these greater ranges with the system described in my parent application is extremely difficult. The optical tandem system however simulates the masking more closely and over a more extended range with much simpler apparatus. Furthermore at the ends of the range I can now control the departures from true masking both in direction and amount to be useful for the correction of some of the minor errors in color reproduction systems. In addition to more accurate color rendition for the various hues and tints, the optical tandem system has greater stability, greater uniformity and numerous other factors all tending toward better color rendition. In fact, not only can this system accurately simulate masking over a range far greater than is necessary in practice but these added controls of the deviations from true masking provide color

correction better than the best obtainable with purely photographic systems.

One embodiment of my invention combines both electrical and optical tandem valve types of correction. In this case both corrections may be of the masking type or one of them may be of a different type to correct for minor errors such as those present in additive processes and hence present to a certain degree in subtractive processes.

The objects and advantages of the invention and the invention will be more clearly understood from the following description when read in connection with the accompanying drawings in which:

Fig. 1 shows an adjustable form of the invention.

Fig. 2 shows one form of electric circuit which can be used to provide the embodiment shown in Fig. 1.

Fig. 3 shows another embodiment of the invention involving various forms thereof.

Fig. 4 shows the circuit for an embodiment of the invention involving light valves in optical tandem.

Fig. 5 illustrates one form of optical tandem light valves.

Fig. 6 illustrates another form of optical tandem light valves.

Fig. 7 illustrates a third form of optical tandem light valves.

Fig. 8 is a graph of light valve response vs. densities of the original.

Fig. 9 is a detailed circuit drawing of the arrangement shown in Fig. 4.

Fig. 10 shows a preferred embodiment of the invention.

In Fig. 1 the green channel includes a green filter 10G through which a corresponding scanning beam falls on a photo-electric cell 11G having a linear amplifying circuit 12G, a non-linear amplifier 13G, a second linear amplifier 14G in series to operate a light valve 15G in any of the usual ways. The non-linear amplifier 13G was introduced, according to the invention to permit a picture to be produced by the light valve 15G having a contrast different from that of the original scanned by the photocell 11G, i. e. to permit differential control of the ratio of output to input energy at different energy levels. The blue channel similarly includes a filter 10B, photoelectric cell 11B, linear amplifiers 12B and 14B, a non-linear amplifier 13B, and a light valve 15B. According to Murray and Morse the energy in the blue channel should be modified in accordance with the energy in the green channel. Applied to this Fig. 1, their system would be such that the output of the linear amplifier 12G through a suitable modifier such as shown at 16 would modify the output of the linear amplifier 12B. According to the present invention the energy in the blue channel is modified in accordance with some non-linear power function of the energy in the green channel. If, for example, the non-linear amplifier 13G has a square root transmission function whereby its output is proportional to the square root of its input, the output of the linear amplifier 12B will be modified through a modifier 18 in accordance with the square root of the energy in the amplifier 12G. Non-linear amplifiers are well known and the type here described are those which employ variable resistances (29 in Fig. 2) commonly called varistors. Such arrangements have an output which is a constant exponential function of the

input over a wide range of input intensities. Since color pictures have densities up to and above 3, the reflectivities or transmissions vary over a range of 1000:1 or more. Therefore to effect a change in a signal from one gamma to another requires the exponential function to be practically constant over this range of 1000:1 or at least over a range of 30:1. This latter range would be satisfactory only for the reproduction of originals whose maximum density difference is 1.5, which is true only for very few color pictures. To clarify this point, attention is drawn to the fact that density is a logarithmic function and that 3 is the log of 1000 and 1.5 is approximately the log of 30.

By suitable adjustment of the resistances in the modifiers 16 and 18 the modification of the energy in the blue channel may be made proportional to any desired additive combination of the linear function and the square root function of the energy in the green channel.

The modification may be linear subtraction e. g. by merely superimposing the potentials corresponding to the energies in opposite directions across a resistance. It may simulate division e. g. by adjusting a resistance in the blue channel in accordance with the energy in the green channel. It may be multiplication either directly or as shown in Fig. 2, where the energy in the blue channel is multiplied by a constant minus the modifying energy which may for example be proportional to the square root of the energy in the green channel. The term modify is used to include all such modifications or embodiments.

If the non-linear amplifier 13B in the blue channel has a transmission factor for example according to the third root power, a modifier 17 which introduces the output of the linear amplifier 12B into the linear amplifier 14B will effectively modify the output of the blue channel in accordance with the third power of the energy in the green channel. A fourth modifier 19 would in the example taken permit modification of the energy in the blue channel in accordance with the three halves power of the energy in the green channel. In all of these cases the modification is uniform over practically the whole range of intensities so that, over the major portion of the total latitude, the linearity of density relationships is maintained at least approximately. Since density is logarithmic this maintenance of linearity with respect thereto is really a maintenance of the constant of non-linearity with respect to intensities themselves, e. g. a constancy of the exponent in an exponential function. As pointed out, specific variations from this constancy may be introduced to correct for minor errors such as the toe and shoulder of the reproduction curves or the errors inherent in additive processes. These latter specific variations are easily obtainable only with the combination of non-linear amplifiers and optical tandem light valves here disclosed.

If it is desired to modify the energy in the blue channel in accordance with some non-linear power function of the energy in the green channel, but to have the light valve 15G react in direct proportion to the input from the photoelectric cell 11G, the light valve 15G may be operated directly from the linear amplifier 12G and the output of the non-linear amplifier 13G to the linear amplifier 14G would be used only for modification of the energy in the blue channel.

In Fig. 2 there is shown a detailed electric

circuit corresponding to Fig. 1. A portion of the output of the photoelectric cell 11G is taken off through a condenser 20 and a rectifier 22 to modulate the energy in the blue circuit in the linear amplifier 12B before the non-linear amplifier 13B and/or alternatively in the linear amplifier 14B after the non-linear amplifier 13B. Similarly a portion of the output of the linear amplifier 14G is taken off through a condenser 21 and a rectifier 22' to modify the energy in the blue channel at either or both of the linear amplifying stages 12B and 14B. The potentials on the points 23, 24, 25, and 26 depend respectively on the output of the condensers 20 and 21 and the setting of the variable resistances 17, 16, 19, and 18. If, as in the example discussed in connection with Fig. 1, the non-linear amplifiers 13G and 13B have transmission functions respectively according to the square root and third root powers, this arrangement shown in Fig. 2 is completely adjustable whereby the output of the blue circuit may be modified by the energy of the green circuit in accordance with any additive combination of linear, square root, three-halves and third powers. More correctly the output of the blue channel will be in accordance with the third root power of the input of the blue channel modified by a function of the energy in the green channel which includes additively, a linear function, a square root function, a cube function i. e. a third power function and a three-halves power function. If the tubes are operating on a straight line portion of their characteristic curves, this modification will be multiplication as discussed above. Otherwise almost any type of modifying is possible by suitably adjusting the tube responses. The rectifiers 22 and 22' act merely as rectifiers and have no appreciable effect on the non-linearity which is established in the non-linear amplifier 13B and 13G. The varistor 29 in this unit includes two copper oxide rectifiers but may be any of the other well known types of varistors, such selenium type, opposed diodes type or saturated core transformers.

Fig. 3 shows a preferred embodiment of the invention wherein through suitable modifiers 30, 31, 32, and 36 various modification functions are introduced. The light valve 15R of the red channel varies according to some power function, introduced by the non-linear amplifier 13R, of the output of the photoelectric cell 11R. The light valve 15G in the green channel varies linearly with the output of the photoelectric cell 11G or if a non-linear function thereof is desired, the amplifier 35G by which the light valve 15G is operated may include a non-linear stage. The output of the photoelectric cell 11G, is however modified linearly by the modifier 30 in accordance with the output of the photoelectric cell 11R and non-linearly by the modifier 32 in accordance with the output of the non-linear amplifier 13R. The light valve 15B in the blue circuit operates non-linearly in accordance with the output of the photoelectric cell 11B passing through the non-linear amplifier 13B. The energy in this channel is modified according to the inverse power of the non-linear amplifier 13B by a modifier 31 which introduces the linear function of the output of the photoelectric cell 11R to the final stage of linear amplification 14B in the blue channel. This energy is also modified non-linearly in accordance with a non-linear amplifier 33G which operates on a portion of the output of the linear amplifier 12G in the

green channel and introduces its non-linear modification through amplifier 34G and modifier 36 into the linear amplifier 12B.

By dividing the output from linear amplifier 12G it is possible to have the light valve 15G operate linearly therewith or according to some non-linear function which is different from the non-linear function used in the modification of the energy in the blue channel.

Numerous other variations of this idea will be apparent from this description, but I have found that an amplifier having an output varying according to the .40 power of the input, when placed in each channel together with a modification of the green channel in accordance with the .45 power of the energy in the red channel and a modification of the energy in the blue channel in accordance with the .40 power of the energy in the green channel, gives satisfactory results. This, of course, reduces the system to a relatively simple form.

For the convenience of those accustomed to think in terms of the masking method of color correction, the following analogy is given. If the above modification is a direct division, this means that the green intensity is divided by the .45 power of the red intensity and that the blue intensity is divided by the .40 power of the green intensity. If the signal intensities were then used directly to control the exposures, this would be the same for example as masking the blue negative by a positive of the green negative which positive is developed to a gamma of .40. However all of these signal intensities are also reduced to the .40 power before controlling their respective light valves (which are assumed here to be linear as is generally the case, but which may have any desired response function). Therefore the total contrast of the printing light is reduced by this power which compensates for the high contrast due to the processing of certain types of monopack films.

For example the blue printing light is proportional to the .40 power of the original blue scanning light minus (.40 $\times$.40) power (i. e. the .16 power) of the original green scanning light. The gamma to which the yellow layer is developed or in photomechanical processes, the gamma to which the yellow printer is developed and prints, is about 2.5. This has been found to give correct tone reproduction in the final reproduction.

The more complicated cases where the above modification is not a direct division and/or the valve response is not linear are almost infinite in number and are increasingly more difficult to explain mathematically. However, it is obvious that something similar or analogous to this reduction in contrast and to this masking with a correcting mask of lower contrast takes place in various types of modification.

For example with multiplication (as in Fig. 2) the masking instead of being by a .40 contrast mask which is a direct positive of the green negative, is by a .40 contrast mask which is a slightly complicated positive function of the green negative. Thus in every case there is something analogous to the reduction in contrast in ordinary masking.

Referring to the specific form shown in Fig. 2, the non-linear amplifier 13G for example may include a resistance in series with one side of the circuit and a shunt across the circuit including an adjustable resistance 28 and two inversely arranged rectifiers 29 parallel to each other, constituting a varistor, and in series with the ad-

justable resistance 28. By using a resistance of 100 ohms for the resistance 27 and impedance equal to 2000 ohms in the output of this non-linear amplifier, i. e. the primary coil of the transformer between the non-linear amplifier 13G and the linear amplifier 14G, and by using varistor 29 whose resistance varies from $\frac{1}{10}$ of an ohm to 100 ohms depending on the current flowing therethrough, which in turn depends upon the setting of the adjustable resistance 28 and the intensity of the input, it is possible to provide an output which varies proportionally to a power function of the input, which power is between .25 and 1.

In Fig. 4 the blue and green channels are each shown as containing linear amplifiers 12B and 12G, band-pass filters 40B and 40G, non-linear amplifiers 13B and 13G, another stage of linear amplification shown at 14B and 14G, a linear rectifier shown at 41B and 41G and a low-pass filter at 42B and 42G. The light modulating devices are shown at 43B and 43G respectively. For the modulation of the blue signal by the green signal, the green circuit includes a branch circuit connected to the output of the linear amplifier 12G and including a non-linear amplifier 44G, a linear rectifier 45G, a low-pass filter 46G and another stage of amplification, in this case a D. C. amplifier 47G, which operates a glow lamp 48G. The output of the rectifier 45G is a pulsating direct current. The high frequency components of these pulsations are stopped by the filter 46G and the amplifier 47G is designed to amplify uniformly D. C. or low frequencies passed by 46G (the range of frequencies may be for example 0 to 1000 cycles per second). The glow lamp 48G and the light valve 43B are in optical tandem, the light from the glow lamp 48G being focused by an optical system 51 on the light valve 43B and then refocused by an optical system 52 onto a sensitive film 53 mounted on a drum for scanning in the usual way. Alternatively, the blue signal may be fed into a glow lamp and the modulator signal fed into a ribbon type valve so that the two valves are interchanged relative to the position shown in this Fig. 4. However, I find it preferable to impose the correction current, i. e. the green modulator signal, on a glow lamp and to have the main signal on a ribbon type valve as shown at 43B.

With the "optical tandem valve type" of color correction shown, the band-pass filter 40B is unnecessary. It is quite useful to have such electrical filters present, however, if one wishes to combine the optical tandem type of correction shown in this Fig. 4 with the purely electrical correction shown in Figs. 1 to 3. To do this, the output of the modulator circuit may also be connected by leads shown by broken line 50 into the linear amplifier 12B in exactly the same way as shown in Fig. 3. Of course, added stages of amplification may be included at any suitable point in the circuit such as in the leads 50. The low-pass filters shown in this figure may conveniently be arranged to pass frequencies less than 1000 cycles. In this case, the band-pass filter 40B is arranged for example to transmit frequencies between 1400 and 3400 cycles. Obviously, the band-pass filter 40B may be in the circuit anywhere between the linear amplifier 12B and the rectifier 41B. The arrangement shown, happens to be the one which has been found to give satisfactory results. Even when the correction is introduced entirely by having the light valves in

optical tandem, there is no harm in including a band-pass filter 40B and there is some advantage because this filter 40B cuts down "noise" and thus extends the range of clear signals.

When the combination of optical tandem light valve correction and purely electrical correction is employed, both corrections may be of the masking type, i. e. the subtraction of densities or alternatively may have various forms. I have found that the optical tandem light valve system simulates masking very closely over a very extended range. If the leads 50 are connected to the linear amplifier 12B as shown in Fig. 2, this type of correction is available over an even a more extended range. That is, the response (effective output) of the light valve 43B is modified both by the electrical correction through leads 50 and by the optical correction through the glow lamp 48G.

If the leads 50 are connected into the linear amplifier 12B so as to give a linear subtraction of the signals, the minor errors which are present even in additive processes may be corrected simultaneously with a masking by the glow lamp 48G. Here "masking" is used in the sense of "correction by the subtraction of densities." Even for linear subtraction of signals, the control of contrast by non-linear amplifiers is useful but is not as important as in masking. Similarly it may be possible to have both the optical tandem light valves, and the electrical correction through the leads 50 arranged generally for masking, but to deviate slightly therefrom to correct for minor errors such as the toe and shoulder of the reproduction curves, etc. For example, to increase the contrast at low densities only and still maintain the same percentage of masking, the resistances (such as 28 of Fig. 2) in series with the varistors of the non-linear amplifiers 44G and 13B, are slightly increased from the normal valve (0 to 2 ohms) up to say 8 to 12 ohms.

The linear amplifier 47G is of course not absolutely necessary, but it is more convenient to operate the glow lamp 48B from the output of such an amplifier. The optical system 52 is arranged so as to provide a scanning spot of variable intensity rather than variable area. A variable area system would be preferable if a halftone record were being made. Other forms of optical tandem light valves are shown in Figs. 5 to 7 and a detailed arrangement of the electrical parts in this Fig. 4 is shown in Fig. 9. All of these figures relate specifically to the correction of the blue signal in accordance with the intensity of the green signal since this is the commonest correction of the masking type. Obviously, the same principle is applicable to the correction of any of the signals. When it is desirable to modify the blue signal by both the green and the red signals, three valves are used in optical series. That is, the blue channel light valve 43B would be placed in optical tandem with both a green modulator light valve and a red modulator light valve.

In the exposing of a negative 53, the light valve 43B is arranged to increase in transmission with increasing blue signal. The glow lamp 48G is arranged to decrease in intensity with increasing green signal. The forms of this response, are described in connection with the graph shown in Fig. 8.

In Fig. 5 a light source 60 focuses a spot by means of an optical system 61 on the aperture 64 of a ribbon type light valve 63 which is connected to the output of the blue channel 62. The separation of the ribbons of the light valve 63 de-

termines the amount of light transmitted through this valve. For convenience the magnet providing the magnetic field for these ribbons is not shown; but may be of any of the usual types. The light from this valve 63 is refocused by a lens 65 on another ribbon type valve 67 having an aperture 68 and connected to the green modulator circuit 66. So that the total transmission of these two ribbon type light valves 63 and 67, in optical tandem as shown, will be the product of the individual responses of these valves, they are arranged at right angles to one another. They may thus be made to simulate masking, even with a linear response of the valves. Obviously, if a variable width image of the valve 63 were focused on the valve 67, with its ribbons parallel to the valve 63, the output of the two valves would not be the product of the separate ones. This output is focused by a lens 69 onto a sensitive film 71 mounted for scanning on a cylinder or drum 70.

Fig. 6 shows an alternative arrangement wherein the light valves 63 and 67 have their ribbons parallel, but the light striking the valve 67 is not an variable width image of the valve 63. The light incident on the valve 67 has variable intensity. The two valves may be at any angle to one another and are shown parallel for comparison with Fig. 5. A lens 72, acting as a field lens is placed adjacent to the light valve 67 to focus an image of the valve 63 in a relay lens 73 which is positioned to focus the valve 67 on the sensitive film 71. This arrangement produces on the film 71 a spot whose intensity is controlled as the product of the two responses of the light valves 63 and 67 or of the responses of all three valves if 78 is present. A change of azimuth of the valve 78 from this right angle position to a parallel one would result in a scanning spot whose intensity is the product of the response of valve 67 and valve 63 or 78 whichever is smaller, but intermediate azimuthal positions of valve 78 give more useful functions.

Still another arrangement of light valves in optical tandem is shown in Fig. 7 wherein both valves are placed in the same magnetic field. Although the ribbons are quite close to one another, they are still in optical tandem. A single ribbon 74 is connected to the output of the blue channel 62 and a single ribbon 75 at right angles thereto is connected to the output of the green modulator circuit 66. The aperture of the valve is indicated by the square 76, but as before, the magnet providing the magnetic field is not shown. This embodiment is described in the above mentioned copending application by Streiffert and myself. With the ribbons at right angles to one another, the joint response is the product of the separate responses, as required in the masking type of color correction.

In Fig. 8, the logarithm of the current operating the final light valve is plotted against the density of the original picture being scanned. This discussion is given in terms of the purely electrical correction, but is equally applicable to the optical tandem system, if the response of the valve is substituted for the current input thereto. The abscissa of the graph may be the density to blue or the density to green.

Considering first the blue valve only, the logarithm of the current input thereto will be linearly negatively proportional to the blue density of the original. This is shown by the curve 80 (actually a straight line) in this Figure 8. If the original has zero blue density, i. e. reflects blue light completely, the logarithm of

the current into the blue light valve has a value slightly greater than 3.0 as shown. These values are selected by way of example from actual operating conditions. Increasing blue density reduces this log current as shown by the straight line 80. Since this line 80 does not take into account any effect of the green modulating circuit, it is also the curve for the case where there is no green signal, i. e. the case where the original has an infinite density to green (or for practical purposes a density greater than 3.5 Say.).

On the other hand, if the original has zero green density, i. e. reflects green perfectly, the various blue signals will be reduced logarithmically and the response will be that shown by the line 81. Thus all of the colors of the original, as far as green and blue components are concerned, fall on this graph somewhere between the lines 80 and 81. The vertical distance between these lines is the density (log current) reduction due to maximum green correction i. e. the correction for zero green density.

For example, if one considers a gray scale, i. e. a scale having equal densities to blue and green, the response should be that shown by the line 83. It will be noted that for zero blue density and zero green density this line 83 coincides with the line 81 and for maximum blue density and maximum green density, it coincides with the line 82.

On the other hand, the horizontal straight line 82 shows the corresponding response for a gray scale when the non-linear amplifiers of the present invention are omitted. In other words, the line 83 is what one should get and does get by the present invention, whereas in the absence of the present invention, the horizontal line 82 is the result. The reason that the line 82 is horizontal, is apparent from the fact that any decrease in current due to increased blue density is offset by an increase in sensitivity of the amplifier due to the equally increased density of the correcting color green. Of course the optical tandem system of the present invention, does not involve any change in sensitivity of amplifiers, but the analogous situation holds, since if the valves were not operated by non-linear amplifiers, the net responses of the blue and green valves would be equal and opposite. That is, as one went to higher densities, one of the valves would close and the other would open by an equal factor. All of this discussion of lines 82 and 83 is in connection with the gray scale, where the blue and green densities are equal.

It will be noticed that for zero density in both the green and blue the log current is reduced from about 3.5 to 1.75. This is the situation which results when the control voltage for modulating the blue signal is the square root of the green signal. Thus for any particular density, the log current on the line 83 is one-half of the log current on the line 80. By way of distinguishing between the blue and green signals it is pointed out for "square root" control, the amount of reduction (in terms of density) is one half of the green signal. For zero green density, the green signal is 3.5; therefore the correction is one-half of this and equals 1.75. This correction applied to any blue signal reduces it to the line 81. For zero blue density, the blue signal is also 3.5 and when the 1.75 is taken away it leaves 1.75 corrected blue signal (in term of log current).

One of the disadvantages of the pure electrical correction is shown by the broken line 84 which is a deviation from the straight line 83. This is

the actual result of the unbalance in the control circuit which shows up at densities greater than 2.0, since it is impossible in practice to hold the two modulating tubes balanced over a range of over 40 decibels electrically i. e. an intensity range of 100 to 1 which corresponds to a density range of 2.0. This deviation shown by the curve 84 is not completely intolerable for the gray scale and in fact the corresponding trouble for other colors is not objectionable in most cases. The gamut of colors which are accurately reproduced, is limited, since if the green density were zero, the curve for various shades and densities of blue is that shown by the broken line 85. This is due to the fact that in practice when the green density is zero, the output of the controlled amplifier of the blue channel can never fall below that corresponding to the control color (green) density of 2.0. In other words, the curve 85 never falls below the log current value given by the curve 83 at the density of 2.0. Such difficulties appear only when the original has a low green density and are objectionable only when it also has a high blue density; thus the purer greens are not accurately and fully corrected.

Even without going over to the optical tandem valve type of control, some of these difficulties and errors are reduced by the expedient which is common in radio practice when one wishes to distinguish between different signals, namely, the use of a band-pass filter as shown in Fig. 4. Referring back to this Fig. 4, the addition of the low-pass filter 46G in the control circuit before the electrical modification through the leads 50 is introduced into the linear amplifier 12B, is possible because the rate of change of amplification in this linear amplifier 12B need never be faster than that corresponding to the finest detail it is desired to reproduce. Therefore, since it is possible to use such a low-pass filter, a band-pass filter 40B may be introduced in the blue channel so that the signal being controlled is amplified at some carrier frequency, e. g. 2400 cycles plus or minus 1000 cycles, and thus it is possible to discriminate between the two channels by this combination of a low-pass filter going into the circuit and the band-pass filter in the output. Obviously, a high-pass filter allowing all frequencies over 1200 cycles to be amplified would be just as satisfactory as a band-pass filter, as far as discrimination between the two signals is concerned, but the cutting out of all frequencies above the carrier plus its side band (3400 cycles in the above example) reduces noise. The word noise is here used in the electrical sense and corresponds to the factor which causes noise in sound reproduction circuits.

However, even with the electrical filters to discriminate between the signals, the gamut of colors which can be satisfactorily corrected, is more limited than that in the embodiment of the invention wherein light valves are used in optical tandem.

The example discussed above in connection with Fig. 4 wherein, at low densities, the contrasts of both the blue signal and the green modifying signal are increased but the degree of masking is maintained constant, results in the line 80 deviating as shown by the branch curve 86 and the line 83 deviating as shown by the branch 87. Such a modification is sometimes useful in certain photomechanical processes.

Fig. 9 shows the circuit details corresponding

to the diagrams given in Fig. 4. Of course each of the stages of amplification may be much more complicated than that shown and it is customary to purchase the various units shown as boxes in Fig. 4 as complete units.

In Fig. 10, the figures correspond to those given in Fig. 4 with the addition of a red channel and scanning drums 53B, 53G and 53R for all of the channels. In this skeleton circuit drawing, the blue signal is corrected by the green and the green signal is corrected by the red. Since the red signal is in general not corrected, a uniform light source 49 is used instead of a glow lamp to illuminate the light valve 43R.

In each branch of the circuit the box representing a non-linear amplifier contains a legend E_B^v etc. This is intended to indicate that the blue energy (blue signal) is non-linearly amplified to an exponential function wherein the exponent is v . The circuits are actually arranged (i. e. resistances such as 28 in Fig. 2 are adjusted) so that v , x and z are substantially constant, but w and y vary slightly, decreasing as E increases.

One particular arrangement which I use will now be described so as to illustrate how masking is simulated. Having arranged the circuits to give the degree of masking required by some particular printing inks—blue to be masked by a 50% green and green to be masked by a 50% red mask, I tested each branch separately. Since only one valve (43R) controls the light spot scanning the red negative, the gray scale gamma of this negative is a measure of the exponent z . Of course the development of the negative also affects its gamma and must therefore be taken into account. The development of all three negatives is preferably done simultaneously and hence the negatives should all have the same gray scale contrast of exposure.

Setting the valve 43G wide open, the effect of the non-linear amplifier 44R can be separately recorded on the negative scanned at 53G. Similarly constant light from the glow lamp 48R provides means for separately testing and measuring the effect of the non-linear amplifier 13G.

In the example just discussed, my measurements show that when linearly responsive light valves are used at 43B, 43G and 43R, the non-linear amplifiers 13B, 13G, and 13R should be purely exponential amplifiers with the exponents v and x respectively equal to about .6 to 1 and z about .3 to .7. The absolute values of these exponents are not critical since the processing of the final negatives can multiply each of them by a factor. The relative values are critical if the negatives are to be processed simultaneously which is of course the most convenient way of getting reproducible results. The different absolute values are important however when the range of the apparatus is considered.

If these circuits involved the actual division of signals

$$\left(\text{e. g. } \frac{E_B^v}{E_G^w} \right)$$

as required theoretically by masking, several relationships between the exponents v , w , x , y and z could be easily written down. Letting V , W , X , Y and Z (upper case) be the theoretical exponents used in the theoretical case of pure division of signals, it is noted that V and X could be unity, W and Y could have the value required for masking e. g. .5 for 50% masking and then Z would have to equal $V-W$ and $X-Y$ in order that the contrast of the gray scale in the three

negatives would be exactly the same. This is all well known in ordinary photographic masking processes. The upper case exponent is intended to refer to the exponent of the signal which actually exposes the final film and this is sometimes referred to as the exposure gamma of signal.

Of course since absolute contrast depends on the processing, the values of V and X can vary over a reasonable range say .6 to 1 with linear light valves.

However one case of great importance is that using two light valves in optical tandem and electrical series in place of each of the single valves; either a single or double valve is indicated by the single box 43B for example. Such double valves as that shown in Fig. 7 but connected in series and to one channel only or as those shown in U. S. 2,137,267 Cowley and U. S. 1,746,729 Ives have the effect of squaring the exposure i. e. of doubling the exposure gamma. When these valves are used the values of V , X , etc., can go up to 2. In practice, a range up to 1.4 or 1.6 has been found to be useful. Therefore since the effect of the light valve can be considered to be part of the circuit as far as these theoretical exponents are concerned, V and X may have a range of .6 to 1.6. I preferably use about 1.2. A .6 amplifier and a double valve system for 43B and 43G would give this value exactly if true division were used—the values of v and x actually used to simulate this are approximately constant and equal to V and X when linear valves are used or equal to $V/2$ and $X/2$ when squaring valves are used.

For useful masking the theoretical exponents W and Y are usually approximately the same and range between .3 and .7 depending on the how much masking is required for the particular inks being used. (I prefer to use .6 for each of these to give a 50% mask with V and X equal to 1.2.)

Now since $V-W$ and $X-Y$ must be equal and must equal Z , Z must range between .6—.7×.6 and 1.6—.3×1.6. That is, between .18 and 1.1. Since the preferred types of non-linear amplifiers do not give a value below .25, this range is between .25 and 1.1 which means that when V and X are as small as .6 one cannot use a 70% mask since anything greater than a 58% mask reduces the gray scale from .6 to below .25.

If W and Y are slightly different (to give different percentages of masking) then V and X will have to differ by the same amount to keep $V-W$ equal to $X-Y$ (for balancing the gray scale when the negatives are developed simultaneously.)

The actual values used (i. e. v , w , x , y and z) depend not only on available varistors but also on the fact that the basic equation

$$D'_b = P \log C_b E_b^M (C_4 - E_b^N)$$

given previously must be made to simulate masking which is represented by

$$D'_b = \log C_b \frac{R_b^K}{R_b^L}$$

Since a rigorously accurate mathematical description of the effect would be so involved as to be confusing and useless, the practical and preferred system only is described here. In practice I arrange the non-linear amplifiers 44G and 44R so that the exponential functions E_B^w and E_R^y are not simple ones but involve exponents which vary slightly with input, decreasing for higher energies. In practice this merely involves adjustment of the resistances and the potentials

on the tubes as is well known to those familiar with non-linear amplifiers.

The simplest case is the red channel which involves no correction. Therefore z equals Z or if Z involves the squaring valves, z must equal $Z/2$. This means z may utilize the whole of its available range .25 to 1.0. From tests I have found the preferred range to be .25-.6 when using the same type (linear or squaring) valves in all three channels. If a linear valve is used in the red channel and squaring valves in the other channels, this range for z might well go up to 1.

In the preferred example, a 50% mask is used both for blue by green and green by red, and squaring valves are used in all three channels with glow lamps (which are essentially linear valves) in the correction branches of the channels. In this example using a 50% mask with $V=X=1.2$, v must equal x which equals .6 and $V-W$ and $X-Y$ must equal .6 and $z=Z/2=.3$. For a 40% mask W and Y equal $.4 \times 1.2$ equals .48, $V-W$, $X-Y$, and Z equal .72, and $z=.36$.

By similar tests I find the preferred range for v and x to be .4 to .8. If the red channel only has a linear valve, the presence of squaring valves in the other channels allows this preferred range to go down to .25.

In the above mentioned preferred example $v=x=.6$. For the 40% mask system $v=x=.6$ as before since this is the valve which is selected to give the most useful printing contrast. Without masking this contrast (exposure gamma) equals 1.2, due to the squaring valves. For the gray scale it is reduced to Z and equals .6 for a 50% mask system and .72 for a 40% mask system.

Masking systems from 30% to 70% cover practically all useful systems and all commercially available printing inks, dyes etc.

It is noted that v and x are equal to $V/2$ and $X/2$ even though a purely divisional electric system is not used. It is of course possible to have v and x vary slightly with energy input but this has not proved to be as useful as the case where they are constant.

And again testing the effect of the glow lamps 48G and 48R alone when the amplifiers 44G and 44R are set as used in the preferred embodiment I find that w and y are preferably between .3 and .8 and that they actually vary within this range depending on the input.

In the preferred example, a 50% masking system requires the average value of w and y to be a little less than .6, which is the value the constant theoretical exponents W and Y must have to reduce V and X to half their values. Similarly a 40% masking system requires the average values of w and y to be about .4 whereas W and Y theoretically should be .48 (i. e. 40% of 1.2).

If an optical tandem system such as shown in Fig. 5 is used with each of the valve systems of the squaring type instead of having the linear glow lamp in the correction circuits, w and y would be lower. Since the varistors described do not conveniently give values below .25 a range of .15 to .4 is not easily obtained. Hence it is preferable to raise this range to .25 to .66 and to raise v and x to 1. Since such an embodiment could use linear amplifiers at 13B and 13G it is a useful one, but I have found the other system somewhat preferable.

Squaring type light valves can be made of two linear valves in optical tandem and connected electrically in series. Thus if each valve in any

of the figures is replaced by two such valves in optical tandem and electrical series, a squaring valve results. For example the valve 43B could be made by connecting valves 63 and 67 of Fig. 5 or Fig. 7 in series to the blue channel only, or by connecting ribbons 75 and 76 of Fig. 7 in series. Similarly the glow lamp 48G could be replaced by a glow lamp and ribbon valve in optical tandem and electrical series.

Having thus described my invention, I wish to point out that it is not limited to the specific structure shown but is of the scope of the appended claims.

What I claim and desire to secure by Letters Patent of the United States is:

1. An electro-optical system for the reproduction of a multicolored original comprising means for establishing in separate electric channels, electric energies corresponding to the color components of each point of the original in scanning succession, each channel corresponding to one color, at least one of the channels including a non-linear amplifier having means therein for varying the energy output thereof in accordance with an exponential function of the input thereof substantially uniformly over a wide range of energies, two light modulating devices in cooperative optical tandem, one device being connected to and operated by the output of the non-linear amplifier and the other of the two devices being connected to and operated by the output of another of the channels, and means for establishing a light beam modulated simultaneously by said two devices in optical tandem.

2. An electro-optical system for the reproduction of a multicolored original comprising means for establishing in separate electric channels, electric energies corresponding to the color components of each point of the original in scanning succession, each channel corresponding to one color, at least one of the channels including a non-linear amplifier having means therein for varying the energy output thereof in accordance with an exponential function of the input thereof substantially uniformly over a wide range of energies, means for supporting a sensitive layer, means for scanning the layer with a light beam and two light modulating devices in cooperative optical tandem for simultaneously modulating said light beam, one of the devices being connected to and operated by the output of the non-linear amplifier and the other device being connected to and operated by the output of one of the channels other than that including said non-linear amplifier.

3. An electro-optical system for the reproduction of a multicolored original, having a plurality of channels respectively carrying energies corresponding to color components of the original and each including a linear amplifying circuit connected to the output of a photoelectric cell, at least one of the channels having a non-linear amplifier connected to the output of its linear amplifying circuit, said non-linear amplifier including means for producing an energy variation in accordance with an exponential function which is substantially uniform over a wide range of energies, means for supporting a sensitive layer, means for scanning the layer with a light beam and two light modulating devices in cooperative optical tandem for simultaneously modulating said light beam, one of the devices being connected to and operated by the output of the non-linear amplifier and the other device being connected to and operated by the output of one

of the channels other than that including said non-linear amplifier.

4. An electro-optical system for the reproduction of a multi-colored original comprising means for establishing in separate electric channels, electric energies corresponding to the color components of each point of the original in scanning succession, each channel corresponding to one color, at least one of the channels including a non-linear amplifier having means for varying the energy therein in accordance with an exponential function substantially uniformly over a wide range of energies, light valves for controlling light intensity connected to the output of each of the channels, and a light valve connected to and operated by the output of said non-linear amplifier in cooperative optical tandem with the light valve in another of the channels for modifying the response of the latter valve in accordance with the energy in the one of the channels including the non-linear amplifier.

5. An electro-optical system for the reproduction of a multi-colored original comprising means for scanning the original in a plurality of colors, photo-electric devices adapted to receive the separate colors from the original for establishing electric energies corresponding thereto, electric amplifying circuits connected to the outputs of the photoelectric devices, at least one of these circuits including a non-linear amplifier having means for varying the energy therein in accordance with an exponential function substantially uniformly over a wide range of energies, light valves for controlling light intensity connected to the output of each of the circuits, and a light valve connected to and operated by the output of said non-linear amplifier in cooperative optical tandem with the light valve in another of the channels for modifying the response of the latter valve in accordance with the energy in the one of the channels including the non-linear amplifier.

6. An electro-optical system for the reproduction of a multi-colored original comprising means for establishing in an electric channel a signal corresponding to primary blue light from each point of the original in scanning succession, means for establishing in a second electric channel a signal similarly corresponding to one of the other primary colors from each point of the original, a non-linear amplifier connected to one of the two channels for amplifying the signal therein substantially exponentially over a wide range of signal energies, two light modulating devices in cooperative optical tandem, one device being connected to and operated by the output of the non-linear amplifier and the other device being connected to and operated by the output of the other channel and means for establishing a light beam simultaneously modulated by said two devices in optical tandem.

7. An electro-optical system for the reproduction of a multi-colored original comprising means for establishing in an electric channel a signal corresponding to primary blue light from each point of the original in scanning succession, means for establishing in a second electric channel a signal similarly corresponding to one of the other primary colors from each point of the original, a non-linear amplifier connected to one of the two channels for amplifying the signal therein substantially exponentially over a wide range of signal energies, means for supporting a sensitive layer, means for scanning the layer with

a light beam and two light modulating devices in cooperative optical tandem for simultaneously modulating said light beam, one of the devices being connected to and operated by the output of the non-linear amplifier and the other device being connected to and operated by the output of the other channel.

8. An electro-optical system according to claim 7 in which both channels include non-linear amplifiers.

9. An electro-optical system according to claim 7 in which the non-linear amplifier is in said second channel.

10. An electro-optical system according to claim 7 in which the non-linear amplifier is in said blue channel.

11. An electro-optical system according to claim 7 in which the light modulating device connected to the blue channel is a ribbon type valve and the other light modulating device is a glow lamp in optical tandem with and for illuminating the ribbon type valve.

12. An electro-optical system according to claim 2 in which the light modulating device connected to the non-linear amplifier is a glow lamp and the other light modulating device is a ribbon type valve positioned to modulate the light from said glow lamp.

13. An electro-optical system for the reproduction of a multi-colored original comprising means for establishing in separate electric channels, electric energies corresponding to the color components of each point of the original in scanning succession, each channel corresponding to one color, at least one of the channels including a non-linear amplifier having means for varying the energy therein in accordance with an exponential function substantially uniformly over a wide range of energies, light valves for controlling light intensity connected to the output of each of the channels, and modifying means connected to and operated by the output of said non-linear amplifier for modifying the response of the light valve in at least one other of the channels in accordance with the energy in the one of the channels including the non-linear amplifier, said modifying means including both electrical means for modifying the electric signal in said other of the channels and a light valve in cooperative optical tandem with the light valve of said other of the channels.

14. An electro-optical system according to claim 2 in which electrical means are connected to and operated by the output of the non-linear amplifier and are also connected to said other one of the channels for modulating the signal in the latter channel in accordance with the signal in the non-linear amplifier.

15. An electro-optical system for the reproduction of a multi-colored original comprising means for establishing in separate electric channels, electric energies corresponding to the color components of each point of the original in scanning succession, each channel corresponding to one color, a light modulating device connected to the output of each channel, another light modulating device in cooperative optical tandem with the light modulating device connected to one of the channels, means including a non-linear amplifier for operating said another light modulating device in accordance with an exponential function of the signal in a different one of the channels and means for forming a spot of light simultaneously modulated by the two devices in cooperative optical tandem.

16. An electro-optical system according to claim 15 in which one of the two devices in optical tandem modulates the width of said point of light and the other modulates the intensity thereof.

17. An electro-optical system according to claim 15 in which the two devices in optical tandem consist of a glow lamp and a ribbon type valve.

18. An electro-optical system according to claim 15 in which the two devices in optical tandem consist of two ribbon type light valves and the means for forming a spot of light includes lens means for focusing an image of one valve to constitute the spot of light, a lens near the latter

valve to focus an image of the other valve at said lens means and means for illuminating said other valve.

19. An electro-optical system according to claim 15 in which a third light modulating device is connected to and operated by a channel different from the channels connected to said devices in cooperative optical tandem, said third device being in cooperative optical tandem with each of the other two devices forming a cooperative optical series of three light devices modulating said spot of light.

VINCENT C. HALL.