March 9, 1943. V. C. HALL ET AL 2,313,542

ELECTRO-OPTICAL COLOR REPRODUCTION CIRCUIT

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FIG. 1.

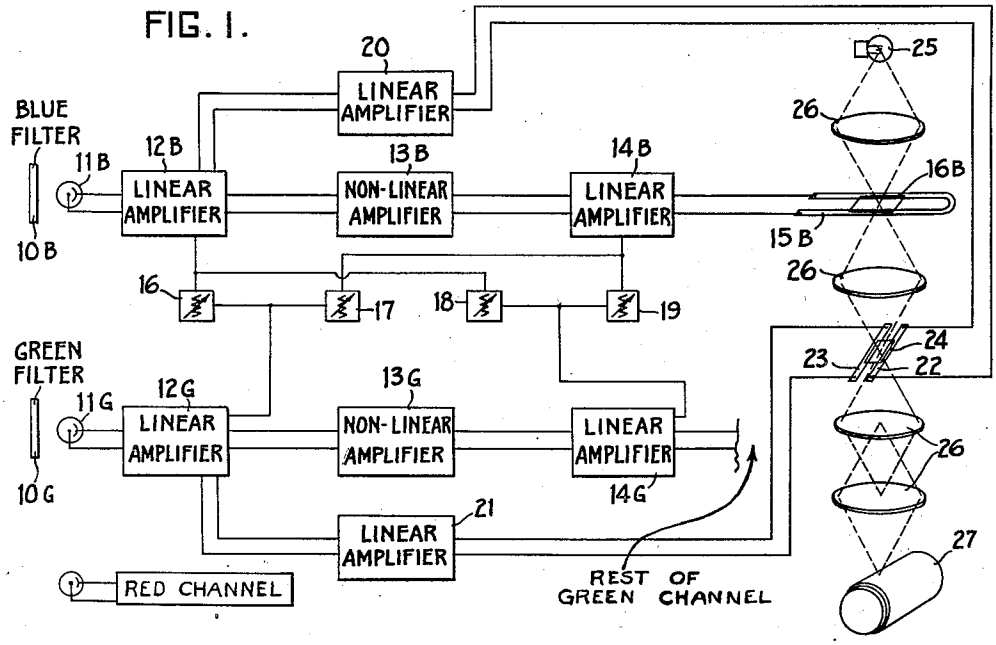
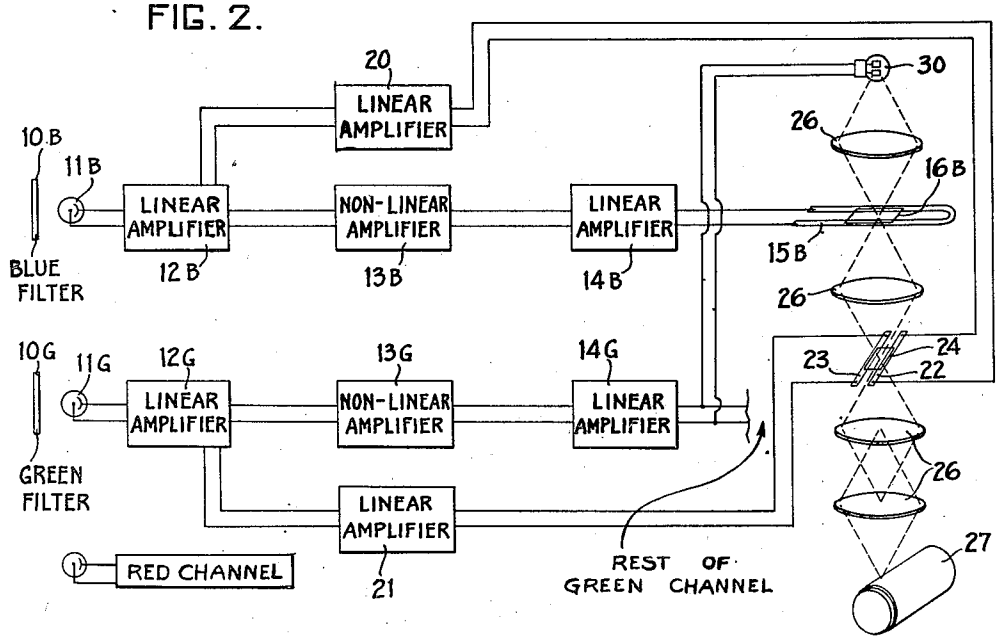


FIG. 2.



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FIG. 3.

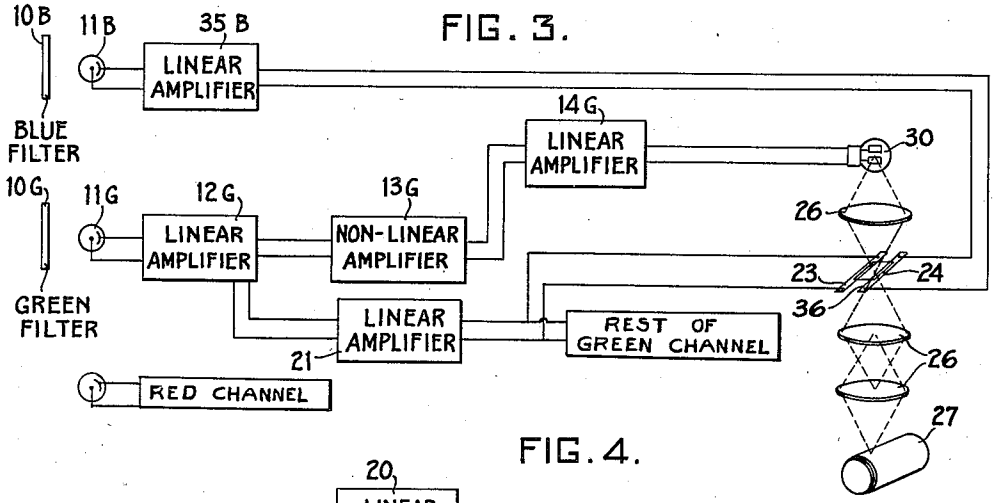


FIG. 4.

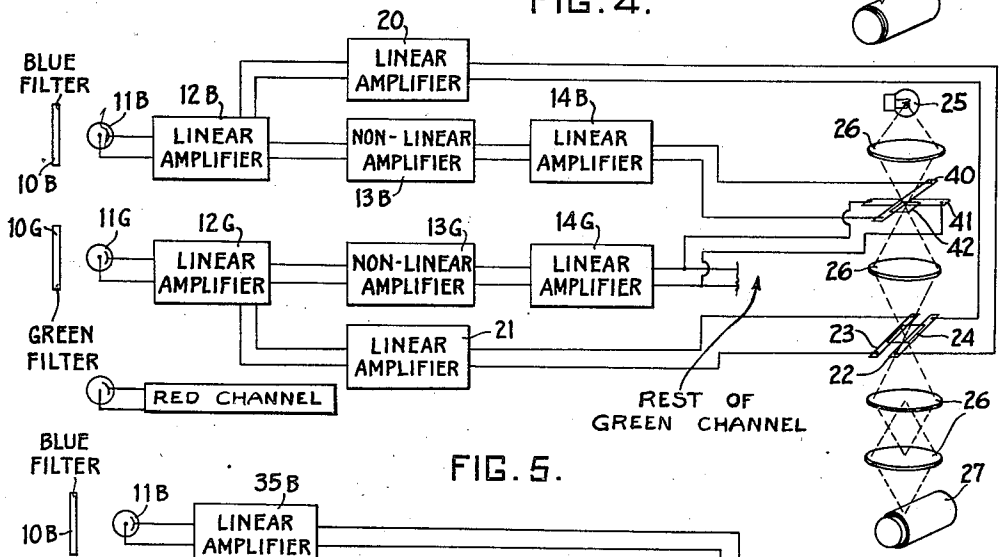
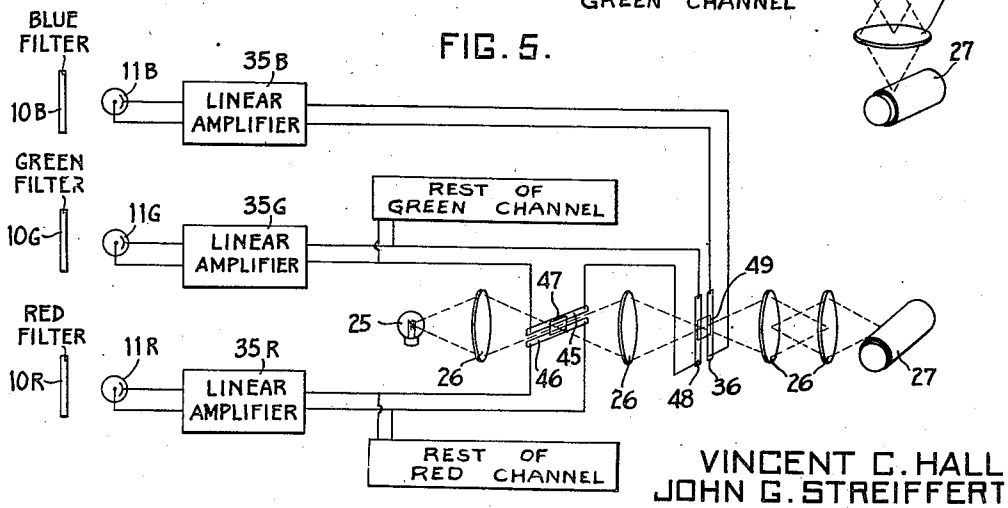


FIG. 5.



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FIG. 6.

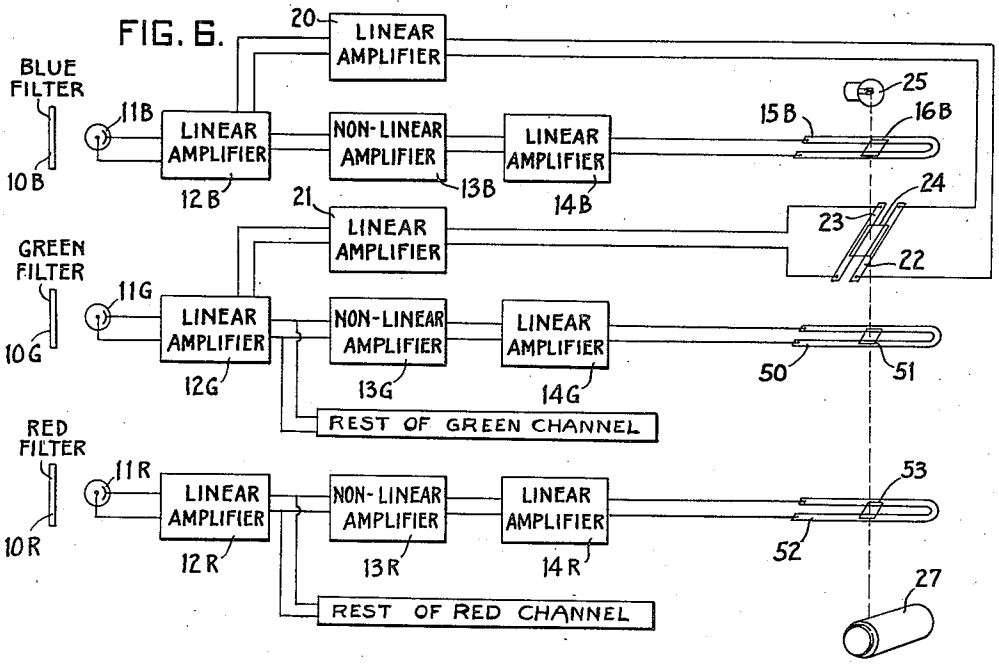
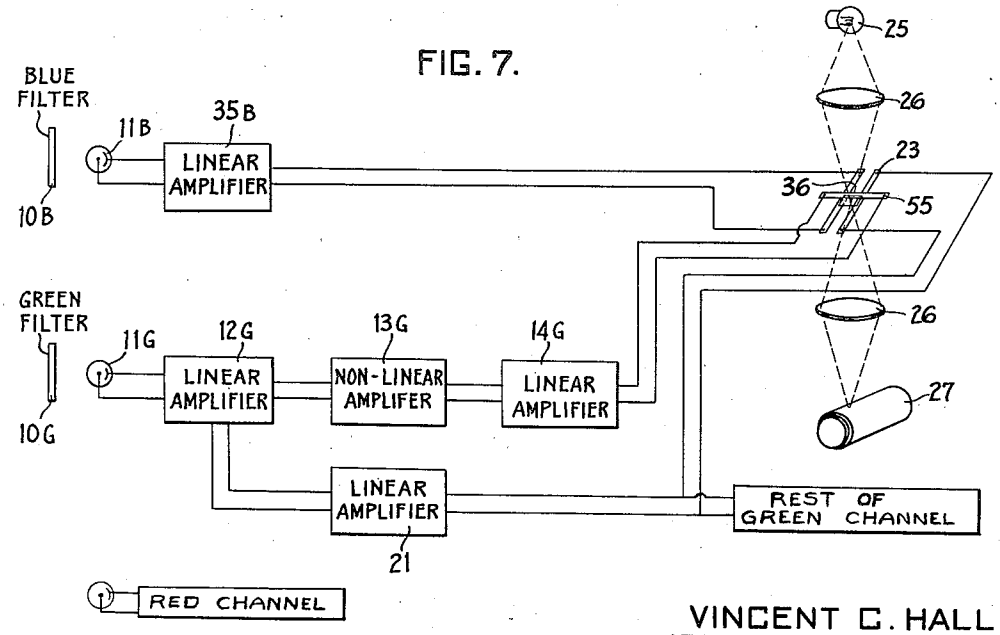


FIG. 7.



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ELECTRO-OPTICAL COLOR REPRODUCTION CIRCUIT

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FIG. 8.

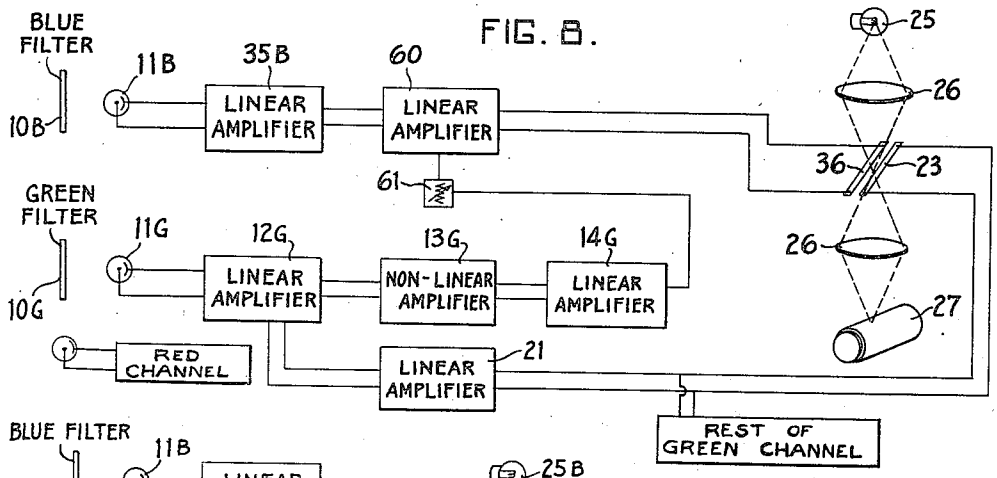
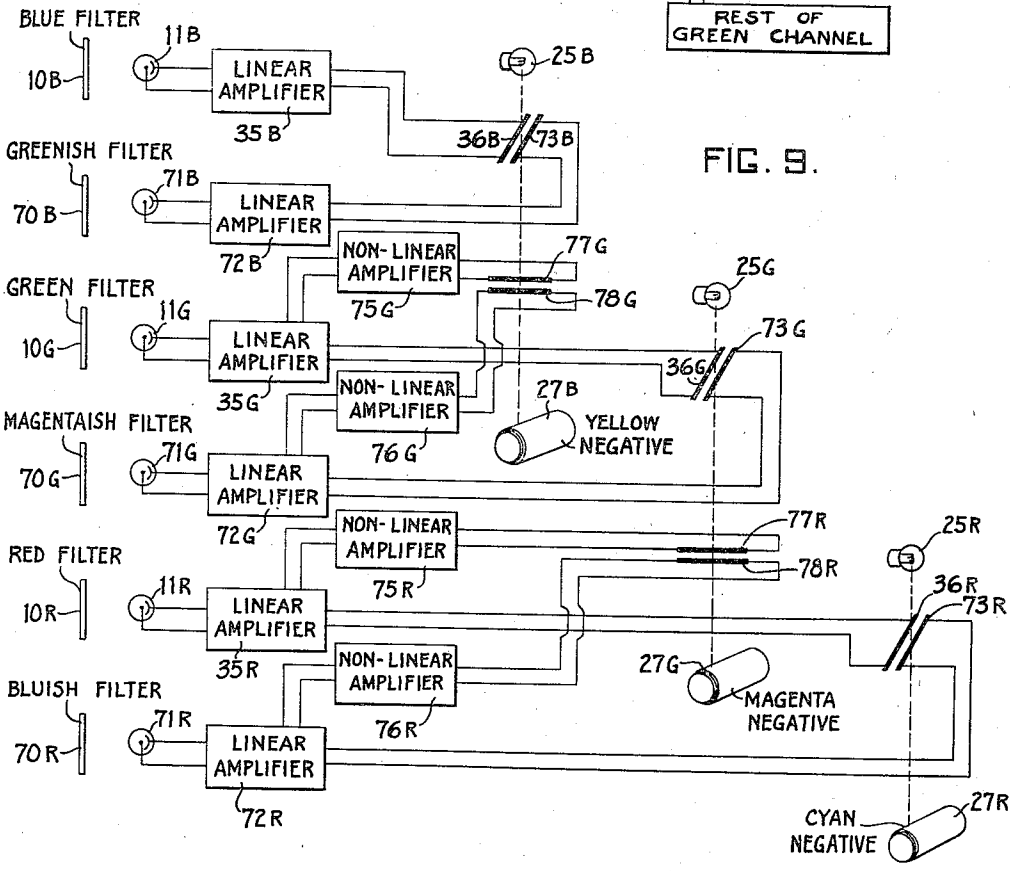


FIG. 9.



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Patented Mar. 9, 1943 2,313,542

UNITED STATES PATENT OFFICE

2,313,542

ELECTRO-OPTICAL COLOR REPRODUCTION CIRCUIT

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Application November 1, 1941, Serial No. 417,540

12 Claims. (Cl. 178—5.2)

This invention relates to electro-optical color reproduction circuits and particularly to color correction circuits.

It is the primary object of the invention to produce an electro-optical circuit which is capable of giving color correction of the types required by various theories of color correction.

One theory of three-color reproduction was outlined by A. C. Hardy and F. L. Wurzburg, Jr., in the Journal of the Optical Society of America, vol. 27, page 227, 1937, which required the color separation images to correspond to colors which included negative values. The realization of such a system involves the linear subtraction of quantities linearly proportional to the reflectivities or transmissions of the original colored subject. It is an object of the invention to provide an electro-optical circuit for obtaining this type of color correction.

It is a particular object of the invention to provide for this type of color correction combined with that corresponding to the "masking method of color correction" which involves the subtraction of densities. Since densities are logarithmically proportional to the reflectivities of the original, the invention must approximate the combination of the subtraction of linear and logarithmic quantities, the subtraction of logarithm quantities being equivalent to the division of linear quantities.

In U. S. Patents 2,176,518 and 2,221,037, J. A. C. Yule has outlined an improved form of masking, which involves the addition of exposures before the subtraction of densities is applied. Possibly this system incorporates the principles outlined by D. L. MacAdam in the Journal of the Optical Society of America, vol. 28, 11, Nov., 1938, wherein he points out that since the "additive" errors outlined by Hardy and Wurzburg, combine vectorially with the errors due to the failure to simulate the phenomena of additive mixtures by the use of subtractive mixtures, properly adjusted logarithmic subtraction can correct substantially for all the errors of both types. In any case, Yule's invention requires the addition of quantities linearly proportional to reflectivities and then the subtraction of quantities logarithmically proportional to reflectivities. It is an object of the present invention to provide an electro-optical circuit for accomplishing this.

All the above objects are accomplished by the fact that the circuit according to the present invention is capable of addition or subtraction of linear quantities. On the other hand, this same device is useful for obtaining the pure division of linear quantities as taught by one of us, namely Hall, in a co-pending application Ser. No. 417,541, filed concurrently herewith.

Broadly, the present invention consists of using a ribbon type light valve with substantially parallel ribbons in a magnetic field, which ribbons are independently operated and one of them is connected to the channel whose signal requires correction whereas the other is connected to the channel carrying the correcting signal. Of course, the ribbon connected to the correcting signal has relatively less response. In the preferred embodiment of the invention applied to linear corrections such as those according to the Hardy or Yule theories, each of the ribbons is operated entirely by linear amplifiers or at least by amplifiers whose output is linearly proportional to the reflectivity of the subject, i. e. to the intensity of the light striking the photoelectric cells at the input ends of the primary color channels.

Furthermore, the Yule theory and the most useful form of the Hardy correction, require the combination of linear subtraction or addition with the subtraction or addition of logarithmic quantities. Following the teachings of U. S. 2,249,522, Hall, the logarithmic correction may be provided by exponential amplifiers and suitable electrical control circuits. Alternatively, it may be provided by an optical tandem light valve system as disclosed in copending application, Serial No. 393,418, filed May 14, 1941, by Vincent C. Hall. Furthermore, in preferred forms of the invention the circuits may be simplified and the logarithmic and linear correction produced with scanning beams in which the primary modulation is obtained solely by one of the two parallel ribbons in the double-ribbon light valve. Ribbon type light valves with independently controlled ribbons are known, but have not previously been applied in any way to color correction and according to the present invention gain all of the above-discussed advantages when so applied. That is, the present invention involves a ribbon type light valve with independently controlled parallel ribbons one of which is operated by a color signal and the other by a correcting color signal. The invention will be more fully understood from the following description thereof when read in connection with the examples disclosed in the accompanying drawings, in which:

Fig. 1 illustrates a circuit for subtraction or addition of linear quantities according to the invention combined with an electrical method

for the subtraction of quantities logarithmically proportional to reflectivities.

Fig. 2 illustrates a similar circuit in which the "logarithmic" co.rection is provided by optical tandem light valves.

Fig. 3 shows a condensed form of the circuit shown in Fig. 2.

Fig. 4 is similar to Fig. 2 and employs crossed ribbons in a single valve for the optical tandem feature.

Fig. 5 illustrates an arrangement for giving a special type of color correction involving the subtraction and multiplication of quantities linearly proportional to reflectivities.

Fig. 6 illustrates an optical tandem system for logarithmic correction by red and green of the blue signal together with linear correction of the blue signal, according to the invention.

Fig. 7 shows a condensed form of the circuit shown in Fig. 4.

Fig. 8 shows the condensed form of the circuit shown in Fig. 1.

Fig. 9 illustrates a complete three-color system, in which the corrected blue and green negatives correspond to a modification of Fig. 2 and the red negative involves only the Hardy type of correction.

Since the various forms and types of color correction involve elaborate explanations, but are well understood by those skilled in the art, and since it can be obtained from the references mentioned above, no detailed description thereof will be given in this specification. However, attention is drawn to some of the pecularities of the language used in this art so that there will be no misunderstanding. An original painting or scene is said to have certain red, green and blue reflectivities, which can be separately measured and which are used to set up the primary color signals in an electro-optical color reproduction system. These reflectivities at each point of the original correspond to the amount of red, green and blue light reflected from that point. In the electro-optical system, the channels, the signals in the channels, the scanning beams, the valves, etc., are all referred to as red, green, and blue, but, of course, they are not actually colored these colors. That is, the red signal is the signal corresponding to the red reflectivities, and the red scanning beam is not red light, but is usually white light scanning a sensitive material which eventually will be a record of the red reflectivities of the original. Since these final records are used to make printers which print respectively with cyan, magneta, and yellow inks, these latter terms are sometimes applied to the various elements, but such nomenclature will not here be used.

Ribbon type light valves are well known and are illustrated in the conventional manner in the accompanying drawings, the magnets producing the required magnetic field not being shown. In Hall's patent and his copending application mentioned above, the fact that the intensity of one color signal multiplied by a constant minus the intensity of the correcting color signal can be made to simulate the division of the two signals is described and will not separately be described here. That is, the actual effect theoretically given by the circuits shown will be specified as well as the relationships they have been found to simulate in practice, but no explanation of this will be attempted since such explanation can at best only be qualitative and very involved and is unnecessary.

In Fig. 1 the light from the original being scanned through a suitable beam splitter passes through a blue filter 10B and a green filter 10G to impinge upon photoelectric cells 11B and 11G whereby "blue" and "green" signals are established in corresponding circuits. Attention is drawn to the similarity of this figure with Fig. 1 of U. S. 2,249,522, Hall. The current passes through suitable linear amplifiers 12B to 12G, non-linear amplifiers 13B and 13G whose non-linearity is in the form of exponential functions so that the modification in the circuits corresponds to the division of logarithmic quantities at different gammas as described in Hall's patent. Through suitable control circuits 16, 17, 18, and 19, between the linear amplifiers 12B and 12G, and between other linear amplifiers 14 B and 14G, the exact degree of correction, which actually is

$$R_b^{\gamma_b}(C_1 - R_g^{\gamma_g})$$

where R_b is the blue reflectivity and R_g is the green reflectivity and the C's are constant, can be controlled. This corrected signal is fed into and operates a ribbon type light valve whose ribbon 15B and aperture 16B are shown. Thus by means of a lamp 25 and lenses 26 there is produced a scanning beam for scanning a sensitive film on a cylinder 27, which scanning beam is modulated by the valve 15B in accordance with the blue signal, corrected by the green signal.

According to the invention this is combined with a second ribbon type valve having substantially parallel ribbons 22 and 23 and an aperture 24 mounted in the scanning beam. The ribbon 22 is operated linearly through a linear amplifier 20 in accordance with the signal input in the blue channel, i. e., in accordance with the intensity of the light striking the phototlectric cell 11B. Similarly, the ribbon 23 is operated by amplifiers 21 linearly in accordance with the green signal. By arranging the ribbons 22 and 23 to move in opposite directions, the effect can be made additive, whereas the modulation of the blue signal by the green signal electrically is effectively the subtraction of logarithmic quantities, so that the whole combination corresponds to Yule's photographic system referred to above. Alternatively, if the ribbons 22 and 23 move in the same direction with increasing signal respectively, this involves the subtraction of quantities linearly proportional to the input signals and hence, the whole combination gives the correction of additive errors combined with correction by masking, i. e. by subtraction of logarithmic quantities.

The same effect is obtained with the arrangement shown in Fig. 2, but in this case the subtraction of logarithmic quantities is obtained by having a glow lamp 30 in optical tandem with the light valve 15B so that as before the correction is

$$R_b^{\gamma_b}(C_1 - R_g^{\gamma_g})$$

which by proper selection of constants can be made to simulate the division of reflectivities over all the range required in practice.

This arrangement shown in Fig. 2 can be further simplified as shown in Fig. 3, if the non-linear amplifier 13G has an exponential function such that the need for another non-linear amplifier in the blue circuit is eliminated. That is, the ribbon 36 is operated entirely by a linear amplifier 35B so that there is no chance to change the exponential or gamma in the blue signal. For example, if in Fig. 3, the non-linear amplifier 13G has a .5 exponent, the effect of the ribbon

36 is masked by a .5 gamma mask, i. e., by the output of the glow lamp 30. Since the ribbon 36 has a linear response, it is also affected linearly (either addition or subtraction) by the ribbon 23 operated by a linear amplifier 21 as before. Going back to Fig. 2, it is pointed out that a .5 mask could be obtained in this more complicated arrangement by having 13G operate at .25 exponential and 13B operate at .5 exponential, the ratio being the effective masking factor.

Fig. 4 also shows an optical tandem system, in which the optical tandem valves are successive ribbons 49 and 41 crossed in a single ribbon type light valve having an aperture 42. As indicated by the use of similar numerals, the other elements of this Fig. 4 correspond exactly to Fig. 2.

On the other hand, Fig. 5 corresponds to an entirely different type of color correction, at least as far as the theoretical intensity of the scanning beam is concerned. In this figure, the red channel is also shown and each of the channels has solely linear amplifiers 35B, 35G, and 35R respectively. In this arrangement, the ribbon 36 operated by the blue signal has its response linearly reduced or increased by a parallel ribbon 46 in the same light valve having an aperture 49. Thus this valve gives either (R_b+R_g) or (R_b-R_g). To simulate the effect of masking except for the logarithmic feature, both by green and red, an additional valve also having independently operated parallel ribbons is placed in optical tandem with the valve containing the ribbon 36. One of the parallel ribbons 45 is operated by the green signal in series with the ribbon 46 and the other ribbon 46 is operated linearly by the red signal. The aperture of the second valve is shown at 47. The net output of this arrangement is given by the following formula

$$(R_b \pm C_5 R_g)\ (C_6 - C_7 R_g \pm C_8 R_r)$$

which in practice simulates

$$\frac{R_6 \pm C_4 R_g}{C_9 R_g \pm C_{10} R_r}$$

more or less.

In Fig. 6 the blue valve 15B is in optical tandem or optical series with valves 50 and 52 having apertures 51 and 53 respectively and operated by proper exponential functions of the green and red channels for masking. As in Figs. 1 and 2 the linear correction is provided by a valve having independently operated ribbons 22 and 23. The valve 50 replaces the glow lamp 30 of Fig. 2 and additional correction by the red signal through valve 52 is provided in this figure.

The similarity of Figs. 7 and 4 becomes apparent when one notices that the ribbon 36 in Fig. 7 is the sole modulator for giving the primary modulation to the scanning beam. Its effect is reduced or increased linearly by the ribbon 23 and is reduced logarithmically by the ribbon 55 mounted at right angles to the other two ribbons in the same light valve and in optical tandem with these other two ribbons. As in the case described in connection with Fig. 3, the control ribbon 36 is operated entirely linearly and hence the non-linearity of the amplifier 13G is exactly the masking factor.

Similarly Fig. 8 is a simplified form of Fig. 1, the non-linear amplifier 13B being eliminated and the exponent of the non-linear amplifier 13G being adjusted so that the right degree of correction is provided in a linear amplifier or modifier 60 controlled by suitable control 61.

Each of the above discussed figures show the correction of the blue scanning beam. Fig. 9 shows all three beams, blue, green and red for printing the yellow, magenta, and cyan printer negatives respectively. According to the theoretically correct spectral sensitivities for a typical additive process, the primary blue should include a negative greenish section, primary green should include a negative blue and a negative red section, and primary red should include a negative section in the blue-green region. In practice the correcting factor corresponds respectively to green, red plus blue, and green respectively. However, in Fig. 9 the correcting colors are shown theoretically different and are labeled respectively greenish, magentish, and bluish. For simplicity the lenses of the optical systems in the scanning beams are omitted from this figure. The blue scanning beam is produced by a light source 25B modulated primarily by a ribbon 36B operated by the blue signal through a linear amplifier 35B. This modulation is linearly reduced by greenish signal through a filter 70B impinging on a photoelectric cell 71B which operates a linear amplifier 72B and a ribbon 73B which is parallel to the ribbon 36B. Thus the main modulation is given by the expression (R_b-R_g). However, this beam requires color correction of the masking type, i. e. the subtraction of a quantity logarithmically proportional to green or in some cases to yellow. In this figure the non-linear amplifier 75G operates a ribbon 77G in optical tandem with the valve 36B to give the color correction of the required type. Similar correction is obtained in the green scanning beam from the lamp 25G, similar numerals being used to illustrate similar features and elements, G and R being substituted for B and G respectively. However, in both of these cases, the masking signal coming in through 77G should also be corrected linearly before it is used to give the masking effect. Theoretically, this requirement is not compatible with the requirement that the ribbon 77G must be operated by a non-linear amplifier. However, for practical purposes, the same effect can be obtained by having a non-linear amplifier 76G carrying the magenta signal into a ribbon 78G and parallel with the ribbon 77G in the same valve. Theoretically this correction is

$$(R_g^c - R_m^c)$$

but is effectively $(R_g-R_m)^c$. As before, similar numerals are used for similar elements in the three channels and B, G, and R refer to the blue, green and red channels. In practice, the elements 70B, 71B, and 72B can be eliminated, the ribbon 73B being operated directly from the amplifier 35G. Similarly, elements 70G, 71G and 72G can be replaced by a linear combination of the output of the amplifiers 35B and 35R. And again, the elements 70R, 71R, and 72R can be omitted and replaced by connections into the amplifier 35G.

In all of these arrangements shown, the independently operated parallel ribbons receive only linear quantities, i. e. quantities linearly proportional to reflectivities, but as described in copending application, Serial No. 417,541, by Hall, mentioned above, parallel ribbons mounted for independent operation by two different colors for color correction can be utilized by Hall's invention to give pure division of reflectivities.

Having thus described various embodiments of the invention, we wish to point out that it is not

limited to these structures but is of the scope of the appended claims.

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

1. In an electro-optical color reproduction circuit with at least three channels respectively for carrying the primary color signals, color correcting means consisting of a ribbon type light valve with substantially parallel ribbons, an amplifying circuit connecting one of the channels to one of the ribbons for deflecting the ribbon in accordance with and relatively greatly with respect to the signal incident into said one of the channels, and a second amplifying circuit connecting at least one other of the channels to the other ribbon for deflecting it in accordance with and relatively less greatly with respect to the signal incident into said other of these channels.

2. Color correcting means according to claim 1 in which each of the amplifying circuits deflect the corresponding ribbon linearly relative to the respective incident signal.

3. Color correcting means according to claim 1 in which each of the amplifying circuits is purely linearly and is connected to the output of a purely linear portion of the corresponding channel.

4. An electro-optical color reproduction circuit comprising at least three channels respectively for carrying the primary color signals, means for modifying the signal in one of the channels exponentially in accordance with the signal in at least one other of the other channels and linearly in accordance with the signal in at least one of said other channels, said modifying means including for its linear part a ribbon type light valve with substantially parallel ribbons and two linear amplifying circuits respectively connecting the ribbons to said one of the channels and to at least one of said other channels.

5. An electro-optical color reproduction circuit comprising at least three photoelectric cells for respectively receiving the primary color components of a colored subject, means for producing a scanning beam modulated primarily by the output of one of said cells, means including an exponential amplifier connected to the output of another of the cells for exponentially modifying the modulation of said beam, a ribbon type light valve with substantially parallel ribbons in the path of said beam, linear amplifying means operating one of the ribbons linearly in accordance with the output of said one of the cells and linear amplifying means operating the other ribbon linearly in accordance with the output of another of the cells.

6. An electro-optical color reproduction circuit in accordance with claim 5 in which the modulated beam producing means includes a light valve and an amplifier for operating the valve by the output of said one of the cells and a control circuit is connected between the exponential amplifier and the operating amplifier for exponentially modifying the signal in the operating amplifier.

7. An electro-optical color reproduction circuit according to claim 5 in which the modulated beam producing means includes a light valve and an amplifier for operating the valve by the output of said one of the cells and another light valve operated by the output of the exponential amplifier is in optical tandem with the last-mentioned valve.

8. An electro-optical color reproduction circuit according to claim 5 in which said one of the ribbons constitutes exculsively the means for modulating the scanning beam by the output of said one of the cells and a control circuit is connected between the exponential amplifier and the amplifying means operating said one of the ribbons for exponentially modifying the signal in the latter amplifying means.

9. An electro-optical color reproduction circuit according to claim 5 in which said one of the ribbons constitutes exclusively the means for modulating the scanning beam by the output of said one of the cells and another light valve operated by the output of the exponential amplifier is in optical tandem with the ribbon type valve.

10. An electro-optical color reproduction circuit comprising at least three photoelectric cells for respectively receiving the primary red, green, and blue components of a color subject, means for producing at least three scanning beams modulated respectively primarily by the outputs of the three cells, blue modifying means for increasing linearly and decreasing exponentially the signal in the beam corresponding to blue in accordance with the signal for at least one of the other cells and green modifying means for increasing linearly and decreasing exponentially the signal in the beam corresponding to green in accordance with the signal from the red cell, the blue modifying means including an exponential amplifier connected to the output of at least one of the green and red cells, means operated by said exponential amplifier for decreasing the signal in the blue beam, a ribbon type valve with substantially parallel ribbons in the blue beam, linear amplifying means for operating one of the ribbons linearly in accordance with the output of the blue cell and linear amplifying means for operating the other ribbons in the opposite direction linearly in accordance with the output of said at least one of the red and green cells, the green modifying means including an exponential amplifier connected to the output of the red cell, means operated by the latter exponential amplifier for decreasing the signal in the green beam, a ribbon type valve with substantially parallel ribbons in the green beam, linear amplifying means operating one of the latter ribbons linearly in accordance with the output of the green cell and linear amplifying means operating the other of the latter ribbons in the opposite direction linearly in accordance with the output of the red cell.

11. An electro-optical color reproduction circuit comprising at least three photoelectric cells for respectively receiving the primary red, green, and blue components of a color subject, means for producing at least three scanning beams modulated respectively primarily by the output of the three cells, blue modifying means for increasing linearly and decreasing exponentially the signal in the beam corresponding to blue in accordance with the signal from the green cell and green modifying means for increasing linearly and decreasing exponentially the signal in the beam corresponding to green in accordance with the signal from the red cell, the modifying means including exponential amplifiers connected respectively to the output of the green and red cells, means operated by the exponential amplifiers respectively for decreasing the signal from the blue and green beams by factors inversely proportional to between the .4 and .8 power of the green and red signals, a ribbon type valve with two substantially parallel ribbons in each

of the blue and green beams, a linear amplifier for operating one of the ribbons of the valve in the blue beam linearly in accordance with the output of the blue cell, a linear amplifier for operating the other ribbon of the latter valve linearly in the opposite direction with about a sixth to a third the response in accordance with the output of the green cell, a linear amplifier for operating one ribbon of the valve in the green beam linearly in accordance with the output of the green cell and a linear amplifier for operating the other ribbon in the latter valve linearly in the opposite direction with about a sixth to a third the response in accordance with the output of the red cell.

12. An electro-optical color reproduction circuit comprising a plurality of channels, three of which carry respectively at their inputs, signals corresponding to the positive portions of theoretically perfect primary colors, and at least one of which carries a signal corresponding to the negative portion of one of said colors, means for producing three scanning beams modulated primarily respectively in accordance with said positive portion signals, a ribbon type light valve with two substantially parallel ribbons in the beam corresponding to said one of said colors one ribbon being connected to and operated by the channel corresponding to said one of said colors, and the other being connected to and operated in the same direction by the negative portion signal, and means for modifying at least one of the beams exponentially in accordance with a positive portion signal different from the one modulating said one of the beams.

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