April 13, 1965 J. G. JARVIS 3,178,281

ELECTROSTATIC COLOR PRINTING

Original Filed July 16, 1956 4 Sheets-Sheet 1

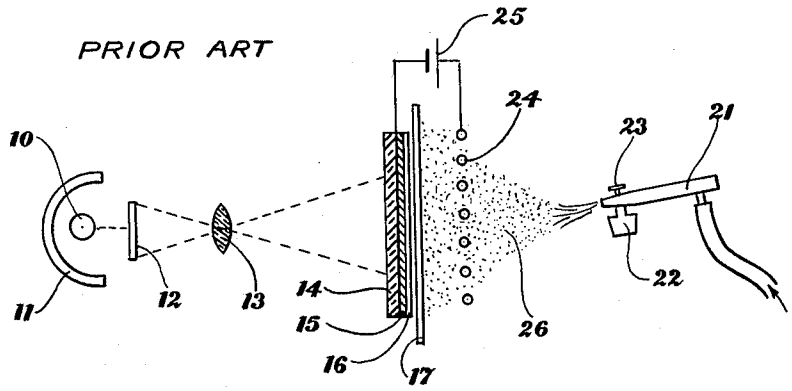


Fig. 1

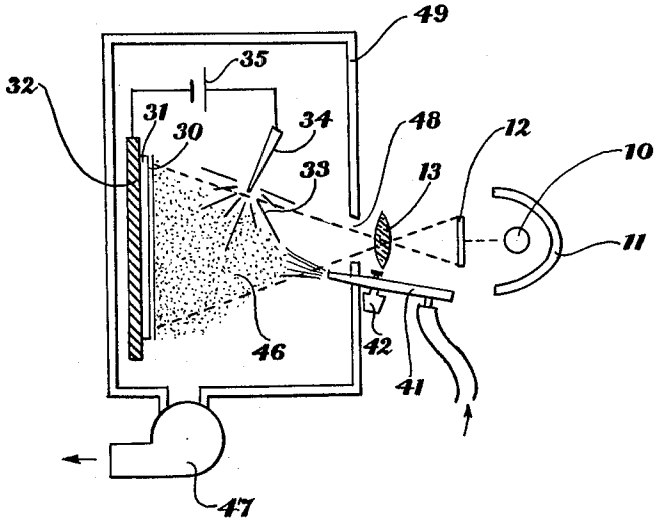
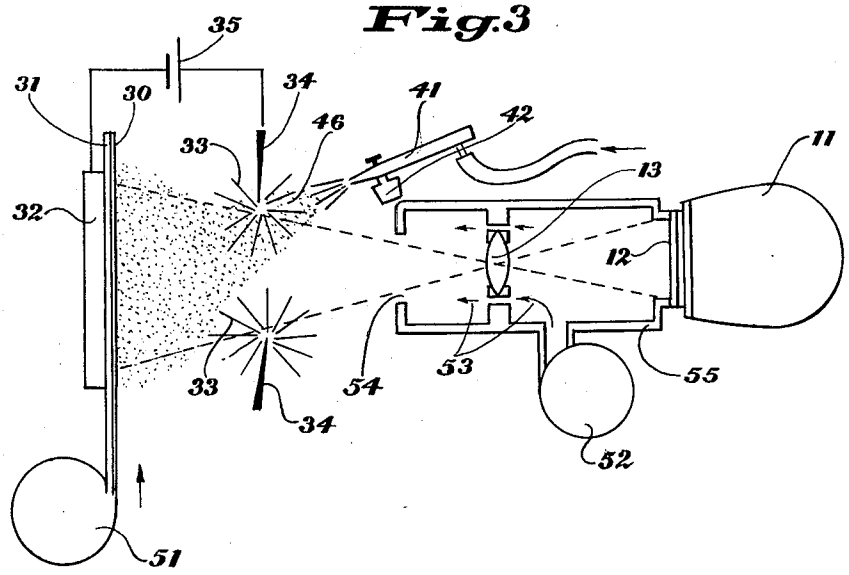


Fig. 2

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Fig. 3



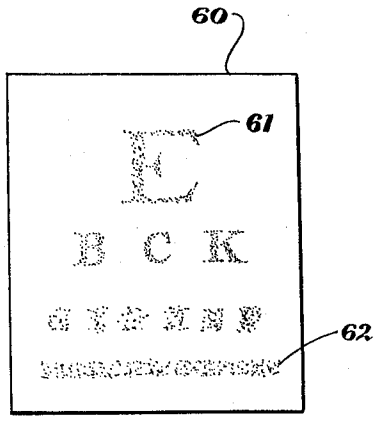
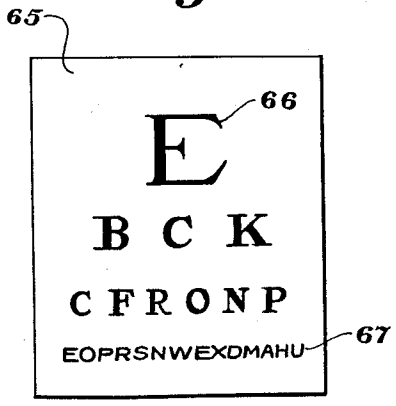


Fig. 4
PRIOR ART

Fig. 5



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April 13, 1965 J. G. JARVIS 3,178,281

ELECTROSTATIC COLOR PRINTING

Original Filed July 16, 1956 4 Sheets-Sheet 3

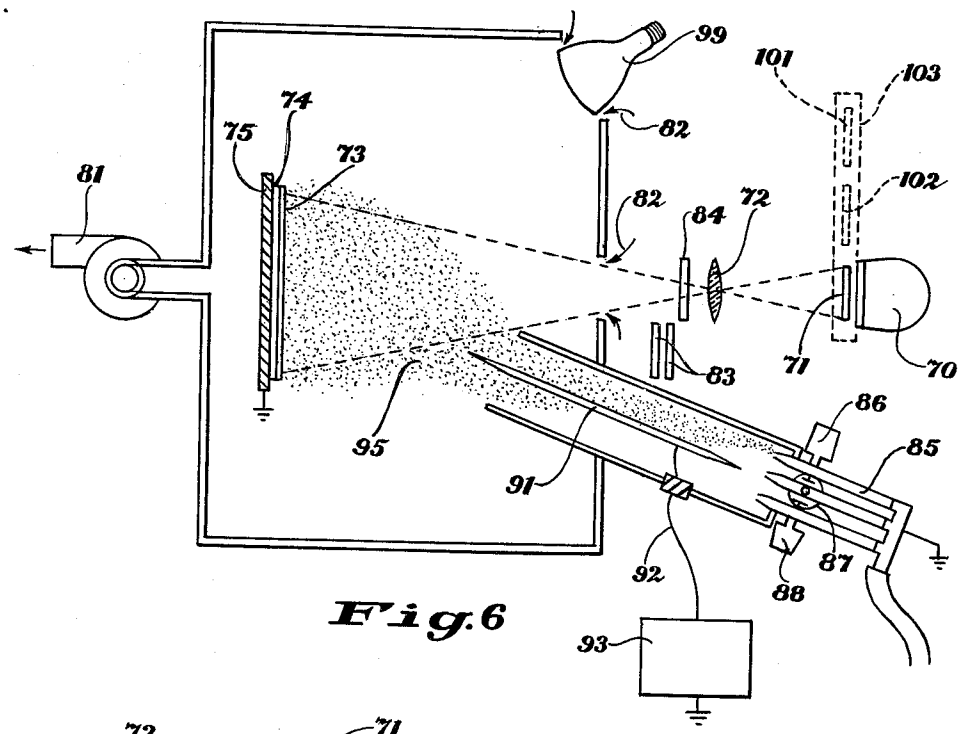


Fig. 6

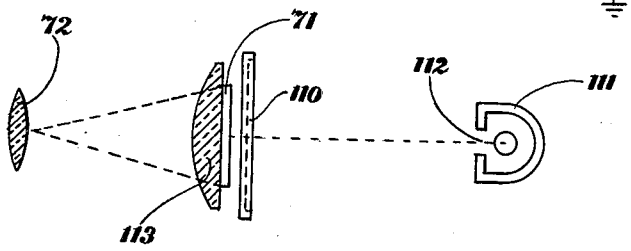


Fig. 7

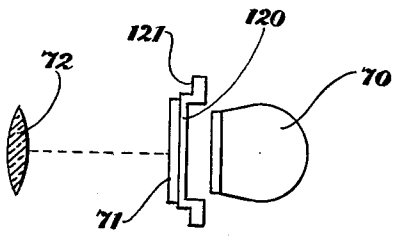


Fig. 8

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April 13, 1965 J. G. JARVIS 3,178,281

ELECTROSTATIC COLOR PRINTING

Original Filed July 16, 1956 4 Sheets-Sheet 4

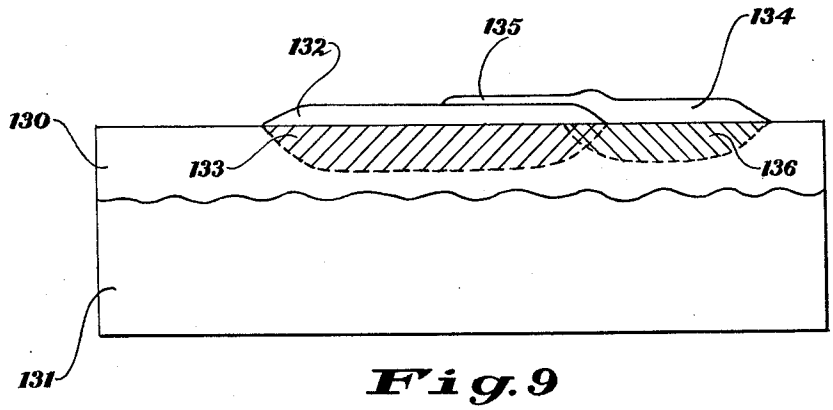


Fig. 9

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3,178,281

ELECTROSTATIC COLOR PRINTING

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Original application July 16, 1956, Ser. No. 598,017. Divided and this application May 24, 1961, Ser. No. 112,380

4 Claims. (Cl. 96—1)

This application is a division of my application Serial No. 598,017, filed July 16, 1956, now abandoned.

This invention relates to electrostatic printing. In such processes, powder, smoke, or liquid mist constituting or containing a pigment or dye is attracted to an image formed of electrostatic charges.

The primary object of the present invention is to provide a simplified form of electrostatic printing producing much better definition than has been obtainable with any of the previous simple forms of such processes. By the present process, it is possible to print details which are so fine that they cannot be seen without a powerful reading glass and still to have these details extremely sharp. All previous simple forms of electrostatic printing failed to reproduce such fine details at all and made even coarse details appear fuzzy.

It is also an object of the invention to permit printing on any desired weight of paper. The simplest of the prior processes was limited to printing on so-called onion skin paper or other thin papers.

An object of one special embodiment of the invention is to extend the process to multicolor printing. Even after it became known that the present invention could give extremely fine definition, it was not apparent that the invention could be extended to color printing. The complications normally anticipated with respect to multicolor printing turn out to be much smaller than expected in the present system, and in some embodiments of the present invention the complications tend to correct each other.

In these color printing embodiments it is an object of the preferred form of the invention to eliminate the problem of registration of the different color images.

The present invention is applicable to either continuous tone or to halftone work. The process produces a fairly long density scale and hence the quality of continuous tone prints made by the invention are quite acceptable. The high resolution and high quality definition make the present invention particularly adaptable to halftone work and to the reproduction of line drawings or printed matter.

According to the invention an image, negative with respect to the final print desired, is projected and focused by means of a lens on the front of a paper-backed photoconductive layer. Of course, the radiation constituting the image must be one to which the layer is sensitive. While this image is on and preferably a few seconds after it has been turned on, a mist of electrostatically charged particles of insulating ink is created in front of the layer. The usual method of creating this mist is to spray the ink from a spray gun through a glow discharge produced by wire, or preferably needles, at high electrical potential. Obviously, if this mist is too dense, forming a heavy fog, it would interfere with the formation of the optical images. I have found, however, that the mist required for the present invention has a density far below the point at which it would cause any substantial interference with the image. The electrostatically charged particles and the glow discharge itself tend to charge the photoconductive layer with the same charge as the particles, and thus, in general, the particles are repelled by the photoconductive layer. However, in areas of the image which are light, the layer becomes photoconducting in proportion to the amount of

light falling thereon. This causes the charge in the light areas to leak away through the paper base and hence the ink particles are no longer repelled by these areas of the layer. The particles are deposited, forming in due time a dense layer of ink in the light areas of the image. Definition is extremely sharp.

This flow of charges (with associated marking particles) is equivalent to a continuous current flowing between the needle electrode and the illuminated areas of the photoconductor.

Of course, in practice, there is some background density due to unwanted deposit of ink in dark areas of the image, but it is surprising how low this background density is. The image quality is quite acceptable for most purposes.

The term "glow discharge" as herein used is synonymous with and refers to the same phenomenon as is sometimes called "corona discharge."

When an actual glow discharge is used for producing the charge on the mist particles, this glow discharge must also be kept at a low enough intensity so as not to reduce the contrast of the image substantially. However, the glow discharge must have sufficient intensity to charge the particles of mist. This also is a range within which it is quite easy to stay in practice. In fact, if the glow discharge intensity has to be reduced, then the quantity of mist should also be reduced to be sure that the particles are substantially all charged. Similarly, as pointed out above, it may be necessary to keep the quantity of mist low so as to avoid absorbing or diffusing the light forming the image. In either case, the reduction in quantity of mist is overcome merely by extending the time of exposure until sufficient ink has deposited to form the required print. In practice, spacings are chosen so that no mist reaches the photoconductor unless an electric field exists. This insures that no uncharged particles are deposited.

The mist tends to deposit on the apparatus, but this is not objectionable unless it happens to deposit on the lens of the image projector or on other elements important to the system. This tendency is overcome by having a gentle draft of air away from the lens so that the mist does not tend to move in the direction of the lens. Deposit on other parts of the apparatus is harmless but even this can be reduced by using insulating plastics since these tend to repel further deposit after the first few charged particles reach it.

Other features of the main invention and the special features involved in the color embodiments will all be described in connection with the accompanying drawings in which:

FIG. 1 schematically illustrates the essential features of a prior simple form of electrostatic printing;

FIG. 2 similarly illustrates an embodiment of the present invention;

FIG. 3 similarly illustrates another embodiment of the invention applied to monochrome printing;

FIGS. 4 and 5 illustrate the results obtained respectively with the arrangements shown in FIG. 1 and FIG. 2;

FIG. 6 is a schematic illustration of a 3-color printing process according to the present invention;

FIGS. 7 and 8 illustrate alternative arrangements of the image projecting features of FIG. 6 when applied to halftone printing, and

FIG. 9 is a greatly enlarged cross-section of a multicolor print according to the present invention, to illustrate the effect of one color ink on the next.

In the prior art arrangement illustrated in FIG. 1, light from a lamp 10 and reflector 11 illuminates a negative transparency 12. An optical image of this transparency 12 is projected by a lens 13 through a glass base

14 and a thin conductive layer 15 onto a photoconductive layer 16. The photoconductive layer has a high dark resistance, but has low resistance in the light areas of the image falling thereon. Immediately in front of, and actually in close contact with, the layer 16, is a thin layer of paper 17 which is to receive the final print. An atomizer or spray gun 21 sprays a mist or smoke from a container 22 whenever the valve 23 is opened. The mist or smoke 26 passes through a grid 24 which is held at a high potential with respect to the conducting layer 15 by suitable means illustrated schematically at 25. In the prior art, the particles 26 are usually solid and hence constitute a smoke rather than a mist. The areas of the paper 17 in front of the dark areas of the photoconducting layer 16 rapidly become charged and repel the particles 26. However, the areas of the paper 17 in front of the light and hence conducting areas of the photoconducting layer 16 lose the charge in proportion to the conductivity of the photoconducting layer 16. This permits the particles 26 to be deposited on the paper 17. The resolution or definition obtained by this system is low for three reasons. In the first place, the optical image is diffused by the layer 15 before reaching the photoconductive layer 16. In the second place, this image falls on the rear surface of the photoconductive layer 16 and is further diffused by the layer 16 itself. In the third place, the thickness of the paper 17 is such that the areas from which the charge leaks away through the paper 17 and through the layer 16 are much more diffused on the front of the paper 17 than they are even on the front surface of the layer 16.

The net result is illustrated in FIG. 4 where large details 61 of a print 60 are fuzzy and small details 62 are completely lost.

In FIG. 2, on the other hand, the optical system is turned around so that the image of the negative 12 as projected by the lens 13 strikes the front surface of a photoconductive layer 30 carried on a paper support 31 held in contact with a metal sheet or other conducting layer 32. The image on the front controlling surface is thus quite sharp and not subject to any of the objectionable features mentioned in connection with FIG. 1. A glow discharge represented by the lines 33 is preferably produced by one or more needles 34 held at high potential relative to the plate 32 by means symbolically indicated at 35. The present invention is limited to the use of a liquid mist rather than smoke for various reasons. The mist has the advantage of forming a permanent deposit on the print surface whereas smoke has to be later fused or otherwise attached to the surface. More important than this is the fact that the mist can easily be made very fine so as not to absorb or diffuse the light forming the optical image, to any substantial degree. A spray gun 41 sprays the ink from a container 42 to form the particles of mist 46. For monochrome work it does not matter whether the ink is primarily a dye solution or a pigment suspension. The advantages of the dye solution for multicolor work is discussed below in connection with FIGS. 6 to 9 inclusive.

Some of the ink stays on the surface and some soaks into the layer 30 when deposited thereon in the light areas of the image. The proportion which soaks in depends on the type of ink used. All ordinary lithographic inks of proper dilution for spraying, work in the present invention. In general, these inks are electric insulators although in most cases their specific resistance is lower than that of the photoconductive layer when dark. This has an advantage in connection with multicolor printing, but for monochrome work, particularly line or halftone work it does not seem to matter much what the specific resistance of the ink is. A highly conducting ink, such as an aqueous one would tend to produce an unnecessarily high background density and spread the image, particularly if the ink soaks into the photoconductive layer thus lowering its dark resistance appreciably. Also, insulating inks tend to take up the charge from the glow discharge more or less uniformly and do not tend to coalesce into large droplets. Accordingly, the preferred embodiments of the invention use electrically insulating inks. As mentioned above, the greasy inks used in lithography appear quite satisfactory and the usual solvents for these inks, such as dipentene, are also satisfactory.

It is conceivable that the glow discharge could be made so intense that it would reduce the effective contrast of the image falling on the surface 30. However, in practice this is not the case. Normal glow discharges are quite low in intensity as far as any substantial effect on the image contrast is concerned. They are just nowhere near high enough to be objectionable in this sense. The rate of ink spraying could be so high as to absorb or diffuse the image unduly, or could conceivably be so high as to be beyond the ability of the glow discharge 33 to charge substantially all of the particles, although as mentioned previously this is easily avoided by selecting such spacing that none of the uncharged particles reach the paper. In practice, it is quite easy to make a very sharp, bright image on the surface 30 and even if the amount of mist had to be reduced, this would merely require longer exposure.

It has been found preferable to have the image on the surface 30 and the glow discharge 33 turned on, for several seconds before the mist is introduced so that the electrostatic image is well established at the time the first particles start to deposit. Two or three seconds' delay is adequate for this purpose, but some quality improvement can be detected even up to 15 seconds delay.

If any of the mist 46 were to deposit on the lens 13 and continue to accumulate there, the image quality would, of course, suffer considerably. Accordingly, a housing 49 is provided to enclose the mist and the parts which are to receive it. A fan 47 tends to draw air from the chamber and hence to draw air into the chamber through the opening 48 in front of the lens 13. This gentle draft prevents the mist from moving toward the lens 13.

A slightly different arrangement is shown in FIG. 3. The paper 31 with the photoconductive layer 30 is moved from a roll 51 in front of the metal plate 32 as each print is made. Two needles 34 for providing the glow discharge 33 are shown in FIG. 3. The main difference is the arrangement of the projector with its own housing 55 having an opening 54 in the front thereof and having a fan 52 for driving air as indicated by arrows 53 through openings in the lens mount and out through the opening 54 to prevent mist reaching the lens 13.

As shown in FIG. 5, the present invention produces a print 65 with the large details 66 quite sharp and with fine details 67 also quite sharp and legible. As mentioned above, in connection with FIG. 4, the prior art produced fuzzy large details 61 and failed to reproduce fine details 62 at all. Printing so fine that it cannot be seen without a reading glass still appears quite sharp when reproduced by the present invention and viewed through such a reading glass.

The arrangement shown in FIG. 6 is representative of the various ways in which the present invention is applied to color printing. Light from a lamphouse 70 illuminates a color negative 71. In alternative arrangements, to be discussed below, this negative may be a black-and-white color separation. However, the preferred embodiment will be described first in which this negative is a multicolor negative transparency. A lens 72 focuses an image of the negative on a photoconductive layer 73 carried by a paper support 74 in contact with a grounded metal plate 75. The device includes a housing 80 with an exhaust fan 81 to provide the gentle intake of air as indicated by arrows 82 so as to prevent the deposit of mist on any of the optical systems, such as the lens 72, filters 83 or 84, and the infrared lamp 99 all to be discussed below.

Color filters 83 one of which 84 is shown in the optical beam are provided to produce color separation images successively on the layer 73. Since the multicolor negative 71 is not moved, the registration problem is eliminated entirely, particularly when making continuous-tone prints. Changing the angle of a screen when making halftone prints is discussed in connection with FIGS. 7 and 8 below.

When one of the color separation images is falling on the surface 73, one of the spray guns 85 is turned on to project a mist of ink from a container 86. In natural color printing from a multicolor negative, the ink is normally a subtractive color ink complementary to the color of the filter 84. Then in succession the other color separation images are produced by introducing in turn each of the other primary color filters 83. The corresponding inks from containers 87 or 88 are then sprayed to form the required mist. The inks pass an elongated needle 91 maintained at a high potential through wire 92 by a source of such high potential indicated at 93. In general, there is a glow discharge around the needle 91 and particularly near the pointed ends thereof. The mist 95 moves toward the surface 73 and deposits on the light areas of the image as it does in the monochrome case.

There are several special features in connection with multicolor printing. In the first place, contrary to expectations, there is not much interference by the first color laid down and the printing of the succeeding colors. Some possible reasons for this are discussed in connection with FIG. 9 below. Also, a choice has to be made in multicolor printing as to the order in which to lay down the inks. A first choice might be that recommended by the particular ink manufacturers to insure the most desirable printing of the ink in terms of adherence and covering power. Contrariwise, it is sometimes desirable to print the inks in some other order, in order to utilize the effect of the first or second print on the subsequent printing. The selection of inks is not a primary concern of the present invention, but it is noted that if the order of printing is selected to get some of these second order effects, then certain inks may be more desirable than others in terms of covering power when printed in this selected order. Obviously, the upper layers should not have too great a covering power or the colors of the lower layers will be lost.

However, there is one effect which each image or at least each print has on subsequent printings. This has to do with the residual electrostatic images on the layer 73 after the optical image is turned off and the spray gun is turned off. Fortunately, it is very simple to remove this afterimage effect. A lamp 99 producing intense infrared illumination is turned on between the successive printing operations. This infrared radiation cleans up or wipes off the afterimage otherwise persisting on the layer 73. The lamp 99 is merely a standard infrared lamp of the type used as a heat lamp.

It should be noted in this connection, however, that the fatigue effect, while a disadvantage for multiple exposures, is actually beneficial for each individual exposure. As the density of an ink deposit increases, the amount of radiation reaching the photoconductor decreases. One would normally expect a corresponding reduction in photocurrent and rate of deposition of ink. However, because of fatigue, the photocurrent persists to permit ink to deposit at a more or less uniform rate until the desired density is attained.

If color separation images are first prepared, there is no need for color filters 83 and 84 and the photoconductive layer 73 need not be panchromatic. Panchromatic photoconductive layers are well known, however. Nevertheless, the use of color separation images as indicated at 101 and 102 has the disadvantage that the successive images must be registered accurately and hence guide means indicated at 103 must be provided to insure precise registration. On the other hand, the use of color

separation images has an advantage in halftone work since the color separation negatives themselves can be screened at the time they are made, and thus there is no need for a halftone screen being present when making the prints. A screen cannot be placed in front of the surface 73 to produce the halftone effect in an image from a continuous tone transparency 71, since this same screen would interfere with the deposit of mist and would become coated with mist so as to be ineffective as a screen and so as to spoil the optical image completely.

Two alternative arrangements for having a screen with the multicolor negative transparency 71, are shown in FIGS. 7 and 8. In FIG. 7 a ruled screen 110 is located at normal screen distance ahead of the transparency 71. In order to get the proper distribution of light in each of the dots, illumination from a light source 111 is confined by an aperture 112 to the proper area at the proper distance from the screen 110. Light passing through the screen 110 and the transparency 71 would not normally be concentrated in the lens 72 and therefore a field lens 113 must be provided to insure proper distribution of light as it passes through the optical system. This arrangement has the advantage that the screen 110 can be rotated to any desired angle between exposures. For example, it is customary to rotate the screen 30 degrees for each separation when making a 3-color print.

As shown in FIG. 8 a light source 70 can be used close to the color transparency 71 if a contact screen 120, preferably neutral, is used in contact with the transparency 71. A rim 121 is provided on the mount for the screen 120 to permit the screen to be moved slightly away from the transparency 71, rotated through an angle and moved again into close contact with the transparency 71 without disturbing the transparency after each exposure is made.

FIG. 9 is purely schematic and is merely to illustrate the types of effects which are or may be present. It is not intended to be an accurate illustration of the amount of these effects. In this greatly enlarged view, a paper base 131 which is conducting enough to carry away electrostatic charges but which is not particularly highly conducting, carries a photoconductive layer 130. As a first color is deposited thereon some of the ink 132 stays on top of the surface 130 and some of it soaks in more or less, as indicated by the shaded area 133. In most cases this area 133 is confined to the very top of the layer 130 and does not reach through into the paper 131. The ink may be completely transparent to some colors, or it may contain a certain amount of pigment or may even be completely opaque to some colors either because of the dye therein or the amount of pigment. Secondly, the ink in the area 132 will have a certain electrical resistance which may be quite high or quite low. Similarly, the ink in the area 133 may have an electrical resistance which may be greater or less than the dark resistance of the photoconductive layer 130 or even less than the light resistance of this photoconductive layer 130. With all of these factors in mind, the effect of the first color on the printing of the second will now be discussed.

Let us assume that the first color printed is yellow. This is the order of printing recommended by some ink manufacturers to provide the best results as far as covering power is concerned. However, it is not the best for color correction as discussed later. This yellow dye or pigment in the layers 132 and 133 will tend to shade the layer 130, particularly with respect to blue light, but also to some degree with respect to the other primary colors—red and green. The areas which are thus shaded act as darker areas of the second image than they would otherwise. Accordingly, the resistance in the layer 130 behind the ink layers 132 and 133 remains high and tends to repel the deposit of the charged ink particles during the second printing. Thus, we have one factor, namely the optical density, which tends to decrease the amount of the second color in any area. This is true

whether the optical density is due to pigmentation or merely to color.

The ink **132** has some specific resistance, and this ink is electrically in series with the resistance of the layer **130** and hence gives a greater electrical resistance in this area. This increased electrical resistance again tends to cause a decrease in the amount of ink deposited during the second printing.

These two effects accordingly result in less ink being deposited in area **135** than in area **134** of the second color as it is overprinted on the first.

However, when the ink has a low specific resistance that part **133** of the ink which soaks into the layer **134** tends to reduce the effective resistance since this ink is electrically in parallel with the layer **130**. One can conceive of the possibility of this reduction in electrical resistance compensating exactly for the increase in electrical resistance due to the series effect and/or due to the optical density. A degree of such compensation appears to take place since the effect of the first printing on subsequent prints is not anywhere nearly as great as at first sight would be anticipated.

It appears in general, however, that the increase in resistance due to the series effect and the density effects, is greater than any decrease in resistance due to the parallel effect. According to a preferred embodiment of the invention, this can be utilized to provide an effect roughly equivalent to masking as used for color correction purposes. To do this the magneta ink is first deposited. Magenta ink has an optical density even for red and blue light. The cyan ink is deposited second, and the amount of cyan ink is decreased wherever magenta has already been deposited because of the increase in resistance due to density and perhaps due to the series effect as discussed above. The yellow ink is deposited last, and the amount of yellow is decreased in areas which have already received magenta and cyan inks due to the fact that the magenta and cyan inks absorb blue light with which the image is printed. As is well known in photographic masking for color correction, the amount of yellow should be decreased wherever magenta and cyan inks are deposited. This is obviously true since, when the magenta and cyan inks are absorbing primary blue light, they are acting as if they had some yellow content, and hence one does not need as much yellow printed in these areas. This is the basic reason for masking. Accordingly, when the inks are printed in this order, the process tends to provide its own color correction thus compensating for the inefficiencies of color inks which inefficiencies are the primary cause of poor color reproduction.

Even when this color correction is required, it is preferable to have inks whose specific resistance is less than the dark resistance of the photoconductive layer **130** so that the electrical parallel effect mentioned above will tend to compensate the electrical series effect also mentioned above and leave the modification of the electrical resistance almost entirely to the color density effect. Also, the color density effect should be that due to the absorption rather than the scattering of the light, and hence the inks should be more or less transparent with a relatively low covering power as distinguished from translucent with high covering power.

I claim:

1. The method of color reproduction which comprises projecting by means of a lens onto the front surface of a photoconductive insulating layer on an electrically conducting backing, in succession, a series of color separation images representing the primary red, green and blue components of a picture, creating in the light beam in front of the layer during the projection of each image a mist of electrostatically charged particles of partly transparent insulating ink of a color complementary to the color separation image then being projected, creating an electrical field between the mist and the photoconductive layer to cause particles of the mist to deposit on the areas of the photoconductor which are conducting due to the light areas of the color separation image then thereon, the blue-separation-yellow-printer image being last in said series and being projected through the two previously deposited ink images.

2. The method according to claim 1 in which the ink for at least the first two colors deposited has a specific resistance lower than that of the photoconductive layer when dark and in which said two inks at least partly soak into the layer when deposited thereon.

3. The method according to claim 1 in which the color separation image is made by passing light through a multicolored negative transparency and a primary color filter.

4. The method according to claim 1 in which the printed layer between the printing of successive color separation images, is flooded with infrared radiation sufficient to remove substantially all residual charges left by the previous deposition.

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