United States Patent [19]

Pressman

[11] **3,824,010**

[45] **July 16, 1974**

[54] **ELECTROSTATIC MODULATOR FOR CONTROLLING FLOW OF CHARGED PARTICLES**

[75] Inventor: **Gerald L. Pressman,** San Jose, Calif.

[73] Assignee: **Electroprint, Inc.,** Palo Alto, Calif.

[22] Filed: **May 15, 1972**

[21] Appl. No.: **283,781**

Related U.S. Application Data

[62] Division of Ser. No. 85,070, Oct. 29, 1970, Pat. No. 3,694,200.

[52] **U.S. Cl.** ..... **355/3 R,** 355/16, 96/1 R

[51] **Int. Cl.** **G03g 15/00**

[58] **Field of Search** ..... 346/74 ES; 355/3 R, 16, 355/17; 96/1 R

[56] **References Cited**

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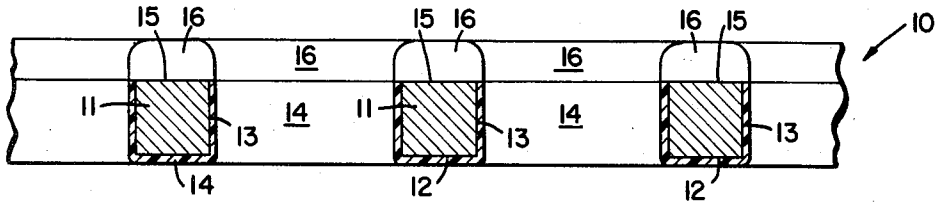
3,645,614	2/1972	McFarlane et al.	355/3
3,680,954	8/1972	Frank	355/3

Primary Examiner—Robert P. Greiner

[57] **ABSTRACT**

A system for controlling the flow of charged particles and for modulated aperture electrostatic printing. An apertured screen having substantially the entire surfaces formed of a dielectric material is charged with like charges over substantially all its surfaces to develop fringing fields in the apertures. The charge distributed across one side of the screen is selectively dissipated in accordance with a pattern to be reproduced thereby establishing a bipolar electrostatic latent image as a modification of the fringing fields for density control of a flow of charged particles directed through the screen. The screen may be formed with dielectric thicker on one face than the other to initially carry a higher potential and provide a uniform charge inequality or potential difference through the screen apertures, oriented to enhance the flow of charged particles through the screen. Full modulation control of particle flow is therefore possible with a single selective charge dissipation. For electrostatic reproduction a print-receiving medium is interposed in the modulated particle flow passing through the screen.

3 Claims, 21 Drawing Figures



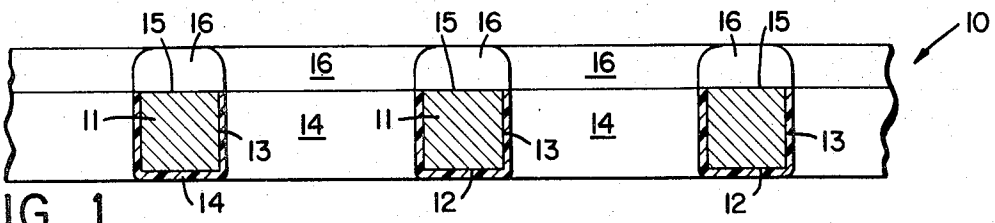


FIG_1

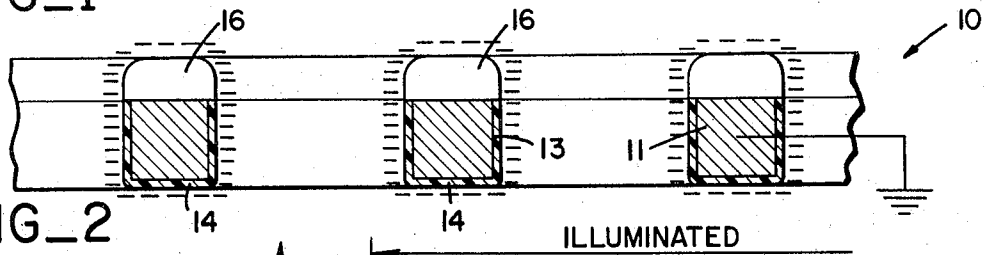


FIG_2

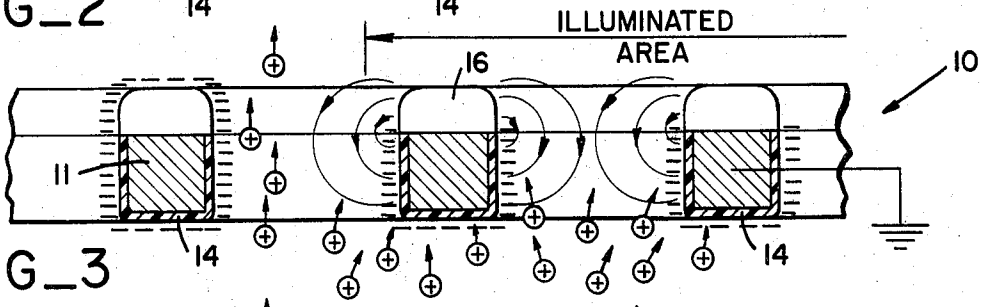


FIG_3

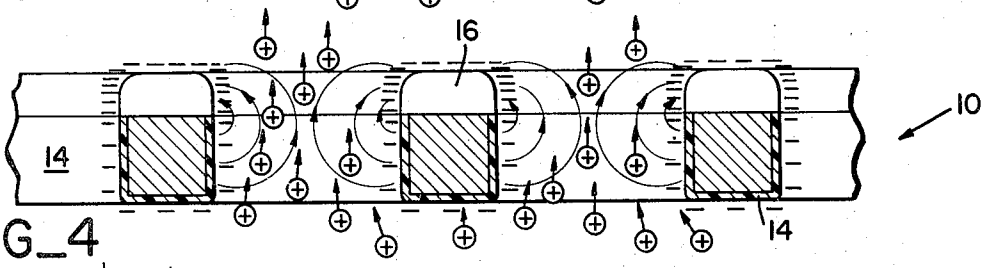


FIG_4

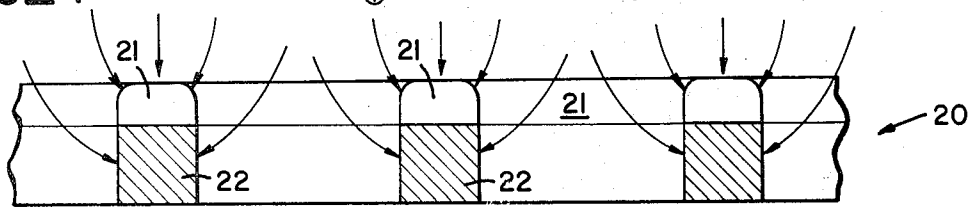


FIG_5a

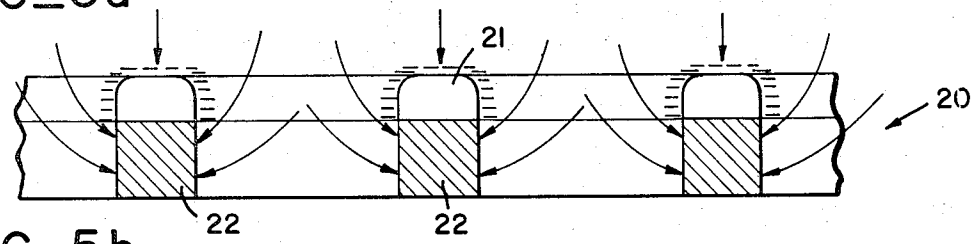


FIG_5b

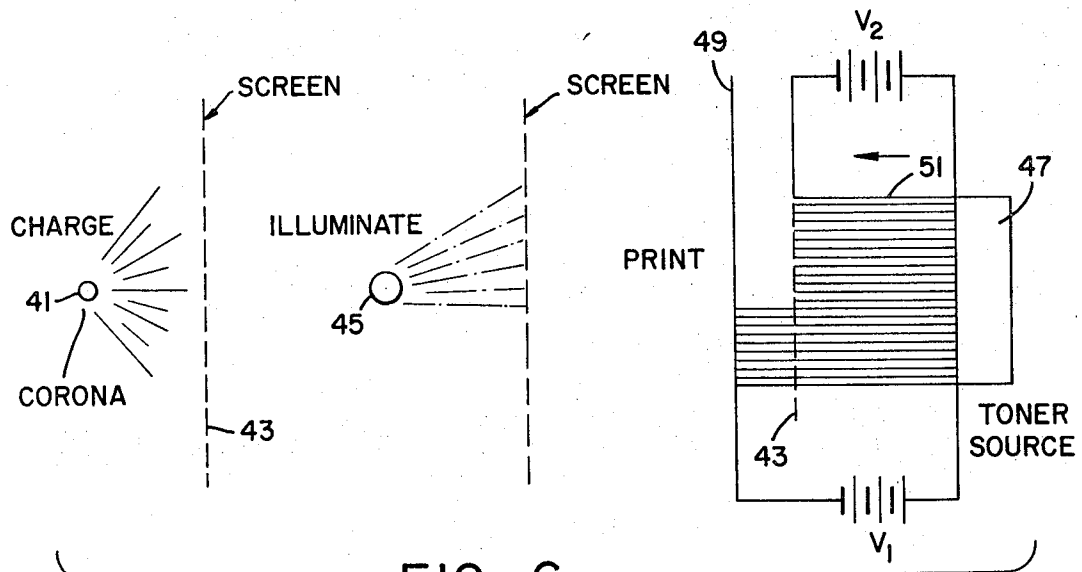


FIG_6

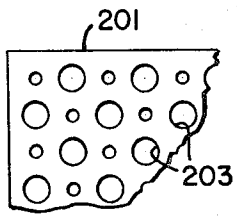


FIG_7a

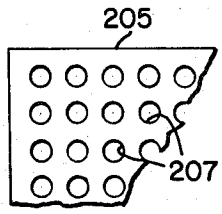


FIG_7b

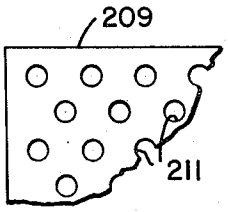


FIG_7c

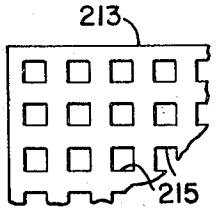


FIG_7d

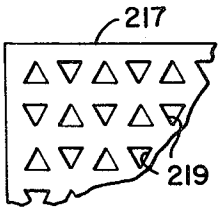


FIG_7e

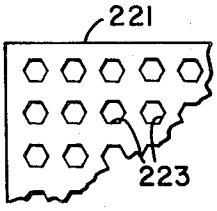


FIG_7f

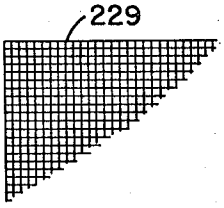


FIG_7g

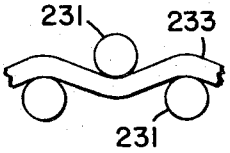


FIG_7h

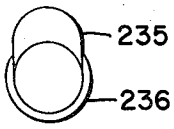
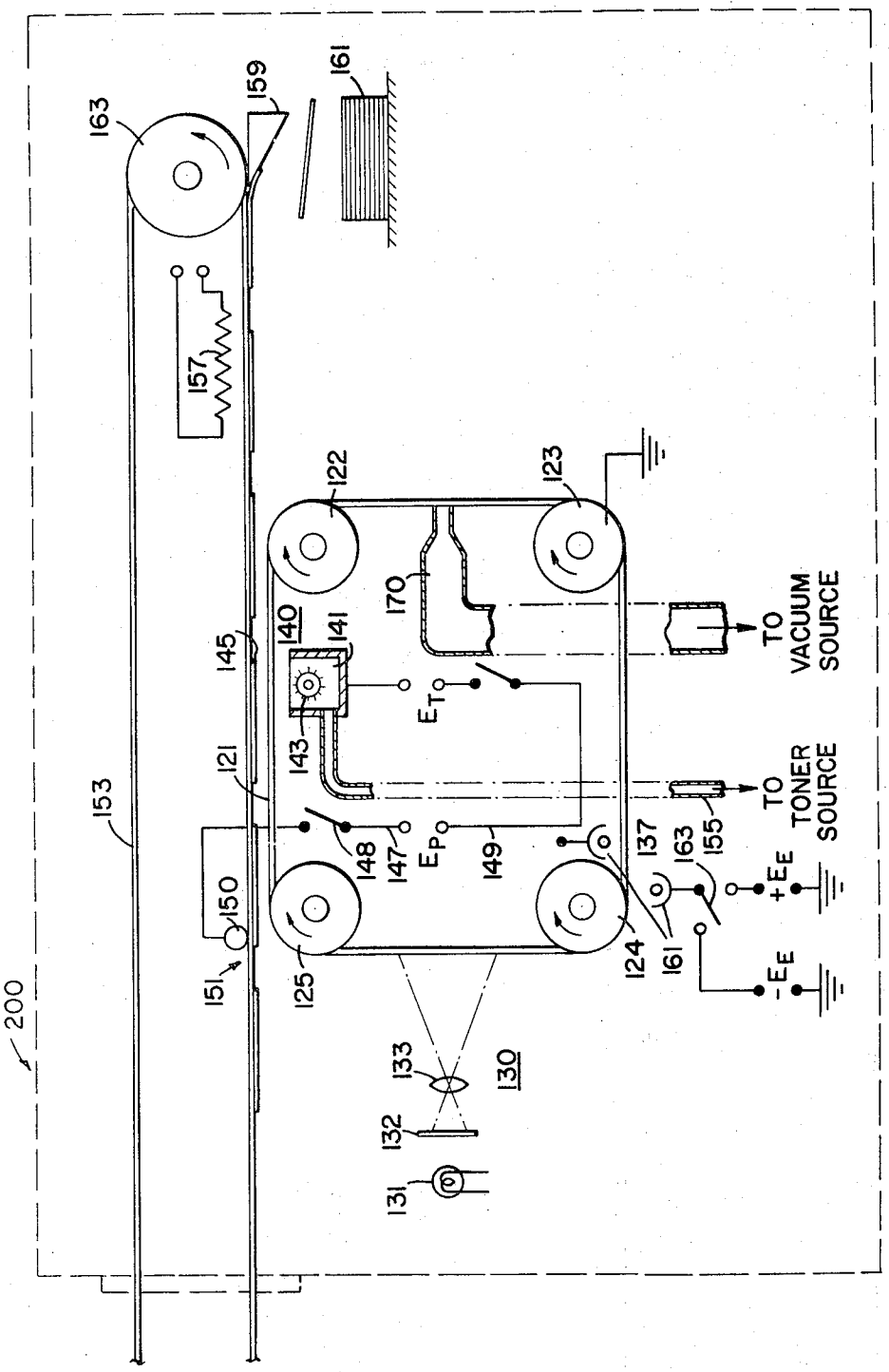


FIG_7i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TO VACUUM SOURCE
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FIG_8

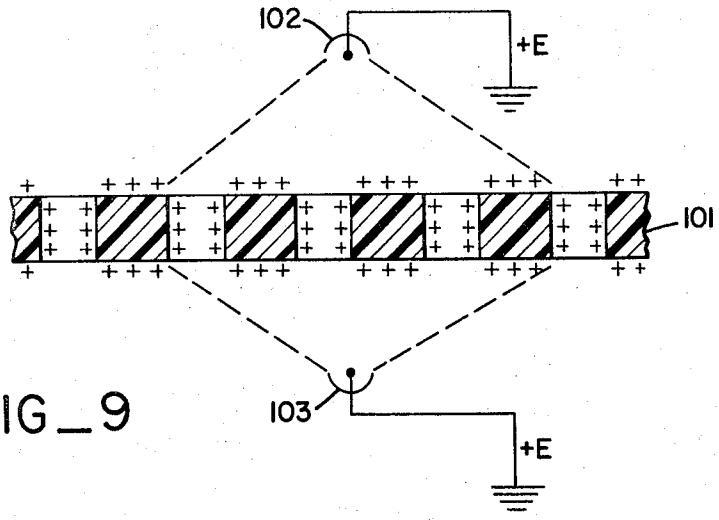

FIG_9

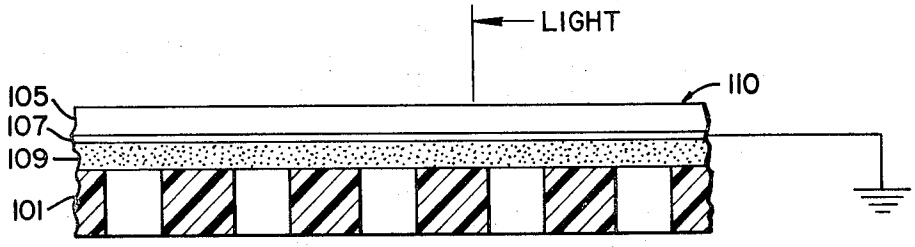

FIG_10

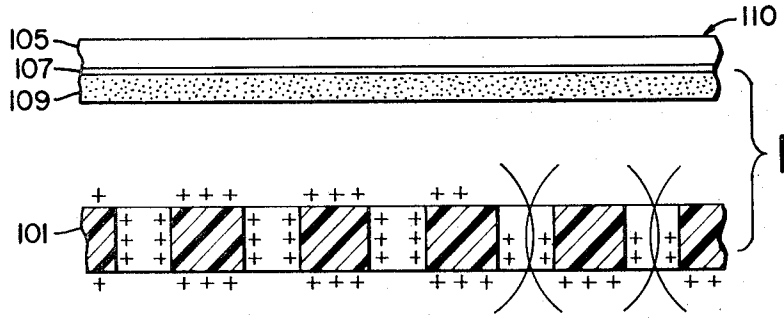

FIG_11

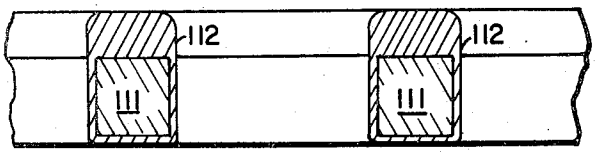

FIG_12

ELECTROSTATIC MODULATOR FOR CONTROLLING FLOW OF CHARGED PARTICLES

This application is a division of Ser. No. 85,070, filed Oct. 29, 1970, now U.S. Pat. No. 3,694,200.

This invention relates to a new and improved system for modulated aperture electrostatic printing and more generally to an electrostatic modulator for controlling the flow of charged particles.

In conventional xerography, a xerographic plate formed of a layer of photoconductive insulating material coated on a conductive surface is used for establishing and supporting electrostatic latent images. The zerographic plate is electrostatically charged uniformly over its surface and a light pattern corresponding to the image to be reproduced is projected on the plate to selectively dissipate the charge. The resultant latent electrostatic image is developed by powdering with toner particles which are electrostatically attached to the xerographic plate in a pattern defined by the charge distribution of the electrostatic image. The powder image is thereafter contact transferred to a sheet of paper or other print-receiving medium. Because of interfering electrostatic lines of force established in the latent image, the field lines of force concentrate at the edges of the latent image resulting in reproductions having hollow centers and emphasized edges.

These problems are overcome in the apparatus and method described in the McFarlane U.S. Pat. Nos. 3,339,469 and 3,220,833 wherein the electrostatic latent image is first formed on a screen or interrupted grid of conductive material coated with an insulative photoconductive material. Developing ink toner may be, in one embodiment, clouded onto the electrostatic latent image by filtering the toner particles through the screen or grid mesh onto the charged boundaries of the interstices of the screen in accordance with the charge pattern. The developed toner image is thereafter transferred by projection of the particles along lines of an overall applied electrostatic force field across a space to a print-receiving medium or other transfer medium. The expedience of non-contact printing, and fine control over the electrostatic latent image charge distribution provided by the interrupted surface of the screen which supports the image, overcome many of the problems of conventional xerography.

Improvements on the McFarlane system are described in the Pressman patent application Ser. No. 673,499 and the Pressman and Kittredge patent application Ser. No. 776,146.

According to these disclosures, there is provided in a preferred embodiment a multi-layered apertured screen including at least a conductive layer and an adjacent insulative layer on which an electrostatic latent image is formed for modulating the flow of charged toner particles or other printing particles directed through the apertures of the screen by an accelerating field. A two-layer screen construction permits the establishing of a double layer charge on the opposite sides of an insulative layer for selectively producing overlapping lines of force or "fringing" fields within the apertures of the screen. Thus, lines for force generating by bipolar electrostatic fields extend within apertures of the screen and can be oriented to oppose the passage of charged particles, enhance the flow of charged particles, or be nautralized to have no effect on charged particles directed through the screen. Thus, the double

layer charge can be selectively established across the face of the screen to substantially completely block the passage of charged particles through certain apertures, enhance and accelerate the passage of charged particles through other apertures, and control the width and density of the particle stream through other apertures along a continuous range in between. A stream or flow of charged particles directed through the screen by an accelerating field is therefore modulated to provide a cross-sectional density variation at least substantially corresponding with the image to be reproduced. The modulated stream of toner particles or other charged particles is transferred by the overall applied electrostatic projection field across a gap to a print-receiving medium and the powder image is thereafter fixed according to known techniques.

In one approach for establishing the double charge layer electrostatic latent image across the screen, a substantially uniform charge distribution may be initially established across both sides of the insulative layer with opposite charges on the respective sides to provide fringing fields within the apertures. These fringing fields include blocking fields to block or partially block particles of a predetermined sign. By use of photosensitive materials the charge distribution and therefore the blocking fields are dissipated according to a light pattern projected on the screen. The fringing fields also may include enhancing fields which are established by adding techniques. The screen must generally be charged initially with blocking fields which block the passage of charged toner particles through the screen. The blocking fields are thereafter selectively neutralized according to the light pattern or reversed to enhancing fields according to additional procedures, and the resulting modulation of the flow of toner particles through the screen results in negative printing. In order to achieve positive printing, special contact charging techniques and other expedients are used.

The present invention is characterized in that it improves, by shortening, the charging time required for establishing an initial uniform charge across a screen, as for example when using corona charging devices. The invention also enables readily the establishing directly of the charge pattern for the modulator, particularly for positive type printing.

It is therefore an object of the present invention to provide an improved modulated aperture electrostatic non-contact printing system which permits direct positive printing with an electrostatic screen modulator which controls the density flow of charged particles directed through the screen.

Another object of the invention is to provide an electrostatic screen modulator for supporting a double charge layer electrostatic latent image and which can be charged to high voltages at desired levels in short periods of time.

A further object of the invention is to provide an electrostatic screen modulator for supporting a double charge layer electrostatic latent image in which the selective charge distribution can be established by simple light protection techniques to provide both blocking and enhancing fields and fields along a continuous range in between for controlling the flow of charged particles directed through the screen by an accelerating field.

Another object is the provision of the screen modulator capable of producing enhancing through blocking

field control from single sign charge while enabling positive or negative printing in electrostatic printing applications.

A still further object is the provision of a unique method for electrostatic latent image modulation control and particularly for control of electrostatic printing processes.

In order to accomplish these results, the present invention contemplates providing an apertured screen having substantially the entire surfaces formed of an insulative dielectric material. The insulative material of the screen is charged over substantially the entire surfaces of the screen with like charges to produce double charged insulation material. The charge across one side face of the screen is thereafter selectively dissipated in accordance with a pattern to be reproduced, thereby establishing a double layer electrostatic latent image. The screen can be incorporated in an electrostatic printer which provides an overall electrostatic accelerating field for directing charged particles through the screen, which modulates the particle flow. The modulated particle flow passing through the screen may be caused to impact a spaced print-receiving medium where it can be fixed (if the particles are of certain marking materials) according to known techniques.

The charges can initially be distributed on both faces of the apertured screen to provide two-charge layers of substantially equal sign and potential so that lines of force do not pass through the apertures of the screen. The screen is therefore passive to a flow of charged particles directed through the screen by an overall applied accelerating field. Upon selective dissipation of the charge across one side of the screen in accordance with a pattern to be reproduced, the resulting charge inequality establishes electrostatic lines of force within the aperture of the screen to selectively block charged particles of one sign according to the magnitude and distribution of the charge inequality and potential difference between the layers.

The invention also contemplates providing an apertured screen formed with insulative material over its entire surfaces and also formed with the insulative material thicker on one side of the screen than on the other whereby a greater potential can be established on one side or face of the screen than the other. The resulting uniform charge inequality (uniform across the face but unequal in the direction of the flight) across the face of the screen thereby establishes uniformly oriented electrostatic lines of force through the apertures of the screen which can be oriented to enhance the flow of a stream of charged particles directed through the screen. The charge distributed on the side or face of the screen having the greater charge density is thereafter selectively dissipated in accordance with the pattern to be reproduced thereby to weaken, neutralize, and even reverse the lines of forces extending through the apertures of the screen according to the inequality between the charges across the respective sides of the screen. Thus, an initially uniform array of enhancing fields can be selectively weakened, neutralized, and reversed to form a distribution of enhancing fields, neutral fields and blocking fields in accordance with a pattern to be reproduced. The resulting double charge layer electrostatic latent image is referred to herein as a bipolar electrostatic latent image. It may now be appreciated that, in the absence of any variation in the thickness of the insulative material, the bipolar electrostatic fields developed by charging the insulative layers is the sole modulating control relative to the accelerating field.

When the insulative material is thickened to retain a higher charge than the associated thinner insulative material, additionally the like potential difference fields may be developed with their useful lines of force, i.e. in the direction of or opposed to particle flight, and oriented parallel with the lines of force of the bipolar fields for each given aperture and these lines of force produced by the like potential fields may aid, neutralize, or overcome and reverse the effective flux in the apertures. But it must be realized that the like potential difference fields lines of flux cannot exist without some bipolar field being present nor without the uneven distribution of insulative material. Thus the initial charging may, by way of example, place a 500 volt potential difference between the screen conductor and the outermost surfaces of the thickest portion of insulative material. Similarly the field from the face of the screen measured from the outside of the thickest insulation through an aperture to the opposite face along the insulative surface may also vary from 500 to 0 volts, the first field being the bipolar field and the latter field being the like potential difference field. In actual practice innumerable variations of these figures will be encountered in accordance with the various degrees of enhancing through blocking manifested by the individual apertures.

Thus, according to one general aspect the invention contemplates the method of establishing a substantially coplanar array of a plurality of bipolar electrostatic fields having lines of force generally parallel to the flow of charged particles to be controlled and orienting the bipolar electrostatic fields to enhance the charged particle screen flow. Additionally, like potential difference fields are established in directions further to enhance the effects of the bipolar electrostatic fields. The invention further contemplates selectively reducing, neutralizing, and reversing the bipolar electrostatic fields according to a pattern to be reproduced thereby establishing a bipolar electrostatic latent image for modulating the charged particle screen flow density. The reducing, neutralizing, and reversing of the bipolar electrostatic fields is effective in the region of increased thickness of insulation material but is progressively less effective in the apertures so that the relative effects above stated are obtained. Thus, selectively across the screen the bipolar fields are reduced in magnitude relative to the like potential difference fields usually by light pattern to effect the modulation.

In a preferred form of the invention the bipolar electrostatic latent image is supported on an electrostatic screen modulator comprising a conductive apertured screen having a layer of insulative material coated on one side thereof and on the inner surfaces defining the screen apertures, and having a layer of photoconductive material coated on the other side thereof so that the entire screen surfaces are coated with insulative material. The photoconductive insulative material is coated to a greater thickness than the insulative material coated on the inner surfaces of the apertures and on the other side of the screen so that a greater potential can initially be established on the side of the screen coated with the photoconductive material by charging from a single sign course. With the conductive screen core connected to a fixed potential such as ground, a

light image is projected on the photoconductive side of the screen thereby to selectively dissipate the initially uniform charge distribution in proportion to the intensity of the incident light. The result is a bipolar electrostatic latent image of overlapping or fringing force fields within the apertures of the screen for modulating the flow of toner particles directed through the screen. The arrangement of the electrostatic screen modulator permits enhancing lines of force or no lines of force to be established within the apertures corresponding to the dark portions of a projected pattern to be reproduced. At the same time, blocking lines of force of variable strength are established within the apertures of the screen corresponding to regions of variable lightness intensity of the projected pattern to be reproduced. The resultant feature and advantage is that direct, positive electrostatic printing is obtained with modulation of a stream of charged dark toner particles by means of an apertured screen supporting a bipolar electrostatic latent image.

Another feature and advantage of the embodiment of the present invention in which the conductive screen surfaces are entirely coated with insulative material so that no conductive surfaces are exposed is that a high voltage charge can be established on the screen in a short period of time using, for example, corona charging currents. It has been found in some prior modulated aperture electrostatic screens comprising adjacent layers of conductive and insulative material that the exposed conductive surfaces tend to draw off the corona charging current as soon as a relatively low voltage charge has been established on the insulative material. Thus, at a low voltage charge level leakage through the conductor layer balances the incoming corona current flow so that no increase in potential is obtained. The present invention contemplates a screen having its entire surfaces formed of an insulative material so that a charge voltage approaching that of a flat dielectric surface can be obtained using corona charging techniques.

The invention also contemplates directly establishing an electrostatic latent image on the screen modulator by, for example, contact charging methods.

Other objects, features and advantages of the present invention will become apparent in the following specification and accompanying drawings.

IN THE DRAWINGS

FIGS. **1** through **4** are end cross-sectional views of an electrostatic screen modulator according to the present invention.

FIGS. **5***a* and **5***b* are end cross-sectional views of a prior art electrostatic screen modulator consisting of a conductive layer and an insulative layer.

FIG. **6** is a diagrammatic view of an electrostatic printing system.

FIGS. **7***a* through **7***i* are fragmentary diagrammatic views of various screen configurations applicable in the present invention.

FIG. **8** is a diagrammatic view of an electrostatic printer.

FIG. **9** is a diagrammatic cross-sectional view of another electrostatic screen modulator.

FIGS. **10** and **11** are diagrammatic views showing one technique for establishing a bipolar electrostatic latent image.

FIG. **12** is a fragmentary cross-sectional view of another electrostatic screen modulator.

In the embodiment of the present invention illustrated in FIGS. **1** through **4**, an electrostatic screen modulator **10** is constructed with a screen or mesh base **11** of metal or other conductive material. The metal screen base **11** is coated on one surface **12** of the screen and on the inside walls **13** of the screen apertures with a layer **14** of ordinary electrical insulator material, preferably having a high dielectric strength as well as high resistivity. The opposite surface **15** of the metal screen base **11** is coated with a layer **16** of a photoconductive insulating material.

In forming the screen, the metal screen base **11** is first coated with the layer **14** of insulator material along one surface **12** of the screen and on the inside walls **13** defining the apertures or holes through the screen. The insulator material can be applied, for example, by spraying the screen from one side. This may result in some deposition of the insulator material **14** on the opposite surface **15** of the screen. Such material can be removed by rubbing the surface **15** with abrasive material after the screen has been sprayed from one side. The photoconducting insulative material is then applied to the uncoated surface **15** of the screen. The photoconductor material is preferably applied so that coating of the internal walls of the screen holes is avoided, but a small degree of internal coating can be tolerated. Such selective coating of the surface **15** of the screen base **11** can be accomplished by electrostatic spraying of the photoconductive material after first charging the insulator layer **14** with charges similar to that applied to the photoconductive material **16.** The photoconductor **16** is thereby repelled from the insulator surfaces **14** during deposition so that separation of the coatings **16** and **14** results. The entire surfaces of the metal screen base **11,** however, are coated with an insulative layer, either **14** or **16.**

According to one mode of operation of the screen **10** shown in FIGS. **2** and **3,** the screen is positioned so that the screen surface coated with insulator layer **14** faces a toner source or other source of charged particles. The modulator screen **10** is first charged uniformly over its entire surfaces so that the potentials on the insulator layer **14** and photoconductive layer **16** on opposite surfaces of the screen are approximately the same. In FIG. **2,** a negative charge is shown by way of example and the conductive screen base **11** is maintained at a ground potential or at a selected fixed potential during the charging process. Charging of the surfaces of the modulator screen **10** is accomplished, for example, by corona discharge currents from a corona spray source or corona wand. As a result of the uniform charge distribution across the surfaces of the screen, there are no potential differences across the screen and no fringing fields or lines of force extend axially through the holes in the screen, as shown in the charge configuration of FIG. **2.** A bipolar electrostatic latent image corresponding to a pattern to be reproduced is thereafter established by selectively dissipating the charges deposited on the photoconductive layer **16.** Selective dissipation of the charge layer on the photoconductive material **16** is accomplished by projecting on the screen **10** and illuminating the photoconductive layer **16** with light in the pattern of the image to be reproduced while the conductive screen base **11** is maintained at a fixed potential or ground potential as shown in FIG. **3.** The

negative charges initially deposited on the photoconductive material **16** are selectively conducted away in the regions illuminated with light, the photoconductor potential approaching the potential of the conductive screen **11** in the illuminated regions. As a result of the selective charge dissipation, a charge inequality of varying magnitude is established across the surfaces of the screen, thereby producing fringing fields of electrostatic lines of force axially through the screen apertures or holes in the illuminated portions of the screen. As shown in FIG. **3**, the fringing fields of force within the apertures act to block or attenuate the passage of positively charged toner particles directed towards the screen. The initial flow of charged particles, such as charged toner particles, is created by an overall applied electrostatic accelerating field in which the modulator screen is interposed to modulate the established flow of charged toner particles. In the non-illuminated portions of the screen, the absence of force fields within the apertures renders those portions of the screen passive to the charged toner particle flow thereby permitting passage of the toner as also shown in FIG. **3**. The strength of the fringing force fields established within the apertures of the screen is proportional to the extent of charge dissipation from the photoconductive layer **16** which is in turn proportional to the extent of light illumination. The apertures of the screen thereby permit a modulated control over the flow of charged particles along a continuous range from passing to completely blocking the flow of charged particles in any particular aperture.

The potentials acquired by the two components of the screen coating during charging are determined principally by the dielectric strength, thickness, and resistivities of the materials comprising the coatings. In some applications it is advantageous to form the screen so that the potential acquired by the photoconductive insulator layer is higher in absolute value than that acquired by the ordinary insulator. As a general rule, this can be accomplished by forming the insulative layer thicker on one side of the screen than on the other. This, however, may also depend upon the charge carrying capacities of the respective materials. Thus, according to another embodiment of the present invention, the photoconducting insulative coating is formed thicker than the ordinary insulative coating formed on the other side of the screen. Under these circumstances and as shown in FIG. **4**, a greater quantity of charge can be acquired on the photoconductive surface of the screen than on the opposite surface, thereby establishing a uniform charge inequality across the face of the screen or at least along the wall or reaches of the apertures. The resulting fringing fields of force established within the screen apertures are oriented to provide "enhancing fields" or accelerating fields in this example with respect to positive toners. The enhancing fields increase the flow of positively charged toner particles through the portions of the screen corresponding to dark areas which have not been illuminated, improving the printing density in these areas. Thus, as shown in FIG. **4**, a flow of positively charged particles, such as charged toner particles established by an overall applied accelerating electrostatic field, are further accelerated and enhanced in the apertures of the screen by the fringing force fields. Illumination of portions of the screen by a light pattern as heretofore described, with the metal screen base **11** maintained at a fixed potential, results in selective dissipation of the charge deposited on the photoconductive layer **16** weakening the enhancing field in some regions, neutralizing or eliminating the fringing fields of force in other apertures, and reversing the bipolar electrostatic fields in other apertures, to produce blocking fields of variable strength. Thus, a bipolar electrostatic latent image, containing established force fields within the apertures ranging from enhancing to blocking, is established in accordance with an image to be reproduced.

In the embodiments of the present invention illustrated in FIGS. **1** through **4**, the metal or other conductive screen base is coated over its entire surfaces with insulative material, either ordinary insulating material or photoconductive insulating material. The insulative coatings can be applied to a variety of conductive screens such as, for example, etched metal or woven wire screens, and in a variety of configurations as illustrated in the examples of FIGS. *7a* through *7i*.

It should be noted that the screens described herein are not limited to any given shape, size, or distribution of apertures and may even contain apertures of varying size and/or shape and/or distribution even in a random fashion as shown in FIGS. *7a* through *7h*. In Screen **201** (FIG. *7a*), apertures **203** are distributed in a random fashion and may have randomly distributed size and irregular shape as well. The screen **205** (FIG. *7b*) consists of the uniform array of circular apertures **207** in essentially a square or 90° pattern. Alternately, the apertures **211** as shown in screen **209** (FIG. *7c*) may be circular, arrayed in a uniform pattern of a triangular or 60° distribution. In screen **213** (FIG. *7d*), the apertures **215** are square and arrayed in a square or 90° pattern, in screen **217** (FIG. *7e*), the apertures consist of triangular holes **219** arrayed in alternating pattern, and in screen **221** (FIG. 7f), the apertures consist of hexagonal holes **223** arranged in a square pattern. It is also possible as indicated in screen **229** (FIG. *7g*) that the screen be composed of a distribution of wires which may be woven into a mesh as indicated in FIG. *7h* in which wires **231** and **233** are interwoven to provide a woven wire screen.

In the event of a woven wire screen comprised of wire of circular cross section, the coating of the entire surfaces of the screen is accomplished in the manner indicated in FIG. *7i*. Thus, the ordinary insulative material is coated in a layer **236** around a major portion of the circumference of the wire so that it covers the portions comprising one surface of the screen and the walls defining the aperture holes through the screen. The photoconductive material is coated in a layer **235** around a minor portion of the circumference of the screen covering the portions comprising the opposite surface of the screen. As explained hereinafter, a significant improvement in the capability of the screen in acquiring and retaining charge results because all of the metal or conductive portions are covered with insulative material. In the various configurations shown in FIGS. *7a* through *7h* the coating of the etched screens can be improved if the corners of the screen are abraded or otherwise rounded before coating.

An advantage of the construction of the present invention in addition to the direct positive imaging which it provides resides in the greater charge acceptance capability by the conductive screen base having its surfaces substantially completely coated with insulative material. In the prior art by using square edges, electro-

static screen modulator **20** consisting of an insulative layer **21** and an adjacent conductive layer **22** as illustrated in FIGS. **5***a* and **5***b* it has been found that the potentials acquired by the photoconductive material **21** are lower than the potentials acquired by the same material coated to the same thickness on a flat metal plate or plane. For example, a 1.0 mil thick coating of photoconducting insulative material which charges to −600 volts on a flat metal plate may only acquire −150 volts on an apertured screen of the type illustrated in FIGS. **5***a* and **5***b* under identical charging conditions. The reason for this difference is that the exposed metal areas of the conductive layer **22** inside the aperture holes of the screen provide a current path which reduces the corona current flow to the photoconductor layer **21** as shown in FIG. **5.** Although the corona charging current flows to all surfaces of the screen initially, a small amount of charge build-up on the photoconductor layer **21** diverts a substantial portion of the corona current flow into the apertures and to the conductive layer as shown in FIG. **5***b*, whence it is conducted to ground or other fixed potential at which the conductive layer **22** is maintained. The inflow of corona charging current and the outflow of current through the conductive layer **22** eventually stabilizes at a point where the leakage in the photoconductor balances the corona current flow to the photoconductive surface and no further increase in potential is achieved. In the electrostatic modulator screen configurations of FIGS. **1** through **4,** however, there is no exposed conductive layer or metal layer to provide a bypass for the corona current flow and the charge quantity and potential acquired by the photoconductive insulator and ordinary insulator layers approaches that of an insulative layer on a flat plate. Because none of the corona current flow is bypassed to ground or other fixed potential, the corona current requirements are greatly reduced and the time required to charge the screen is also reduced.

The improved functioning provided by the electrostatic screen modulator contemplated by the present invention makes it advantageous for use not only in positive imaging but even in negative imaging if desired. Negative imaging is achieved using the type of screen illustrated in FIGS. **1** through **4,** for example, by using a toner material of opposite charge than that used for positive printing. Thus, in the examples illustrated in FIGS. **1** through **4** a negatively charged toner particle would be used or, the screen surfaces would be charged with a positive charge similar to the toner particles. In general, if the toner or other charged particles and the screen are given the same sign charge, negative imaging results using the screen contemplated by the present invention. If the toner or other charged particles and screen are given charges of opposite signs, positive imaging results.

A positive electrostatic printing system according to the present invention is shown diagrammatically in FIG. **6.** An electrostatic screen modulator **43** of the type, for example, illustrated in FIGS. **1** through **4** is initially charged from both sides by means of, for example, corona wand **41** so that a like charge is established over substantially all of the surfaces of screen **43,** as heretofore described. The screen **43** can be charged uniformly over all of its surfaces so that there are no fringing fields within the aperture of the screen, or so that a greater quantity of charge is accumulated on the photoconductive side of the screen to establish a uniform charge inequality across the face of the screen and enhancing fringing fields of force within the screen apertures. The screen **43** is thereafter illuminated by a source **43** which displayed on the surface of the screen coated with photoconductive insulating material a light pattern corresponding to an image to be reproduced. At the same time, the metallic or other conductive screen core is grounded or maintained at a fixed potential to selectively dissipate the charge deposited on the photoconductive layer in proportion to the intensity of light projected on different portions of the screen. A bipolar electrostatic latent image is thereby established and is supported on the screen and the screen **43** is interposed between a toner source **47** and a back electrode and print-receiving medium **49.** The toner source **47** is maintained at a fixed potential for charging the toner particles and an overall accelerating or propulsion field is established between the toner source **47** and back electrode and print-receiving medium **49.** The polarities are arranged so that charged toner particles from source **47** are accelerated toward the electrode **49** creating a flow of charged toner particles. The flow of particles is intercepted and modulated by screen **43** interposed in the toner flow path. The unilluminated portions of screen **43** corresponding to the dark portions of a pattern to be reproduced are passive to the flow of toner particles having a charge opposite that on the screen or enhance the flow of toner particles permitting deposition of dark toner particles on print-receiving medium **49** corresponding to the dark areas of a pattern to be reproduced. On the other hand, the illuminated portions of screen **43** corresponding to the light portions of an image to be reproduced block the passage of dark toner particles to varying degrees resulting in light areas on print-receiving medium **49** corresponding to the light areas of an image to be reproduced. The fringing fields established within the apertures of screen **43** in fact vary in strength and polarity from blocking to enhancing and over a continuous range in between to permit continuous tone positive reproduction with continuous gray scale. Thus, the system achieves direct positive electrostatic printing.

The electrostatic screen modulator of the present invention is applicable not only for controlling the flow of charged toner particles or droplets or other printing material, but also for controlling the flow of charged particles generally. For example, the modulator can be utilized for controlling a flow of ions as set forth in United States patent application Ser. No. 709,578, filed on Mar. 1, 1968, and entitled "APERTURE-CONTROLLED ELECTROSTATIC PRINTING SYSTEM AND METHOD EMPLOYING ION PROJECTION."

An electrostatic printing system incorporating an electrostatic screen modulator of the type illustrated in FIGS. **1** through **5** but in the form of an endless web or belt **121** is shown in FIG. **8.** The screen **121** is supported by four motor-driven drums **122** through **125** and is oriented with the surface of the screen coated with photoconductive insulating material facing outward. As the endless screen **121** is driven by the supporting drums a corona discharge spray emanating from sources **161** on each side of the screen charges the screen with like charges over substantially its entire surfaces. If the outwardly facing photoconductive insulator layer has a greater charger capacity than the ordinary insulative layer coated on the inner surface of the

screen and on the walls defining the apertures through the screen, then a uniform charge inequality established across the face of the screen produces uniform enhancing fields within the apertures of the screen as heretofore described. The surfaces of screen **121** can be charged either positively or negatively by means of switch **163** which controls the polarity of the potential source simultaneously applied to the corona spray sources **161** positioned on each side of screen **121.**

The screen is next positioned before an imaging station generally designated **130** which includes a light source **131,** transparency or other image pattern to be projected **132,** and lens system **133** which directs light in the pattern of the image to be reproduced onto the outer surface of screen **121.** The conductive metal screen core is exposed, for example, along one side of the endless web for continuous electrical contact with drum **123** which is connected to ground or maintained at a fixed potential. As a result of the light pattern projected on the photoconductive layer of screen **121,** the photoconductive insulating material becomes selectively conductive and the uniform charge pattern is selectively dissipated through the conductive metal core leaving a bipolar electrostatic latent image of enhancing, passive and blocking fields of force within the apertures of the screen for controlling a flow of charged particles.

The portion of screen **121** supporting the electrostatic latent image is next positioned at the printing station generally designated **140** which includes a toner supply of charged particles **141** and a back electrode in the form of an endless web **153** intermediate which the screen is positioned. The toner supply **140** is maintained at a toner potential E_T and a revolving brush **143** is provided within the toner supply to agitate the toner material facilitating movement of the toner particles toward screen **121** under influence of an electrostatic accelerating or propulsion field E_P established between the toner supply **141** and the back electrode web **153** on which the printing paper **145** or other printing medium is supported. The propulsion field is derived from source E_p connected by lead **147** and switch **148** to a roller **150** which is in continuous electrical contact with the endless electrode web **153.** Web **153** also supports the paper or other printing medium. The source E_p is also connected by lead **149** to the toner supply. The flow of charged particles originating from toner source **141** and accelerated toward the back electrode is intercepted and modulated by the bipolar electrostatic latent image supported on screen **121** and a modulated flow of particles comes to rest on a paper **145** or other printing medium positioned at the printing station in a pattern corresponding to the image to be reproduced. The paper **145** on which charged particles in the desired pattern adhere is transferred by web **153** to the heater **157** which fixes the image permanently to the printing medium. The printed sheets are thereafter delivered by means of, for example, wedge **159** which drops the printed paper onto stack **161.** The endless web **153** is driven by a motor driven drum **163** synchronized with the screen **121,** with intermittent motion to permit printing at the station **140.**

A continuous supply of toner in powdered or atomized form is provided through conduit **155** from a suitable source (not shown). A vacuum scavenger is shown in the form of conduit **170** for removing the toner or other mixing particles or droplets from the screen as it passes beyond the printing station for recharging. Switch **148** which controls propulsion field E_p is closed upon arrested motion of the endless screen **121** at printing station **140** and simultaneous arrested motion of the endless web **153** to permit transfer of the toner particles across the air gap between the toner source and back electrode intermediate which screen **121** and its bipolar electrostatic latent image is interposed.

Exposure and printing are preferably carried out with the conveyor intermittently stopped for imaging and printing, although exposure may be accomplished line-by-line fashion on a continuous basis and the printing done intermittently as described above. Similarly, sequential color reproduction can be achieved with the present invention in accordance with the apparatus and method described in United States patent application, Ser. No. 565,284, entitled *Method and Apparatus of Electrostatic Color Reproduction*, filed July 14, 1966 and assigned to the same assignee as the present invention, and as set forth in United States patent application, Ser. No. 800,236, entitled "Method and Apparatus for Aperture Controlled Electrostatic Image Color Reproduction or Constitution," filed Feb. 18, 1968, and assigned to the assignee of the present invention. Furthermore, the apparatus of FIG. **8** is useful for both positive and negative reproductions depending upon the charges applied to the screen **121** and the toner in toner supply **141.**

It can be appreciated that the present invention is characterized by an electrostatic modulating screen of sufficient thickness compared to the hole or apertured diameter to permit development of blocking or repulsing fields of force within the holes or apertures which can overcome the overall population field established between the toner supply and back electrode. Electrostatic charge levels for the screen and accelerating fields must therefore be selected accordingly. Furthermore, fringing fields of polarity and strength over a continuous range from enhancing to blocking can be established within the apertures of the modulating screen to permit continuous tone gray-scale and color printing.

When using photosensitive and photoconductive insulating materials to the components of the system in FIG. **8,** a light tight box indicated by dotted line **200** is employed with suitable ingress and egress openings.

It has been found that the preferred gap for transferring charged toner or other marking material or droplets between the electrostatic flow modulating screen and the print-receiving paper is in the order of 1/16 to ¼ of an inch but it is to be noted that contact printing can also be achieved with the process of the present invention. Toner particles as large as 20 microns have been found to be operative in a system of the present invention and to provide good quality printing. Even smaller sizes, however, are, of course, preferred. Dielectric materials for the screen can be selected from any of a number of suitable dielectrics, such as plastic, quartz, and many others.

An electrostatic screen modulator formed entirely of insulative dielectric material is shown in FIG. **9.** According to this embodiment of the invention, there is provided an apertured screen **101** formed entirely of a dielectric material. Alternately, the screen can be formed with a metal base **111** coated on all surfaces with a dielectric material **112** which can be thicker on one side to permit development of a uniform charge in-

equality or potential difference through the screen apertures upon charging of the surfaces. A fragment of such a screen is shown in FIG. **12.** The screen **101** is charged over substantially the entire surfaces including both sides of the screen and the wall defining the aperture thereof with like charges from corona sources **102** and **103.** In the example shown, the corona spray sources are connected to positive potentials for depositing positive charges over the surfaces of the screen. The charges deposited along one surface or side of the screen are thereafter selectively dissipated by one of the contact discharging techniques described in United States patent application, Ser. No. 673,499, referred to above, and illustrated by way of example in FIG. **10** hereof. As shown in that Figure, selective discharge of the charges deposited along one surface of screen **101** is accomplished by using a multilayered discharge plate **110** consisting of a transparent support **105,** a transparent conductor layer **107,** and a layer **109** of photoconductive insulating material. The discharge plate **110** is placed in contact with screen **101** along one side so that the photoconductor layer **109** is in contact with the dielectric material of the screen. A light image corresponding to a pattern to be reproduced is projected through the transparent layers **105** and **107** onto the photoconductive insulative layer **109.** At the same time, the transparent conducting layer **107** is connected to a ground potential or other desired fixed potential for selectively neutralizing the charge initially uniformly distributed across the screen **101.** After a bipolar electrostatic latent image is established across screen **101** the discharge plate **110** is removed leaving the screen **101** on which the electrostatic latent image is supported. The result of the charging operation in FIG. **10** on the screen of FIG. **9** is illustrated in FIG. **11.** As heretofore described, the bipolar electrostatic latent image comprises fringing fields within the apertures of the screen for selectively blocking and passing a flow of charged particles directed through the screen. Screen **101** is thereafter incorporated in a system such as that diagrammatically set forth in FIG. **6** for modulating a flow of charged particles.

Direct contact charging methods for establishing an electrostatic latent image as set forth in United States patent applications Ser. No. 673,499 and Ser. No. 776,146, referred to above can also be applied to the various screen modulators of the present invention. Thus, instead of selectively dissipating an initially uniformly established charge layer, one surface of the screen modulator can be directly selectively charged by transferring an electrostatic latent image to the surface, using the contact charging methods. A uniform charge layer is established over the opposite surface of the screen modulator to provide a bipolar electrostatic latent image.

It is apparent that a variety of other dielectric screen configurations can be formed according to the present invention. Thus, the screen of FIG. **9** could be formed of adjacent layers of dielectric materials of different charge storage capacity for initially establishing a uniform charge inequality across the face of the screen and therefore enhancing fields within the apertures of the screen as heretofore described.

By way of example a particular apertured screen electrostatic modulator used successfully according to the present invention is here set forth. A stainless steel etched screen base was formed having a thickness of 1.5 mils and 5.5 mil diameter holes spaced at 1.5 mils apart edge to edge. The base was coated with an insulator coating of plastic polymer 0.2 mils thick on one side face of the screen and in the walls of the apertures. A photoconductor coating of cadmium sulphide dispersed in a plastic binder was coated on the other side face of the screen to a thickness of 1.0 mil. The photoconductor layer was charged electrostatically to a potential of 400 volts relative to a zero ground potential applied to the metal screen base. The insulator layer on the other side of the screen was charged to a 200 volt potential relative to the base. This particular screen had an open area ratio, i.e., a ratio of hole area to the screen area of approximately 65 percent.

With reference to the screen parameters it has been found that a ratio of photoconductor thickness to hole diameter in the range of .2 to .5 mil provides optimum results. This also applies when an insulating material is applied on both sides of the screen with a uniform greater thickness on one side of the screen. In that instance the preferred range .2 to .5 applies to the ratio of the coating thickness on the thicker side to hole diameter. It has also been found that an open area ratio in the range of 50–70 percent is preferable.

What is claimed is:

1. An electrostatic modulator for controlling the flow of charged particles comprising: an apertured member having substantially its entire surface of electrically insulative material including opposed first and second surface areas, said apertured member having an electrically conductive core between said first and second surface areas, said core held at fixed potential, said electrically insulative material at said first surface area being thicker than at said second surface area; means for establishing first and second equipotential layers of electrical charge on said first and second surface areas respectively, said first equipotential layer having a greater electrical potential than said second equipotential layer; and means for selectively diminishing the electrical potential of said first equipotential layer across a predetermined area in accordance with a pattern to be reproduced.

2. An electrostatic modulator as recited in claim **1** wherein said means for establishing first and second equipotential layers comprises a source of ions.

3. An electrostatic modulator as recited in claim **1** wherein said material comprising said first surface area is photoconductive and wherein said means for selectively diminishing includes means for projecting an optical image of the pattern to be reproduced on said photoconductive material.

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