United States Patent

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[54] **CATHODE-RAY TUBE SYSTEM**
6 Claims, 9 Drawing Figs.

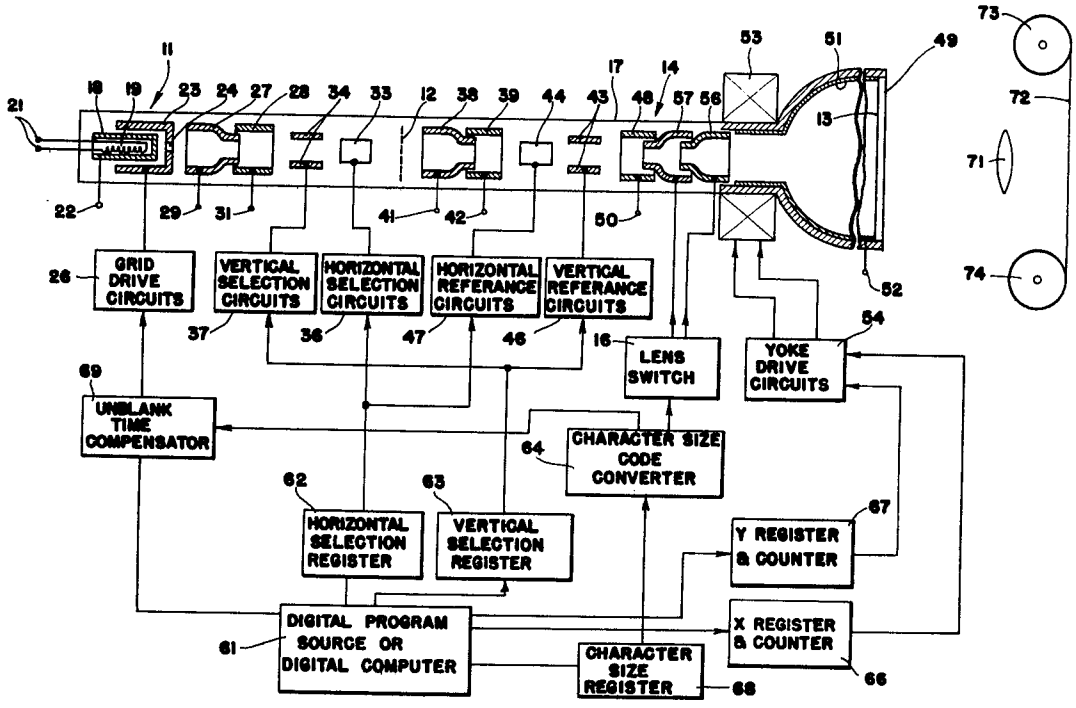
[52] **U.S. Cl.** ..... **315/31 R,** 315/17
[51] **Int. Cl.** **H01j 29/56**
[50] **Field of Search** 315/5.25, 5.35, 14, 17, 31

[56] **References Cited**
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Assistant Examiner—Brian L. Ribando
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ABSTRACT: A cathode-ray tube system is described for producing a graphic image having areas of different tone levels. The image is produced by a plurality of dots of different sizes, each size corresponding to one of the tone levels. The cross section of the electron beam is shaped by passing it through an aperture, and the size of the cross section is regulated by controlling the degree of magnification thereof.



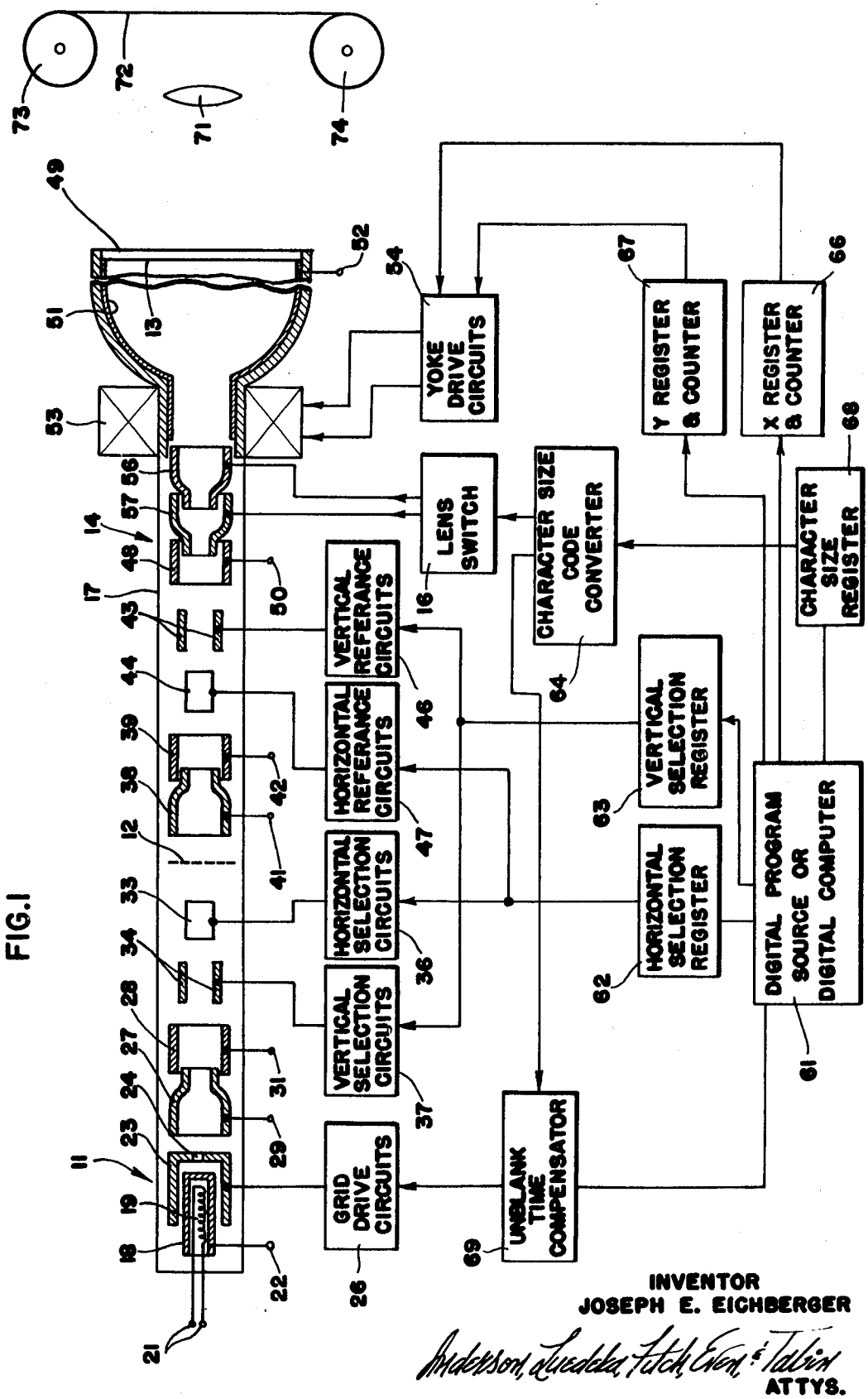


FIG. 1

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FIG.2

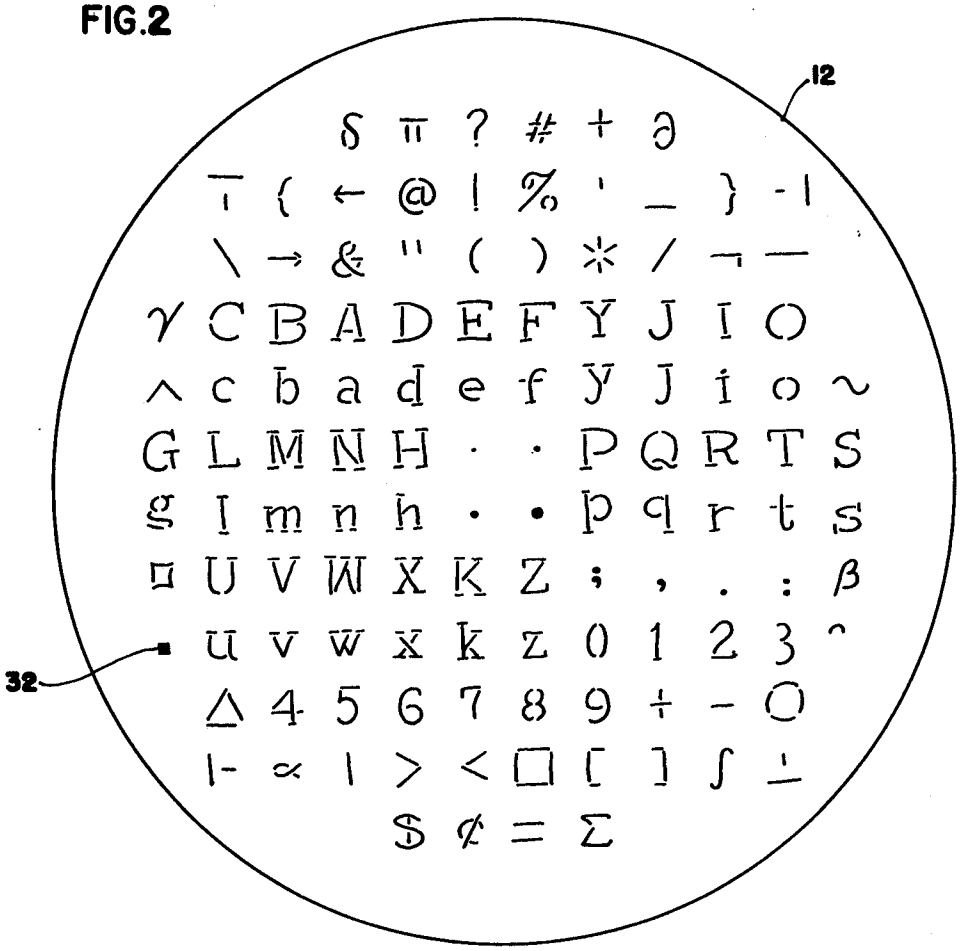
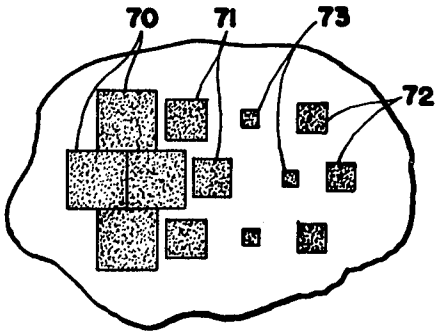


FIG.3



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FIG.4

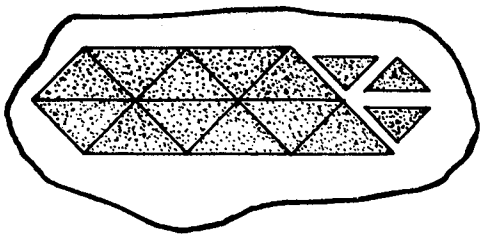


FIG.5

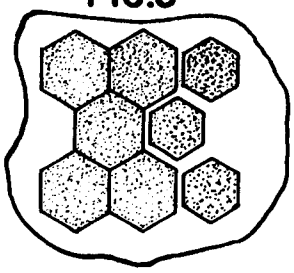


FIG.6

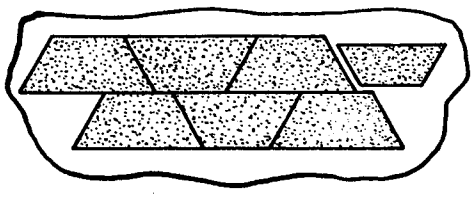


FIG.7

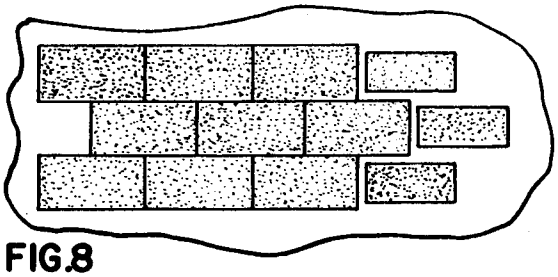


FIG.8

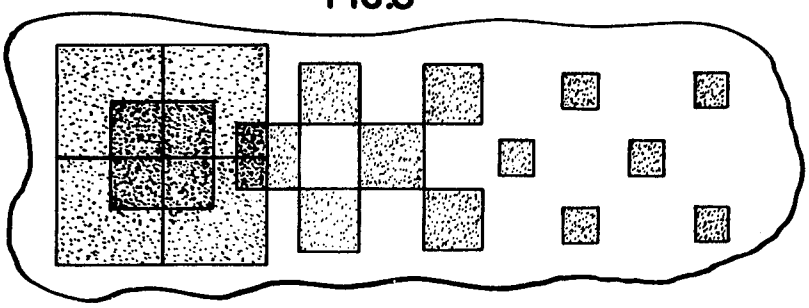
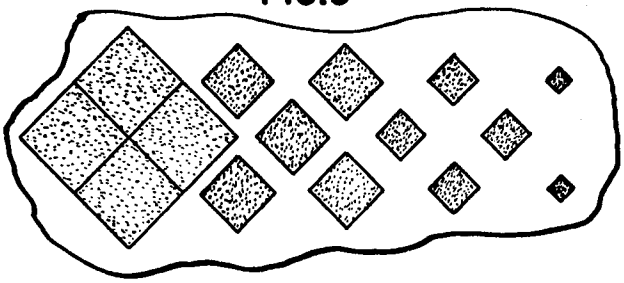


FIG.9



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CATHODE-RAY TUBE SYSTEM

BACKGROUND OF THE INVENTION

This invention relates generally to cathode-ray tube systems and, more particularly, to an improved cathode-ray tube system for producing a graphic image having areas of different tone levels.

Cathode-ray tubes may be employed in some circumstances for providing a visual representation of information stored in an electronic information storage system or of information produced by operation of a computer. Frequently, electronic information storage systems or electronic computers provide output information in digital form. Such an output form readily lends itself to the production of alphanumeric visual data through the use of a suitable data printout system. Cathode-ray tube displays of electronic digital information may be produced by various forms of tubes, including the so-called shaped beam tubes. The display may be for direct visual observation, or may be for exposing microfilm. In the latter case, the display may be formed as a negative (i.e., white on black background rather than black on white background) to produce a positive image directly on the microfilm.

In character generating tubes of the shaped beam type, one or more electron beams are shaped as they pass from an electron gun to a target such that the resulting cross section of each shaped beam is of predetermined configuration. The area of the target energized by impingement of each beam thereon therefore corresponds in shape to the resulting cross section of the beam.

The desired beam cross section is attained by passing the beam through a shaping aperture in an electron opaque plate. The plate generally contains a plurality of apertures of various shapes. In tubes of the so-called aperture selection type, the shaping apertures are all flooded by a large beam to produce a plurality of shaped beams. Another electron opaque plate having a single selection aperture therein is positioned downstream from the first plate. The shaped beams are deflected together in a desired manner so that one of the shaped beams is selected by passing through the selection aperture and on to the target screen. The unselected beams are blocked and do not reach the target. In the beam selection type of shaped beam tube, a smaller beam is deflected to select only one of the plurality of apertures, and is subsequently deflected to a desired position on the target screen.

Cathode-ray tubes of the shaped beam type are highly satisfactory for producing information in the form of alphanumeric characters, mathematical symbols, or other convenient visible symbols. Occasionally, however, it may be desirable to record a graphic image having areas of different tone levels, such as a pictorial image. The recording of pictorial information places additional requirements of the cathode-ray tube recording system, since pictorial information contains a variety of areas with different tone levels, and the various tone levels must be reproduced for a satisfactory image. As used herein, the term "tone" refers to the shade (i.e., darkness or lightness) of an area of the image. For example, the tone of a given area of an image may be black, white, or one of a variety of intermediate grays.

May printing processes including the offset printing process and some electrostatic printing processes, when adapted for the reproduction of images generated on a cathode-ray tube, are inherently incapable of reproducing intermediate grays. When such printing processes are used, therefore, the pictorial image is divided into a multiplicity of elemental areas of uniform size. Each elemental area of the pictorial image contains a tiny dot, and the size of each dot relative to the size of the elemental area is varied to produce variations in tone. In such processes the individual dots are either entirely white or entirely black, and tone variations are produced when the dots do not completely occupy an elemental area. Pictorial images reproduced in this manner are called "halftone images." It is characteristic of the printing processes which utilize the halftone principle that the best copies are obtained when the dots

on the printing master are all of the same optical density, as the printing process can then be optimized for the common dot density. When an image to be reproduced is continuous and of varying tone, it must be converted into a halftone image by a screening process which divides the continuous image into a multiplicity of dots. The screening process may be eliminated if the original image is in the form of discrete dots. It is thus advantageous to produce halftone records which are initially recorded as a sequence of dots so that screening is not required and in which the recorded dots are all of the same density so that optimum quality is obtained in the printed copies.

It is known to reproduce pictorial information by beam intensity modulation in cathode ray tubes for television and facsimile applications. When recorded images are produced by intensity modulation, the images have corresponding variations in tone. Such images must be screened to break them into dots, and an attempt must be made to equalize the densities of the individual dots insofar as possible. It has been proposed that halftone images be recorded from a cathode-ray tube as a multiplicity of spaced dots, where the dot center-to-center spacing is variable, but the implementation of this method requires complex electronic deflection circuits. It has also been proposed that spaced dots be produced by a cathode-ray tube in which the beam current is modulated so that the inherent spreading of the beam as the current is increased will produce a variation in the recorded spot size. The latter method produces dots which are not all of the same density on the record. Both proposed methods produce dots for which the boundaries are vaguely defined.

For the reasons above, the quality and definition of graphic images produced by such prior art cathode ray tubes have sometimes been unsatisfactory. Furthermore, known cathode-ray tubes have not offered sufficient versatility as to be able to produce alphanumeric information, graphical information, and graphic images with a high quality for all types of information.

Accordingly, it is an object of the present invention to provide an improved cathode-ray tube system for producing a graphic image having areas of different tone levels.

Another object of the invention is to provide a cathode-ray tube system for producing graphic images wherein variation in image tone is not directly dependent upon variation in beam current, thereby improving image quality.

A further object of the invention is to provide a cathode-ray tube system for producing graphic images and which is low in cost and of simple construction.

It is another object of the invention to provide a cathode-ray tube system for producing both graphic images and alphanumeric information.

BRIEF DESCRIPTION OF THE DRAWING

Other objects of the invention will become apparent to those skilled in the art from the following description, taken in connection with the accompanying drawings wherein:

FIG. 1 is a schematic diagram of a cathode-ray tube system constructed in accordance with the invention;

FIG. 2 is a plan view a beam shaping matrix plate utilized in the cathode-ray tube of FIG. 1;

FIG. 3 is a plan view of a portion of the target screen of the cathode-ray tube of FIG. 1 illustrating various dot sizes and a dot pattern which may be reproduced thereon when the system is operated in a preferred mode; and

FIGS. 4, 5, 6, 7, 8 and 9 are plan views of a portion of the target screen of the cathode-ray tube of FIG. 1, illustrating dot patterns which may be produced in alternate embodiments of the invention.

SUMMARY OF THE INVENTION

Very generally, the cathode-ray tube apparatus of the invention comprises an electron beam source 11 and an electron opaque member 12. The electron opaque member has at least

one aperture therein which forms the cross section of the beam into a dot of a predetermined shape. An electron responsive target screen 13 is provided for displaying the image. The cathode-ray tube system also includes means 14 for focusing an electron image of the aperture on the screen at a selected one of a plurality of magnifications, each corresponding to a different image tone level. Means 16 are provided for selecting a magnification in accordance with the desired tone level in an area of the image being reproduced. The beam is then directed to a succession of predetermined areas on the target screen to define the graphic image by means of a plurality of dots having sizes corresponding to the respective image tone levels.

DETAILED DESCRIPTION OF THE INVENTION

Referring now more particularly to FIG. 1, the specific embodiment of the invention illustrated therein comprises a shaped beam tube of the beam selection type having an evacuated envelope 17 of glass, metal, or other suitable material. The envelope is shaped in the typical manner of such tubes, having a bell-shaped portion at one end and a narrow neck portion extending therefrom. Mounting of the various elements described below within the envelope 17 may be accomplished in any suitable manner in accordance with known techniques in the cathode-ray tube manufacturing art.

The electron beam source 11 includes a cup-shaped cathode 18 and a heating filament 19 disposed within the cathode. Current is passed through the filament 19 from a pair of filament power supply terminals 21 located exteriorly of the glass envelope 17. The leads from the terminals 21 pass through the end of the glass envelope as is well known in the art. The cathode may be comprised of nickel coated with barium oxide on its outer surface and is maintained at a suitable cathode potential by connection to a cathode potential terminal 22.

In order to control blanking and unblanking of the beam and regulate the intensity thereof, a cup-shaped grid 23 is provided surrounding one end of the cathode 18. The grid is provided with an opening 24 therein on the axis of the tube and through which the electron beam produced by the cathode is accelerated. The grid 23 is connected to grid drive circuits 26 located exteriorly of the glass envelope 17, and such drive circuits operate to regulate the grid potential in a desired manner, as will be explained more fully below. The electron beam produced by the cathode 18, when passed through the opening 24, is accelerated and focused by means of a pair of electron beam lens elements 27 and 28 which are maintained at suitable potentials by connection to terminals 29 and 31, respectively.

The illustrated cathode-ray tube is known as a shaped beam tube of the beam selection type. The tube is utilized for displaying information in the form of alphanumeric characters, graphs and charts and also in the from of graphic images as described below. The electron opaque member 12 comprises an electron opaque plate which is disposed perpendicular to the axis of the tube in the path of the electron beam. Referring to FIG. 2, the electron opaque member or plate 12 may be seen in a plan view in which the various symbol apertures are illustrated. The apertures comprise stencillike openings for defining upper and lower case alphanumeric characters and various other symbols such as abbreviations and mathematical notations and line segments for producing such things as graphs and charts. The various symbols are arranged in a matrix of rows and columns, and the beam is deflected as explained below to flood a selected one to the apertures. The potentials applied to the lens elements 27 and 28 are controlled to focus the beam so that its cross section in the plane of the plate 12 is just large enough to cover the selected aperture. The cross section of the beam is thus formed in accordance with the shape of a selected symbol.

For purposes which will be explained more fully below, one of the apertures, located next to the lower case *u* is formed in the shape of a square 32. For clarity of illustration, the square aperture 32 is shown about one-fourth the upper case character height. In actual practice, it is preferable that the square 32 be about one-tenth the height of the upper case character.

In order to select a desired aperture, one or more pairs of vertical plates 33 are provided for deflecting the beam from its initial path a desired amount in the horizontal direction. In addition, one or more further pairs of horizontal plates 34 are provided for deflecting the beam from its initial path in the vertical direction. Horizontal selection circuits 36 are connected to the selection plates 33, and vertical selection circuits 37 are connected to the selection plates 34. In accordance with the potential developed across the plates by the appropriate selection circuits, the bean is deflected from its initial path a precisely regulated amount in order to select one of the apertures in the electron opaque member or plate 12.

A pair of convergence lens elements 38 and 39 are located downstream from the plate 12. The elements 38 and 39 are connected to a pair of potential sources 41 and 42 for maintaining the elements at a potential which causes the electron beam to be focused and to be returned to the axis of the tube form its off axis deviation position for the particular selected aperture. In the region where the beam intersects the axis of the tube, it is directed along the axis of the tube by a pair of horizontal plates 43 and a pair of vertical plates 44. The plates 43 reference the beam in the vertical direction and are driven by vertical reference circuits 46. The plates 44 reference the beam in the horizontal direction and are driven by horizontal reference circuits 47. The plates 43 and 44 are driven by voltages which complement the voltages driving the plates 34 and 33 so that the vertical and horizontal deviation of the beam direction from the axial direction is corrected precisely, thereby aligning the beam on the axis of the tube once more. Final acceleration of the beam to the screen is accomplished by an accelerating element 48 positioned downstream from the plates 43 and 44, and by an aquadag coating 51 on the interior of the bell-shaped portion of the tube envelope 17. The element 48 is maintained at a suitable accelerating potential by electrical connection thereof to a potential source 50. The aquadag coating 51 is maintained at a suitable accelerating potential by electrical connection thereof to a potential source 52. The large end of the bell-shaped portion of the envelope 17 is closed by a glass face plate 49, the interior of which supports the target screen 13. The target screen may be any suitable electron responsive material to emit visible light or to darken upon the impingement of electrons thereon.

The visible image produced on the target screen 14 may be a pattern of luminescent spots on a dark background, if the screen is a phosphor. The image on the screen 14 is projected onto a photosensitive recording material 72 by an objective lens 71. The recording material 72 is in the form of a strip of photographic film which is unwound from a supply reel 73 before exposure to the image of the screen 14, and is wound up on a takeup reel 74 after exposure. A fiber optics bundle set into the faceplate 49 may be used in place of the objective lens 71, if desired.

A yoke 53 surrounds the neck of the envelope 17 adjacent the larger bell-shaped portion thereof and produces electromagnetic deflection fields to direct the beam to a particular spot or address on the target screen 13. Driving currents are supplied to the yoke 53 from the yoke drive circuits 54, and the yoke drive circuits are controlled in a manner which will be described below in connection with the particular controlling means employed.

In order to vary the size of the dots on the target screen 13 when producing graphic images, as will be described in detail below, the size of the square cross section of the beam (produced by passing it through the aperture 32, FIG. 2) is varied. Variation in cross-sectional size is accomplished by regulating the magnification of the beam in order to produce a given level of magnification of the aperture 32 in a sharp image on the target screen. Two lens elements 56 and 57 are

provided positioned between the accelerating electrode **48** and the aquadag coating **51**. There are three effective gaps or potential discontinuities along the axis of the tube between the plates **43** and the target screen **13**, which may contribute to the focusing effect in producing an image of the aperture **32** on the target screen. These gaps are between the accelerating electrode **48** and the lens element **57**, between the lens element **57** and the lens element **56**, and between the lens element **56** and the aquadag coating **51**. For a given set of dimensions on the various elements, the maximum and minimum available magnifications may be approximated by using the formula:

$$m=k\,Q/P$$

where M is the magnification, k is a constant determined by the ratio of the diameters of the cylinders at each gap, and Q and P are the image and object distances, respectively, as measured from the appropriate gap under consideration.

Various combinations of voltages on the lens elements **57** and **56** may be utilized to provide a variety of sharply imaged character sizes. Such potentials may be determined empirically through appropriate observation and measurement of image sizes under varying conditions. The operation of the lens elements **56** and **57** may be thought of as a compound lens for which the effective position of the lens is shifted along the tube axis by appropriate voltage variation. When there is a substantial potential difference across the gap between element **48** and element **57**, and no potential difference between elements **57** and **56**, and no potential difference between the element **56** and the dag **51**, the effective center of the lens is near the **48–57** gap. When there is a substantial potential difference across the **56–51** gap, and no potential difference across the other gaps, the effective center of the lens is near the **56–51** gap. Since the magnification is proportional to the quotient of the lens to image (screen) distance divided by the lens to object (aperture) distance, voltage variation may produce an effective decrease in the numerator and increase in the denominator, or vice versa.

The illustrated lens element arrangement may also be operated in a manner sometimes referred to as the cascade lens mode, which is analogous to an optical system using a sequence of relay lenses to form successive new images. In the cascade lens mode, a large potential difference is applied across the gap between the accelerating element **48** and the lens element **57**. The strong focusing effect of the element **48–57** gap produces a beam crossover or plane of minimum cross section within the element **57** and an image of the aperture plane of the plate **12** is formed in the vicinity of the gap between the elements **57** and **56**. A large potential difference is also applied across the gap between the lens element **56** and the aquadag coating **51**. The strong focusing effect of the element **56**—aquadag gap produces a beam crossover or plane of minimum cross section in the vicinity of the deflection yoke **53**, and a second image is formed in the plane of the target screen **13**. The first image thus serves as the "object" for the second lens formed by the element **56**—aquadag gap. In this mode the magnification of the entire lens arrangement is the product of the individual magnifications of the first and second lenses.

By combining suitable potentials on the lens elements **56** and **57**, the lens arrangement may be operated in one or both of the above modes and through a variety of magnifications. Suitable circuitry for producing the appropriate voltage combinations is utilized in the lens switch **16**, the lens switch **16** thereby operating to select a magnification in accordance with a desired intensity level in an area of the image being reproduced. Further information on operating a lens arrangement of the type described is set forth in copending application Ser. No. 725,115 of Robert H. Compton, assigned to the assignee of the present invention.

To provide a sufficient variety of dot sizes, the lens arrangement for effecting the various levels of magnification of the image of the aperture **32** should have a dynamic range of greater than two to one, and preferably greater than four to one Under the latter conditions, the square aperture **32** may be scaled to measure 2/4096 of the image width when the lens is set for the smallest size. For convenience, 1/4096 of the image width on the screen **13** will be referred to as an address unit, for reasons which will be revealed by subsequent description of a specific embodiment. Sizes of two, three, four, five, six, seven and eight address units are therefore achievable, with the various dots being spaced eight address units apart center to center. Under such conditions it is possible to generate an image having 512 rows eight address units apart, and having 512 elements in each row. Such a system has eight subjectively distinguishable tone levels, from solid black to solid white.

Referring to FIG. **1**, a particular manner of operating the cathode-ray tube system of the invention to produce graphic images having areas of different tone levels will be described. In order to produce a graphic image, the tube system of the invention is operated in a manner which causes the yoke drive circuits **54** to produce deflection currents in the yoke **53** to produce deflecting fields which step the beam across the target screen **13** in a raster pattern. As the beam is scanned across each row, it is moved incrementally, i.e., in steps of equal length, to define a plurality of discrete beam positions for each row. An image having areas of different tone levels is produced by a plurality of dots, the beam being unblanked in each discrete position. Each position corresponds to an elemental area of the image. Tone variation is governed by the size of each dot, relative to the elemental area in which it is placed. Assuming a target material which is white and which darkens upon electron impingement, or assuming the display is for exposing microfilm in which case the tube produces a negative of the image on the target screen, lighter image tones are produced by utilizing smaller dot sizes.

The size of the dots utilized is determined by selecting an appropriate magnification of the image of the aperture **32** in the electron opaque plate **12**. The squares produced by the electron beam on the target are of uniform center to center spacing within each row. A scan pattern, however, is selected so that the squares in adjacent rows are offset from each other by one-half the maximum square width. This is illustrated in FIG. **3**. It may be seen that the largest squares **70** are of a size which is equal to the spacing of the rows and to the spacing of the incremental beam positions in each row. The largest squares therefore fit flush against each other to completely fill the area, making it of maximum darkness. The smaller the square, the less a particular region is darkened, as indicated by the progressively smaller square sizes **71**, **72**, and **73**, respectively, in FIG. **3**. The tone levels available vary from solid black with the largest size square, to nearly white with the smallest size square. Where the smallest square is one-fourth the width of the largest, it occupies only one-sixteenth of the incremental area for a particular beam position. Thus, a graphic image in an area where all squares are of the smallest size is 93.75 percent white or transparent and 6.25 percent black or opaque. If desired, the grid **23** may be used to cut off beam current to produce 100 percent white image elements. The apparatus utilizing such a construction is capable of producing eight or nine gray levels, all of which are at least subjectively distinguishable from each other.

A satisfactory system may be designed to produce nine tone levels from solid black to solid white, where the largest square is eight address units wide and where center to center spacing is eight address units, by using square widths as listed below. The percentage of elemental area which is black for each square width is also listed; and it may be noted that this percentage changes in uniform increments.

Width of Square Relative to Largest Square	% of Elemental Area Covered
1.000	100.0
0.936	87.5
0.866	75.0

Table – Continued

0.791	62.5
0.707	50.0
0.613	37.5
0.500	25.0
0.354	12.5
0.000 (cutoff)	0.0

The square sizes in the table can be provided by a lens arrangement **14** having a dynamic range of less than three to one.

By utilizing image producing dots of square shape, it is possible to maximize the range of tones achievable with a minimum range of magnifications in the lens arrangement **14**. A similar result may be obtained by using other geometric shapes capable of being mated in a complementary manner to completely cover a desired area. For example, triangles (FIG. **4**), hexagons (FIG. **5**), trapezoids (FIG. **6**) or rectangles (FIG. **7**) may be utilized, rather than squares. If triangles are used, it is necessary to have two sets of triangles, one with points up and the other with points down, as illustrated in FIG. **4**. If points up triangles are used in all the odd positions of a row, then points down triangles are used in the even positions of a row, thereby achieving complete coverage of the area. If hexagons are used, oriented so as to have two vertical sides, then the odd rows in an image should be staggered with respect to the even rows, as is done with the squares, to achieve complete darkening of an area without overlap when the largest size hexagons are used. If complete darkening of an area is not essential, other geometric shapes, including circles, may be utilized. Moreover, complete darkening of an area even in the case of nonmating geometric configuration may be achieved if sufficient overlap is utilized. When the shape or arrangement is such that overlap is required in some areas to achieve complete darkening in others, the range of sizes required in the cathode-ray tube to produce a full range of image tones is increased. Furthermore, the overlapped areas may have a different optical density than nonoverlapped areas on the film **72**. The shapes which require no overlap are thus used in the preferred embodiment.

Returning now to FIG. **1**, a particular operating technique and apparatus for carrying the technique out will be described in connection with the system of the invention. In the example, the image is produced on the target screen for the purpose of exposing microfilm upon which the image is to be recorded. Thus, the image produced is a negative of the desired microfilm image (i.e., white or bright dots on dark background on the screen produce black or opaque dots on clear background on the film). For ease of description, however, the tube will be described as producing black dots as is the final result on the film.

The displayed image is produced from the output of a digital program source or digital computer **61**. The horizontal selection circuits **36** and the horizontal reference circuits **47** are controlled by a horizontal selection register **62** which may comprise a plurality of flip-flops. Similarly, the vertical selection circuits **37** and the vertical reference circuits **46** are controlled by a vertical selection register **63**, which may consist of a like plurality of flip-flops. The lens switch **16** is controlled by a character size code converter **64** which is supplied, as described below, with a binary code indicative of the desired image density. The yoke drive circuits **54** are controlled by an X-register and counter **66** and a Y-register and counter **67**, both operated by appropriate signals from the output of the digital program source or digital computer **61**. The beam therefore can be positioned by digital signals to any one of a number of positions, or addressable points, each defined by a digital address in the X-axis and a digital address in the Y-axis. The latter is also connected to the grid drive circuits **26** for blanking and unblanking the electron beam at the discrete beam positions.

The digital program source or digital computer **61** may be designed to supply a 3-bit binary code to a character size register **68**. Each size code is representative of the designed tone of a particular elemental area of the image being produced. Typically, a new or changed size code is generally required for each successive picture element or dot exposed. The character size register **68** through the code converter **64**, controls the lens switch **16** to select the appropriate combination of voltages on the lens elements **56** and **57** and thereby produce the desired degree of magnification corresponding to the desired area tone.

The operation of the apparatus may best by described by way of example in producing an image comparable to a 7-inch × 7-inch halftone newspaper photo made with a 72 line per inch screen, or comparable to a 5-inch × 5-inch magazine photo-screened at 100 lines per inch. An image of such quality may be produced by utilizing 512 horizontal lines, each line having 512 discrete beam positions. Assuming the X-register and counter **66** and the Y-register and counter **67** are each comprised of **12** flip-flops providing 12 binary bits, there are 4096 available digital addresses in each axis. The desired 512 beam positions in each axis are obtained by spacing the centers of the squares in each row at intervals of eight address units in the X-axis, and spacing the centers of the rows at intervals of eight address units in the Y-axis. The largest squares **70** are made eight address units in height and width so any elemental area of the image on the screen **14** is just filled by a square **70**.

At the beginning of an image scan, the register and counter **66** and the register and counter **67** may each be set to 000,000,000,100 binary or 0004 decimal by the digital program source or digital computer **61**. These two conditions of the registers establish yoke currents to direct the beam to the center of the first elemental position of the image.

The source or computer **61** also operates to set the horizontal and vertical selection registers to suitable binary codes which will select the square aperture **32** in the matrix plate **12** (FIG. **2**) and maintain the beam passing through the square aperture **32** throughout the production of the graphic image.

The digital source or computer **61** also sets the character size register **68** to a binary code representing the dot size desired at the first position. The grid drive circuits **26** are then operated to unblank the beam and produce the first image element.

The X-register is then reloaded or counted up to an address which is greater by eight address units, in this case to 000,000,001,100 binary, or 0012 decimal, while the Y-register is unchanged. The character size register **68** is then reset to a code representing the dot size desired at the second position, and the grid circuits unblank the beam again. This process of increasing the X-register by eight units, resetting the size register **68**, and unblanking the beam continues until one entire row is completed.

In a 12-bit system a row is a maximum of 4096 address units, or 512 element positions. The second row is started by setting the Y-register and counter **67** to 000,000,001,100 binary, or 0012 decimal, either by reloading it from the computer or source **61**, or by increasing its count by eight address units. The X-register is set 000,000,000,000 binary, or 0000 decimal, for the first element in the second row. This staggers the second row by one-half an element interval, or four address units with respect to the first row, as shown in FIG. **3**. The second row in then produced by successive setting of the size register, unblanking, and stepping of the X-register and counter in increments of eight address units, as before. The second X-address in the second row will be 000,000,001,000 binary or 0008 decimal, etc. The third row starts at Y=0020 decimal and X=0004 decimal. The process continues until the entire image is completed.

The X- or Y-counter can be easily increased by eight counts, by injecting a single pulse into the fourth flip-flop from the least significant end of the string of flip-flops in the counter. The least significant flip-flop has a weighting value of 1 and the fourth flip-flop a value of 8. This technique for incrementing a binary counter is well known in the art.

In the operation of the preferred embodiment of the invention described herein, two images are generated by each

3. A cathode-ray tube system according to claim 1 wherein said aperture is of a polygonal shape capable of being distributed in a pattern in which the shapes complement each other to leave no space therebetween and to provide no overlap areas at the largest magnification.

4. A cathode-ray tube system according to claim 1 wherein said electron opaque member includes a plurality of further apertures shaped to define characters, whereby said tube may be operated to display written information as well as graphic images.

5. A cathode-ray tube system according to claim 1 wherein said beam directing means are adapted to distribute the dots within each row with uniform center to center spacing.

6. A cathode-ray tube system according to claim 5 wherein said beam directing means are adapted to distribute the dots in a rectilinear pattern in which the dots in each horizontal row are offset from the dots in the immediately adjacent horizontal rows.

complete scan of the image area. One image is generated on the screen **14** of the cathode-ray tube, typically appearing as a pattern of tiny luminescent squares on a nonluminescent background, if the screen is a phosphor. The intensities of all of the squares are effectively equal. The incremental areas of the image on the screen **14**, however, appear to have different intensity levels, depending on the sizes of the bright squares within them. The second image is a corresponding image recorded on recording material **72**. The recorded image typically appears as a pattern of tiny opaque squares on a clear background, if the recording material is conventional microfilm. As will be explained, the optical densities of all the dots are about equal, but the incremental areas or regions of the image appear to have varying densities, depending on dot size. The apparent intensity in the first image, and the apparent density in the second, are both intended to be included in the term "tone" as used herein.

As previously mentioned, the grid drive circuits **26** operate to periodically unblank the electron beam and thereby produce a dot on the cathode ray tube screen within an elemental area of the image. When the square image of the aperture **32** is made larger on the target screen **13**, by increasing the magnification of the beam by the lens elements **56** and **57**, the electron beam density impinging on the target screen is correspondingly reduced. This is because, although the total beam current is the same, the area is larger. The reduced current density results in reduced light intensity. When microfilm is being exposed to the image, it is desirable to maintain a constant level of exposure of the film in the camera, and the exposure depends upon the light flux per unit area produced by the phosphor of the target screen **13**. To compensate for reduced current density with increased image size, the character size code converter **64** also provides size signals to an unblank time compensator circuit **69**. The unblank time compensator **69** is connected to the grid drive circuits **26** to vary the duration of the unblanked interval in accordance with the time required. The required unblanked time varies approximately with the area of the square. Thus, for example, if the linear size of the square is increased by two, the unblanked time is increased by about four.

As an alternative to the previously described scheme of producing a graphic image, it is possible to produce an image of 512×512 elements by utilizing digital addressing of only 10 bits per axis (1024 addressable points or address units). Moreover, if staggering between adjacent rows is not utilized, nine bits are sufficient for a 512×512 element image.

As an alternative mode of operation, the center to center spacing of the elemental positions in a row may be made equal to the maximum square width, while the center to center spacing of the rows is made one-half the square height. This is illustrated in FIG. **8**. The centers of the elemental positions in the odd numbered rows are staggered with respect to even numbered rows by one-half the maximum square width, as in FIG. **3**. As indicated by the left portion of FIG. **8**, overlap of the squares at the corners is required to achieve full coverage of the image area. The alternate mode of FIG. **8** has the disadvantage that the range of sizes required in the cathode-ray tube is greater, but has the advantage that the recorded image may appear to have a greater resolution than the image produced by the mode of FIG. **3** since both the rows and columns are staggered with respect to adjacent rows and columns, respectively. The alternate mode of FIG. **8** is particularly advantageous when the succeeding steps in the printing of the image provide insufficient resolving capability to reproduce the narrow lines separating the squares in FIG. **3**. In the alternative of FIG. **8**, the near-black areas are comprised of tiny white dots on the black background, and the near-white areas by tiny black dots on a white background, so the subsequent process need not be capable of resolving fine lines.

FIG. **9** illustrates an alternate embodiment of the invention. The squares in the shaping plate **12** are rotated until their sides are at a 45° angle to the rows and columns of the matrix. The squares then appear on the screen **14** to be "diamond shaped." In this embodiment, the center to center spacing of the rows is one-half the center to center spacing of the squares in a row. The diagonal of the largest square is made equal in length to the center to center spacing within each row, so that incremental areas of the image can be completely filled by the squares without overlap. The advantage of the alternate embodiment of FIG. **9** is that the recorded image may appear to have greater resolution, since both rows and columns are staggered with respect to adjacent rows and columns, as in FIG. **8**, but the squares in FIG. **9** do not overlap, unlike the squares in FIG. **8**. FIG. **9** thus achieves the advantage of staggering in both axes, while avoiding the disadvantages attendant upon overlapping.

It may therefore be seen that the invention provides an improved cathode-ray tube system for producing graphic images having areas of different tone levels. The apparatus of the invention operates on digital information, and thereby may be utilized to produce a visible output of information derived from a digital program source or digital computer. By utilizing uniform center to center element spacing in producing the image, variation in image intensity may be readily achieved by variation in the size of dots produced by the electron beam at each element position. Image production is accomplished by utilizing an apertured plate to produce a dot shape, and a lens system which produces appropriate magnification of the dot resulting in varying sizes of the dot produced. Accordingly, the apparatus of the invention is of relatively simple construction and correspondingly low in cost. Moreover, in view of the simple manner in which spot size variation is achieved, the apparatus is of high reliability. Variation of beam intensity is compensated for high quality microfilm recording, and a wide variation in image tone is readily achievable. Although described in connection with a shaped beam tube of the beam selection type, the invention may utilize a tube of the aperture selection type as well.

It will be obvious to those skilled in the art that the instant invention may be used to produce halftone images by electron beam recording directly on electron sensitive film. Upon appropriate modification of the cathode-ray tube envelope **17**, the film **72** may be placed inside the envelope **17**, replacing the target screen **13**. A latent image is then produced on the film by impingement of the electron beam thereon. The film may then be removed and developed to make the latent image visible.

Various modifications of the invention in addition to those shown and described herein will become apparent to those skilled in the art from the foregoing description and accompanying drawings. Such modifications are intended to fall within the scope of the appendant claims.

I claim:

1. A cathode-ray tube system for producing a graphic image having areas of different tone levels, comprising, an electron beam source adapted to issue a beam of a substantially constant current, an electron opaque member having at least one aperture therein to form at least a portion of the cross section of the beam into a predetermined shape, an electron responsive target screen for displaying the image, means for forming an electron image of said aperture on said screen at a selected one of a plurality of magnifications corresponding to different image tone levels, means for selecting a magnification in accordance with a desired tone level in an area of the image being reproduced, and means for directing the beam to a succession of predetermined areas on the target screen and means for varying the time duration which the beam impinges on each of the succession of predetermined areas on the target screen according to the dot area, thereby to define a graphic image by means of a plurality of dots having sizes corresponding to the desired image tone levels.

2. A cathode-ray tube system according to claim **1** wherein said focusing means define at least two electron lenses, and wherein said selecting means include means for varying the effective focal length of each of said electron lenses.