

United States Patent [19]

Sunstein

[11] 3,851,093

[45] Nov. 26, 1974

[54] COLOR TELEVISION DISPLAY SYSTEM
AND METHOD FOR REDUCING VISIBILITY
OF GEOMETRIC PATTERN OF
COLORED-LIGHT SOURCES, AND
METHOD FOR FABRICATION THEREOF

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[52] U.S. Cl. 358/67 F, 178/7.85

[51] Int. Cl. H04n 9/22

[58] Field of Search 178/5.4 F, 5.4 H, 7.85,
178/7.86, DIG. 2; 350/167

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[57] ABSTRACT

A diffuser is placed in front of a color television picture tube of the type which employs vertical lines of different color phosphors, the diffuser elements being such as to reduce or eliminate the visibility of the line structure without introducing substantial degradation in the quality of the reproduced color image. The diffusing elements may be formed by abrasion, molding, etching, flexing of plastic or by glass fibers.

22 Claims, 21 Drawing Figures

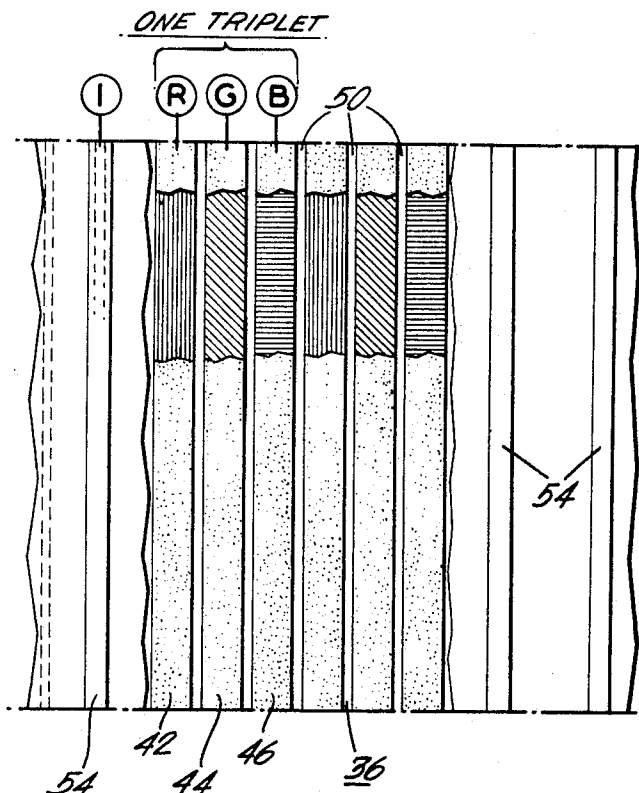


FIG. 1.

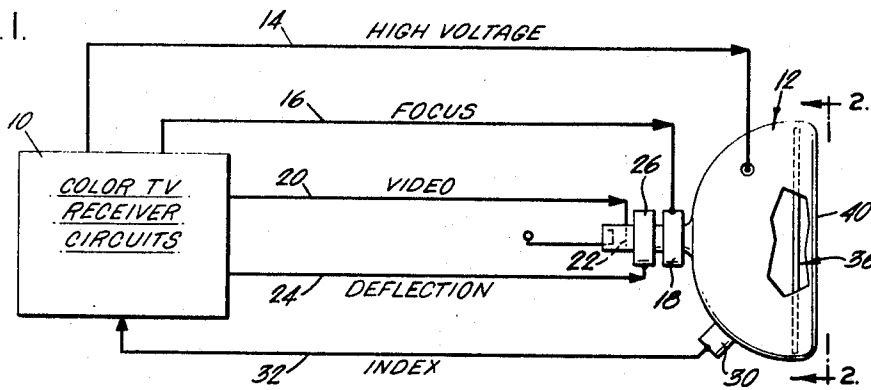


FIG. 2.

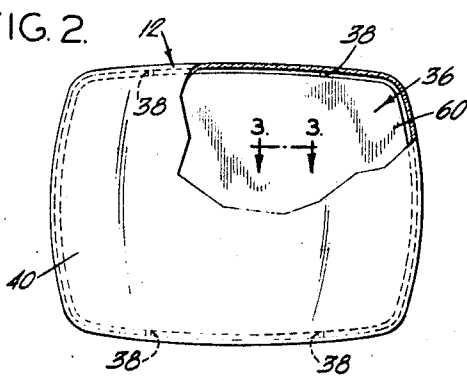


FIG. 5.

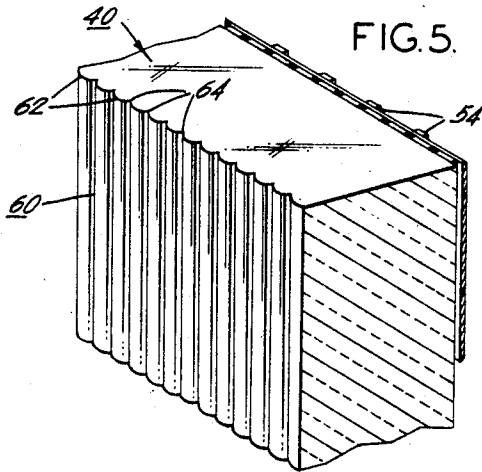


FIG. 3A.

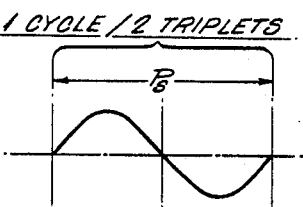


FIG. 3B.

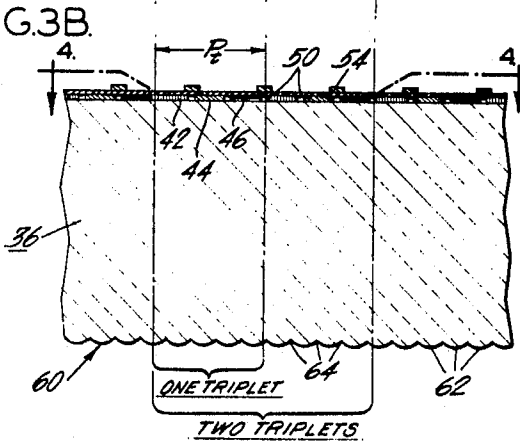
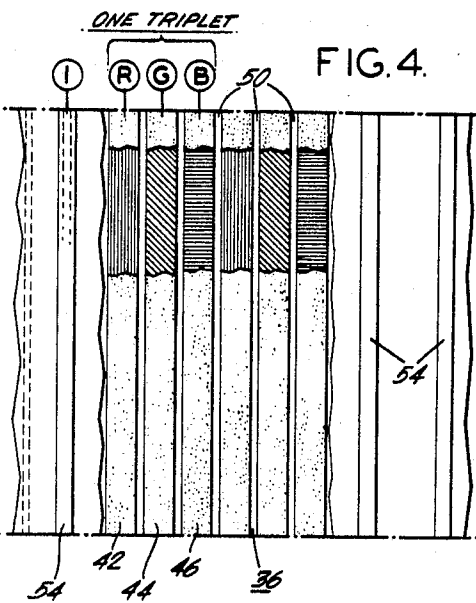


FIG. 4.



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FIG. 6.

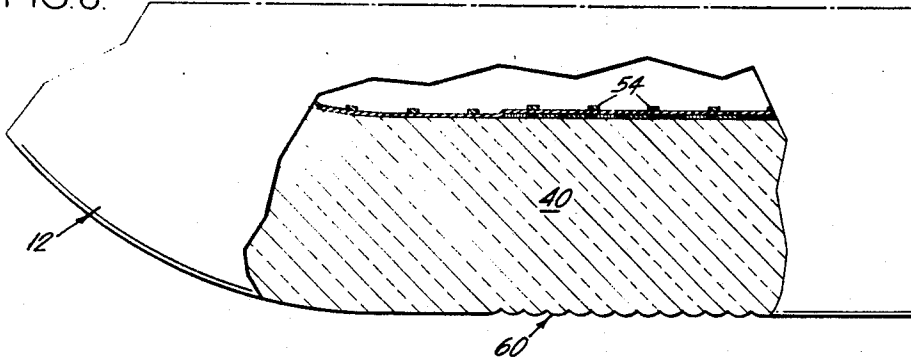


FIG. 7.

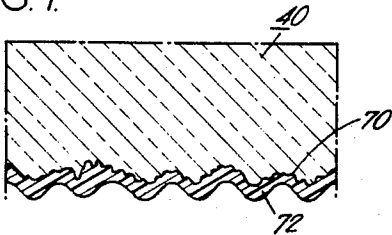


FIG. 8.

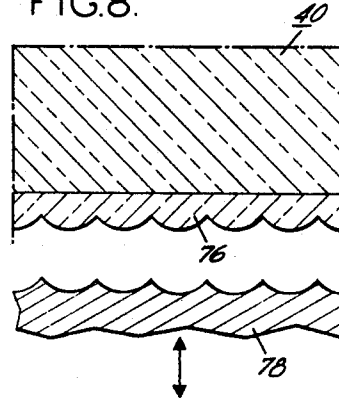


FIG. 9.

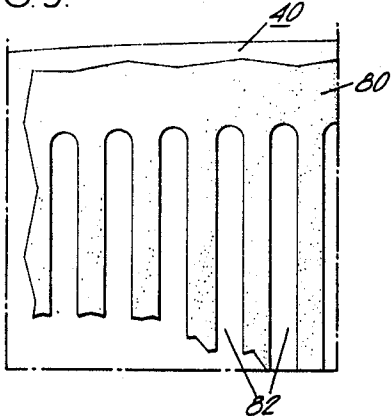


FIG. 11.

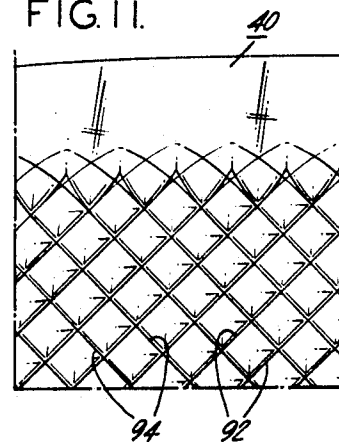
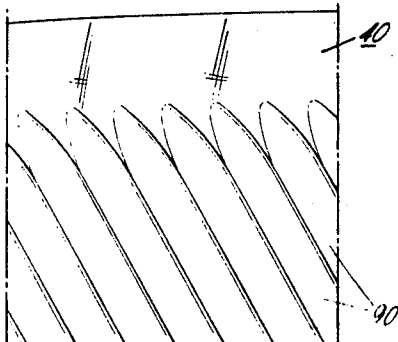
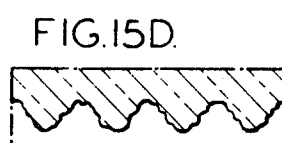
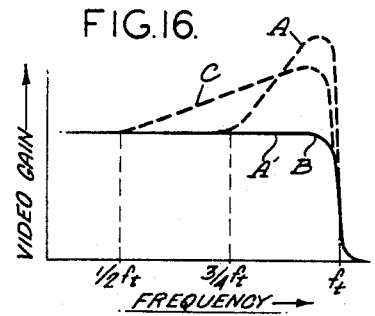
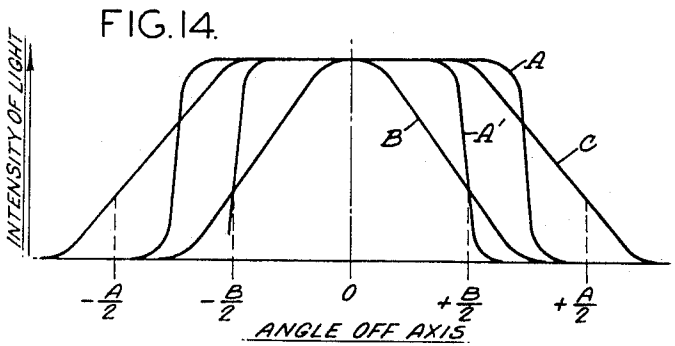
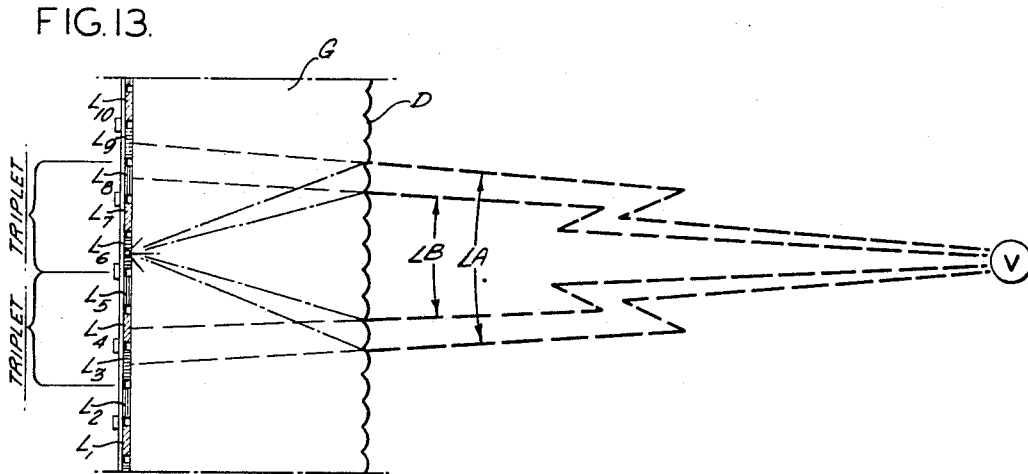
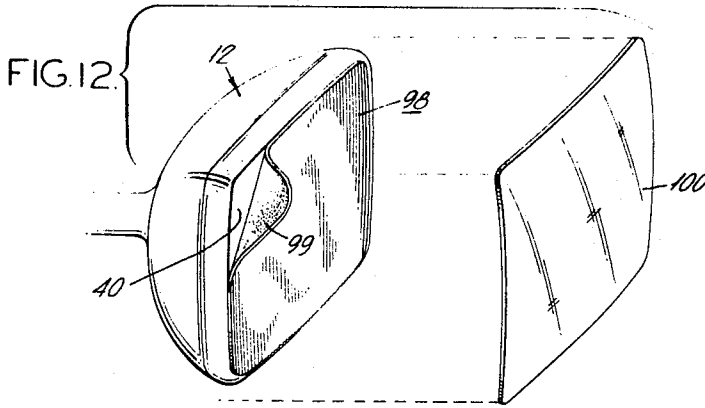


FIG. 10.



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COLOR TELEVISION DISPLAY SYSTEM AND METHOD FOR REDUCING VISIBILITY OF GEOMETRIC PATTERN OF COLORED-LIGHT SOURCES, AND METHOD FOR FABRICATION THEREOF

BACKGROUND OF THE INVENTION

Color television image-display systems are known in the prior art in which the proper color at any point in the display is produced by means of a fine geometric pattern of colored-light producing elements, the light produced by different ones of these elements being of respective different primary colors and controlled in relative intensities so that, when viewed simultaneously, the differently-colored light outputs combine additively to produce the desired apparent color.

For example, it is known to provide a color television image-display system in which this pattern is in the form of groups of fine phosphor lines covering the entire image-display area, the lines of each group producing light of different colors; each such group may comprise a triplet made up of one line producing red light, one line producing blue light and one line producing green light in response to impingement by a cathode ray beam. One such image display system is disclosed, for example, in my U.S. Pat. No. 2,892,123, issued June 23, 1959.

When such an image display is viewed from a sufficient distance, the eye of the observer will not distinguish the line structure of the light-producing elements in each group or triplet, but if the observer approaches the display sufficiently closely, there do appear to be brightness bars at the triplet spacing; and at extremely close viewing distances, the separate individual stripes of different colors will even become apparent. For example, on a 21-inch color television tube having color triplets spaced on 0.06 inch centers, the line structure at triplet frequency will begin to become perceptible when one moves within about 6 feet of the screen; and while at several foot distance the desired illusion is still obtained of observing only a single color within each triplet, the visibility of the line structure in itself is nonetheless aesthetically displeasing to some people; and at much closer distances, the color illusion itself may break up, allowing the viewer to see the individual color stripes themselves. It will be understood that at a proper recommended viewing distance, the line structure typically is completely invisible to the observer, and that he obtains no advantage in clarity in approaching the screen more closely since the resolution of the image is generally limited by the bandwidth of the television signal finally delivered to the cathode-ray tube. Nevertheless, some people under some conditions will observe the screen from a closer distance and find the triplet line structure objectionable, or at least notice that it is different in appearance from certain other color television displays.

One way to make the line structure less apparent is to make the structure finer, i.e., to utilize more color lines and triplets per inch by making each line narrower. However, since the spot size of the cathode-ray beam should not be substantially greater than the width of each individual color line, such a remedy requires a finer cathode-ray beam spot. Assuming that the brightness of the image is to be maintained, this smaller spot would have to pass the same total beam current, and

hence the beam current density would have to be increased under such conditions. Providing such an increased density of beam will in general increase the cost of the system and reduce its reliability, since it increases the performance requirements for the cathode, for the electron optics in the electron gun, for the deflection coil, and for the high-voltage supply. It may also require a larger electron-optical path between the cathode and the focus region of the electron gun, and hence require a deeper cathode-ray tube and deeper cabinet for the TV receiver. The increased difficulty of fabricating the phosphor segments and other portions of the image display apparatus when the line widths are decreased will also be apparent.

It will therefore be appreciated that it is desirable to reduce the visibility of the structure of the individual colored light producing elements, but without reducing the size of the individual elements.

Accordingly, it is an object of the invention to provide new and useful color image display apparatus.

Another object is to provide such apparatus of the type in which a line structure of elements producing light of different colors is employed, and in which the visibility of this line structure is reduced.

It is a further object to provide such apparatus in which the visibility of the line structure is reduced without reducing the size of the colored-light producing elements.

It is also an object to provide such apparatus in which the visibility of the structure of the colored-light producing elements is reduced, without reducing the dimensions of the individual elements and without materially reducing the resolution, apparent sharpness, brightness, contrast or color fidelity of the reproduced image.

It is also an object to provide such apparatus in which the above-described improvements in image display are realized without requiring changes in the electrical components of the image display system, particularly changes which might cause additional expense, criticality or unreliability.

Other objects of the invention in various of its aspects include the following:

to provide method and apparatus permitting use of the coarsest possible color stripe structure consistent with reproduction of the highest frequency signals to be represented in the television image, while preventing objectionable visibility of the triplet structure and without materially degrading the image quality;

to provide a light diffusing means for use in front of a vertically-striped color-image reproduction tube to reduce the visibility of the line structure due to said stripes, without materially degrading the image quality; and

to provide methods for the making of such diffusing means.

These and other objects of the invention are achieved by providing optical diffusing means covering the colored-light producing lines, the length of the spatial period of the sets of colored-light producing elements, measured along the direction of beam scanning, being generally smaller than one-half of the spatial periodicity along this direction of the highest video frequency for brightness-components to be reproduced, the diffusing means serving to diffuse light from the colored-light producing elements by an amount, measured along the direction of beam scanning, which is suffi-

cient to reduce substantially the visibility of the line structure but insufficient to degrade substantially the reproduction of the brightness portion of the image content represented by said highest video frequency.

In a preferred form, the groups of colored-light producing elements are positioned and spaced so as to be scanned at a group-scanning rate of about twice the frequency of the highest video brightness frequency component to be reproduced, and the diffusing means is effective to smear the light from any point on one of the colored-light producing elements along the direction of scanning throughout a distance equal to about one of said spatial periods of the groups. As an example, if the groups comprise triplets of individual lines producing different colors of light in response to impingement by the beam, and if they are scanned by the beam at the rate of 6 million triplets per second, and if the highest video frequency which is present for reproduction is about 3 megacycles per second, the spatial periodicity of the triplets will be about 60 mils in a 21 inch diagonal TV set; and the smearing produced by the width of an elemental color stripe as spread by the diffusing means along the beam scanning direction should be sufficient to spread the apparent visual width of each individual color stripe to cause it to span an apparent horizontal distance equal to about the distance occupied by a full unsmeared color triplet, or in this case 60 mils. The smearing action can be greater than this amount, for example it could be 100 mils, but it should not be as great as 120 mils in the case cited, for this latter distance of 120 mils is the spatial period of the 3-megacycle maximum video frequency. Accordingly, the diffusing means can produce sufficient diffusing action to blur the individual 6 m.c. triplet line structure substantially completely without irretrievably producing any substantial degradation in the maximum picture resolution provided by the 3-megacycle maximum video frequency.

In one preferred form, the diffusing means comprises a translucent plate having closely-spaced lenticular elements on the side toward the viewer, and having phosphor lines on the opposite side, the lenticular elements being either regularly spaced and precisely formed, or more random in position and configuration, and preferably extending generally transversely to the direction of scanning by the cathode ray beam.

The lenticular elements have a spatial period along the direction of scanning which is preferably small compared with the spatial period of the triplets, and have shapes such as to diffuse light from any point on the phosphor lines along the direction of scanning of the beam to an extent sufficient to blur the triplet line structure, significantly degrading the reproduction of the finest video brightness detail. In various of the preferred embodiments, the phosphor and lenticular elements may be disposed on opposite sides of a glass plate within the cathode-ray tube; or the phosphor may be on the inside of the front face of the cathode-ray tube with the lenticular elements formed on the outside thereof; or separate diffusing means may be provided in contact with the outside of the front face of the cathode-ray tube, preferably behind or as part of a safety glass in front of the tube.

Preferred methods for providing the desired lenticular diffusing means include scratching the front of the cathode-ray tube face plate with a moving substrate having small abrasive particles thereon, followed by op-

tical polishing of the randomly grooved surfaces thus formed; molding appropriate lenticular grooves into the softened outer front surface of the cathode-ray tube; providing the lenticular diffusing means in the form of a plastic sheet placed over the front face of the cathode-ray tube and having the lenticular elements molded therein; etching the lenticular elements through a photographically formed mask of a photosensitive resist material; affixing glass fibers of appropriate optical characteristics on or in the face plate; or flexing a normally-rigid plastic sheet beyond its elastic limit along lines where diffusing elements are to be formed.

To the degree that the optical smearing exceeds one triplet in distance, some attenuation of the highest video frequency may take place; but so long as this smear is less than two triplets, there is still left some visual response at video frequencies of one-half triplet frequency, and high-frequency video peaking may be used in the circuits which precede the cathode-ray tube to compensate for such equivalent high-frequency attenuation as does take place in the optical path.

BRIEF DESCRIPTION OF FIGURES

These and other objects and features of the invention will be more readily understood from a consideration of the following detailed description, taken with the accompanying drawings in which:

FIG. 1 is a simplified schematic diagram illustrating a system using the invention;

FIG. 2 is a front view of an image-presentation cathode-ray tube with parts broken away, embodying the invention;

FIG. 3A is a graphical representation illustrating the relation of the highest frequency of the brightness component of the video signal, in relation to the fragmentary section of FIG. 3B, which is taken along lines 3—3 of FIG. 2;

FIG. 4 is a sectional view taken along lines 4—4 of FIG. 3B;

FIG. 5 is a fragmentary perspective view of a portion of an alternative form of picture tube;

FIG. 6 is a fragmentary view, partly in section, of a portion of the tube of FIG. 5;

FIGS. 7 and 8 are fragmentary sectional views to which reference will be made in describing methods for making the diffusing means of the invention;

FIG. 9 is a fragmentary elevation view of a portion of a diffuser to which reference will be made in describing a method of fabrication thereof;

FIGS. 10 and 11 are fragmentary elevational views of two alternative forms of the diffusers of the invention;

FIG. 12 is an exploded perspective view illustrating another embodiment of the invention;

FIG. 13 is a diagram to which reference will be made in explaining the principle of the invention;

FIGS. 14 and 16 are graphical representations to which reference will be made in explaining design principles of the invention; and

FIGS. 15A, 15B, 15C, 15D and 15E are fragmentary perspective views illustrating various configurations of diffusing means in accordance with the invention.

DESCRIPTION OF SPECIFIC EMBODIMENTS

Referring now to the particular embodiments of the invention shown in the drawings by way of example

only, FIG. 1 illustrates a typical color television receiving system to which the invention is applicable. The usual color television receiver circuits 10 are connected to the cathode-ray tube image display device 12 by a high voltage line 14 for supplying the cathode-ray tube final anode voltage, by a focus-current line 16 for supplying focusing current or voltage to a focusing coil or element 18, by a video line 20 for supplying the video brightness and chroma signals which control image reproduction to the grid 22 of the cathode-ray tube, and by a deflection-signal line 24 for supplying horizontal and vertical deflection signals to the deflection yoke 26. A photo-sensitive device 30, which views photo-indexing elements positioned within the cathode-ray tube, derives suitable index signals and supplies them over index signal line 32 to the receiver circuits 10.

The cathode-ray tube 10 contains an image display device which will be described in detail hereinafter, and comprises a glass plate 36 having phosphor stripes or lines on the rearward surface thereof across which the cathode-ray beam scans during its horizontal scans, the intensity of the beam being controlled during scanning by the color television signal so as to energize the various differently colored phosphor stripes or lines to the extent necessary to reproduce the color image represented by the signal. The glass plate 36 may be mounted to and within the cathode-ray tube envelope by appropriate supports such as 38 so that the front of the plate is near and parallel to the front face plate 40 of the cathode-ray tube.

FIGS. 2 through 4 illustrate details of the image-display device utilized in this embodiment of the invention. The glass plate 36 is provided on its rearward face, by conventional processes now known in the art, with triplets of vertical lines of phosphor material responsive to impingement by the cathode-ray beam to produce light of a different color from each line in each triplet. More particularly, the phosphor line 42 may produce red light, the phosphor line 44 may produce green light, and the phosphor line 46 may produce blue light, when impinged by the cathode-ray beam. These lines are arranged in a repetitive pattern so that each successive triplet of lines is substantially like each of the adjacent triplets. The spatial period P_T shown in FIG. 3, for example, is the length of one triplet along the direction of horizontal beam scanning. The phosphor lines may cover the entire rear surface of the glass plate 36 so as to fill the usual image-display area of the cathode-ray tube, except for the small guard spaces such as 50 which may be left between immediately adjacent phosphor lines. A metal layer of a material such as aluminum, for example, so thin as to be pervious to the cathode-ray beam, preferably covers the rear surfaces of all of the phosphor lines, and photo-indexing lines 54 may be positioned as shown to produce indexing signals in response to impingement by the cathode-ray beam, which indexing signals are detected by the photo-sensitive device 30. As described in my above-cited patent, the index lines are preferably positioned so as to be scanned by the horizontally scanning beam at a frequency which is, for example, $3/2$ of the rate at which the triplets are scanned, so that there are three such indexing lines for each two triplets in this example.

The image-display system thus far described will respond to received color television signals to energize the phosphor lines in a manner such as to reproduce

the color and brightness of the television image. However, since each phosphor line in each triplet produces light of a different color from that produced by other lines in the triplet, when the viewer is sufficiently close to the image-display device the triplet structure of the phosphors will become visible and, to some people, objectionable.

Accordingly, diffusing means 60 are provided in front of the array of phosphor stripes to diffuse the light from the individual phosphor lines over the distance of about one triplet (but not as much as two triplets) measured along the direction of horizontal beam scanning, whereby the line structure is blurred or obscured so as to be substantially invisible to a viewer even at close range. In this example the diffusing means 60 comprises an array of vertically-disposed elongated lenticular element such as 62 substantially covering the front face of the plate 36, and in fact in this example formed integrally therewith. Each lenticular element may for example be in the form of an elongated semi-cylinder having its convex surface directed forwardly toward the viewer, with the smallest possible "land" separating the adjacent lenticular elements from each other. In this example the spatial period of the triplets may be about 60 mils, in which case the width of each of the lenticular elements may be of the order of 2 to 15 mils in typical cases. The extent of the diffusing or spreading of light from the phosphors on the rear side of the plate 36 produced by such lenticular elements will depend upon such factors as the spacing from phosphor to lenticular element, occasioned in this example by the thickness of the glass plate 36, and the transverse shape of the lenticular elements, particularly the shape of the sloped portions thereof and the degree of steepness of slope.

Referring now particularly to FIGS. 3A and 3B, FIG. 3A is a graph of beam intensity as ordinate and transverse position on the phosphor lines as abscissa. The sinusoidal curve shown on the graph represents the highest brightness-representing video frequency component which the color television receiver passes to the grid of the cathode-ray tube to modulate the intensity thereof, and therefore also represents the finest brightness detail which can be provided in the reproduced image. The distance P_S represents the spatial period of this highest frequency video signal and defines the maximum brightness definition of which the system is capable.

FIG. 3B shows the spatial period P_T at which triplets of phosphor stripes recur transversely of the plate 36. It is noted that in this example the spatial period P_T of the triplets is one-half the spatial period P_S of the maximum frequency of video signal.

By comparing FIGS. 3A and 3B it will be appreciated that diffusing or smearing of light over a distance equal to two of the triplet periods P_T may be provided before such smearing obscures the image detail provided by the highest video frequency signal, and that such diffusing or smearing over one period P_T will be sufficient to blur and render invisible the individual phosphor lines in each triplet. Accordingly, the degree of diffusing or blurring provided by the diffusing means 60 is preferably equal to about one (but less than two) spatial periods P_T of the triplet structure. With this degree of diffusing or smearing, the lines will become substantially invisible yet the brightness detail in the picture will not be materially degraded.

FIGS. 5 and 6 illustrate a modification of the arrangement shown in the preceding figures in which the phosphor stripes, aluminum layer and photo-indexing elements are deposited directly on the inner surface of the glass front 40 of the cathode-ray tube 12, rather than on the separate plate 36. In this example the diffusing means 60 is provided on the front surface of the tube front 40, the shape and number of these elements and the considerations relating to the degree of diffusing produced being the same as for the previously described embodiment utilizing the separate internal support plate 36.

While the use of the internal glass plate 36 provides certain advantages, particularly in simplicity of fabrication, since it can be made entirely apart from the cathode-ray tube by a simple printing of phosphors on one side of the plate and simple forming of the diffuser elements on the opposite side, this arrangement does have the drawback of being more sensitive to imperfections in the glass of the front of the cathode-ray tube. This is because any local defects which bend light as it passes through the glass forming the front of the cathode-ray tube will produce more noticeable distortions when the phosphors are located farther away, as they will be if on the rear side of the plate within the tube rather than on the inside of the front face of the tube.

To form the desired optical diffusing elements on the front of the cathode-ray tube or on the front of the support plate within the tube, any of the methods now to be described may be used.

In one method, a belt or cloth is impregnated or coated with diamond dust of a fineness appropriate to provide grooves 64 of the desired spacing for forming the lenticular elements, and the belt or cloth is passed vertically along the front of the glass surface. The grooves or scratches thus formed on the front of the glass will be in the desired direction and with a random spacing and form approximating that desired. Although they may be randomly positioned with respect to the phosphor stripes and not exactly regular in form, they will still produce a diffusing effect like that described previously. However, the raw scratches produced by the diamond dust typically will be rough, and will tend to appear white or frosted to the eye, which may not only be objectionable in appearance but also may tend, because of the optically rough sides of the grooves, to diffuse the light more than is desired, and both horizontally as well as vertically. Therefore, the raw grooves cut in this manner are preferably subsequently optically polished, either mechanically, chemically, or by flame polishing.

A mechanical method of polishing the grooves is to rub them in the same direction in which the grooves were cut with a suitable polishing compound embedded in the matrix. Among such suitable compounds are cerium oxide, zirconium oxide, and ferric oxide, which can be emmeshed in a soft backing material of cloth or carried in paste form on a moving belt, so that the fine particles of the polish can penetrate and rub against each of the previously cut grooves, thereby to polish them to a smooth optical finish.

Chemical polishing can be accomplished by application to the cut grooves of a conventional polishing solution, comprising for example equal parts of 70 percent hydrofluoric acid and 98 percent sulfuric acid (see for example page 568 of "Encyclopedia of Chemical Tech-

nology," vol. 10 by Kirk-Othmer, 1967, John Wiley & Sons Inc.).

Flame polishing can be accomplished in conventional manner by rapidly and briefly passing the face of the glass into which the raw grooves have been cut near a high temperature flame, which will cause a momentary increase in temperature of the front surface of the glass, raising it momentarily above the softening point and allowing the glass, through surface tension, to partially smooth itself; the glass is not held in the flame long enough to cause the grooves themselves to disappear.

Another method similar in effect to those described above for smoothing the surface variations of the diffuser is represented in FIG. 7. In this case the glass body 40 of the diffusing means has the rough, highly angular groove pattern 70 formed on the front surface thereof, and a thin film 72 is then disposed over the rough base 70 so as to provide an optically smooth surface along the interface with the surrounding air. The film 72 is in optical contact with the rough side walls of the grooves 70, and has an index of refraction closely approximating that of the main body of the glass plate 40.

One method of providing such a film is as follows: A plastic air-drying liquid may be sprayed on to the front face plate of the cathode-ray tube and allowed to dry in smooth, polished form; or, for greater ruggedness, a thin glass film can be applied by spraying on to the face plate a fine powder, comprising a low-temperature glass such as high-lead glass embedded in a water slurry, allowing the water to evaporate under mild heating, and subsequently heating the face plate further to cause the low-temperature glass to melt and form a glaze. Preferably the latter heating is at a temperature which is low compared to the melting temperature of the main face plate.

In another method, the grooves are pressed or molded directly in the front of the glass plate, which may be the front face of the cathode-ray tube. As represented in FIG. 8, when the grooves are to be formed in the relatively high-temperature glass used for the front face of the cathode-ray tube, a layer 76 of lower-temperature glass may be first applied to the front face of the tube, as by the method described above in connection with FIG. 7, with the exception that in this case the layer 76 is thick enough so that the grooves can be formed entirely therein. The latter layer is raised to a temperature high enough so that the grooves can be molded therein by forcing the mating mold 78 against the heated glass layer. If desired, this operation can be followed by one of the polishing procedures described previously. Particularly in the case where the low-temperature glass layer 76 is not used, high pressures greater than 100 lbs per square inch may be used, pressures higher than the pressures normally used to mold the face plate itself so that the grooves may be molded at temperatures sufficiently low to avoid erasure of the grooves by surface tension.

FIG. 9 illustrates another method of forming the diffusing means, whether on an internal glass plate or on the front face of the cathode-ray tube. Assuming that the diffusing means is to be on the front face 40 of the cathode-ray tube, an etch resist 80 is applied to the front surface thereof in a pattern to leave exposed the regions such as 82 in which grooves are to be formed, and this surface is then immersed in a suitable etchant

for glass, to form the desired grooves. To achieve rapid initial etching, a rapid etchant may initially be used, which will leave a rough or frosted appearance to the grooves; and this may be followed by a fine polishing etchant, such as described earlier. The pattern of the resist 80 may, for example, be formed by utilizing a photo-resist which is photographically exposed and washed to remove the resist in the areas to be etched, in a manner known in the art.

While the groove patterns of the diffusing means have thus far been shown as extending exactly vertically, they need not be so oriented. For example, as illustrated in FIG. 10, the grooves 90 in the glass face plate 40 may be at an angle, such as 30°, from the vertical, and since the diffusing or smearing occurs at right angles to the length of the grooves, this will cause a major amount of diffusing along the direction of the horizontal scan of the cathode-ray beam, and a lesser but substantial amount of smearing in the vertical direction normal to the direction of horizontal scanning. The effect of the vertical diffusing or smearing is to reduce the visibility of the horizontal scanning lines. Since viewers normally expect to see some horizontal line-scanning pattern on the screen, it is preferred to use an amount of diffusing which will not render this pattern completely invisible, although so long as the amount of vertical smearing is not greater than the spacing between successive horizontal scanning lines there will not be any appreciable loss in vertical picture detail.

FIG. 11 shows another arrangement of diffuser grooves wherein more than one set of grooves, extending at different angles, are utilized for the diffusing means; in this example, one set of grooves 92 extends along a direction about 45° from the vertical in one sense, and another set of grooves 94 extends along a direction 45° from the vertical in the opposite sense. The latter cross-lenticular pattern may be formed by two successive groove-cutting operations performed mechanically, or both sets may be formed simultaneously as by chemical etching or mechanical pressing or molding.

FIG. 12 illustrates another embodiment of the invention in which the diffusing means comprises a plastic sheet 98 bonded to the front face plate 40 of the cathode-ray tube 12 by means of a clear cement 99, so as to be positioned between the face plate 40 and the usual bonded safety-glass plate 100. In one method of fabrication, the plastic sheet is affixed to the front of the cathode-ray tube and the diffusing pattern formed on the front face thereof by pressing or dissolving of the material in the region to be grooved. In another preferred method of fabrication, the plastic sheet is first provided with the desired diffusing pattern by pressing from a master, much as is done in the making of plastic phonograph records, after which the sheet is applied to the front of the cathode-ray tube. Such a construction has been found satisfactory using a commercially-available diffusing sheet material in which the space in between centers of the lenticular elements was about 15 mils and the lenticular elements were disposed at 30° to 45° from the vertical, the spatial period of the triplets in this example being about 60 mils.

The following factors and considerations are believed to be helpful to one designing diffusing means in accordance with the invention for use in different specific applications.

Referring to FIG. 13, there is represented a cathode-ray tube glass front face plate G having a lenticular front surface D, and having on its inner face the phosphor lines L_1 through L_{10} . Assume that the cathode-ray beam strikes the line L_6 causing it to glow over its entire width, and that the front face of the cathode-ray tube is viewed from the position V by the viewer. The angle A subtended at the eye of the viewer is drawn embracing six phosphor lines, or two color triplets. The angle B subtended at the eye of the viewer just embraces three phosphor lines, or one triplet, centered about the line L_6 . If no diffusing at all were present, light from the line L_6 would reach the eye of the viewer along straight lines, and subtend a viewing angle of less than one-third of angle B. However, by using the diffusing means D, light from line L_6 is preferably diffused or smeared over approximately one triplet, so as to appear to the eye of the viewer as coming from points on the diffuser spread out so as to subtend an angle equal to angle B. In this way the light from each three adjacent lines is similarly spread out and interspersed so that the line structure is not visible to the viewer, yet the maximum brightness detail of the picture is not degraded by the diffusing action. It is assumed here that the maximum video frequency of the brightness signal corresponds to a spatial period no less than twice the spatial period of the triplets, as represented in FIGS. 3A and 3B. If the spatial period of the triplets or of the maximum video frequency signal differs from this, the diffusing properties should be adjusted accordingly, so that the line structure becomes invisible or at least less prominent, but the picture detail is not degraded.

It will be appreciated that the exact nature of the diffusing surface used to meet these criteria will depend upon the combination of a number of factors, including for example: (a) the index of refraction of the diffuser, or more particularly the difference between the indices of refraction of the diffuser and that of the medium (air, or plastic or cement or glass) with which its lenticular faces interface; (b) the form and curvature of the diffusing elements, particularly the slopes of the side-walls of the grooves which comprise the lenticular elements; and (c) as a consequence of interdependence on (b), also the number of lenticular diffusing elements per inch along the direction of horizontal scanning.

As mentioned hereinbefore, the diffusing means may have an irregular structure in that the lenticular elements need not recur exactly periodically nor in known fixed relation to the phosphor lines, which makes their fabrication less critical in certain cases. Because the amount of diffusing used can be anywhere from approximately one to almost two triplet periods and still provide excellent results, and since somewhat more or less than this amount of diffusing, at least in portions of the image, can be tolerated, the use of such random structure of diffusing elements is feasible in many cases.

When a regular pattern of lenticular elements is used, the spatial periodicity thereof is preferably chosen to avoid producing a visible moire pattern or beat with the periodicity of the phosphor lines. One way of preventing such moire patterns is to use lenticular elements for the diffuser which are quite narrow and closely spaced compared to the spatial period of the triplets. That is, a plurality of lenticular elements are provided for each triplet, preferably on the order of five to 10 lenticular elements per triplet. Also, the number of lenticular ele-

ments per triplet is preferably a non-integral multiple, to reduce moire effects.

In addition, the curved lenticular surfaces of the elements are preferably positioned closely adjacent to each other with very little intervening flat glass, if any, left between them, since the flat glass will allow transmission of light from the phosphor lines without the desired diffusion.

If the lenticular elements are made excessively narrow, the unavoidable small non-lenticular region comprising the junction between these elements becomes a greater proportion of the total front area of the diffuser, which is undesirable not only from the viewpoint of the reduction in the percentage of light which is diffused in the desired manner, but also because such junctions will tend to reflect room light back into the room causing the face of the cathode-ray tube to be more visible and "whitish" than otherwise, which is generally undesirable. To minimize such reflections, the surface of the diffusing means may be coated with a non-reflecting coating such as is employed on photographic lenses to make them nonreflective.

FIG. 14 represents an idealized plot of the intensity of light from a given phosphor line versus the angle subtended at the eye of the observer viewing the light from that line after it has passed through the diffuser. Curve A' shows an ideal characteristic, in that the intensity of the light from the diffused line remains high and constant throughout a range of angles extending in either direction up to an angle of $B/2$, as defined with respect to FIG. 13, with a sharp cut-off for angles greater than $B/2$. Such a diffuser will substantially totally eliminate the visibility of the triplet structure, as well as the visibility of the line structure within the triplets, while at the same time, causing very little reduction of the high-frequency response conveyed by all video frequency components of less than one-half of the triplet frequency. An equally useful diffusion characteristic is that shown by the curve A of FIG. 14, which has the same sharp angular cut-off characteristic as Curve A', but which spreads in angle by about 50 percent more, causing a spread in either direction halfway between $A/2$ and $B/2$ where A and B are as defined with respect to FIG. 13, with little or no intensity of light beyond these angles. Under these conditions the line structure will again be entirely invisible; but the uncompensated high-frequency video detail will be slightly attenuated, although not irretrievably so. The compensation suitable for inclusion in the video amplifier or other circuits ahead of the cathode-ray tube to fully compensate for the attenuation of high-frequency detail introduced by the diffuser of characteristic A of FIG. 14 is shown by the curve A of FIG. 16, which provides a rise in gain starting at approximately three-fourths of the triplet frequency f_t , and continuing up to the point of high-frequency video cutoff, just below the triplet frequency f_t . The rise should in this case be about 2:1.

Also shown in FIG. 16 is the relative video response which would be used for the narrower-angle diffuser A' of FIG. 14 previously described, as represented by the flat response curve A' of FIG. 16. While in practice it may be desirable to have the overall pass-band other than flat, for various reasons well known in the art of television-set design, such as to compensate for noise at small signal-to-noise ratios, or to provide greater sharpness than otherwise, the curve A' of FIG. 16 may be taken as a reference relative to which the other

curves in FIG. 16 may be compared, on the assumption that the overall response in the presence of diffuser A' is assumed to be chosen to be a flat overall video response.

Curve B of FIG. 14 is one which provides substantial intensity of light over a major part of the angular interval between $-B/2$ and $+B/2$, and substantially no light beyond $-A/2$ and $+A/2$, but a reduced intensity between zero angle and $+A/2$ and $-B/2$. The latter characteristic will provide substantial obscuring of the phosphor line structure, although not complete invisibility, and requires no video high-frequency peaking, as illustrated by curve B of FIG. 16. Curve C of FIG. 14 shows a characteristic which provides more complete obscuring of the phosphor line structure than does characteristic B, but which produces, without compensation, a small reduction in video detail since some light occurs, for angles beyond $+A/2$ and $-A/2$. Characteristics like B and C are readily obtainable, as are characteristics between these two, and the particular characteristic used, whether like these or like A or A' will depend upon the desires of the designer with respect to the extent of obscuring of the line structure and the extent of attenuation of the maximum video detail and the compensation therefore, considered together with ease and cost of producing a diffuser providing the characteristic selected.

It will be understood that for light from a single spot on a single phosphor line, the characteristics of FIG. 14 will actually comprise a plurality of narrow peaks, each representing a highlight created on a portion of the sidewall of a single groove of the lenticular diffuser array of grooves; and the characteristics shown in FIG. 14 approximately constitute the envelopes of such narrow peaks. However, since the phosphor lines are each of finite width the light from all points across the width of a single phosphor line will result in a characteristic close to the types shown in the drawings.

FIGS. 15A through 15E illustrate schematically various types of cross-sections or profiles of lenticular elements which may be utilized to accomplish the purposes of the invention. In FIG. 15A the lenticular elements are convex and approximately in the form of a set of tips of a rectified sine wave, placed next to each other. In FIG. 15B, these elements are of the same general form, but concave; in FIG. 15C, the configuration of the exposed surface of the diffusing means is approximately in the form of a sine wave. FIG. 15D illustrates a profile generally of sine-wave form, but with roughnesses thereon so as to provide a wider angle dispersion of light from each line. FIG. 15E illustrates a type of configuration which may be obtained with the random groove-cutting process described hereinbefore, the periodicity and amplitude of the variations being non-uniform but sufficiently near the optimum to produce useful obscuring of the line structure without producing substantial or noticeable degradation of the video detail.

I have also found that the diffusing means of the invention may be made by using glass fibers as the diffusing elements, or by using flex lines in plastic as the diffusing elements. In the first method glass fibers may be positioned on the front of a glass plate such as the front of the television picture tube in the locations desired for the diffusing elements (e.g., vertical and immediately adjacent each other, with at least several fibers per color triplet), and secured thereto by heat-

softening of the fibers and/or the surface of the glass plate, or by the use of low-melting point glass frits used in effect as a solder. Alternatively, the glass fibers may be embedded in the glass plate at the time of molding of the plate, using fibers having a higher melting point than that of the glass plate and an index of refraction differing from that of the plate. In the second method mentioned, a thin, relatively rigid sheet of plastic is flexed repeatedly slightly past its elastic limit to form a flex line, which line has been found to provide optical properties suitable for use as one of the diffusing elements. The line of flexing is then advanced by small steps to form an array of closely spaced flex lines serving as the diffusing means, with at least several lines per triplet.

It will be understood that the diffusing elements need not have cylindrical surfaces, and that instead of using elements which are continuous in the vertical direction throughout the viewing area, one may use a plurality of small-area diffusing elements of small vertical dimension, e.g., having the form of pimples or small mesa-shaped elements, which need not be arranged along straight lines.

Also, the diffusing elements need not be all the same in their diffusing power. For example, certain cathode-ray tubes are made with front face plates which are appreciably thinner near the center than at the edges. In this case, if the phosphor lines are on the inside of the face plate and the diffusing elements on the outside of it, the spacing of phosphor lines from diffusing elements will be smaller near the center than near the edges. Accordingly, the diffusing elements near the center of the face plate are then preferably made to have a compensatory and inherently greater amount of diffusing "power" than those near the edges, as can be accomplished by providing the diffusing elements in the central regions with steeper sloping sides on each groove, as by making the above-mentioned more-centrally located grooves deeper. In this way the extent of the actual optical angular diffusion (as illustrated in FIGS. 13 and 14) which is produced by the diffuser can be made to be relatively constant over the entire face of the cathode-ray tube, despite variations of the face-plate thickness over the tube face. Note that the number of grooves per horizontal inch need not vary over the tube face to achieve this result, but only the depth (and hence the steepness of groove sidewalls) need vary over the tube face, in which case the grooves can all be parallel to each other and disposed vertically or at any desired angle.

In inspecting tubes for phosphor uniformity and application precision in the manufacture of tubes made in accordance with the invention, a problem arises in that, if the final color composition is not correct as seen on a completed tube, one may wish to ascertain if the non-uniformity is a result of non-uniform phosphor line width, or other variation such as non-uniform phosphor thickness or efficiency. The problem results from the fact that the diffuser deliberately and effectively prevents viewing the width of the phosphor stripe from outside of the tube face. I have found therefore that in manufacturing inspection operations it is desirable to examine the phosphor as though the diffuser were not present. A method I have found suitable for this is to place the tube, face down, in a shallow tank, the bottom of which tank is a sheet of plate glass. The tube is preferably supported so that its face-plate is held

slightly above the plate glass. The tank is filled sufficiently to cover the part of the face plate being inspected, with a liquid having substantially the same index of refraction as that of the lenticular diffusing elements. Plain water is a fair approximation, suitable in most instances. A detergent wetting agent is preferably added to accomplish wetting of all parts of the fine-grooved glass surfaces. For a better match to the index of refraction of the particular material used, a wide variety of liquids are available as listed in standard handbooks, and which can be used singly or mixed, including oils, alcohols, and solutions of various dissolved salts. When the tube is now viewed from beneath the tank, with the naked eye or with the aid of an optical magnifier, the optical effect of the diffuser is completely defeated, and the phosphor lines can be viewed in the same manner as though the diffuser were not present. A tilted mirror can be used located below the plate glass to allow the test observer to relieve neck-strain over protracted periods of observation, by allowing him to look horizontally instead of in a generally upwardly direction. Alternatively, the liquid of index of refraction matching the diffuser material may be placed on the cathode-ray tube face with the face oriented upwardly, the liquid being held in position by an appropriate boot or the like, and the lines observed through the liquid either with the naked eye or through an optical magnifying device.

This inspection process is generally applicable to all tubes made with the lenticular diffusers on the outer face. Other types described should be inspected for phosphor non-uniformity at an earlier stage of manufacture, as from the rear, or before the phosphor is placed behind the diffuser.

Accordingly, while the invention has been described with particular reference to specific embodiments thereof in the interest of complete definiteness, it will be understood that it may be embodied in a variety of forms diverse from those shown and described, without departing from the spirit and scope of the invention as defined by the appended claims.

What is claimed is:

1. In electronic color-image display apparatus comprising an array of similar adjacent groups of elements for producing intensity-modulatable observable colors, said groups extending throughout the image-display area, each of said elements in each of said groups being energizable to display light of a color differing from that displayed by one or more others of said elements in said group for producing an image for viewing from a viewing position in front of said array, said elements extending along lines generally parallel to each other thereby imparting a visually-observable line structure to said image, and means for energizing said elements sequentially along a direction transverse to said elements to an extent dependent upon the corresponding values of an image-brightness controlling signal, thereby to cause said array to produce said image, said groups recurring along said direction at intervals which are substantially one-half the spatial period, measured along said direction, of the highest-frequency component of the brightness variations in image content desired to be displayed, the improvement comprising:

optical diffusing means positioned between said array and said viewing position for optically spreading the apparent location of the source of the light from said elements, the extent of said spreading

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along said transverse direction being substantially equal to or greater than said intervals of recurrence of said groups thereby to reduce substantially the visibility of said line structure at said viewing position, but insufficient to degrade substantially the display of said highest-frequency component.

2. The apparatus of claim 1, in which said amount of spreading is substantially as great as said intervals of recurrence of said groups and not substantially greater than said spatial period of said highest-frequency component.

3. The apparatus of claim 1, in which said amount of spreading is substantially equal to said interval of recurrence of said groups.

4. The apparatus of claim 1, in which said amount of spreading is greater than said intervals of recurrence of said group but less than said spatial period of said highest-frequency component.

5. The apparatus of claim 1, comprising means for selectively enhancing the amplitude of frequency components of said image-brightness controlling signal the optical effects of which components on said viewed image are attenuated by said diffusing means, said enhancing being of an amount sufficient to compensate substantially for said attenuation.

6. The apparatus of claim 1, in which said optical refracting means comprises optical diffusing elements each smaller along said direction than said intervals of recurrence of said groups.

7. The apparatus of claim 6, in which said refracting elements are located adjacent each other throughout said image display area.

8. The apparatus of claim 7, in which each of said refracting elements is an elongated lenticular element extending completely across said viewed area, said refracting elements being parallel to each other.

9. The apparatus of claim 8, in which said refracting elements are of glass.

10. The apparatus of claim 6, in which said refracting elements comprise a plurality of lenticular elements each small in all dimensions compared with said spatial period of said groups.

11. The apparatus of claim 6, in which each of said refracting elements comprises a flex line in a plastic sheet.

12. The apparatus of claim 6, in which each of said

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refracting elements comprises a glass fiber.

13. Apparatus in accordance with claim 1, in which said diffusing means comprises a plurality of adjacent parallel lenticular elements each extending completely across said image.

14. The apparatus of claim 1, in which said elements comprise phosphor stripes, and said energizing means comprise the scanning cathode-ray beam of a cathode-ray color television tube, and comprising a glass plate supporting said phosphor stripes on the side thereof facing said beam, said diffusing means being positioned on the opposite side of said plate.

15. The apparatus of claim 14, in which said plate comprises the front of the envelope of said tube.

16. The apparatus of claim 14, in which said diffusing means comprises corrugations in said plate.

17. The apparatus of claim 16, in which said phosphor stripes are supported on the inner side of the front face plate of said tube, and said diffusing means is positioned in contact with said front face plate forwardly of said phosphor stripes.

18. The apparatus of claim 17, in which said diffusing means is positioned along the front surface of said front face plate.

19. The apparatus of claim 18 in which said diffusing means comprises an array of optical refracting elements formed integrally with said front surface.

20. The apparatus of claim 1, in which said elements comprise phosphor stripes and said energizing means comprise the scanning cathode-ray beam of a color television cathode-ray tube, and in which said diffusing means comprises a first array of optical refracting elements aligned at an intermediate angle between normal and parallel to said direction of scanning, thereby to spread light from said phosphor stripes both vertically and horizontally.

21. The apparatus of claim 20 in which said diffusing means comprises another array of optical refracting elements disposed along a direction extending at said intermediate angle with respect to said scanning direction but in the opposite angular sense with respect to said normal.

22. The apparatus of claim 1, in which said diffusing means comprises a sheet of plastic material having light-refracting elements formed therein.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,851,093 Dated November 26, 1974

Inventor(s) David E. Sunstein

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 15, lines 25 and 26, thereof, "refracting" should be --diffusing--;

line 26, "diffusing" should be --refracting--.

Signed and sealed this 18th day of February 1975.

(SEAL)
Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents
and Trademarks

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