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(54) Title: PROJECTION SYSTEMS FOR MULTIPLE-PANEL, PLANAR LIQUID CRYSTAL LIGHT VALVES

(57) Abstract: Pixel arrays situated on a planar substrate are imaged, and the images converged. Relative differences in pixel array magnification can be compensated or corrected electronically, or pixel arrays of different sizes can be provided. Optical systems that image all the pixel arrays with a single projection lens include one or more field lenses configured to provide virtual images at optical distances from the projection lens so that projected images of the arrays appear to be in focus. In one example, a pixel array at a center of a set of arrays is associated with a positive field lens, and a pixel array displaced from the center pixel array is associated with a negative field lens.

WO 2004/015484 A2

PROJECTION SYSTEMS FOR MULTIPLE-PANEL, PLANAR LIQUID CRYSTAL LIGHT VALVES

CROSS-REFERENCE TO RELATED APPLICATIONS

5 This application claims the benefit of U.S. Provisional Application
60/403,207, filed August 12, 2002, that is incorporated herein by reference.

TECHNICAL FIELD

10 The disclosure pertains to optical systems for liquid crystal light valves.

BACKGROUND

 Full color liquid crystal light valve (LCLV) display systems typically use
three separate monochromatic LCLVs that are driven to produce red, green, and blue
images. A representative configuration is shown in FIG. 1. The LCLVs are
15 typically mounted to a color-combining cube, and a single lens is used to project a
combined image. This configuration cannot be used for some LCLV configurations,
and improved methods and apparatus are needed.

BRIEF DESCRIPTION OF THE DRAWINGS

20 FIG. 1 is a schematic diagram of an LCLV system using a color-combining
cube.

 FIG. 2 is a schematic diagram of a substrate that includes three pixel arrays.

 FIGS. 3-9 are schematic diagrams of optical projection systems configured to
converge images of three pixel arrays.

25

SUMMARY

 Display systems comprise a display panel that includes a first pixel array
having an axis and a second pixel array having an axis that is displaced from the axis
of the first pixel array. An illumination system is configured to provide a first
30 illumination beam to the first pixel array along the axis of the first pixel array and a
second illumination beam to the second pixel array along the axis of the second
pixel array. The first pixel array and the second pixel array are configured to

modulate the respective illumination beams. A field lens is situated in an optical path of the first modulated illumination beam and is configured to form a virtual image of the first pixel array. A beam combiner is configured to receive the first modulated illumination beam from the field lens and the second modulated illumination beam and direct the modulated illumination beams along a projection axis. A projection lens is situated on the projection axis and configured to receive the modulated illumination beams from the beam combiner and produce an image based on a combination of the modulated illumination beams. The virtual image of the first pixel array is optically conjugate to the second pixel array with respect to the projection lens.

In additional examples, the projection axis is the axis of the second pixel array, and the field lens has a negative focal length. In additional examples, the projection axis is the axis of the first pixel array, and the field lens has a positive focal length. In further examples, the display panel includes a third pixel array that modulates an illumination beam provided to the third pixel array by the illumination system along a third axis displaced from the first and second axes. The beam combiner is configured to receive the third modulated illumination beam and direct the third modulated beam along the projection axis. The projection lens produces an image based on a combination of the first, second, and third modulated illumination beams. In other examples, the first, second, and third illumination beams are configured to provide red, green, and blue illumination beams. In other examples, a field lens is situated in an optical path of the third modulated illumination beam and configured to form a virtual image of the third pixel array. The virtual image of the third pixel array is optically conjugate to the second pixel array with respect to the projection lens. In additional examples, the projection axis is the axis of the second pixel array and the field lenses have negative focal lengths. In other examples, the projection axis is the axis of the first pixel array and the field lens has a positive focal length. In still other examples, respective field lenses are situated in optical paths of the second and third modulated illumination beams and configured to form virtual images of the second and third pixel arrays. The virtual images of the second and third pixel arrays are optically conjugate to an image of the second pixel array with respect to the projection lens. In other representative examples, dimensions of

the first pixel array and the second pixel array are based on respective magnifications produced by the projection lens.

Display systems comprise a display panel that includes at least two subpanels and an illumination system configured to direct illumination beams to the
5 at least two subpanels along respective subpanel axes. An axis-shifting optical system is configured to displace the axis of a selected one of the subpanels away from the axis of the unselected subpanel. Projection lenses are associated with each of the at least two subpanels and configured to produce a combined image of the subpanels.

10 Optical projection systems comprise a beam-combiner having a first input axis and a second input axis and an axis-turning optical system configured to direct a first modulated optical beam to the beam combiner along the first input axis. A projection lens is configured to form a combined image based on the first modulated optical beam and a modulated optical beam received along the second input axis of
15 the beam combiner. A field lens is configured to receive one of the modulated optical beams and produce a virtual image based on the received optical beam, wherein the virtual image is conjugate to an image associated with the other modulated optical beam with respect to the projection lens.

Methods of displaying an image produced on a display panel comprise
20 producing a first modulated optical beam associated with a first display subpanel and a second modulated optical beam associated with a second display subpanel. A virtual image of the first display subpanel is produced that is conjugate to the second display subpanel. The first and second modulated optical beams are combined and a combined image is produced based on the first and second modulated optical beams.
25 In additional examples, a third modulated optical beam associated with a third subpanel is produced. The third modulated optical beam is combined with the first and second modulated optical beams, and the combined image is produced based on the first, second, and third modulated optical beams. In other representative examples, the first, second, and third modulated optical beams are associated with
30 red, green, and blue. In other examples, a virtual image of the third display subpanel is produced that is conjugate to the second display subpanel. In additional examples, the virtual image of the first display subpanel is formed with a converging lens. In

other examples, the virtual image of the first display subpanel is formed with a diverging lens. In still further examples, the virtual image of the first display subpanel is formed with a converging lens and the virtual image of the third display subpanel is formed with a diverging lens. In additional representative examples, the
5 virtual image of the first display subpanel is formed with a diverging lens and the virtual image of the third display subpanel is formed with a diverging lens.

These and other features are described below with reference to the accompanying drawings.

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DETAILED DESCRIPTION

With reference to FIG. 2, a full-color, single-panel LCLV includes red, green, and blue pixel arrays 201-203 defined on a substrate 206. The pixel arrays are separated by intermediate regions that typically include metallization. In one example, the substrate is about 20 mm by 32 mm and each of the pixel arrays
15 includes 864 columns by 480 rows of pixels. Because the pixel arrays are defined on a single substrate, the conventional projection system of FIG. 1 cannot be used. The single-panel LCLV can be referred to as a display panel, and the pixel arrays can be referred to as subpanels. The following examples are described with respect to liquid crystal display panels, but other types of display panels can be used in other
20 examples. As used herein, images or surfaces are referred to as optical conjugates with respect to a projection lens or other imaging system if the images and/or situated at locations imaged onto each other by the projection lens. In some examples, lenses are shown as single lens elements or multiple lens elements, and generally single lenses or compound lenses can be used. In addition, lenses such as
25 holographic optical element (HOE) lenses can be used.

With reference to FIG. 3, a display system includes a substrate 302 on which liquid crystal pixel arrays 304, 306, 308 that are associated with a red, a blue, and a green image, respectively are defined. The arrangement of these subpanels can be changed, and the depicted arrangement is only an example. An illumination source
30 316 is configured to direct an illumination beam to a red reflector 314, a blue reflector 312, and a mirror 310 that are configured to direct red, blue, and green portions of the illumination beam to the associated pixel arrays. Such an assembly

can be referred to as a dichroic ladder. A first prism assembly includes prisms 318, 320 and a second prism assembly includes prism 322, 324. The first and second prism assemblies are configured to direct respective optical axes 340, 342 away from an optical axis 344 associated with the pixel array 306. Projection lenses 330, 332, 334 are provided for each color and are arranged to project images onto a common plane. To avoid image distortions, such as keystone distortion, axes 351, 352 of the lenses 330, 334 are displaced inwardly with respect to the axes 340, 342, respectively, for convergence. The prisms 318, 320, 322, 324 can be right angle prisms or other prisms that provide total internal reflection, or mirrors such as metal or dielectric mirrors that can be arranged to provide corresponding reflective surfaces. As shown in FIG. 3, the lenses 330, 332, 334 are a common optical distance from the associated pixel arrays, and produce the same magnification for each of the pixel arrays. For convenience, polarization components are not shown in FIG. 3.

Adjustments to the display system of FIG. 3 can be made as follows. For focus, the projection lenses and/or the prism/LCLV assembly can be moved along one or more of the axes 340, 342, 344 (i.e., moved left or right in FIG. 3). Image convergence can be adjusted by moving the projection lenses laterally (vertically in FIG. 3), and alignment/registration of the axes of the pixel arrays can be done with lateral movement of the LCLV with respect to one or more of the prism assemblies.

With reference to FIG. 4, a projection system is configured to project and converge images of three pixel arrays 402, 404, 406 formed on a substrate 409. Optical spacers 420, 422 are situated between the pixel arrays 402, 404, 406 and respective turning prisms 408, 410, and a cross-polarizer 412 is configured to combine the images of the pixel arrays 402, 404, 406. A field lens 417 is situated between the array 404 and the combiner 412, and is typically displaced from the array 404. A projection lens 414 is situated along an axis 418 and forms a combined image. The prisms 408, 410 can be glued to the combiner 412 for increased mechanical integrity.

In the example of FIG. 4, the pixel arrays 402, 406 are optically farther from the lens 414 as measured along the axis 418 (and along folded counterparts) and thus the lens 414 provides a different magnification for the arrays 402, 406 and the array

404. Image size on the array can be electronically controlled or the image area can be adjusted based on the magnification so that the magnified images match. The field lens 417 is selected and configured to form a virtual image of the array 404 that is an optical distance from the lens 414 that is substantially the same as the optical distances of the arrays 402, 406 from the lens 414. As shown in FIG. 4, the field lens 417 has a positive focal length. As a result, the lens 414 can produce in-focus, converged images of the arrays 402, 404, 406. Because the optical path associated with the array 404 and the arrays 402, 406 are different, images of these arrays exhibit different magnifications, and the size of the arrays can be selected to compensate this magnification difference. Typically, the array 404 is configured to be smaller than the arrays 402, 406 as the magnification associated with the array 404 is larger than the magnification associated with the arrays 402, 406.

Adjustments to this optical system can be performed as follows. Focus is achieved by adjustments along the axis 418. Convergence is fixed by the nominally fixed locations of the combiner 412, the arrays 402, 404, 406, and the prisms 408, 410. Pixel array drivers can be configured to adjust image locations on the arrays 402, 404, 406, and a portion of the arrays can be reserved for this adjustment and are typically not used otherwise.

FIG. 5 illustrates an alternative display configuration similar to that of FIG. 4. In FIG. 5, a field lens 502 is situated toward a surface 504 of a substrate and is spaced apart from a combiner.

With reference to FIG. 6, a display system includes a display panel 600 that includes pixel arrays 601-603. An optical spacer 604 is situated at a surface 606 of the display panel 600. Turning prisms 608, 610 are configured to direct optical beams from the arrays 601, 603 to a combiner 612. An optical beam from the array 602 is directed to the combiner 612 without a turning prism or mirror. Field lenses 620, 622 are provided for the beams from the arrays 601, 603, respectively. The optical components can be secured with glue or otherwise secured using glass support plates or other supports.

The combined beams are directed to a lens 614 that produces an image based on the pixel array images. Because the pixel arrays 601, 603 are farther from the lens 614 as measured along a lens axis than the pixel array 602, the field lenses 620,

622 are selected to produce virtual images of the arrays 601, 603 that are approximately the same distance from the lens 614 as the array 602. As shown in FIG. 6, the lenses 620, 622 are plano-concave lenses and have negative focal lengths. The lens 614 produces a higher magnification of the array 602 than the arrays 601, 603, and a display driver can be configured to electronically adjust image size on the arrays so that projected images overlap. Image convergence can be adjusted by moving image locations on the arrays. The optical system and the arrays are typically fixed together and after assembly no additional alignment is performed.

10 With respect to FIG. 7, a display system similar to that shown in FIG. 6 includes field lenses 720, 722 associated with two outer pixel arrays and a field lens 721 associated with a central pixel array. The lenses 720, 722 are shown as negative focal length, plano-concave lenses and the lens 721 is a positive focal length, plano-convex lens. The field lenses are selected so that optical path lengths from projection lens to the virtual images of the pixel arrays are substantially the same. The magnification produced by the projection lens can be different for the different pixel arrays, and such magnification differences can be compensated based on image sizes written to the pixel arrays, or by providing pixel arrays of different sizes. FIG. 8 shows a similar display system in which a field lens associated with the central pixel array is situated closer to the central pixel array.

20 FIG. 8 illustrates a configuration similar to that of FIG. 7, wherein a dichroic latter 802 is configured to illuminate three sub-panels, and a central subpanel is associated with a converging field lens 804.

25 With respect to FIG. 9, display system includes pixel arrays 901-903 that produce images that are combined with a color-combing dichroic prism 912 and directed to a projection lens 914. Rectangular prisms 904, 906 are situated in optical paths associated with the arrays 901, 903, respectively, and turning prisms 908, 910 direct optical beams from the arrays 901, 903 to a color-combing prism 912. An optical beam associated with the array 902 is directed through a space 920 to the color-combining prism 912. The thickness and refractive index of the prisms 904, 906 are selected so that images associated with the three arrays are at a common optical distance from the lens 914. An optical path length to the array 902 from the

lens 914 is shorter than optical path lengths associated with the arrays 901, 903, and image size at the array can be adjusted electronically or the array 902 can be smaller than the arrays 901, 903.

5 Several examples have been described and it will be apparent that these embodiments can be altered in arrangement and detail without departing from the scope of the disclosure. These examples are not to be taken as limiting the disclosure and we claim all that is encompassed by the appended claims.

We claim:

1. A display system, comprising:
 - a display panel that includes a first pixel array having an axis and a second
 - 5 pixel array having an axis that is displaced from the axis of the first pixel array;
 - an illumination system configured to provide a first illumination beam to the first pixel array along the axis of the first pixel array and a second illumination beam to the second pixel array along the axis of the second pixel array, wherein the first pixel array and the second pixel array are configured to modulate the respective
 - 10 illumination beams;
 - a beam combiner configured to receive the first modulated illumination beam and the second modulated illumination beam and direct the modulated illumination beams along a projection axis; and
 - a projection lens situated on the projection axis and configured to receive the
 - 15 modulated illumination beams from the beam combiner and produce an image based on a combination of the modulated illumination beams.
2. The display system of claim 1, further comprising a field lens situated in an optical path of the first modulated illumination beam, wherein the field lens is
- 20 selected so that a virtual image of the first pixel array is optically conjugate to the second pixel array with respect to the projection lens.
3. The display system of claim 2, wherein the projection axis is the axis of the second pixel array, and the field lens has a negative focal length.
- 25
4. The display system of claim 2, wherein the projection axis is the axis of the first pixel array, and the field lens has a positive focal length.
5. The display system of claim 2, wherein the display panel includes a third
- 30 pixel array that modulates an illumination beam provided to the third pixel array by the illumination system along a third axis displaced from the first and second axes, and wherein the beam combiner is configured to receive the third modulated

illumination beam and direct the third modulated beam along the projection axis and the projection lens produces an image based on a combination of the first, second, and third modulated illumination beams.

5 6. The display system of claim 5, wherein the first, second, and third illumination beams are configured to provide red, green, and blue illumination beams.

10 7. The display system of claim 6, further comprising a field lens situated in an optical path of the first modulated illumination beam, wherein the field lens is selected so that a virtual image of the first pixel array is optically conjugate to the second pixel array with respect to the projection lens.

15 8. The display system of claim 7, further comprising a field lens situated in an optical path of the third modulated illumination beam and configured to form a virtual image of the third pixel array, wherein the virtual image of the third pixel array is optically conjugate to the second pixel array with respect to the projection lens.

20 9. The display system of claim 8, wherein the projection axis is the axis of the second pixel array, and the field lenses have negative focal lengths.

25 10. The display system of claim 5, wherein the projection axis is the axis of the first pixel array and the field lens has a positive focal length.

30 11. The display system of claim 10, further comprising respective field lenses situated in optical paths of the second and third modulated illumination beams and configured to form virtual images of the second and third pixel arrays, wherein the virtual images of the second and third pixel arrays are optically conjugate to an image of the second pixel array with respect to the projection lens.

12. The display system of claim 1, wherein the display panel is a liquid crystal display panel.

13. The display system of claim 1, wherein dimensions of the first pixel array and the second pixel array are based on respective magnifications produced by the projection lens.

14. A display system comprising:
a display panel that includes at least two subpanels;
an illumination system configured to direct illumination beams to the at least two subpanels along respective subpanel axes;
an axis-shifting optical system configured to increase a displacement of the axes of the subpanels; and
projection lenses associated with each of the at least two subpanels and configured to produce a combined image of the subpanels.

15. An optical projection system, comprising:
a beam-combiner having a first input axis and a second input axis;
an axis-turning optical system configured to direct a first modulated optical beam from a first pixel array to the beam combiner along the first input axis; and
a projection lens configured to form a combined image of the first pixel array and a second pixel array situated in a common plane with the first pixel array based on the first modulated optical beam and a second modulated optical beam received from the second pixel array along the second input axis of the beam combiner.

25

16. The optical projection system of claim 15, further comprising a field lens configured to receive one of the modulated optical beams and produce a virtual image based on the received optical beam, wherein the virtual image is conjugate to an image associated with the other modulated optical beam with respect to the projection lens.

30

17. A method of displaying an image produced on a display panel, comprising:

producing a first modulated optical beam associated with a first display subpanel and a second modulated optical beam associated with a second display subpanel;

producing a virtual image of the first display subpanel that is conjugate to the second display subpanel;

combining the first and second modulated optical beams; and

producing a combined image based on the first and second modulated optical beams.

18. The method of claim 17, further comprising producing a third modulated optical beam associated with a third subpanel, combining the third modulated optical beam with the first and second modulated optical beams, and producing the combined image based on the first, second, and third modulated optical beams.

19. The method of claim 18, wherein the first, second, and third modulated optical beams are associated with red, green, and blue.

20. The method of claim 19, further comprising producing a virtual image of the third display subpanel that is conjugate to the second display subpanel.

21. The method of claim 16, wherein the virtual image of the first display subpanel is formed with a converging lens.

22. The method of claim 17, wherein the virtual image of the first display subpanel is formed with a diverging lens.

23. The method of claim 18, wherein the virtual image of the first display subpanel is formed with a converging lens and the virtual image of the third display subpanel is formed with a diverging lens.

24. The method of claim 18, wherein the virtual image of the first display subpanel is formed with a diverging lens and the virtual image of the third display subpanel is formed with a diverging lens.

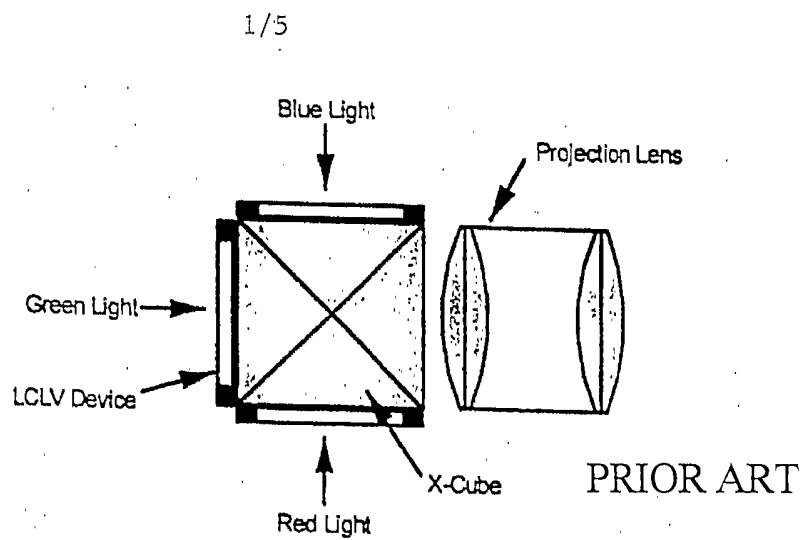


FIG. 1

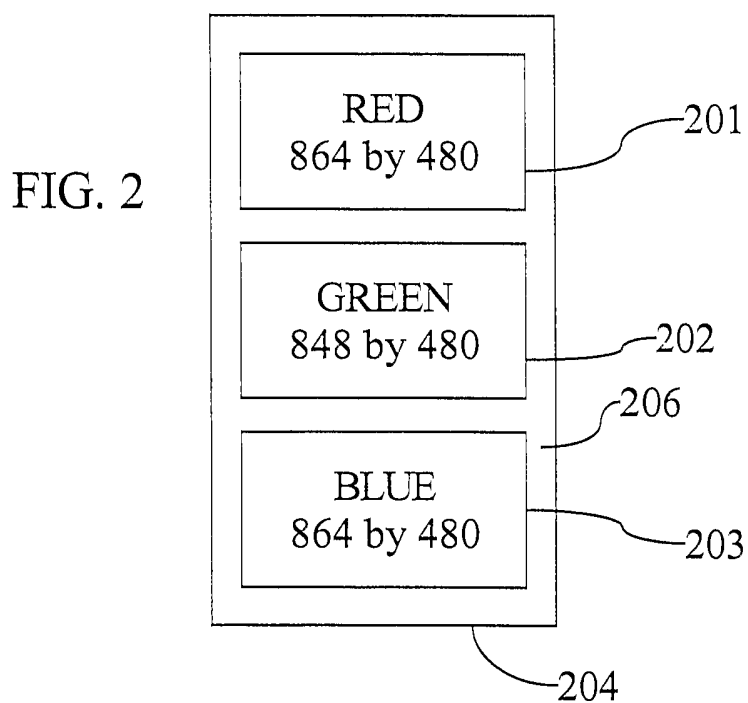


FIG. 2

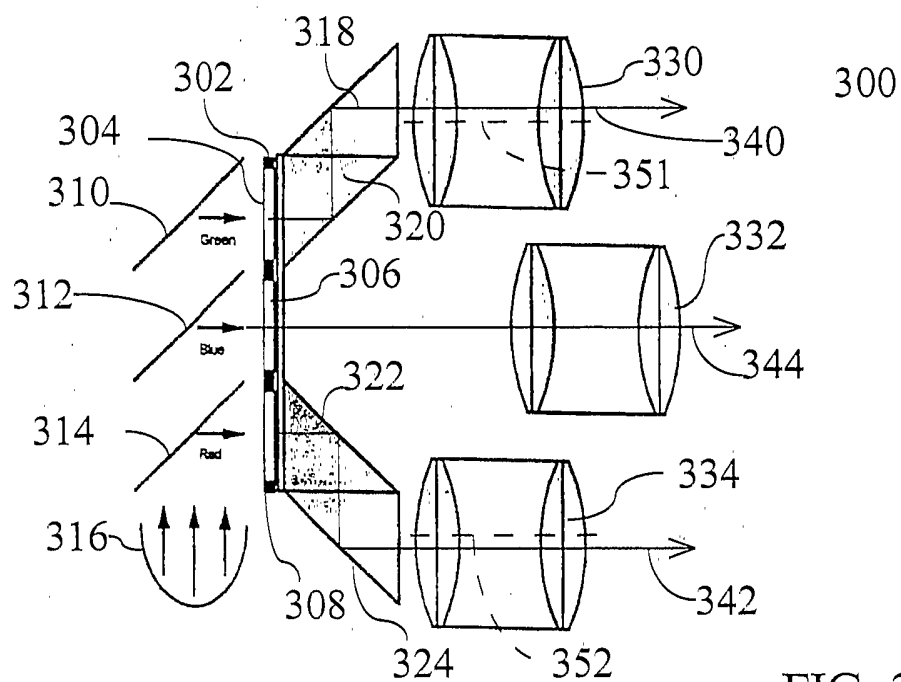


FIG. 3

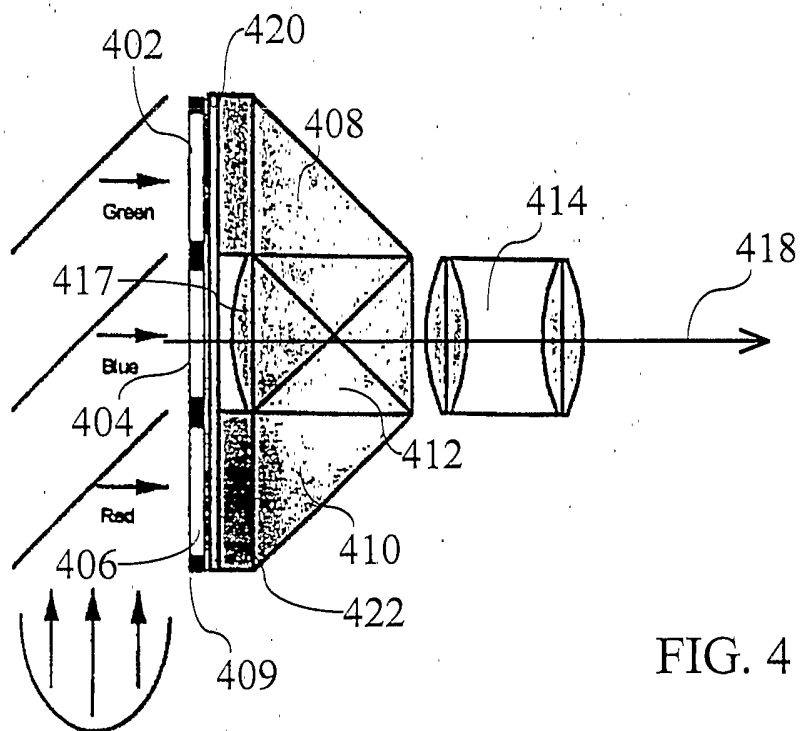


FIG. 4

3/5

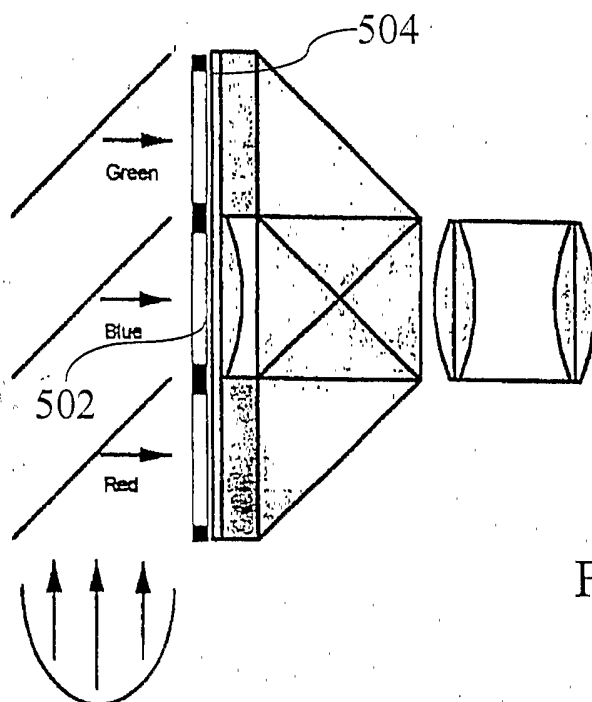


FIG. 5

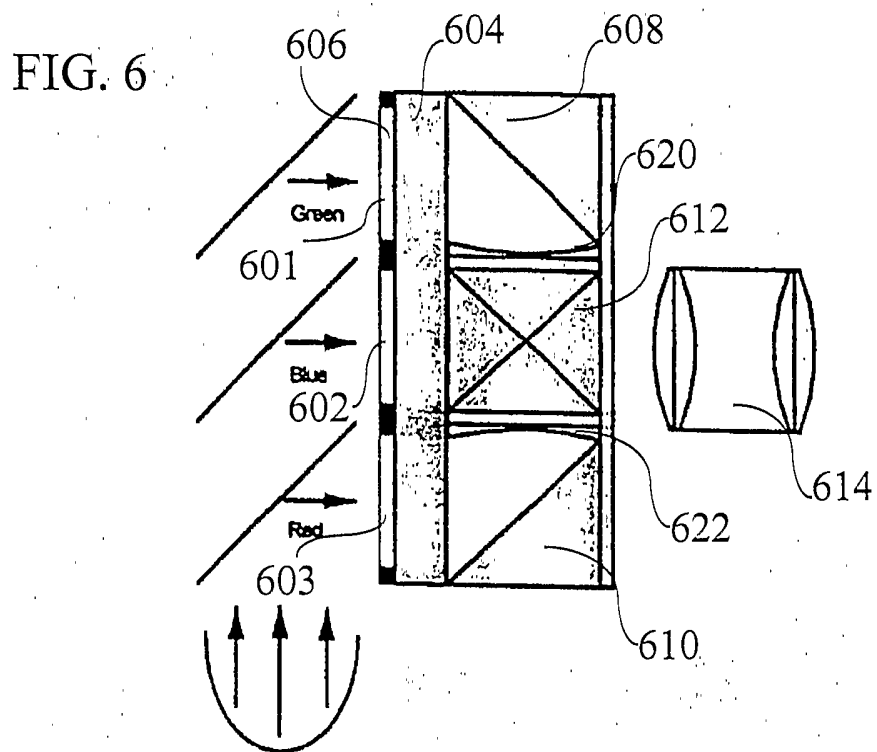


FIG. 6

4/5

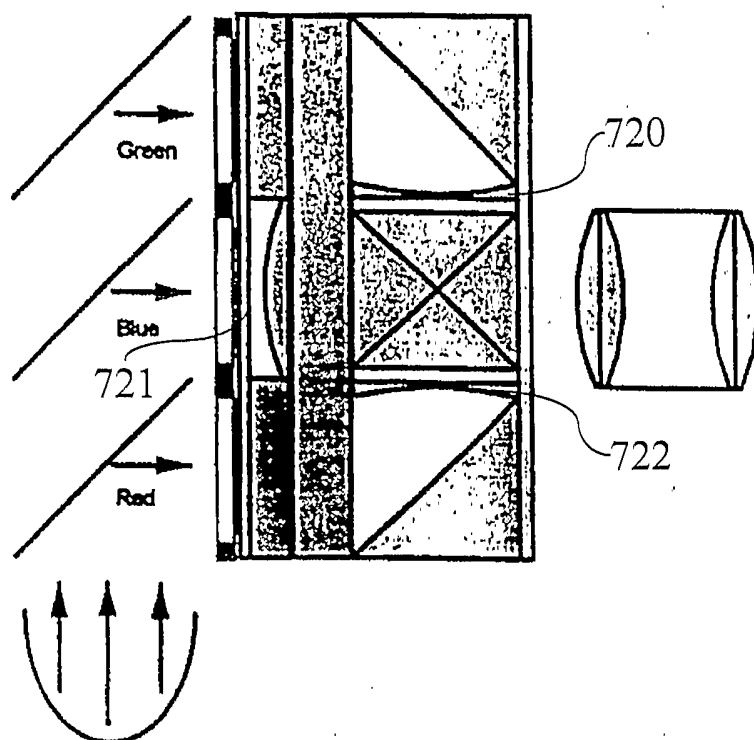


FIG. 7

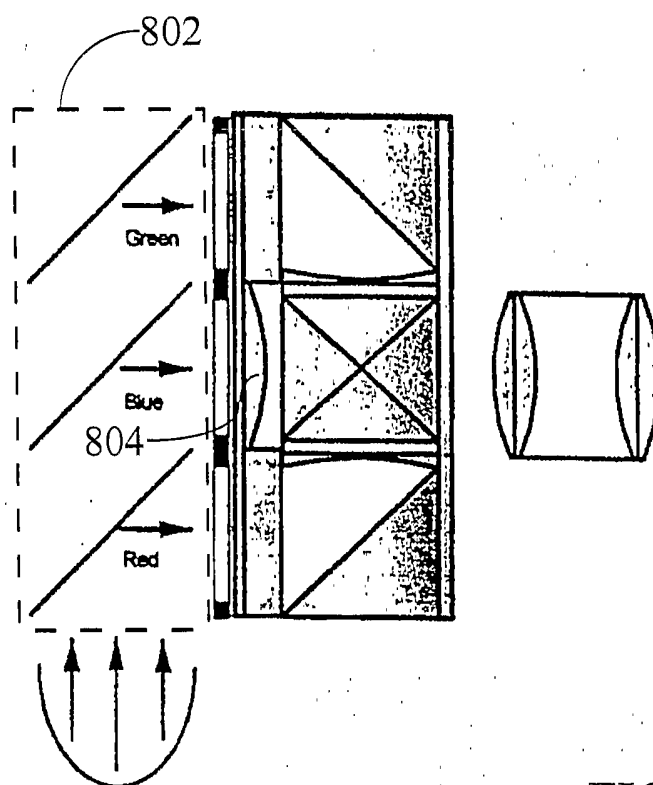


FIG. 8

