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(54) **ILLUMINATION SYSTEM FOR A HEAD UP DISPLAY**

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F21V 7/04 (2006.01)

(52) **U.S. Cl.** **362/600; 362/26; 362/27; 362/607; 362/612; 362/618**

(58) **Field of Classification Search** 362/600, 362/26, 27, 607, 612, 613, 618, 227, 235, 362/246; 348/115; 359/630, 599, 565, 742; 345/7-9, 204, 690-694; 349/61-65
See application file for complete search history.

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(57) **ABSTRACT**

An illumination system for use in illuminating a spatial light modulator for a head up display system. The illumination system includes a high power light emitting diode (LED) array assembly; and, a Fresnel lens array operatively associated with the LED array assembly for receiving light produced by the LED and providing a nearly collimated light output for use by the spatial light modulator. Utilization of the ultra bright LED array and Fresnel lens array provides the capability of the illumination source to be made very thin, light weight, and efficient. The Fresnel lens array, which converges the light to be nearly collimated, enhances the harvest of the available flux thus increasing the system efficiency and providing a system that gives the illusion of having an image at infinity. Additional components such as holographic elements, optical compensation films, and brightness enhancement films can be used to tailor the light if required.

18 Claims, 3 Drawing Sheets

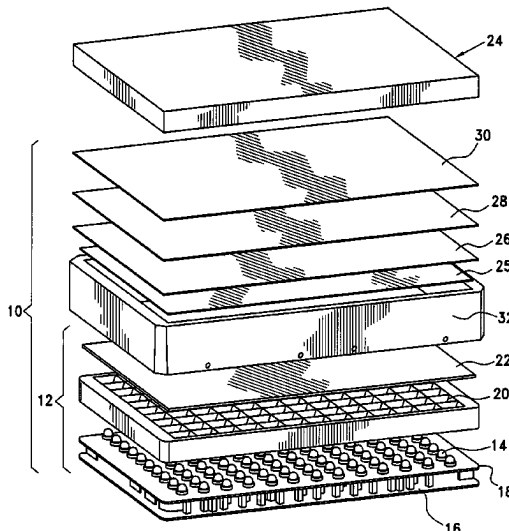


FIG. 1

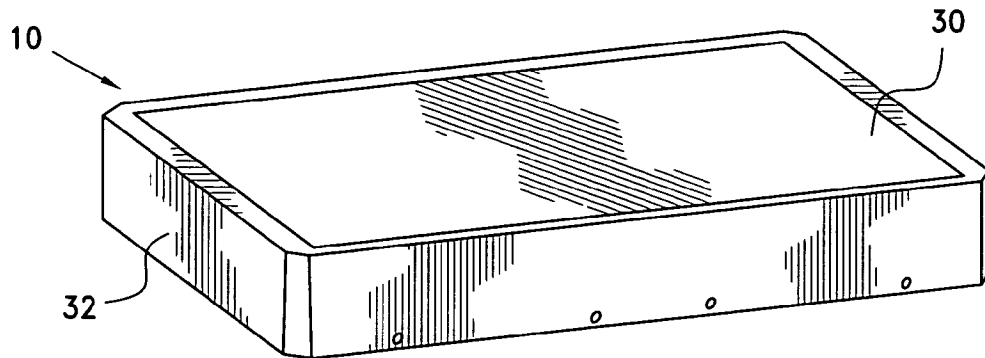
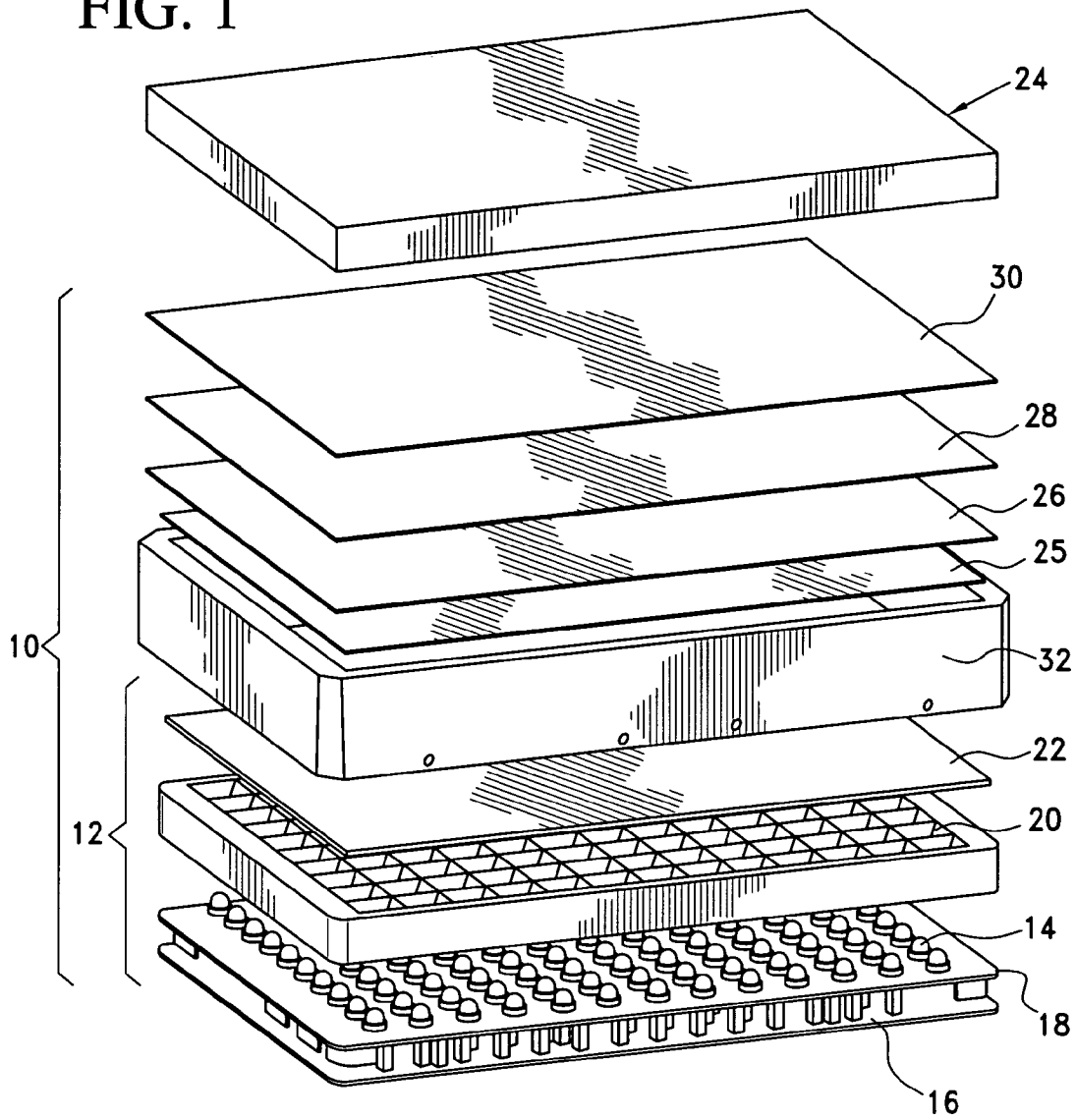


FIG. 2

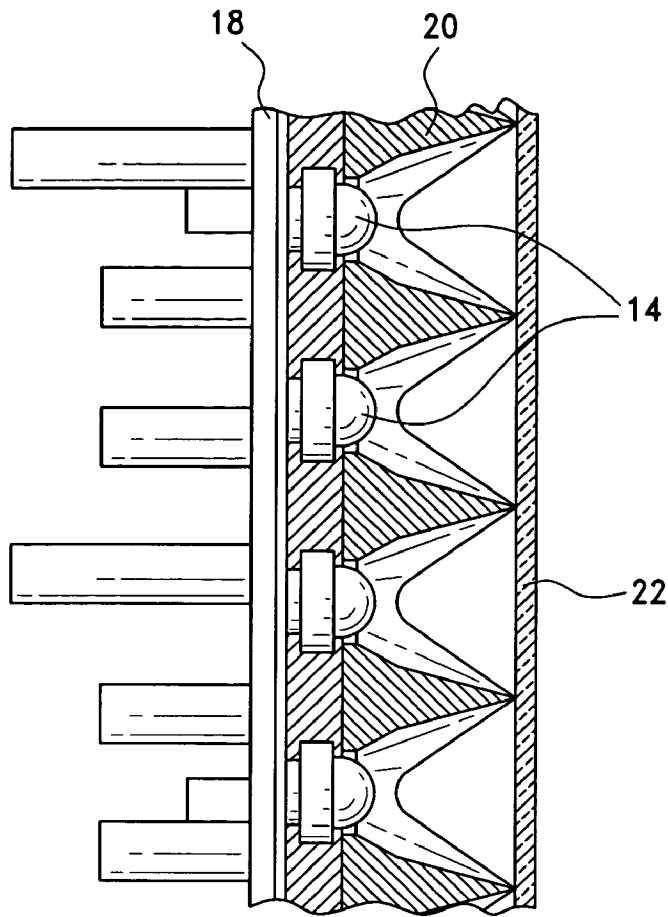


FIG. 3

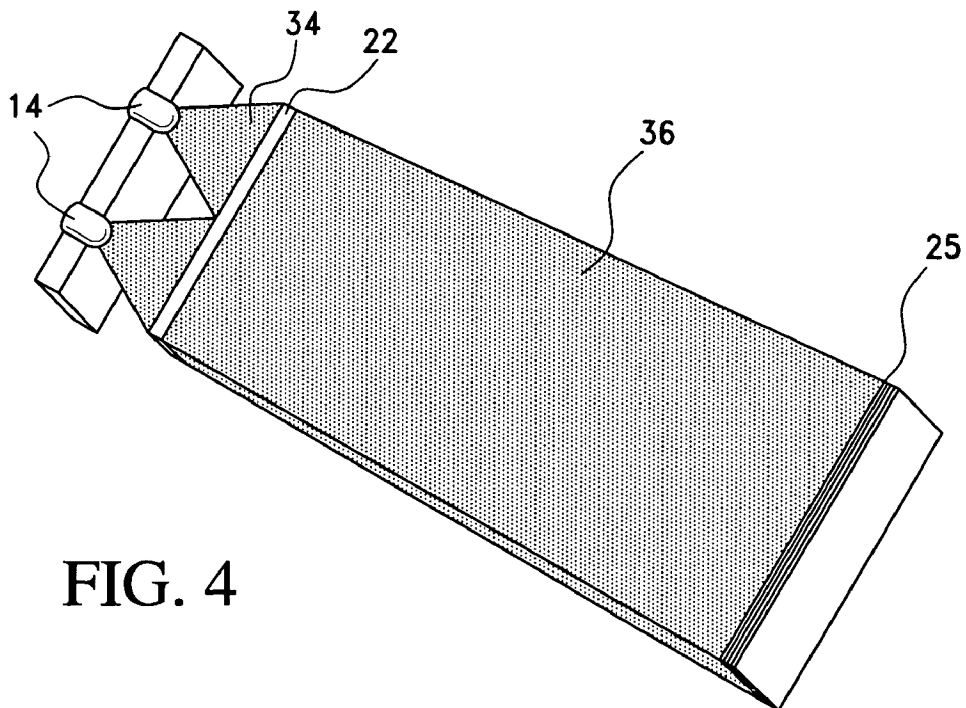


FIG. 4

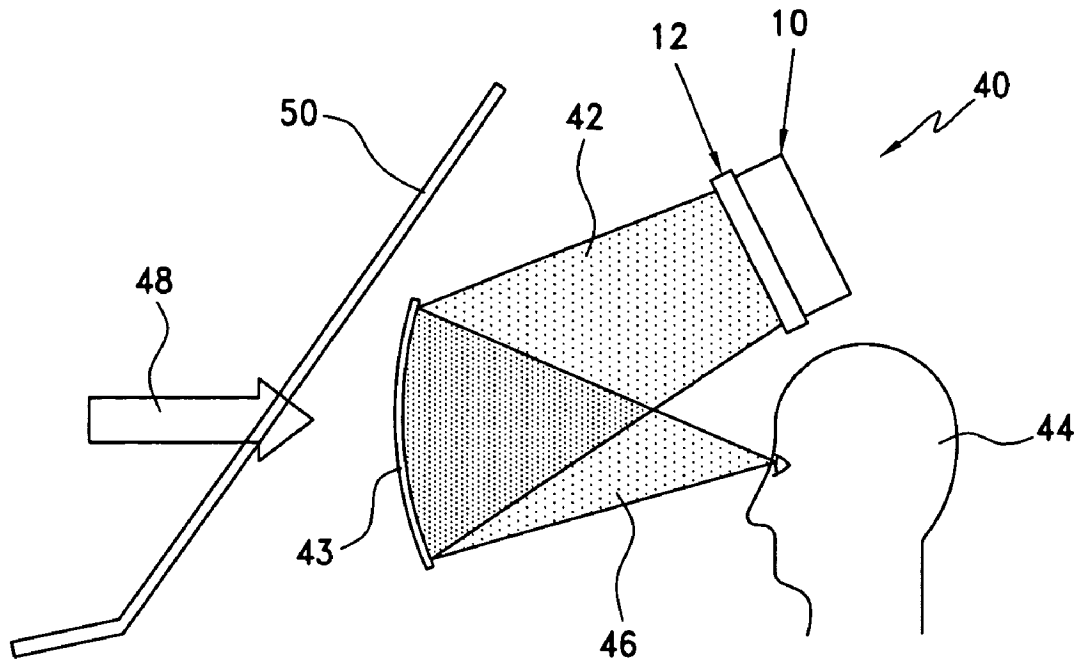


FIG. 5A

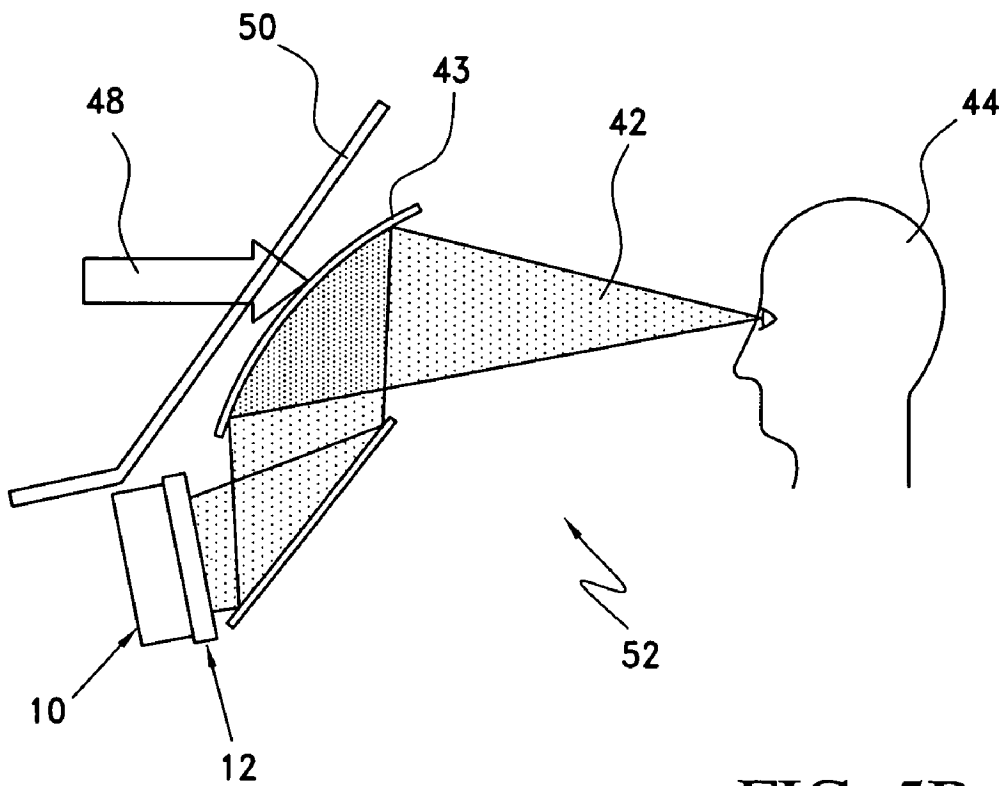


FIG. 5B

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ILLUMINATION SYSTEM FOR A HEAD UP DISPLAY

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to display systems and more particularly to an illumination system particularly adapted for use in illuminating a spatial light modulator for a head up display system.

2. Description of the Related Art

A Head Up Display (HUD) is a means of projecting information directly into a human's visual field. The HUD was pioneered for military aviation and has since been used in other applications. HUDs are typically used in aircraft to provide pilots with information superimposed onto their forward field of view through the aircraft windshield. The information displayed may be data or symbolic images indicative of flight conditions such as the operating condition of the aircraft, environmental information or guidance information for use in directing the aircraft to its destination. These images are presented in overlying fashion on the pilot's field of view so as not to interfere with the pilot's view of the background scene.

The HUDs that exist today have problems relative to volume, cost, mechanical constraints, and high ambient contrast. Typical overhead mounted HUD systems of today consist of cathode-ray tubes (CRTs), projecting onto a combiner via a series of large and complex lenses. Military HUDs are typically mounted behind the forward cockpit displays. Again, they typically consist of CRTs and a series of large lenses with a turning mirror employed in order to project onto the see-through combiner.

An example of an image source for an HUD is described in U.S. Pat. No. 5,436,763, issued to C. W. Chen et al, entitled "Wide Spectral Bandwidth Virtual Image Display Optical System". The '763 patent discloses a vertical image display optical system that uses a CRT in combination with a relay lens group to present an image to a combiner. The relay lens group includes a number of optical elements. U.S. Pat. No. 6,236,511, issued to R. D. Brown, entitled "Beam Combining Optical Element", discloses the use of an image source that is typically a cathode-ray tube that emits an image that includes a green component carried by multiple wavelengths of light within the range of approximately 540-560 nanometers (nm). Both of these patents illustrate the inherent bulkiness of the image sources in prior art HUD systems.

SUMMARY OF THE INVENTION

In a broad aspect, the present invention is an illumination system for use in illuminating a spatial light modulator for a head up display system. The illumination system includes a high power light emitting diode (LED) array assembly; and, a Fresnel lens array operatively associated with the LED array assembly for receiving light produced by the LED and providing a nearly collimated light output for use by the spatial light modulator.

Utilization of the ultra bright LED array and Fresnel lens array provides the capability of the illumination source to be made very thin, light weight, and efficient. The Fresnel lens array, which converges the light to be nearly collimated enhances the harvest of the available flux thus increasing the system efficiency and providing a system that gives the illusion of having an image at infinity. Additional components

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such as holographic elements, optical compensation films, and brightness enhancement films can be used to tailor the light if required.

Although particularly adapted for use with a head up display system the illumination system can be utilized for a direct view LCD display system. Furthermore, although a Fresnel lens array is preferably utilized, this component may optionally be substituted with a collimating lens.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an exploded perspective view of a preferred embodiment of the illumination system of the present invention, shown in relation to an LCD.

FIG. 2 is a perspective view of the assembled illumination system of FIG. 1.

FIG. 3 is a cross-sectional view of the illumination system of FIG. 1.

FIG. 4 is a schematic view of the light output from two LEDs, illustrating the collimation of the light and its passage through the illumination system.

FIG. 5A shows utilization of the present invention in an overhead mounted HUD.

FIG. 5B shows utilization of the present invention in an in-dash mounted HUD.

The same elements or parts throughout the figures of the drawings are designated by the same reference characters.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawings and the characters of reference marked thereon, FIGS. 1-3 illustrate a preferred embodiment of the illumination system of the present invention, designated generally as **10**. The illumination system **10** includes a high power light emitting diode (LED) array assembly, designated generally as **12**. The LED array assembly **12** includes LEDs **14** that are "high power". In the context of this patent this refers to LED's each having a luminous output of greater than 15 lumens and preferably greater than 20 lumens. In a preferred embodiment each LED has an output of about 36 lumens. (Green LEDs are the most typical for HUD use.)

The LED array assembly **12** includes suitable driving electronic circuitry **16** for powering the LEDs **14** and an LED heat sink **18**, as is well known in this field. Furthermore, a suitable LED light baffle **20** is utilized as is also well known in this field. Such a light baffle **20** is typically aluminum but could also be manufactured from almost any metallic or plastic material and then may be painted with reflective paint if the material is not already reflective. In applicant's present application for use with a compact HUD a 10x13 LED array is utilized. It may be, for example, a Lumen™ emitter.

A Fresnel lens array **22** is operatively associated with the LED array for receiving light produced by the LED and providing a nearly collimated light output for use by a spatial light modulator **24**. The Fresnel lens array should be consistent in size with the LED array assembly **12**. A Fresnel lens may have the following description including approximate ranges, shown along with present applicant's preferred Fresnel lens array designed for this compact HUD application:

Focal length: 0.1-3.0 inches, preferably about 0.67 in

Lenslet spacing: 0.25-5.0 inches, preferably about 0.6 in

Grooves per inch: 10-500, preferably about 125

Thickness: 0.01-0.3 inches, preferably about 0.06 inches

Array size: 1 inchx1 inch-72 inchesx72 inches, preferably about 6 inchesx7.8 inches

Overall size: 1 inch×1 inch-72 inches×72 inches, preferably about 6.4 inches×8.6 inches

Conjugate: groove— ∞ , flat—0.01-3.0, preferably about 0.67

Lenslet edge Error: <500 μ m, preferably <100 μ m

A diffuser **25** is positioned to receive light from the Fresnel lens array. The diffuser **25** may be, for example, a holographic diffuser (i.e. holographic light shaping diffuser (HLSD)) or bulk scattering diffuser. For the HUD application discussed above, the diffuser angle may be less than 20 degrees.

At least one brightness enhancement film (BEF) **26, 28** is preferably used to receive the light from the diffuser **25**. Such prismatic BEFs are commercially available from companies such as 3M Company, St. Paul Minn. that markets BEFs under the trademark Vikuiti™. A dual enhancement filter, DBEF, may be utilized.

An image directing film (IDF) **30**, typically a transparent optical composite prismatic film, redirects the output image of the BEF **28**, to the optimum viewing angle. IDFs are manufactured by 3M Company under the trademark Vikuiti™ and by Physical Optics Corp., Torrance, Calif.

The image from the IDF **30** is finally directed to the spatial light modulator **24**. The spatial light modulator **24** may be an LCD, preferably a TFT (thin film transistor) (i.e. active-matrix) LCD. Although particularly adaptable for use with a HUD, the illumination system of the present invention can be utilized with a direct view LCD such as, for example, a laptop computer or desktop computer flat panel.

The illumination system **10** is typically housed in a metal frame **32** but could be manufactured from any applicable material such as metal or plastic.

Although the invention has been preferably described as having diffusers, BEFs and IDFs some or none of these components may not be essential to the invention. They are utilized in accordance with the design parameters and desired performance of the system. If the optical performance gains are viewed as providing only marginal improvement for a given set of specifications these optical elements may or may not be included in the design.

Referring now to FIG. **4** the light emission path for two LEDs in the LED array **14** is illustrated. It can be seen that each of two LEDs emits light that is maintained substantially conical (numeral designation **34**) by the light baffle **20**. Upon passing through the Fresnel lens array **22** the light is nearly collimated, as shown by numeral designation **36**.

Implementation of the present invention with a HUD is illustrated in FIGS. **5A** and **5B**. FIG. **5A** illustrates the utilization of the illumination system **10** and LCD **12** in an overhead mounted HUD, designated generally as **40**. The illuminated light output **42** from the LCD **12** is directed to a beam combination mirror (BCM) **43**. The BCM **43** may be positioned so that the observer **44**, in a line of sight **46**, may see a visual exterior view of an outside scene **48** through the BCM **42** and the projected image **42** in the BCM **42**. The windshield is designated **50**.

According to the present invention, the image source **10, 12** may be located at any angle relative to the line of sight **42** of the observer **44**. For example, the image source **10, 12** may be located above the line of sight as illustrated in FIG. **5A**, or below the line of sight, as shown in FIG. **5B**. FIG. **5B** illustrates the utilization of the illumination system **10** and LCD **12** in an in-dash mounted HUD, designated generally as **52**. This way, flexibility in terms of relative positions between the combiner **43** and the image source may be provided, thereby leading to a great convenience when placing the optical display system in a crowded place (e.g., an airplane cockpit, a combat tank, or the like). The optical display system may

allow wide viewing angles to enable at least one of cross-cockpit viewing or crosschecking of the projected image in the beam combination mirror (BCM) **43**.

Other embodiments and configurations may be devised without departing from the spirit of the invention and the scope of the appended claims. For example, instead of utilizing a Fresnel lens a collimating lens may be used for providing a nearly collimated light output for use by the spatial light modulator. In such an instance, the collimating lens may, for example, be molded into the plastic case of the LED array assembly.

Although the present invention has been described with respect to the use of a combiner that comprises a beam combination mirror (BCM), it can be utilized with a variety of other types of combiners. For example, it can be used with a curved beam combination mirror (CBCM). U.S. Ser. No. 10/951,295, filed Sep. 27, 2004, entitled "Compact Head Up Display With Wide Viewing Angle", by co-applicants, G. Peng and M. J. Steffensmeier, and assigned to the present assignee, discloses the use of such BCM's and CBCM's in an optical display system. Patent application Ser. No. 10/951,295 is incorporated by reference herein in its entirety.

In a preferred embodiment of a HUD the illumination system of the present invention is utilized with a meniscus combiner. U.S. Ser. No. 11/196,904, entitled, "Meniscus Head Up Display Combiner", filed concurrently herewith, by co-applicants, G. Peng and M. J. Steffensmeier, and assigned to the present assignee, discloses a meniscus combiner that includes a meniscus lens; a multi-layer dichroic coating formed on a first surface of the meniscus lens; and, an anti-reflection coating formed on a second, opposite surface of the meniscus lens. This co-filed patent application is incorporated by reference herein in its entirety.

The HUD in which this illumination system may be incorporated in may be foldable up into or adjacent to a cockpit ceiling of an aircraft. Or, it may be positionable behind a dashboard of an aircraft. U.S. Ser. No. 11/197,006, entitled, "Advanced Compact head Up Display", filed concurrently herewith, by co-applicants, G. Peng and M. J. Steffensmeier, and assigned to the present assignee, discloses a HUD display system including these features. This co-filed patent application is incorporated by reference herein in its entirety. This provides a head-motion-box having dimensions greater than about 3 inches horizontal, 2 inches in vertical, and 4 inches in depth. (The head-motion-box defines a volume within which at least part of the HUD image information can be viewable.) Alternative combiners may include, for example, doublet lens, or combiners coated surfaces which are spherical, toric, aspherical, or asymmetric aspheric.

The invention claimed is:

1. An illumination system for use in illuminating a spatial light modulator for a head up display system, comprising:
 - a) a high power light emitting diode (LED) array assembly, comprising:
 - a plurality of LEDs, said LEDs each generally having a luminous output of greater than 15 lumens;
 - an LED light heat sink operatively positioned relative to said plurality of LEDs; and,
 - an LED light baffle operatively positioned relative to said plurality of LEDs;
 - b) a Fresnel lens array operatively associated with said LED array assembly for receiving light produced by said LED array assembly and providing a nearly collimated light output for use by a spatial light modulator, said LED light baffle positioned between said plurality of LEDs and said Fresnel lens array;

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- c) a diffuser positioned to receive light from said Fresnel lens array prior to being received by the spatial light modulator;
 - d) at least one brightness enhancement film (BEF) positioned to receive light from said Fresnel lens array prior to being received by the spatial light modulator; and,
 - e) an image directing film (IDF) positioned to receive light from said Fresnel lens array prior to being received by a spatial light modulator,
- wherein an image is formed at optical infinity.

2. The illumination system of claim 1, wherein said spatial light modulator comprises an active matrix liquid crystal display (AMLCD).

3. The illumination system of claim 1, wherein said LED array assembly comprises a plurality of LEDs, each LED having a luminous output of greater than 20 lumens.

4. The illumination system of claim 1, wherein said LED array assembly comprises a plurality of LEDs, each LED having a luminous output of about 36 lumens.

5. The illumination system of claim 1, wherein said diffuser is selected from the group consisting of holographic diffusers and bulk scattering diffusers.

6. The illumination system of claim 1, wherein said at least one brightness enhancement film (BEF) comprises a single BEF.

7. The illumination system of claim 1, wherein said at least one BEF comprises a plurality of brightness enhancement films (BEF).

8. An illumination system for use in illuminating a spatial light modulator for a direct view LCD display system, comprising:

- a) a high power light emitting diode (LED) array assembly, comprising:
 - a plurality of LEDs, said LEDs each generally having a luminous output of greater than 15 lumens;
 - an LED light heat sink operatively positioned relative to said plurality of LEDs; and,
 - an LED light baffle operatively positioned relative to said plurality of LEDs;
 - b) a Fresnel lens array operatively associated with said LED array assembly for receiving light produced by said LED array assembly and providing a nearly collimated light output for use by a spatial light modulator, said LED light baffle positioned between said plurality of LEDs and said Fresnel lens array;
 - c) a diffuser positioned to receive light from said Fresnel lens array prior to being received by the spatial light modulator;
 - d) at least one brightness enhancement film (BEF) positioned to receive light from said Fresnel lens array prior to being received by the spatial light modulator; and,
 - e) an image directing film (IDF) positioned to receive light from said Fresnel lens array prior to being received by a spatial light modulator,
- wherein an image is formed at optical infinity.

9. An optical display system, comprising:

an illumination system, comprising:

- a high power light emitting diode (LED) array assembly, comprising:
 - a plurality of LEDs, said LEDs each generally having a luminous output of greater than 15 lumens;
 - an LED light heat sink operatively positioned relative to said plurality of LEDs; and,
 - an LED light baffle operatively positioned relative to said plurality of LEDs; and,

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a Fresnel lens array operatively associated with said LED array assembly for receiving light produced by said LED and providing a nearly collimated light output;

- a spatial light modulator for receiving said nearly collimated light output, said spatial light modulator comprising an active matrix liquid crystal display (AMLCD);
- a combiner operatively associated with said spatial light modulator for receiving a transmitted output from said spatial light modulator for observation by a viewer in combination with an observer's visual exterior view of an outside scene;
- a diffuser positioned to receive light from said Fresnel lens array prior to being received by the spatial light modulator;
- at least one brightness enhancement film (BEF) positioned to receive light from said Fresnel lens array prior to being received by the spatial light modulator; and,
- an image directing film (IDF) positioned to receive light from said Fresnel lens array prior to being received by a spatial light modulator.

10. The illumination system of claim 9, wherein said LED array assembly comprises a plurality of LEDs, each LED having a luminous output of greater than 20 lumens.

11. An illumination system for use in illuminating a spatial light modulator for a head up display system, comprising:

- a high power light emitting diode (LED) array assembly, comprising:
 - a plurality of LEDs, said LEDs each generally having a luminous output of greater than 15 lumens;
 - an LED light heat sink operatively positioned relative to said plurality of LEDs; and,
 - an LED light baffle operatively positioned relative to said plurality of LEDs,
 - said LED array assembly further including a collimating lens for providing a nearly collimated light output for use by a spatial light modulator;
 - a diffusers positioned to receive light from said collimating lens prior to being received by the spatial light modulator;
 - at least one brightness enhancement film (BEF) positioned to receive light from said collimating lens prior to being received by the spatial light modulator; and,
 - an image directing film (IDF) positioned to receive light from said Fresnel lens array prior to being received by a spatial light modulator,
- wherein an image is formed at optical infinity.

12. The illumination system of claim 11, wherein said spatial light modulator comprises an active matrix liquid crystal display (AMLCD).

13. The illumination system of claim 11, wherein said LED array assembly comprises a plurality of LEDs, each LED having a luminous output of greater than 20 lumens.

14. The illumination system of claim 11, wherein said LED array assembly comprises a plurality of LEDs, each LED having a luminous output of about 36 lumens.

15. The illumination system of claim 11, wherein said diffuser is selected from the group consisting of holographic diffusers and bulk scattering diffusers.

16. The illumination system of claim 11, wherein said at least one brightness enhancement film (BEF) comprises a single BEF.

17. The illumination system of claim 11, wherein said at least one BEF comprises a plurality of brightness enhancement films (BEF).

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18. An illumination system for use in illuminating a spatial light modulator for a direct view LCD displays system, comprising:

- a high power light emitting diode (LED) array assembly, comprising:
 - a plurality of LEDs, said LEDs each generally having a luminous output of greater than 15 lumens;
 - an LED light heat sink operatively positioned relative to said plurality of LEDs; and,
 - an LED light baffle operatively positioned relative to said plurality of LEDs,
- said LED array assembly further including a collimating lens for providing a nearly collimated light output for use by a spatial light modulator;

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a diffuser positioned to receive light from said collimating lens prior to being received by the spatial light modulator;

at least one brightness enhancement film (BEF) positioned to receive light from said collimating lens prior to being received by the spatial light modulator; and,

an image directing film (IDF) positioned to receive light from said Fresnel lens array prior to being received by a spatial light modulator,

wherein an image is formed at optical infinity.

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