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(54) **HIGH CONTRAST PROJECTION**

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5, 2002, now Pat. No. 6,637,894.

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6, 2001.

(51) **Int. Cl.**
G03B 21/14 (2006.01)
G02B 9/00 (2006.01)
G02B 3/00 (2006.01)

(52) **U.S. Cl.** **353/97**; 353/1; 359/740;
359/649

(58) **Field of Classification Search** 353/99,
353/97, 31, 33, 81; 359/292, 740, 589, 634,
359/649, 837, 833; 349/8; 352/216, 209
See application file for complete search history.

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Primary Examiner—W. B. Perkey

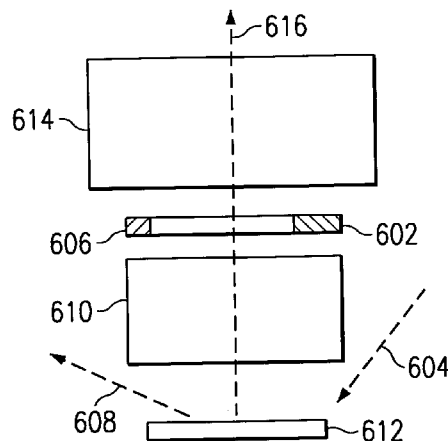
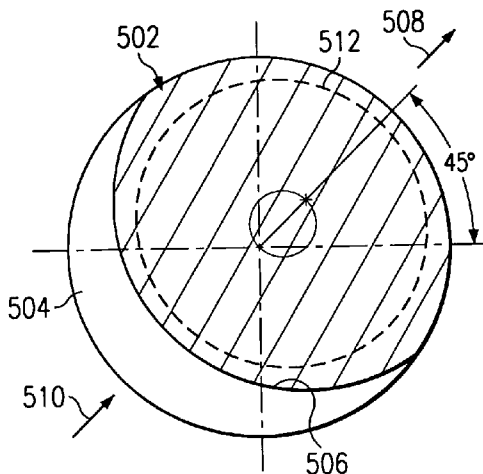
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(57) **ABSTRACT**

A method and system for improving the contrast ratio of a projected image. An asymmetric aperture stop improves the contrast ratio of a projected image. Using slightly offset projection, the majority of the on-state projection light from the modulator array passes through a region that is not centered in the projection lens pupil. The blocked region of the asymmetric aperture is oriented toward the illumination path and away from the specular reflection path. The asymmetric aperture is able to block a significant portion of the diffracted light using the blocked region, without blocking much of the desired projection light passing through the remainder of the aperture. The result is that dark regions of the image become significantly darker, while light regions remain about the same. The same effect occurs without offset illumination.

15 Claims, 3 Drawing Sheets



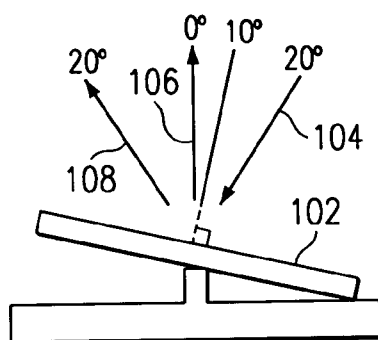


FIG. 1

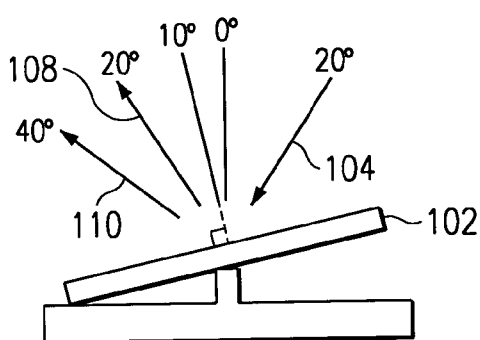


FIG. 2

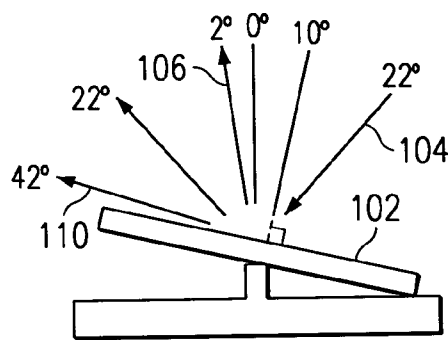


FIG. 3

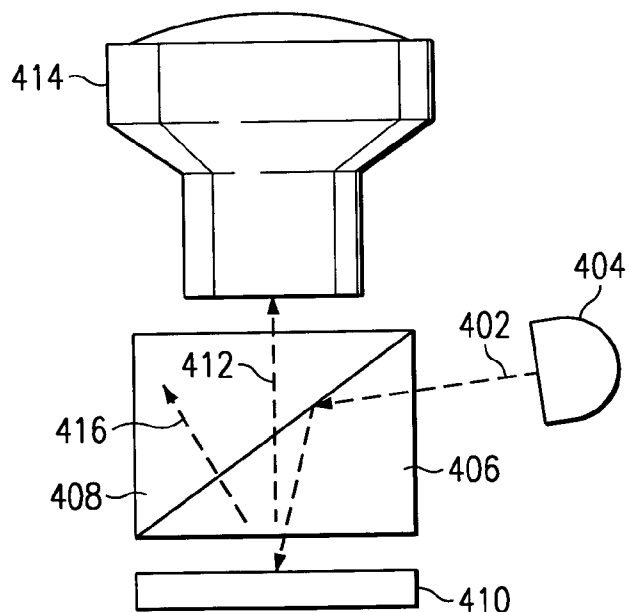
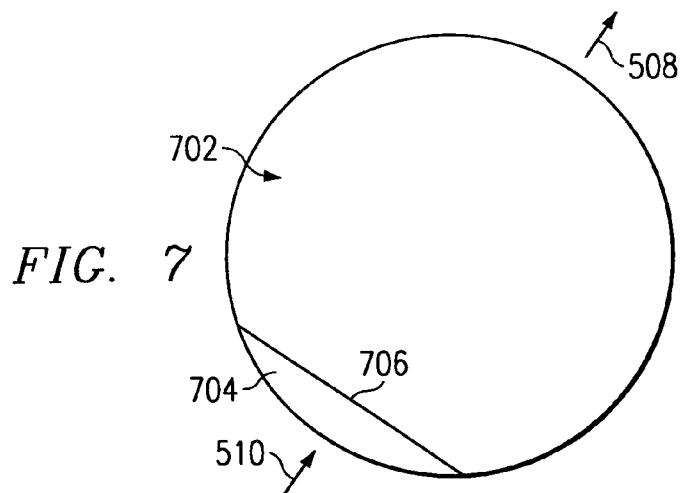
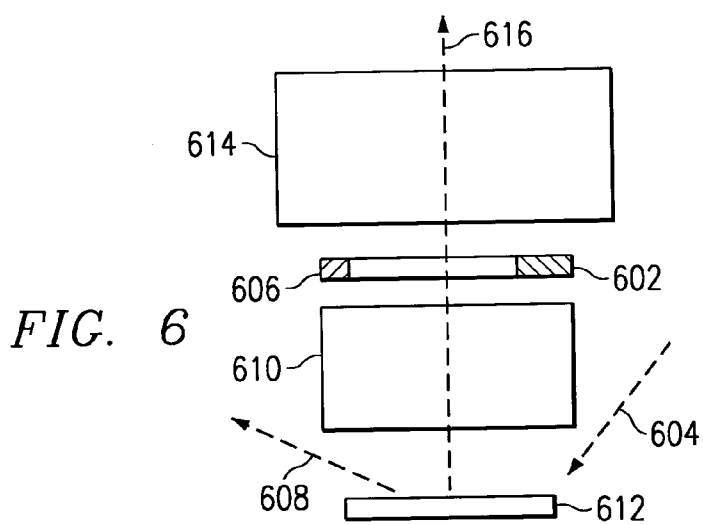
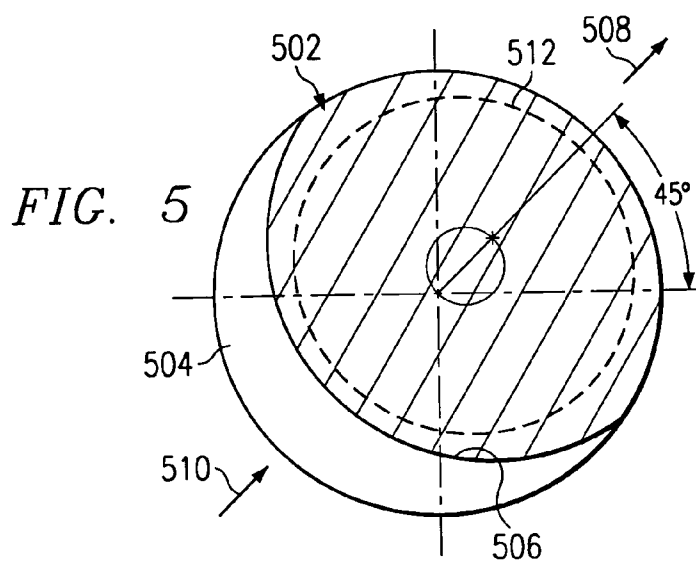


FIG. 4



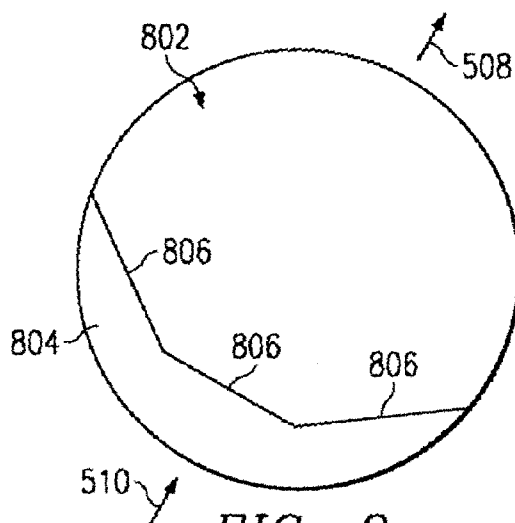


FIG. 8

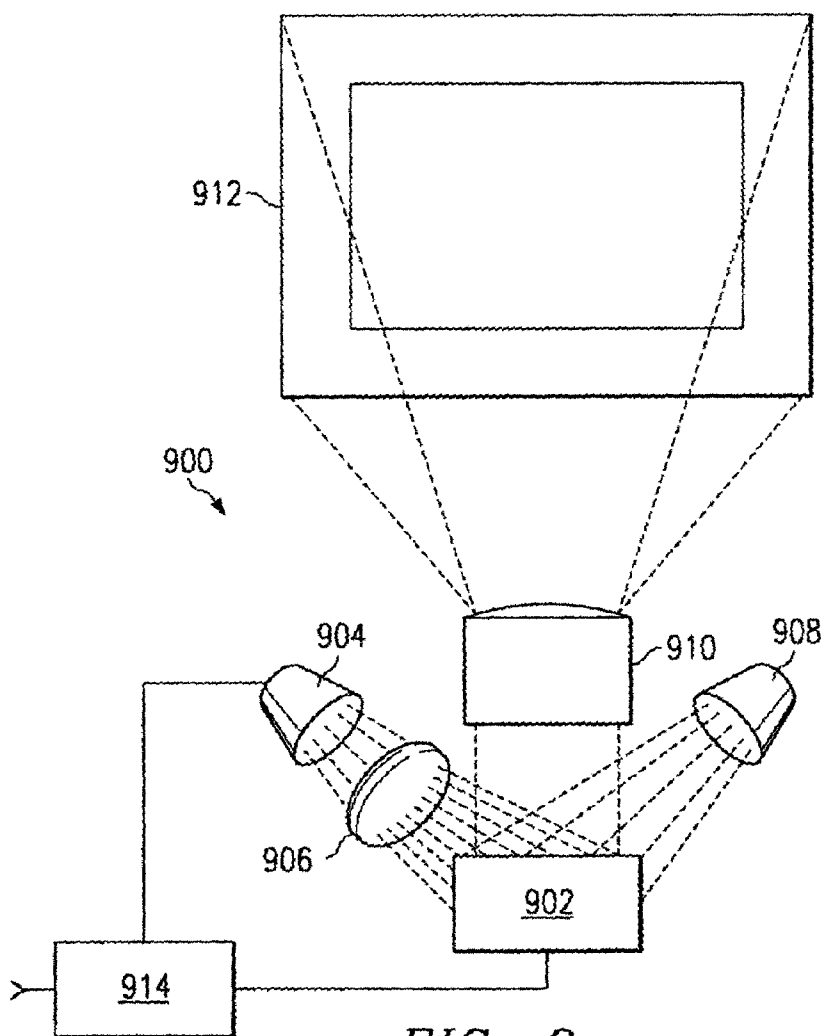


FIG. 9

HIGH CONTRAST PROJECTION

This application is a Divisional of application Ser. No. 10/092,043, filed Mar. 5, 2002 now U.S. Pat. No. 6,637,894 and Provisional Application No. 60/273,756, filed Mar. 6, 2001.

FIELD OF THE INVENTION

This invention relates to the field of lens systems, more particularly to lens systems used with micromirror based projection display systems.

BACKGROUND OF THE INVENTION

Micromirror projection display systems are rapidly gaining acceptance in a wide variety of applications, from sub-three pound portable projectors to cinema-quality projectors. The cinema projectors provide the image quality of traditional film projectors, without the expense and degradation associated with filmstrip projection. Existing cinema projectors provide contrast ratios in excess of 1000:1. What is needed is a method of increasing the contrast ratio of micromirror projectors.

SUMMARY OF THE INVENTION

Objects and advantages will be obvious, and will in part appear hereinafter and will be accomplished by the present invention which provides a method and system for increasing the contrast ratio of a display system. One embodiment of the claimed invention provides a lens system. The lens system comprising: a first lens group on a light path; a second lens group on the light path; and an asymmetric aperture stop on the light path between the first and second groups.

Another embodiment of the present invention provides a display system. The display system comprising: a light source for providing a beam of light along an illumination path; a micromirror device on the illumination path for receiving the beam of light and selectively reflecting the beam of light along a projection path; a lens system on the projection path. The lens system comprises: at least one lens; and an asymmetric aperture stop receiving light from at least one of the lenses.

Yet another embodiment of the present invention provides a method of projecting an image. The method comprises: receiving an illumination light beam along an illumination path; selectively reflected the illumination light beam along a projection path in response to image data; focusing selectively reflected light using a projection lens; and blocking a portion of light passing through the projection lens using an asymmetric aperture.

According to one embodiment of the present invention, the asymmetric aperture stop is formed by adding a blocking region to an otherwise circular aperture. The blocking region is oriented towards the illumination path and away from a spectral reflection path. One embodiment uses a crescent shaped blocking region. The thickness of the crescent is 17% of the diameter of the aperture. The inside radius of the crescent is equal to the radius of the circular portion of the aperture. Alternative embodiment use blocking regions having other shapes.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following description taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a schematic side view of a single micromirror element in a first deflected position showing the path of illumination light and reflected projection light.

FIG. 2 is a schematic side view of a single micromirror element in a second deflected position showing the path of illumination light and reflected light.

FIG. 3 is a schematic side view of a single micromirror element in a first deflected position showing the path of shifted illumination light and reflected projection light.

FIG. 4 is a side view of a portion of a display system showing illumination and projection paths passing through a prism assembly.

FIG. 5 is a plan view of a pupil in a projection lens showing one embodiment of an asymmetric aperture.

FIG. 6 is a side view of a portion of a display system showing an orientation of the asymmetrical aperture stop of FIG. 5.

FIG. 7 is a plan view of a pupil in a projection lens showing another embodiment of an asymmetric aperture.

FIG. 8 is a plan view of a pupil in a projection lens showing another embodiment of an asymmetric aperture.

FIG. 9 is a schematic view of a micromirror-based projection system utilizing an improved projection lens according to one embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A new method and system for projecting an image has been developed. The method and system use an asymmetric aperture stop in a projection lens to block scattered light without blocking the desired projection light. The method and system provide an 20–30% improvement in contrast when applied to a micromirror-based display system using off-axis illumination.

FIG. 1 is a schematic side view of a single micromirror element in a first deflected position showing the path of illumination light and reflected projection light. In FIG. 1, a single element or mirror 102 of a micromirror device is shown. Most useful micromirror devices have many mirrors, often on the order of one million. The mirror 102 of FIGS. 1–3 is operable to tilt 10° in one of two directions. The mirror 102 is tilted to a first position in FIG. 1. The first position shown in FIG. 1 is often called the “on” position since it causes light from a source to be reflected approximately normal to the surface of the micromirror array to a projection lens. The projection lens focuses the light onto an image plane such that the light from an “on” mirror creates a bright pixel. Of course, the conventions described herein can be altered without destroying the application of this invention.

In FIG. 1, the illumination path 104, the path of the light from a light source, strikes the micromirror at an angle of 20° relative to the normal of the mirror when it is not deflected. The mirror 102 is rotated about an axis perpendicular to the plane of FIG. 1 in a clockwise direction towards the illumination path 104 at an angle of one-half of the angle of the illumination path. The result is the light reflected by the on-state mirror is reflected along a path 106 normal to the plane of the device.

In addition to the light reflected by the mirror **102**, light is reflected by the structures surrounding the mirror **102**, including any aperture around the mirror array (not shown). Reflection by structures parallel to the plane of the array is considered specular reflection or flat state reflection and follows specular path **108**.

In addition to the specular reflection and the light reflected by the deflected mirrors, light striking between the mirrors may be scattered by multiple reflections from structures under the mirrors and the underside of the mirrors. Light is also diffracted by the edges of the structures. Scattered light and diffracted light exit the micromirror array in virtually all directions. The scattered light and diffracted light reaching the projection lens tend to raise the black level of the projected image. This lowers the contrast ratio of the image since the contrast ratio is the ratio of a maximum brightness pixel and a minimum brightness pixel.

FIG. **2** is a schematic side view of the single micromirror **102** of FIG. **1** in a second deflected position. In FIG. **2**, the mirror is rotated 10° in a direction opposite the "on" direction shown in FIG. **1**. In FIG. **2**, light at a 20° illumination angle is reflected by the "off-state" pixel at an angle 40° away from the normal angle. Comparing FIGS. **1** and **2** shows a 40° separation between on-state light and off-state light, and a 20° separation between illumination light and on-state light.

Separation between the illumination path **104** and the projection path **106** is necessary to prevent interference of the light source optics and the projection optics. Separation between the projection path **106** and the off-state light path **110**, or dump light path, is necessary to allow the projection optics to collect the on-state light while avoiding the off-state light. The projection optics should also avoid collecting the specularly reflected light, the scattered light, and the diffracted light.

FIG. **3** is a schematic side view of the single micromirror element **102** in the first deflected position showing the illumination light path shifted away from the device normal in the illumination direction. Typically, a micromirror that is capable of rotating 10° in either direction is illuminated at an angle of 22° . Keeping the axis of the projection lens normal to the micromirror array when using a 22° illumination angle in combination with a 10° micromirror tilt angle provides a separation between the projection lens and the illumination path of 22° , a 22° separation between the projection lens and the specular reflections, and a 42° separation between the projection lens and the off-state light. This increased separation has been found to reduce the amount of specular reflection entering the pupil of the projection lens.

One common method of further separating the projection and illumination paths is shown FIG. **4**. FIG. **4** is a side view of a portion of a display system showing illumination and projection paths passing through a prism assembly. Light **402** from a light source **404** enters a first prism **406** and is reflected at an interface between the first prism **406** and a second prism **408**. The reflected light travels to the micromirror array **410** and is selectively reflected by the array depending on the state of the mirrors. Light reflected by the on-state mirrors travels along path **412** and, because it strikes the interface at a steeper angle than the illumination light, passes through the interface and enters a projection lens **414**. Light reflected by the off-state mirrors follows path **416** and does not enter the pupil of the projection lens **414**.

FIG. **5** is a plan view of a pupil of a projection lens showing one embodiment of an asymmetric aperture. In FIG. **5**, the aperture stop forms an asymmetric aperture, shown by cross-hatched region **502**. The asymmetric aper-

ture has a predominately circular shape, but a portion **504** of the circular aperture is blocked. The aperture stop may be formed using multiple components, including lens holders or other components of the lens such as the lens barrel.

In a preferred embodiment, the blocked region is a crescent shape with an inside edge **506** having a radius equal to the radius of the circular portion of the aperture. The center of curvature of the inside edge is shifted away from the center of the circular aperture by approximately 17% of the diameter of the circular portion of the aperture in a direction toward the specular reflection **508** and away from the illumination path **510**.

As shown in FIG. **6**, this arrangement orients the blocking portion **602** of the aperture stop toward the illumination path **604**, and the thinner portion **606** of the aperture stop toward the specular reflection path **608**. Also shown in FIG. **6** are a first lens group **610** located between the aperture stop and the spatial light modulator **612** and a second lens group **614** on the projection path **616** on an opposite side of the aperture stop from the first lens group **610**. Both of the lens groups **610**, **614** may comprise a single lens or more than one lens.

The asymmetric aperture stop described above provides a 20–30% improvement in the contrast ratio of a projected image. Returning to FIG. **5** it is seen that the majority of the on-state projection light from the modulator array passes through a region **512** that is not centered in the projection lens. This offset, while not necessary to the operation of this present invention, is caused by the increased illumination angle of FIG. **3** which results in the projection lens operating in a slightly offset mode. The asymmetric aperture **502** is able to block a significant portion of the diffracted light using the blocked region **504**, without blocking much of the desired projection light passing through the remainder of the aperture. The result is that dark regions of the image become significantly darker, while light regions remain about the same. The same effect occurs without the offset illumination shown in FIG. **3**, but to a lesser extent.

FIG. **7** is a plan view of a pupil in a projection lens showing another embodiment of an asymmetric aperture **702**. In FIG. **7**, a circular aperture is blocked over region **704**. As with the other examples described herein, the basic aperture need not be circular. The blocked region **704** of FIG. **7** is defined by a straight edge **706**.

FIG. **8** is a plan view of a pupil in a projection lens showing another embodiment of an asymmetric aperture **802**. In FIG. **8**, the otherwise circular aperture is blocked over region **804**. The blocked region **804** is defined by three straight edges **806** and the circular perimeter of the basic aperture.

FIG. **9** is a schematic view of a micromirror-based projection system **900** utilizing an improved projection lens **910** according to one embodiment of the present invention. In FIG. **9**, light from light source **904** is focused on the spatial light modulator **902** by lens **906**. Although shown as a single lens, lens **906** is typically a group of lenses and mirrors which together focus and direct light from the light source **904** onto the surface of the micromirror device **902**. Image data and control signals from controller **914** cause some mirrors to rotate to an on position and others to rotate to an off position. Mirrors on the micromirror device that are rotated to an off position reflect light to a light trap **908** while mirrors rotated to an on position reflect light to projection lens **910**. Projection lens **910** includes the asymmetric aperture stop and focuses the light modulated by the spatial light modulator device **902** onto an image plane or screen **912**.

Thus, although there has been disclosed to this point a particular embodiment for a high contrast lens, display

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system, and method therefore, it is not intended that such specific references be considered as limitations upon the scope of this invention except insofar as set forth in the following claims. Furthermore, having described the invention in connection with certain specific embodiments thereof, it is to be understood that further modifications may now suggest themselves to those skilled in the art, it is intended to cover all such modifications as fall within the scope of the appended claims. In the following claims, only elements denoted by the words "means for" are intended to be interpreted as means plus function claims under 35 U.S.C. § 112, paragraph six.

What is claimed is:

- 1. A lens system comprising:
 - a first lens group on a light path;
 - a second lens group on said light path; and
 - an asymmetric aperture stop on said light path between said first and second groups, said asymmetric aperture stop forming a predominately circular aperture, said aperture having a side portion thereof blocked by said asymmetric aperture stop.
- 2. The lens system of claim 1, said side portion comprising a crescent shaped portion.
- 3. The lens system of claim 2, said side portion comprising a crescent shaped portion encroaching approximately 17% into said aperture.
- 4. A lens system comprising:
 - a first lens having an axis;
 - a second lens on said axis; and
 - an asymmetric aperture stop on said axis between said first lens and said second lens, said asymmetric aperture stop forming a predominately circular aperture.
- 5. The lens system of claim 4, said aperture having a side portion thereof blocked by said asymmetric aperture stop.

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- 6. The lens system of claim 5, said side portion comprising a crescent shaped portion.
- 7. The lens system of claim 6, said side portion comprising a crescent shaped portion encroaching approximately 17% into said aperture.
- 8. The lens system of claim 6, said crescent shaped portion comprised of at least one straight segment along a boundary between said aperture and said side portion.
- 9. The lens system of claim 6, said crescent shaped portion comprised of at least one curved segment along a boundary between said aperture and said side portion.
- 10. A lens system comprising:
 - a first lens on a projection light path;
 - a second lens on said projection light path; and
 - an asymmetric aperture stop on said light path between said first lens and second lens, said asymmetric aperture stop forming a predominately circular aperture.
- 11. The lens system of claim 10, said aperture having a side portion thereof blocked by said asymmetric aperture stop.
- 12. The lens system of claim 11, said side portion comprising a crescent shaped portion.
- 13. The lens system of claim 11, said side portion comprising a crescent shaped portion encroaching approximately 17% into said aperture.
- 14. The lens system of claim 13, said crescent shaped portion comprised of at least one straight segment along a boundary between said aperture and said side portion.
- 15. The lens system of claim 13, said crescent shaped portion comprised of at least one curved segment along a boundary between said aperture and said side portion.

* * * * *