

PROJECTING IMAGES

The invention relates to projecting images.

5 Referring to Figure 1, light projectors are used, for example, to display images on large surfaces, such as movie or television screens. In a front projection system 20, an image beam 24 is projected from an image source 21 onto the "front" side of a reflection-type
10 angle transforming screen, which then reflects the light toward a viewer 27 positioned in front of the screen. In a rear projection system, the image beam is projected onto the "rear" side of a transmission-type angle transforming screen 26 and transmitted toward a viewer 29
15 located in front of the screen.

Due to the physical properties of light, the size of the image beam 24 when it reaches the screen 26 depends upon the magnification rate of the image source 21 and the distance between the screen 26 and the image
20 source 22. To efficiently utilize the screen 26, the image beam 24 should just fill the entire height S and width (not shown) of the screen 26. In Figure 1, the image beam 24 fills the screen 26 when the source 22 is at an appropriate distance D from the screen 26, i.e.,

when the center of the image beam 24 follows an optical path 28 of length D . The optical path length D depends upon the screen height S and the magnification rate of the image source. Any non-transparent object placed in the path of the image beam 24 typically will obstruct the image beam 24 and form a shadow on the screen 26.

Referring to Figure 2, designers have reduced the size of the typical image projection system 30 by "folding" the optical path of the projected image beam to reduce the apparent projection length L of the system 30.

The "folded" system 30 includes one or more mirrors 34, 36 placed at strategic points along the optical path to redirect the projected image and to form multiple optical subpaths $D1$, $D2$, $D3$. The overall system configuration in this optical system 30 is more rectilinear than the conical system configuration of Figure 1.

In the folded image projection system 30, assuming that the image source 40 and the screen 32 are similar to those in Figure 1, the image 38 fills the screen 32 entirely when the mirrors 34, 36 are positioned such that the combined length of the optical subpaths $D1$, $D2$, and $D3$ equals the optical path length D in Figure 1, even though the apparent projection length L is less than D .

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An "extra-folded" projection display system includes a selectively reflective material (e.g., a linear reflecting polarizer) placed immediately behind the system's imaging screen. The display system includes an image projector that projects an image beam containing light of a predetermined linear polarization toward the imaging screen. The linear reflecting polarizer reflects the light in the image beam away from the screen. The reflected image beam then encounters a $1/4$ -wavelength achromatic retarder which converts the linear polarization to circular polarization. The image beam

next hits a mirror that reflects the light back through the 1/4-wavelength achromatic retarder, which converts the circular polarization back to linear polarization, with the polarization director rotated 90° from the
5 original polarization director. The linear reflecting polarizer then allows the light to pass through to the image screen.

Embodiments of the invention may include the following features. The system may include a powered
10 optical element to further increase the "folding" of the image beam, change the magnification rate, provide distortion correction, or optimize packaging. The image beam may be folded even further by allowing it to reflect from the mirror twice and to pass through the achromatic
15 retarder four times. The mirror may be positioned between the image source and the imaging screen.

Advantages of the invention may include one or more of the following. An optical element placed immediately behind the screen in a projection imaging
20 system may act as a "mirror" that increases the amount of folding that the light undergoes and therefore may reduce the apparent projection length, or depth, of the system to a greater extent than previously possible. The image source may be placed behind all optical elements in the
25 display system, further reducing the size of the system.

Other advantages and features will become apparent from the following description and from the claims.

30 Figure 1 is a side view of a prior art projection display system.

Figure 2 is a side view of a prior art folded projection display system.

Figures 3, 4, and 5 are side views of an "extra-
35 folded" projection display system.

Figures 6A and 6B are "patchwork" polarizers that

may be used in the system of Figures 3, 4, and 5.

Figures 7A, 7B, and 7C are specialized achromatic retarders that may be used in the system of Figures 3, 4, and 5.

5 Figures 8, 9, and 10 are side views of alternative "extra-folded" projection video systems.

Figures 11A and 11B are side and front views of a configuration of multiple projection video systems of Figure 8.

10 Figures 12A and 12B are side and front views of a configuration of multiple projection video systems of Figure 9.

Figures 13, 14A, and 14B are side views of alternative "extra-folded" projection video systems with
15 powered optical devices.

Figure 15 is a computer system having an "extra-folded" projection video display.

Referring to Figure 3, an "extra-folded"
20 projection video system 50, such as a projection television, includes a diffusive screen 52 having a surface 54 that is covered by a selectively reflective or transmissive material. The selectively reflective or transmissive surface 54 allows the screen 52 to act at
25 times as a mirror and at times as a transmissive imaging screen. As a result, an image 55 contained in an image beam 56 projected by an image projector 58 reflects from the rear surface 54 of the screen the first time it encounters the surface 54. The image beam 56 then
30 travels toward a mirror 60 located behind the screen 52, which in turn reflects the light 56 back toward the screen 52. When the image 55 in the image beam 56 encounters the rear surface 54 of the screen 52 the second time, the image 55 passes through the screen 52
35 toward the viewer 62.

In this manner, the screen 52 essentially acts as

a "mirror" placed directly between the viewer 62 and the rear mirror 60. The screen 52 reflects the image beam 56 away from the viewer but does not block the image beam 56 or significantly deteriorate the quality of the image 55
5 seen by the viewer. Because a "mirror" is placed at a position along the optical path that previously had to be free from such objects, the image beam 56 projected from the image source 58 is "extra-folded", i.e., folded more often and over a much smaller linear distance L' than is
10 possible with existing systems.

The projection system 50 receives an electronic signal through an input cable 51 and provides it to a signal splitter 53. The signal splitter 53 divides the electronic signal into a video signal and an audio signal
15 and provides these signals to the image source 58 and a sound system 57, respectively. The image source 58 converts the video signal into light and projects the light as an image beam 56. The image source 58 may be any type of image projection engine, such as a liquid
20 crystal display ("LCD") projector. The electronic signal may be any type of signal containing video information, such as a television signal received by an antenna or over cable lines or a computer video signal received through a computer video cable. The audio signal and the
25 sound system 57 are optional.

Referring also to Figure 4, the screen 52 is able to act as a mirror at some times and as an imaging screen at other times because its rear surface 54 is covered by a linear reflecting polarizing material, such as
30 Minnesota Mining & Manufacturing Company's double brightness enhancement film (DBEF) material. The linear reflecting polarizing material forms a polarizer 64 that transmits substantially all light linearly polarized in one direction (the "direction of transmission") and
35 reflects substantially all light linearly polarized in a direction orthogonal to the direction of transmission.

For example, if the linear reflecting polarizer 64 is oriented to transmit p-polarized light, it reflects substantially all s-polarized light because s-polarized light is orthogonal to the polarizer's direction of greatest transmissive efficiency. Conversely, when p-polarized light encounters the polarizer 64, substantially all of the light passes through the polarizer 64 and the diffusive screen 52 toward the viewer because the p-polarized light is aligned in the direction of the polarizer's greatest transmission efficiency.

The linear reflecting polarizer should have a transmission efficiency of at least 99%, so that less than 1% of s-polarized light escapes the projection system and all but 1% of p-polarized light is projected to the viewer. A linear absorption polarizer 68 may be used to further filter improperly polarized light from the image beam. Both the reflecting polarizer 64 and the absorption polarizer 68 may be attached to the screen 52 (e.g., by an index matching glue) or may be suspended in the display system (e.g., by a one or more frames connected to the system's housing).

Referring also to Figure 5, the polarization of the light traveling between the image source 58 and the imaging screen 52 is altered by a $1/4$ -wavelength achromatic retarder 70 positioned between the imaging screen 52 and the rear mirror 60. The retarder 70 may be attached to the front surface of the mirror 60 or suspended in the system by other means.

The $1/4$ -wavelength achromatic retarder 70 comprises a material that delays one linear component of a light wave passing through it by $1/4$ -wavelength. Such a material is produced by Nitto Denko Corporation of Japan under the name WB- $1/4$, and similar materials are available from other sources. Therefore, the retarder 70 transforms linearly polarized light into circularly

polarized light and transforms circularly polarized light into linearly polarized light. Furthermore, light that twice passes through the retarder 70 has the same linear component delayed twice, or by $1/2$ -wavelength. So
 5 linearly polarized light passing through the retarder 70 two times emerges with a polarization orthogonal to that at which it began.

For example, s-polarized light 72 travelling along optical sub-path D_2' is transformed into circularly
 10 polarized light 74 when it passes through the achromatic retarder 70. After reflecting from the second mirror 60, the circularly polarized light 74 becomes p-polarized light 76 when it passes through the retarder 70 again. The p-polarized light 76 then travels along optical sub-
 15 path D_3' and eventually passes through the linear reflecting polarizer 64 and onto the diffusive imaging screen 52.

Referring also to Figures 6A and 6B, the "extra-folded" projection system can include a "patchwork"
 20 polarizer 90 or 92 that compensates for trapezoidal distortions occurring when the image is reflected in the system. The linear reflecting polarizing material 64 may be slightly sensitive as to the incoming angle of the light. That is, the polarization of the reflected light
 25 may not be perfectly s-polarized but may be slightly circular. The patchwork polarizer 90 or 92 compensates for this potential condition. The patchwork polarizer 90 or 92 may be located anywhere between the image source 58 and the last reflective element in the system.

30 The "patchwork" polarizer 90 of Figure 6A may be placed within the image source 58 (Figure 3), such as on the surface of the lens that typically forms the last stage of an LCD projector. The substantially circular polarizer 90 is a linear absorption polarizer having
 35 several regions 90a-90f with different transmissive properties. Each pair of adjacent regions is divided by

a linear boundary 91a-91e extending through the polarizer 90. The polarizer 92 of Figure 6B may be placed on one of the reflective surfaces in the display system and preferably is incorporated into the DBEF material of the linear reflecting polarizer 64 (Figure 4) on the system's display screen 52. The transmissive properties, size, and shape of each region in the patchwork polarizer 90 or 92 are determined by the structure of the display system and, in particular, by the trapezoidal distortions imparted by the system.

Referring to Figures 7A, 7B, and 7C, the achromatic retarder 70 can be constructed to accommodate the varying angles of incidence at which light from the image source 58 impinges upon the retarder 70. If the image source is located below the page and toward the reader, light from the image source will hit the page at higher angles of incidence on the lower half of the page and at lower angles of incidence on the upper half of the page. Likewise, if the image source is positioned below the center of the page, light from the source will hit the page at higher angles of incidence on the center of the page and at lower angles of incidence on the left and right edges of the page. Because the retarder's effect on a particular light ray may depend upon the angle of incidence at which the light ray strikes the retarder, the retarder 70 can consist of several regions having different retardation properties.

As shown in Figure 7A, the retarder 70 may be divided into two regions 69a, 69b having two different retardation values α_1 and α_2 . Region 69a accommodates light passing through the retarder 70 at lower angles of incidence, and region 69b accommodates light passing through at the higher angles of incidence. Referring to Figure 7B, the retarder instead may be divided into a linear grid having, e.g., two retardation values α_1 and α_2 along a vertical axis α and three retardation values

β_1 , β_2 , and β_3 along a horizontal axis β . The retarder 70 then is divided into six sections 71a-71b, the retardation value for each of which is determined by the corresponding vertical value α_1 or α_2 and the

5 corresponding horizontal value β_1 , β_2 , or β_3 .

Alternatively, as shown in Figure 7C, the retarder 70 may be divided into several substantially circular or elliptical regions 73a-73h intersecting at the center point 75 of the retarder's bottom edge 77. The innermost
10 region 73a accommodates light passing through the retarder 70 at the highest angles of incidence and the outermost region 73h accommodates light passing through the retarder 70 at the lowest angles of incidence. A retarder manufacturer (e.g., Nitto Denko Corporation of
15 Japan) can create an appropriate retarder given the structure and dimensions of the projection display system.

Referring to Figures 8 and 9, the "extra-folded" projection display system 50 may be constructed with
20 various spacial configurations. In the system of Figure 8, the image source 58 projects an image beam directly onto the linear reflecting polarizer 64, which first reflects the image beam toward the achromatic retarder 70 and then allows the reflected image beam to pass to the
25 imaging screen 52. In the system of Figure 9, the image source 58 is located behind the mirror 60. The image source 58 projects an image beam downward onto a smaller mirror 100 that in turn reflects the image beam toward the linear
30 reflecting polarizer 64 then reflects the image beam toward the achromatic retarder 70 and the rear mirror 60, and then allows the reflected p-polarized light to pass to the display surface 52.

Referring to Figure 10, the "extra folded" projection display system 50 may be folded even further
35 by allowing the image beam to reflect (or "bounce") from

the rear mirror 60 twice, instead of the single bounce shown in Figure 3. In this embodiment, the image source 58 projects p-polarized light directly toward the rear mirror 60. After reflecting from the mirror 60 and
 5 passing through the achromatic retarder twice, the light in the image beam 56 has s-polarization. The s-polarized light then reflects from the linear reflecting polarizer on the screen 52 back toward the rear mirror 60. Another reflection from the mirror 60 and two additional passes
 10 through the achromatic retarder direct the image beam, which again contains p-polarized light, back toward the screen 52, where the light passes through the linear reflecting polarizer to form images on the imaging screen 52.

15 Figure 11A is a side view of an arrangement of multiple units of the projection display system 50 of Figure 8. Each unit 250a, 250b includes an outer housing 200. The housing 200 mounts the screen 52, the mirror 60, and the image projector 58 in the proper positions.
 20 The bottom front surface 202 of the housing 200 is recessed below the screen 52 to allow stacking, as shown in Figure 11A, so that the screens 52 of the units 250a, 250b are substantially coplanar. A support 204 mounted on the back surface of the lower unit 250b holds the
 25 upper unit 250a in place. Referring to Figure 11B, the front view of the arrangement is shown. As can be seen, the screen 52 is approximately the width of the unit 250a, so that there is very little border. As a result, a plurality of units 250a-250d can be arranged in an
 30 array or "tiled" configuration with very little gap between individual units.

Figure 12A is a side view of an arrangement of multiple units of the projection display system 50 of Figure 9. Each unit 260a, 260b includes an outer housing
 35 210. In this instance, the outer housing is substantially a rectangular parallelepiped, unlike the

recessed and angled shape of housing 200 in Figure 11A. However, the imaging screen 52 goes to substantially the edge of the housing 210 on all four sides, without a recessed surface 202 as in housing 200 (Figures 11A and 11B). Figure 12B is the front view of the arrangement of Figure 12A. The design of Figure 9 thus has trade offs with the design of Figure 8 relating to depth and base dimensions, with the final use affecting the choice of designs.

Referring to Figure 13, in another alternative embodiment, the image source 58 is placed behind the rear mirror 60 near the top of the projection system. In this arrangement, the image source 58 projects the image beam upward onto a small mirror 102 at the top of the projection system. The small mirror 102 in turn reflects the image beam downward and onto a larger mirror 104 located at the bottom of the projection system. To prevent the image beam from diverging too rapidly between the image source 58 and the lower mirror 104, the image source 58 projects the image beam with only slight divergence (or magnification). As a result, the lower mirror 104 is a "powered" optical device that magnifies the image beam as it reflects the beam toward the linear reflecting polarizer 64. The lower mirror 104 magnifies the image beam enough to fill the entire surface of the imaging screen after reflecting once from the linear reflecting polarizer 64 and once from the rear mirror 60.

The upper mirror 102 also may be a "powered" optical device, as shown in Figure 14A. Alternatively, the upper mirror may be a "negatively powered" optical device that causes the image beam to converge until it reaches the lower mirror 104, as shown in Figure 14B.

Referring to Figure 15, an "extra-folded" image projection system may be incorporated into a computer display 106 small enough for use with a desktop computer 108. Like conventional CRT or LCD panel displays, the

projection display subsystem 106 may be driven by a conventional CPU 112 and video controller 113 that provide video data to the projection display subsystem 106 through a standard video cable 114. Because the
5 screen 116 is used as a "mirror" to "fold" the video image into a very small area, the projection display subsystem 106 combines the benefits of flat screen technology and projection video yet requires only a small area on the desktop.

10 Other embodiments are within the scope of the following claims. For example, the video projection system may be incorporated into many types of video display systems, such as small and large screen televisions, laptop and desktop computers, overhead
15 projectors, movie theaters, and holographic imaging systems.

What is claimed is:



1 1. An apparatus, comprising:
2 an imaging surface;
3 an optical device; and
4 an optical image path which reaches the optical device
5 twice on its way to the imaging surface, the optical device at
6 one time reflecting the image and at a different time
7 permitting the image to pass through the optical device.

1 2. The apparatus of claim 1, wherein the optical device
2 comprises a reflective polarizer.

1 3. The apparatus of claims 1 and 2, further comprising:
2 a second optical device which rotates the polarization of
3 an image passing through the second optical device, the second
4 optical device located to receive the image reflected from the
5 optical device and to provide the rotated polarity image to
6 the optical device.

1 4. The apparatus of claim 3, wherein the second optical
2 device comprises an achromatic retarder.

1 5. The apparatus of claims 3 and 4, wherein the second
2 optical device comprises a reflecting material.

1 6. The apparatus of claims 1-5, wherein the optical
2 device is essentially parallel to the imaging surface.

1 7. The apparatus of claims 1-6, wherein the optical
2 device is near the imaging surface.

1 8. The apparatus of claims 1-7, wherein the optical
2 device is attached to the imaging surface.

1 9. The apparatus of claims 1-8, further comprising a
2 linear absorption polarizer interposed across the optical
3 path.





1 10. The apparatus of claims 1-8, further comprising an
2 image source which projects the image.

1 11. The apparatus of claim 10, further comprising a
2 polarizer interposed in the optical path between the image
3 source and the optical device.

1 12. The apparatus of claims 3-5, wherein the optical
2 image path reaches the second optical device prior to reaching
3 the optical device.

1 13. The apparatus of claims 1-11, further comprising a
2 reflective device located in the optical path prior to the
3 optical device.

1 14. The apparatus of claim 13, wherein the reflective
2 device is a powered optical element.

1 15. The apparatus of claim 13, further comprising:
2 a second reflective device located in the optical path
3 prior to the optical device.

1 16. The apparatus of claim 15, wherein the second
2 reflective device is a powered optical element.

1 17. The apparatus of claims 1-16, wherein the image
2 surface has an outer periphery and the optical device, the
3 optical path and the image source are located within the outer
4 periphery and behind the image surface.

1 18. The apparatus of claims 1-17, wherein the image
2 source receives video data in the format of electrical
3 signals.

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1 19. The apparatus of claim 18, further comprising:
2 a computer including a video controller providing the
3 video data to the image source.

1 20. A method for displaying images in a projection
2 display system, comprising the steps of:
3 projecting an image;
4 reflecting the image from an optical device; and
5 passing the image reflected from the optical device back
6 through the optical device onto an imaging surface.

1 21. The method of claim 20, wherein the reflected image
2 and the passed image have different polarities.

1 22. The method of claims 20 and 21, further comprising
2 the step of:
3 rotating the polarity of the image reflected from the
4 optical device.

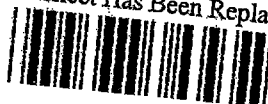
1 23. The method of claims 20-22, further comprising the
2 step of:
3 polarizing the image prior to reflection from the optical
4 device.

1 24. The method of claim 23, further comprising the step
2 of:
3 rotating the polarity of the image prior to reflection
4 from the optical device.

1 25. The method of claims 20-24, further comprising the
2 step of:
3 reflecting the image prior to reflection from the optical
4 device.

1 26. The method of claim 25, wherein the reflection is
2 powered.

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1 27. The method of claims 20-26, further comprising the
2 step of:
3 reflecting the image a second time prior to reflection
4 from the optical device.

1 28. The method of claim 27, wherein the second
2 reflection is powered.

1 29. The method of claims 20-28, further comprising the
2 step of:
3 converting electrical signals providing video data to
4 from the image which is projected.

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