

Light Source for Projection Display ✓**Field of the Invention**

The invention is directed towards the field of projection displays. In particular, the invention relates to the manufacture of rear projection flat panel displays.

5 BACKGROUND OF THE INVENTION

Real image displays can be separated into three categories: cathode ray tubes (CRT), flat panel displays, and projection displays. Currently, CRT displays range from 1-40 inches along the image diagonal. These displays have good image quality and can be manufactured economically. The shape of the display requires a depth that can
10 exceed the length of the image diagonal for high resolution graphic displays. The displays are bulky, especially for sizes above 20 inches because the wall thickness of the glass must be increased to withstand the atmospheric pressure. CRTs are popular in the desktop monitor market where the common length of the image diagonal is 14-17 inches.

15 Flat panel displays are used in many portable applications. They are thin and light in weight but have an image quality that is inferior to the CRT. At this time, the majority of displays are used in applications requiring 2-12 inches along the image diagonal. Flat panel displays are more costly to manufacture than the CRTs.

As a result, display applications that require an image size above 40 inches are
20 dominated by projection displays: either front or rear. Both technologies can create an image by one of two methods: using three small high brightness monochromic CRTs for red, green, and blue (RGB) or creating a color image via a spatial light modulator.

These projection systems have low image brightness and are costly to manufacture.

It is not economical to reduce the conventional rear projection display to 17-20
25 inches along the image diagonal. The cost of the light valve is dominated by the drive

circuitry. To illustrate, the drive circuitry of an XGA display (768x1024x3) is approximately \$120 regardless of the screen size. A 70W metal halide arc lamp capable of producing 5000 lumens with its corresponding power supply, ballast, and hot re-ignition capability are required. The total cost is prohibitive and unattractive compared
5 to the OEM cost of a 17 inch CRT.

SUMMARY OF THE INVENTION

A compact, light weight, and energy efficient projection display can be made by starting with relatively pure red, green, and blue light sources. The output beams of the colored light sources are received by at least one spatial light modulator. The
5 modulated output beams are collimated and combined. A projection lens receives the collimated and combined output beams and directs them towards a projection screen. All of the above may be contained in a housing to provide a compact and lightweight projection display.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates a preferred embodiment of the projection display.

Figure 2 illustrates an alternate embodiment of the present invention.

Figure 3 illustrates another embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is a light weight and compact projection display that is based on a spatial light modulator, typically a 1 cm² CMOS IC that is in direct contact with a ferro-electric liquid crystal material. Light transmitted through the liquid crystal material will rotate as a function of its plane of polarization with respect to the local surface voltage of the IC. Illuminating the LC/IC cell with consecutive flashes of red, green, or blue light from three separate LEDs creates a color-sequential image of the surface voltage of the IC.

The address circuitry is buried in the 1 cm² IC. All display information is sent to the IC on one or several high speed I/O lines. The IC/LCD combination is equivalent to a reflective active matrix liquid crystal display (AMLCD) light valve at much lower cost and higher performance. For instance, the transmissive design of an AMLCD light valve blocks 60% of the light due to the shadowing of metal lines and transistors. In contrast, the reflective cell has estimated losses of only 20%, mainly reflective losses from the aluminum pads covering the IC surface. By using sequentially strobed RGB light sources instead of a white light source, the more than 75% light loss in the color filter is also eliminated.

The present invention, a rear projection display using a spatial modulator and three LED power sources can be optically efficient.

	Conventional Design (Prior Art)	LED Design
Collimation	40%	60%
Polarizer	50%	50%
Rect/Circular Conversion	70%	70%
Color Filters	25%	100%
Valve Aperture	40%	80%
Misc. Refl./Absorption	60%	60%
Total	0.8%	10%

Table 1

Table 1 illustrates the optical efficiency of a rear projection system based on conventional design and LED design of the present invention. Flux exiting the front surface of the screen, ϕ_{exit} , is defined as follows:

$$\phi_{exit} = BA\Omega$$

A is the area of the screen and B is the brightness of the desired Lambertian light distribution. If the screen has a gain g of 1.5 by reducing the angular distribution below a Lambertian distribution, then the exiting flux is:

$$\phi_{exit} = BA\Omega/g$$

For a high resolution desktop monitor, the brightness required is 100 cd/m². A 17 inch monitor has an image area of 25x30 cm² or A= 0.075m². Because a desktop monitor may have a smaller viewing angle than a comparable sized television, the screen gain may be selected to be g=2. For these assumptions, the exit flux is computed to ϕ_{exit} = 12 lm. For an optical system design having an overall efficiency of 10%, a source flux of

$\phi_{\text{source}} = 120 \text{ lm}$ is required. This flux may be distributed over all three sources as follows:

Red 30 lm

Green 75 lm

Blue 15 lm

5 Figure 1 illustrates a preferred embodiment of a projection display 10 that includes three light emitting diodes 12₁, 12₂, 12₃, emitting a red, green, and blue light beam, respectively. Each light beam is received by a collimator 14₁, 14₂, 14₃. Each collimated light beam passes through a polarizing beam splitter 16₁, 16₂, 16₃. A spatial light modulator 18, having MxN pixels, modulates the split beams. The spatial light
10 modulator 18 is controlled by a display driver 20. A projection lens 22 receives the modulated beams and directs them towards a projection screen 24, positioned at the front of the housing 26. A sequence controller 28, attached to the three light sources, controls the red, green, and blue light beams. The spatial modulator and the three light sources are connected to a power supply (not shown).

15 The red, green, and blue light emitting diodes, in combination, have a luminous flux of 10-1000 lm. It is preferred that the approximate flux ratio is 65% green, 25% red and 10% blue light.

The housing may optionally include at least two folding mirrors to receive the red, green, and blue light beams and to fold the red, green, and blue light beams. The
20 folding mirrors allow the housing to be compact.

In this embodiment, the color subframes are sequential.

Figure 2 illustrates another embodiment of the present invention. There are three spatial modulators 18₁, 18₂, 18₃, one for each light beam to allow for parallel color subframes. In this embodiment, the color subframes are parallel.

Figure 3 illustrates another embodiment of the present invention. The multiple light emitting diodes shown in Figure 1 are replaced by a single light source 12. The single light includes light emitting diodes on a unitary substrate that emit red, green, and blue light. There is only one light path in the system as contrasted to 5 the embodiments shown in Figures 1 and 2.



CLAIMS

I claim:

1 1. A projection display comprising:
 2 red, green, and blue light units, each light unit includes,
 3 at least one light emitting diode that emits a light beam,
 4 a collimator, optically connected to the light source,
 5 producing a collimated light beam, and
 6 a beam splitter, optically connected to the collimator,
 7 generating a split beam;
 8 a spatial light modulator, having MxN pixels, optically connected to the
 9 beam splitters of the red, green, and blue light units;
 10 a projection lens, optically connected to the spatial light modulator, operative
 11 to focus the red, green, and blue light beams;
 12 a projection screen, optically connected to the projection lens;
 13 a drive circuit, connected to the spatial light modulator, being operative to
 14 generate color subframes;
 15 a power supply, connected to the spatial modulator and the red, green, and
 16 blue light units; and
 17 a housing that contains the red, green, and blue light units, the spatial light
 18 modulator, the projection lens, the projection screen, the control circuitry, and the
 19 power supply.

1 2. A projection display, as defined in claim 1, wherein any one of the red,
 2 green, and blue light sources is an array of N light emitting diode chips, where $N \leq$
 3 10, the array having a diameter of $\leq 3\text{mm}$.

1 3. A projection display, as defined in claim 2, wherein any one of the red,
 2 green, and blue light sources further comprises:
 3 a reflector that surrounds the array of light emitting diode; and



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4 an immersion lens, receiving light from the array of light emitting diodes,
5 operative to pre-collimate the light into a solid angle of 3 steradians or less.

1 4. A projection display, as defined in claim 3, wherein the array of light
2 emitting diodes has an apparent source size less than 5 mm in diameter.

1 5. A projection display, as defined in claim 1, wherein any one of the red,
2 green, and blue light sources further comprises:
3 a reflector that surrounds the light emitting diode; and
4 an immersion lens, receiving light from the light emitting diode, operative to
5 pre-collimate the light into a solid angle of 3 steradians or less.

1 6. A projection display, as defined in claim 5, wherein the light emitting
2 diode has an apparent source size, after magnification, less than 5 mm in diameter.

1 7. A projection display, as defined in claim 1, wherein the red, green, and
2 blue light emitting sources have a combined luminous flux of 10-1000 lm with an
3 approximate ratio of 65% green, 25% red and 10% blue light.

1 8. A projection display, as defined in claim 2, wherein one of the red, green,
2 and blue light emitting diodes is a laser.

1 9. A projection display, as defined in claim 8, wherein the laser is a
2 frequency-doubled Nd:YAG laser that emits the green light beam.

1 10. A projection display, as defined in claim 1, further comprising:
2 at least two mirrors, that receive the red, green, and blue light beams,
3 operative to fold the red, green, and blue light beams.



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1 11. A projection display, as defined in claim 1, further comprising:
2 three spatial light modulators, each spatial light modulators receiving one of
3 the red, green, and blue light beams, respectively; and
4 wherein the drive circuit generates the color subframes in parallel.

1 12. A projection display, as defined in claim 1, wherein the drive circuit
2 generates the color subframes sequentially.

1 13. A projection display comprising:
2 a light unit that includes,
3 at least one red, one green, and one blue light source on a
4 unitary substrate, wherein the red, green, and blue light sources are
5 independently switched, and
6 a collimator, optically connected to the red, green, and blue
7 light source, producing collimated red, green, and blue beams;
8 a beam splitter, receiving the collimated red, green, and blue beams,
9 operative to output split red, green, and blue beams;
10 a spatial light modulator, having $M \times N$ pixels, optically connected to the
11 beam splitter;
12 a projection lens, optically connected to the spatial light modulator, being
13 operative to focus the red, green, and blue beams;
14 a drive circuit, connected to the spatial light modulator, being operative to
15 generate color subframes;
16 a power supply, connected to the spatial light modulator and the light unit;
17 and
18 a housing that contains the light unit, the spatial light modulator, the
19 projection lens, the projection screen, the control circuitry, and the power supply.

1 14. A projection display, as defined in claim 13, wherein the light unit
2 generates a white light comprised of 25% red, 60% green, and 15% blue light.



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1 15. A projection display, as defined in claim 13, wherein the red, green, and
2 blue light sources are a single array of N light emitting diodes, wherein N is less
3 than 10 and the array having a diameter of $\leq 3\text{mm}$.

1 16. A projection display, as defined in claim 15, wherein the red, green, and
2 blue light sources further comprise:
3 a reflector that surrounds the array of light emitting diodes; and
4 an immersion lens, receiving light from the array of light emitting diodes,
5 operative to pre-collimate the light into a solid angle of 3 steradians or less.

1 17. A projection display, as defined in claim 16, wherein the array of light
2 emitting diodes has an apparent source size, after magnification, of less than 5 mm
3 in diameter.

1 18. A projection display, as defined in claim 13, wherein the red, green, and
2 blue light sources have a combined luminous flux of 10-1000 lm with an
3 approximate ratio of 65% green, 25% red and 10% blue light.

1 19. A projection display, as defined in claim 13, wherein the drive circuit
2 generates the color subframes sequentially.



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