Optical Short Course International

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What's "Inside The Box"?

Optics of Digital Projectors Weekly Newsletter

Dual Lamp Illumination Systems

By Michael Pate, President, OSCI

Over the last several issues we have been looking at illumination systems and their components and how they work in light engines. This week we will continue our look at illumination systems again with the goal of understanding something about how to combine the output from two lamps into one light engine. The dual lamps are typically used to increase the screen luminance, but they can also be used for backups in mission critical applications. We have learned in earlier versions of In The Box e-newsletter that the lamps and their cooling apparatus require a large percentage of the volume of the digital projector box. This large volume requirement for two lamps and their cooling paraphernalia tells us that the dual lamp systems will typically be in large box volume fixed conference room, RPTV, and large venue digital projector models. It is a large challenge to cram two lamps and all the cooling goodies into a small volume road warrior box, but I am sure there is some thermodynamics wizards working on this problem as we speak. Note to wizards: Can I have a sneak peak at what your doing to solve the problem?

Rules We Must Try To Beat

I like to say, that all good illumination designers must try to violate one of the key laws of optics called Étendue at least once per week, or they are not trying hard enough. We will learn about Étendue next spring in an up coming edition of In The Box but for now lets talk about a simple definition. Étendue is simply (sic) the product of the area of an optical surface times the projected solid angle of the rays at this surface, so the units are cm^2-Sr. This product is important as it helps us calculate how much light can pass through an optical surface, element, or optical system. I like to think of Étendue as the 3D version of the 2D law known as the optical invariant or Lagrange Invariant.

The Lagrange Invariant tells us the relationship between the height of a ray and the angle the ray makes with the optical axis. If we want to make a small spot or object height then the ray will make a large angle with the optical axis. This concept transfers to 3D easily in that if we want to take a collimated beam of rays and focus them down to a small spot or diameter then these rays at the small spot will have a large solid angle at the spot.

In general, if we increase the Étendue at an optical surface somewhere in the light engine this will have a negative effect on getting all of the light from the fire ball of the light source to the screen. It is like pinching a water hose, you will restrict the flow of photons down the optical axis. So if we put two collimated light sources right next to each other we have doubled the area at this surface and this increases the Étendue and you loose some friends. Next, you try to focus these two lamps onto the same spot so the area at the focus stays the same as one lamp. The area is the same but the solid angle of these two lamps together is now larger and the Étendue increased again and now if you have any friends left in the office they surely will not let you borrow their illumination design software key any more.

Étendue = Area X Projected Solid Angle

Radiance/Luminance of a Light Source

We have not covered the radiance or luminance of a light source yet, but it also is coming up in a future edition of In The Box. We must talk about it here as it is one of the metrics we are trying to increase by combining two light sources in a digital projector light engine. The units of radiance are $W/cm^2/Sr$ and luminance is $lumens/m^2/Sr$. The emitting surface area of a light source will emit a certain amount of radiant or luminous flux in Watts or lumens from this emitting area into a solid angle. If we can get more luminous flux into the emitting area on a particular surface without increasing the solid angle we are illumination heroes because we just increased the luminance.

Increasing Radiance in the Temporal Domain

Both radiance and luminance have units of power which is energy per unit time. Some clever inventors have moved to the time domain to increase the time average power by pulsing two different light sources with higher energy and using a 50% duty cycle or less. In Figure 1 below we can see a two lamp system from US Patent 6,147,720 assigned to Philips. This design uses two lamps focused to the same optical axis and they are time multiplexed by a spinning filter wheel.

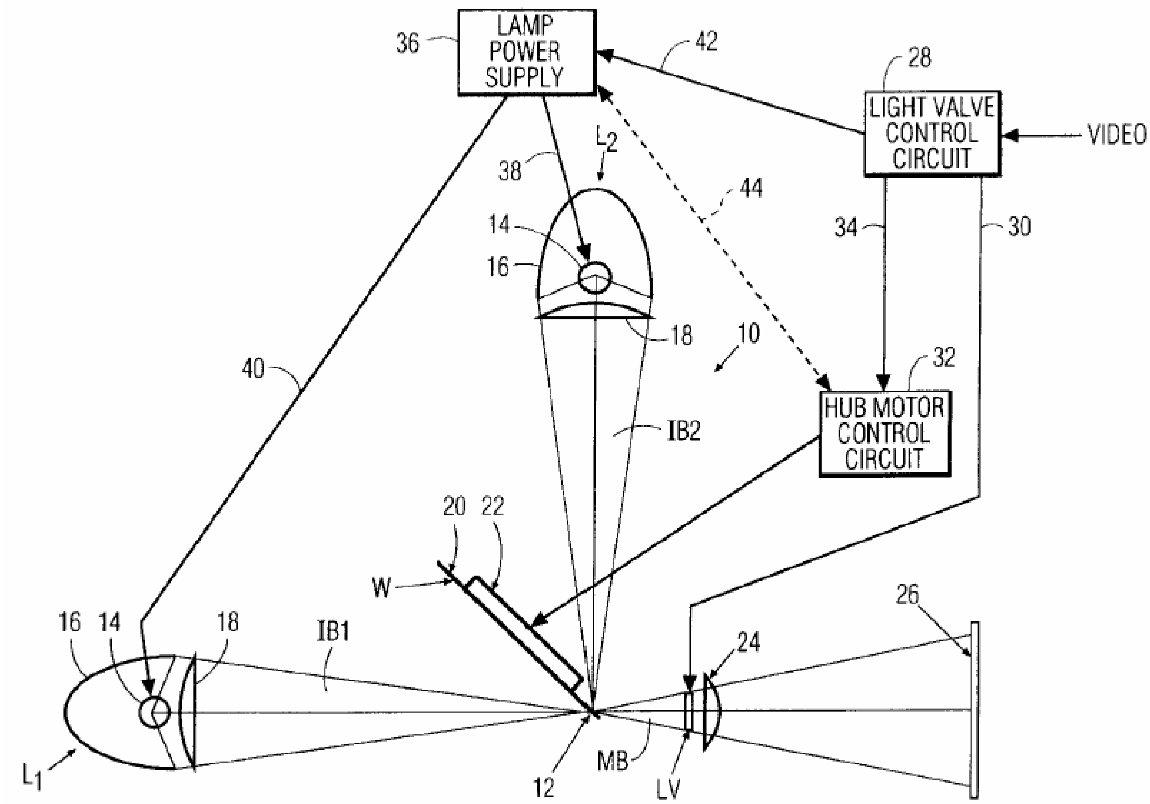


Figure 1. Dual Lamp by Time Multiplexing

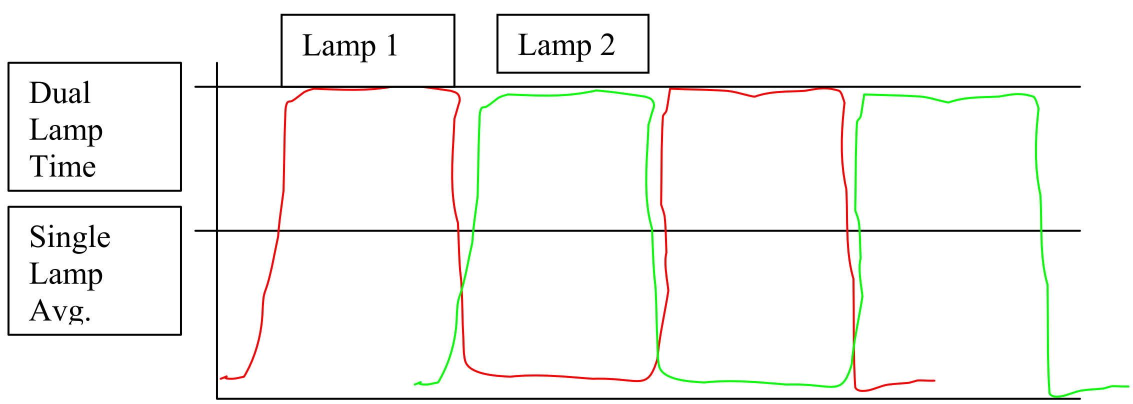


Figure 2. Time Multiplexed Pulsed Lamps 2X Time Averaged Power vs Single Lamp

In Figure 2 above we can see that the single lamp has about one half of the time average power as the dual lamps which are pulsed. Each lamp is pulsed with more energy for slightly less than 50% of the time. The spoke blanking time on the filter wheel is the reason for slightly less than 50% duty cycle. The spinning filter wheel in this scenario will have a mirror and a window coating for reflection or transmission respectively. When the mirror is in the light path the vertically oriented light source in Figure 1 is reflected to the common focal spot and when the window is in the horizontal light source is transmitted.

In Figure 3 below, from US Patent 5,796,526 from TI, we see that four light sources can be temporally multiplexed by having a Red, Green, Blue, and White light sources (LED's) pulse sequentially in time.

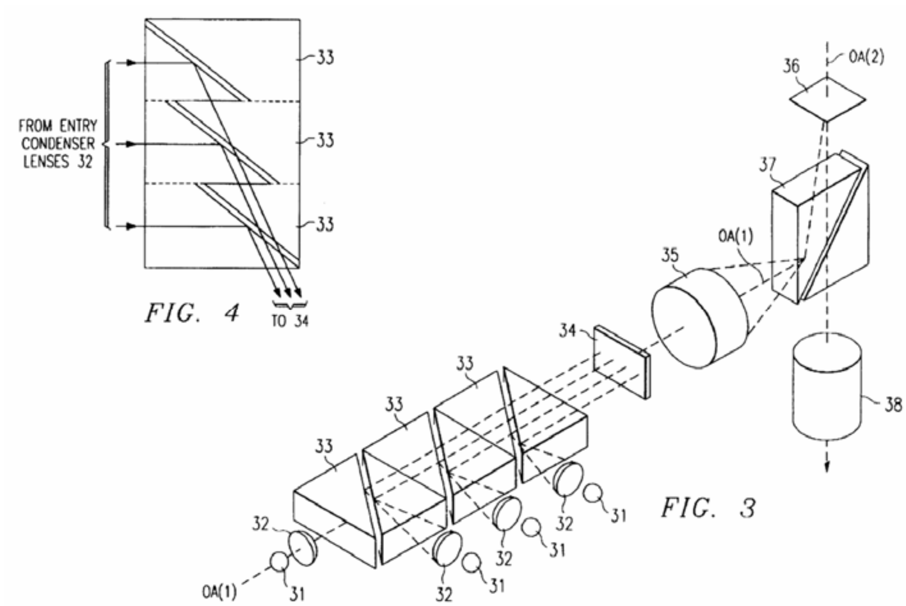


Figure 3. Time Multiplexed LED's in RGBW Light Engine

Spatial Combination of Two Light Sources

The spatial combination of two or more light sources usually involves mirrors or prisms to optically bring the two light sources into optical coincidence. In the first example of spatial combination is done with total internal reflection off of micro prisms. We can see a schematic layout of a digital projector using this technique in Figure 4 below. In Figure 5 below from US Patent 5,504,544 from 3M we can see that the collimated light from two lamps is incident upon the micro prism array. The light enters the prism face at normal incidence so there is no refraction and/or color dispersion. The light hits the internal surface and total internally reflects and is normal to the exit face of the micro prism array where again no refraction takes place.

The apex angle of these micro prisms is 60 degrees and the preferred angle of incidence, labeled theta, of the two collimated beam is 60 degrees. Because there is no refraction upon entrance or exit of the rays the index of refraction of the prism has no effect on the dispersion or operation of the device, as long as the rays are perpendicular to the entrance and exit face.

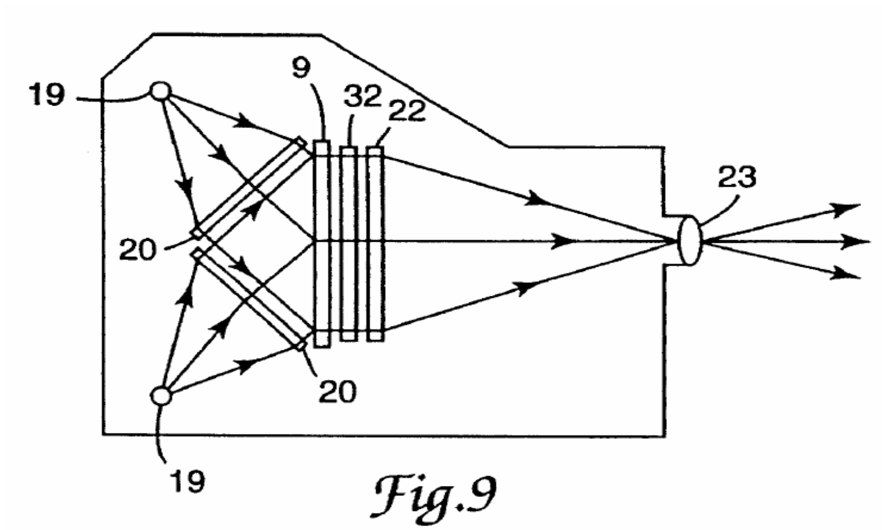


Figure 4. Dual Lamp Digital Projector Configuration Schematic

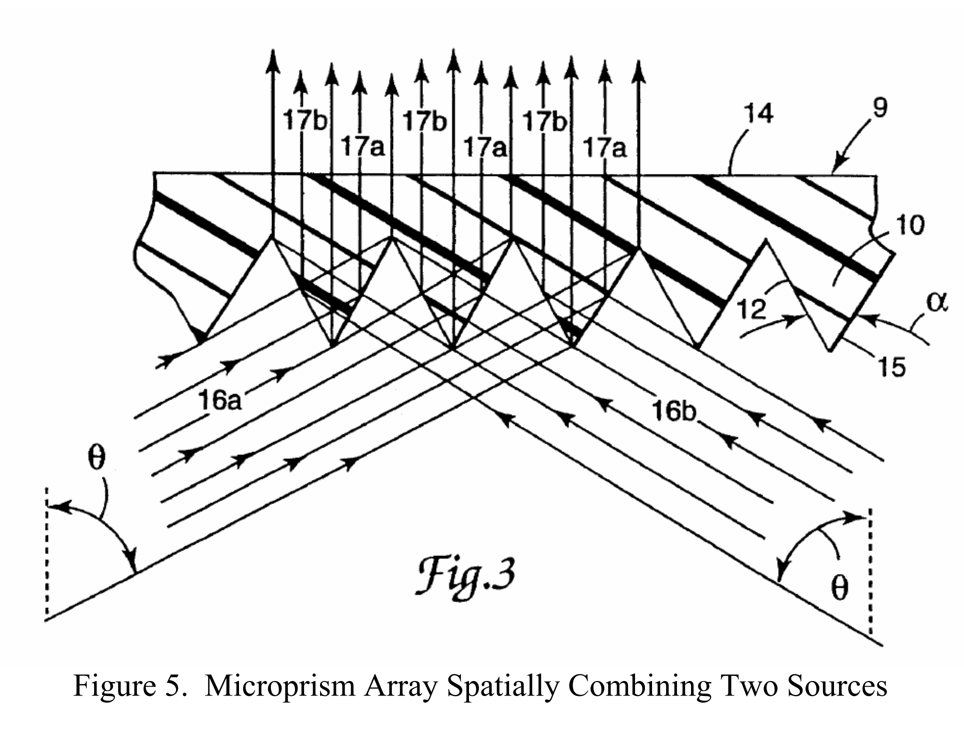


Figure 5. Microprism Array Spatially Combining Two Sources

Another design that also works on reflection but front surface reflection is shown in Figure 6 below. These figures are from US Patent 6,517,212 B2 assigned to Sharp. We can see this dual lamp LCD light engine layout. There is an array of mirrors with a 90 degree apex angle and they are aligned vertically so that there are no spaces. The mirror facets are sized, dimension d, to coincide with the aperture of the fly's eye array, dimension labeled fd. The aperture of the lamp on the left is intercepted or segmented by the left side of all of the mirror arrays and the aperture of the lamp on the right is segmented by the right side of all the mirror arrays.

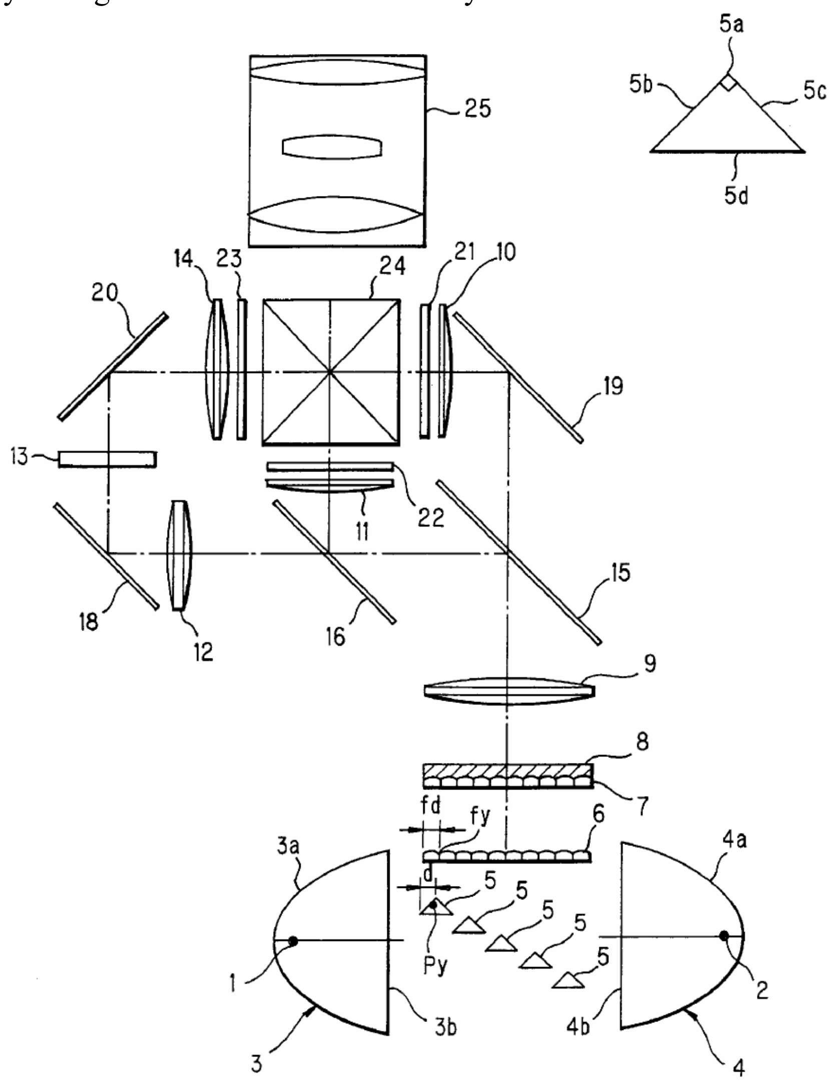


Figure 6. Dual Lamp LCD Light Engine

We can see how the rays from a single lamp reflect off of the mirror array and are aligned to and refract in the fly's eye array in the Figure 7 below from the same patent.

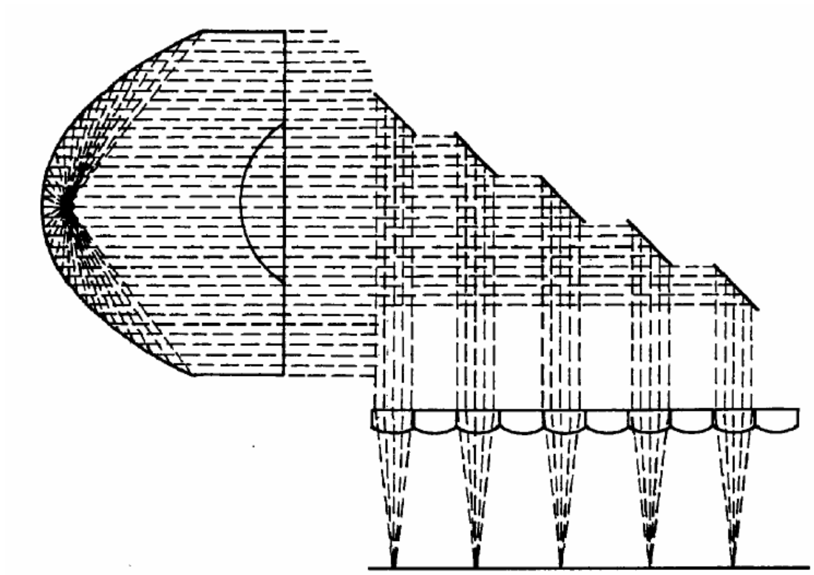


Figure 7. Parabolic Reflector and Mirror Array into Fly's Eye Array

You can find this type of dual lamp illumination system on several LCD digital projectors that are used for fixed conference room and large venue applications. They are:

Sharp XG-V10W with 4700 lumens from 2 – 200W UHP Lamps
Christie LX-77 with 6500 lumens from 2 - 300W lamps
Barco iQ-G350 with 3500 lumens from 2 – 250W UHP lamps

A quick calculation of light engine efficiency and we can see how these dual lamp engines compare to conventional single lamp light engines. The Sharp has 11.75 screen lumens per lamp watt, Christie has 10.83 lumens/watt, and the Barco has 7 lumens/watt.

Anamorphic Squeeze Combiner

This method of light source combining uses anamorphic optics to squeeze the spot image area in one dimension to partially make up for the increased angle from two sources. We can see one of the system layouts in Figure 8 below from US Patent 6,499,863 B2 assigned to TI. The two lamps are converged first in the plane of the lamps and then in a plane orthogonal to the lamps. The focal lengths of the lamps are chosen so that the size of the spots at the entrance to the integrating rod is about one half of the in the plane of the two lamps. Since there is a larger angle from the two source I am not sure how much actual gain is achieved yet. Figure 9 and 10 below from the same patent show to variations on this same anamorphic squeeze concept. I think the one shown in Figure 9 is very elegant because it uses one element, the concave cylinder, to do several functions. It compresses the two beams in one direction (a 2 for 1 deal), it reflects the direction of the beams (another 2 for 1 deal). This system also appears that it could fit into a smaller digital projector box maybe with some compound optical angles on the mirrors.

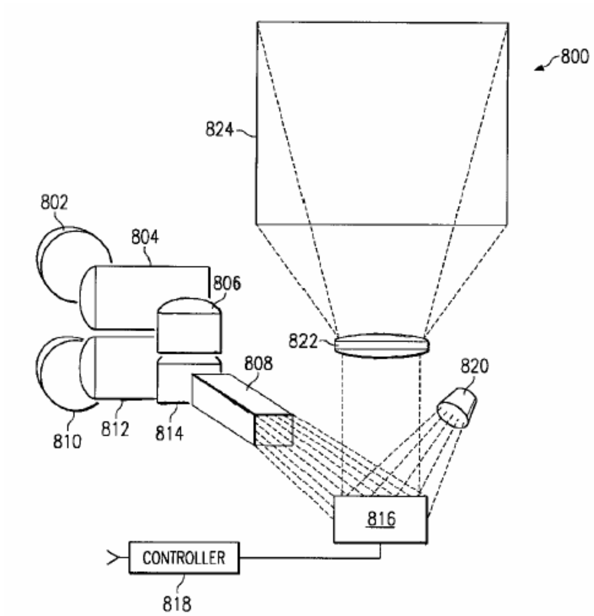
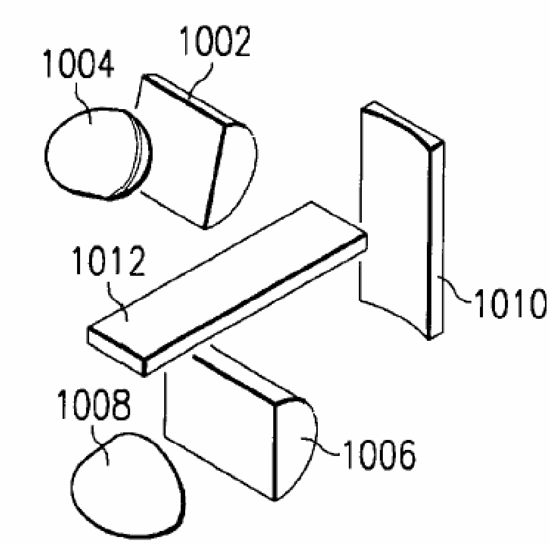


Figure 8. Dual Lamp Anamorphic Cylinder Combiner



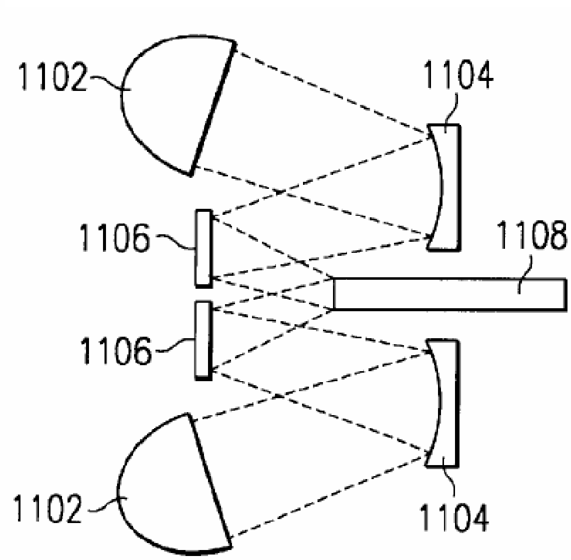


Figure 9. Elegant Combination Method Figure 10. Crossed Cylinder Method

In Figure 10 from the same patent is another variation with the two concave cylinders and then the two convex cylinders (in the plane of the page) reflecting the beam into the integrating rod. In this figure we can see the larger angle entering the integrating rod from two squeezed beams versus a single beam from one lamp.

Summary

We have looked at several different methods to combine two lamps into one digital projector light engine. We have seen the temporal multiplexing method used to achieve a time averaged luminance gain by pulsing the two lamps. We have also seen a color multiplexing method used where the lamps are pulsed to get the highest output from each of the different color lamps (LED's). Next we saw the spatial combination of two lamps using two different reflection methods. The first was the micro prisms that use TIR and the second was an array of front surface mirrors to combine the two sources. Finally we saw the anamorphic squeeze method of combining two sources by using anamorphic optics to trade off smaller area for increased angle. We also understand that these techniques are generally employed in large volume digital projector applications, like fixed conference room and large venue projectors, where we can fit the cooling paraphernalia for two lamps.

Stay tuned and keep looking for your weekly dose of "In The Box" to understand the optics of digital projectors. If you enjoy increasing your knowledge about digital projector optics please tell a friend about this e-newletter, your referral is the kindest compliment we can get to show your appreciation.