Optical Short Course International

6679 N. Calle de Calipso, Tucson, AZ http://www.oscintl.com 520-797-9744

What's "In The Box"?

Optics of Digital Projectors Weekly Newsletter

Rear Projection Screen Technology Digital Projectors

By Michael Pate, President, OSCI

The projection screen performance is a large part of the perceived image quality in a digital projector system. In this version of In The Box we are going to discuss rear projection screens technology to understand how they work and how they help deliver a high quality image for our eyes to view.

Function of a Rear Projection Screen

A projection screen must serve as a diffuse surface that will accept a specular incident image from a projector and diffusely reflect or transmit this energy into a directional pattern with high efficiency and color accuracy. We have all seen projection screens in class rooms, conference rooms, and even the movie theaters. The projector is on the opposite side of the screen in a rear projection scenario. An image from the projector is incident on the rear of the screen, and the screen is often one side of the RPTV box. If the projection lens optical design, fabrication, and assembly were completed properly then a high fidelity image is incident on the screen for your viewing pleasure.

Because the light source is incident from behind the screen, the screen substrate must be optically transparent with a high optical transmission. The screen must also scatter light from this plane so our eyes can view the image located on this plane. The method of scattering the light is by roughening one side of a glass window substrate with the required roughness. Another method is to deposit a layer of ground silicon dioxide or glass particles onto the flat window surface and encapsulate the material in place.

If we study the graphic illustration below on the left side of the illustration we can see that if a surface scatters light from the ground silicon dioxide it will scatter light in all directions, namely forward and backwards from the direction of incidence. This means that some of the energy is being reflected back into the RPTV box and some is being transmitted out to the viewer. Clearly we would like for all of the light to scattered forward to the viewer so it is not wasted. Remember a photon is a terrible thing to waste.

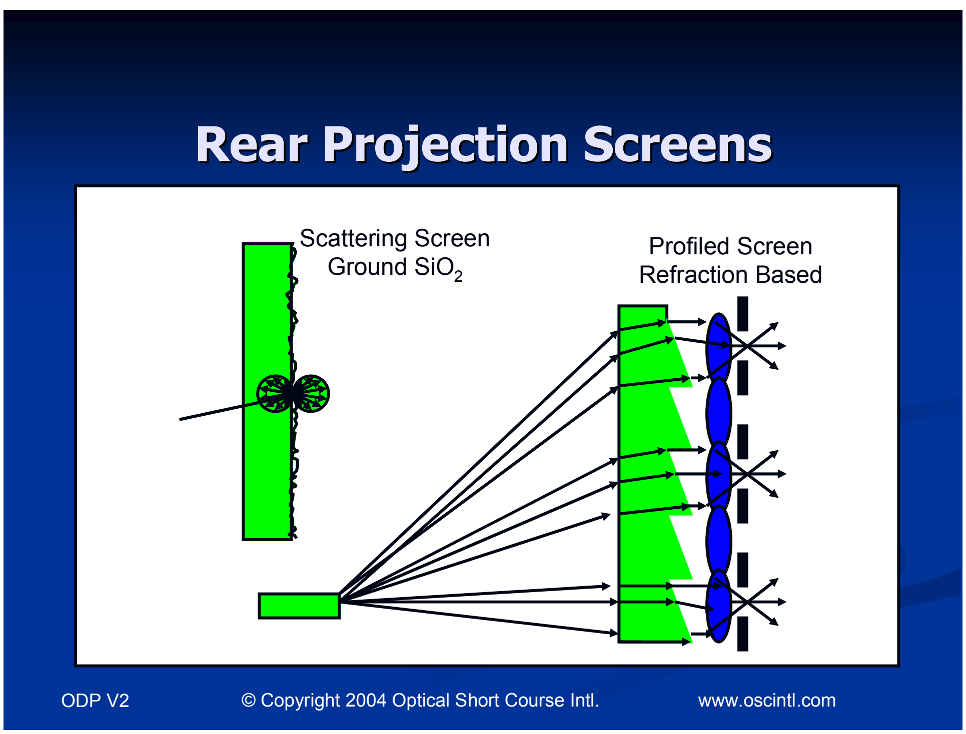

Figure 1. Rear Projection Screen Technology

The screen will diffusely scatter this image in the both directions with an angular energy distribution that follows some mathematical distribution. If we look at Figure 1 we can see that an incident ray will be diffusely scattered into an angular hemisphere about the surface in both directions forward and backwards. We can see that the magnitude of the reflection has a variation with respect to the surface normal or angle of incidence.

$$I_{reflected} = \rho_{screen} I_{incident} \cos\theta_{AOI}$$

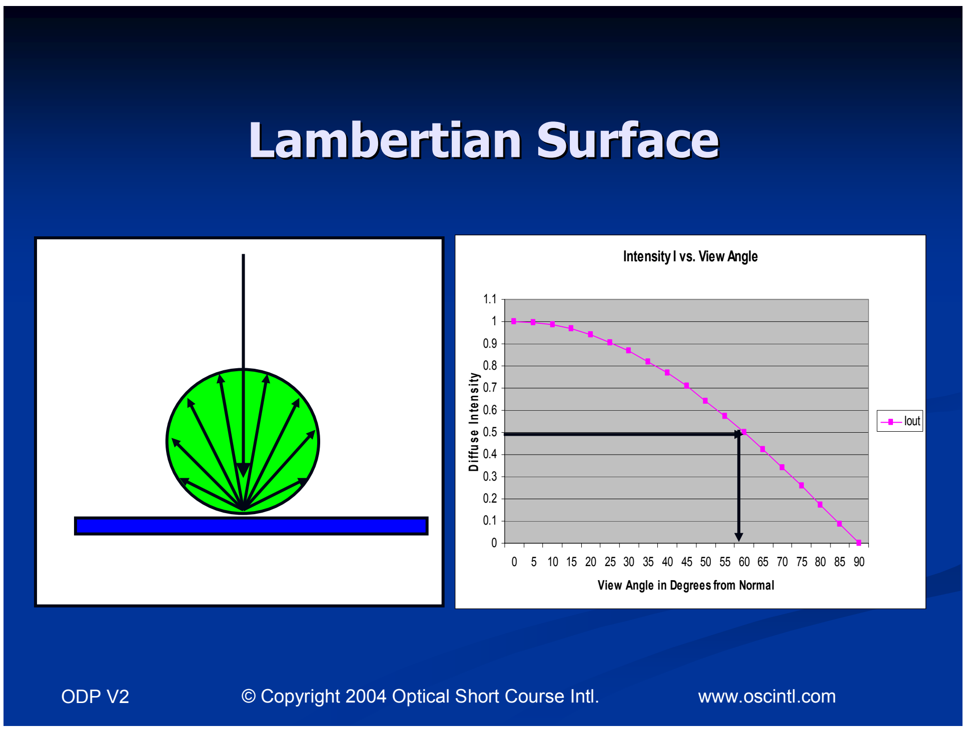

Figure 2. Lambertian Screen Diffuse Reflectivity or Scattering Distribution

If this diffuse/scattering reflection magnitude follows a cosine distribution as shown in the figure we define it to be a Lambertian diffuser. A perfect diffuser will have a 100% diffuse reflectivity or ρ. Some screens have a lower 80% diffuse reflectivity/scattering to help try to maintain image contrast in bright rooms. The graph above shows the diffuse reflectivity/scattering as a function of the angle of reflection with respect to the surface normal. If the magnitude of this reflection/scatter versus angle follows this cosine or spherical magnitude then the diffuser is said to be Lambertian. The gain of the screen is also said to be 1.0 because the axial magnitude of the diffuse reflectivity/scattering is equal to 1.0. If the gain was smaller than one then the reflectivity/scattering may be 0.8 or the light might be redistributed by surface structures into other angles.

Besides gain the viewing angle from normal at which the diffuse reflectivity reaches 50% is an important comparison point for different screens. In this particular graph the 50% reflectivity point is at 60 degrees.

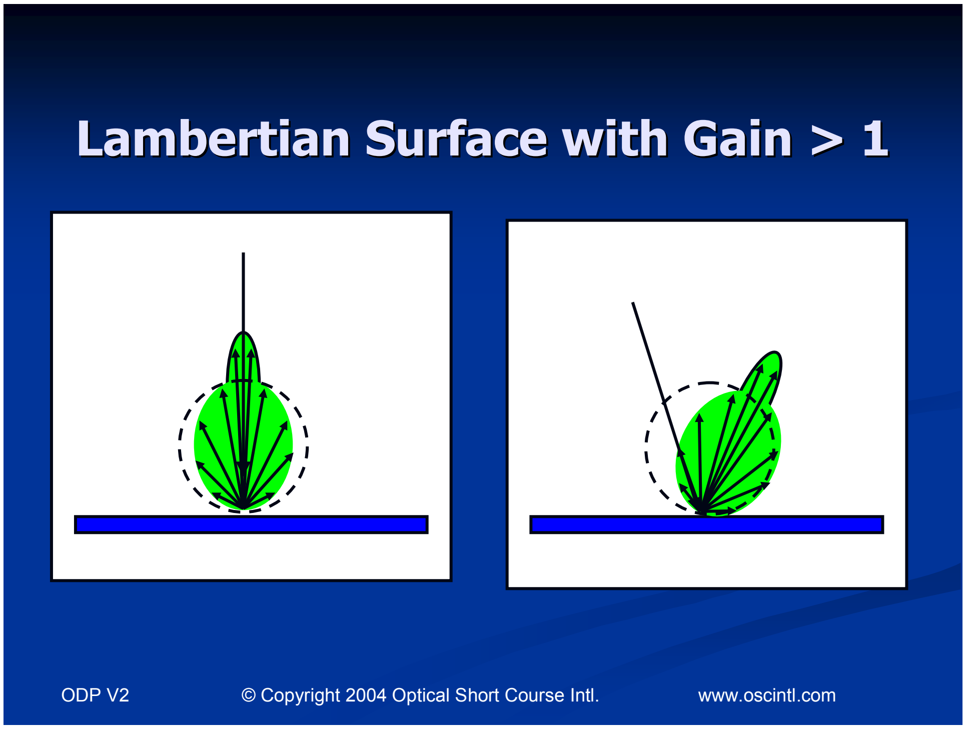

Figure 3. Screen Gain and Energy Redistribution

Many times the gain is required to be larger than one. A gain of greater than one means that we must take energy out to of the higher angles and put it into the near normal angles as shown in Figure 3. We can see that conservation of energy is at work here if more of the energy is being reflected at near normal incidence then this energy must come from somewhere. We can see that the angles from about 20 to 90 degrees have a smaller magnitude of reflectance/scatter than a Lambertian (dashed circle in the figure) diffuser.

How Do We Get Screen Gains of Greater Than One with Rear Screens?

A flat window is used as the starting substrate for rear projection screens. This plastic window material is often molded with a Fresnel lens into one side of the window. A Fresnel lens is a series of segmented annular rings which has the same surface curvature as a continuous lens surface but a much smaller thickness. In cross section Fresnel lenses look like triangles or saw tooth patterns.

The function of the Fresnel lens on one side of the rear screen substrate is to take the rays which are incident at large angle of incidence and get them refracted or steered down the optical axis normal to the screen or viewer. See Figure 1. on the right side of the illustration. If we are steering or refracting the light mostly down the optical axis and away from the steep angles of refraction near the plane of the surface the screen gain will increase. This increase in gain is acceptable because most people do not view a rear screen at a 90 degree angle of incidence to the surface normal as they know the viewing conditions will be poor in addition to the cosine compression of the image.

Some other techniques in rear screen technology to achieve a direction energy distribution from the screen are the use of glass beads, lenticular cylindrical lens strips, and shaped refractors. In the glass beads some rear projection screen companies have used a Fresnel lens technology as we discussed along with glass beads embedded into a black opaque polymer. Only the very vertex of the glass bead is in contact with the rear screen and the light is focused on this small circular spot and the light gets focused through these spots and propagates to the viewer's eye.

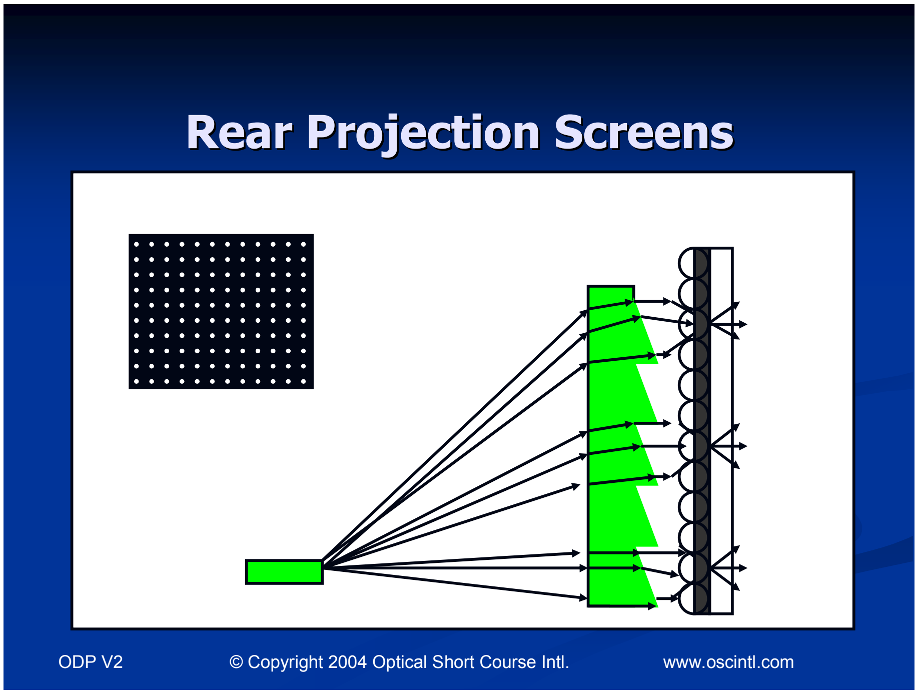

Figure 4. Glass Beaded Rear Screen

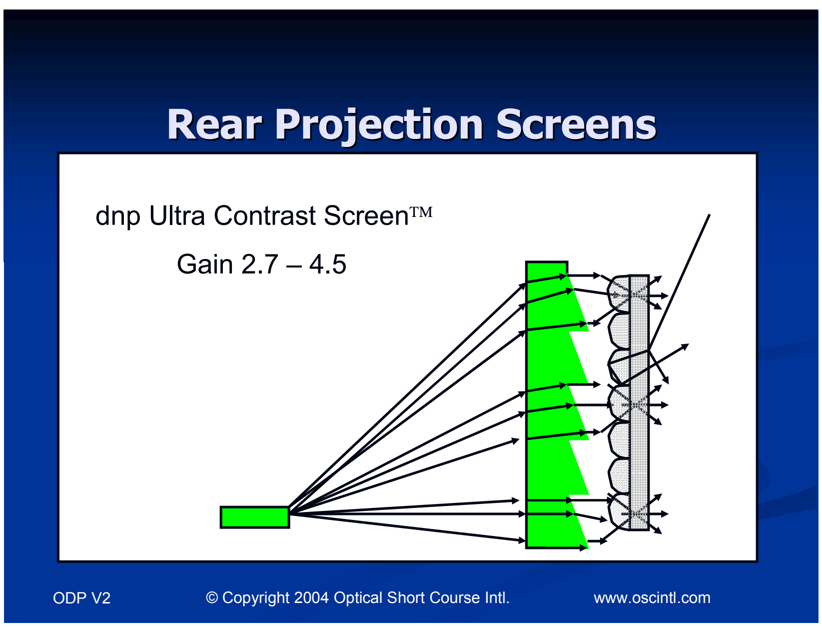

Figure 5. High Contrast Tinted Screen for Use in Ambient Light

In high contrast screen there is often a tint or absorbent particles added into the bulk or on a surface of the screen. The idea of using these absorbent materials is that the ambient light from the room will be incident upon the screen and be absorbed by these materials. The light from the projector behind the screen is typically focused by a Fresnel lens and then another mechanism like the glass balls or hemispherical lenses as shown in Figure 5 above. While there is a loss of light being transmitted through the tinted or absorbing material the overall contrast from the screen in ambient light is vastly improved because of a reduction in the reflection from the room lights. The black stays grey from the room light reflection and scatter from the front parts of the screen.

If the gain is too high for an application you will see a halo or very bright reflection from the screen where a partially specular component is giving a high gain directly on axis from the light source. This non-uniformity effect is disturbing as the viewer will see a bright reflection in one part of the screen that will be much higher than the periphery away from the bright spot. For this reason high gain screens must be used with care in selecting the proper application.

I think it is very important for viewers to compare screens side by side to see the differences of gain and half power angles to understand intuitively what these numerical specifications really mean from a viewers standpoint. We recommend viewing various colors, still data images, landscapes, dynamic video images, various digital images, as well as textures such as skin tones and dark scenes. We also recommend trying to simulate the various lighting conditions under which the screen will be used to see how ambient room lights will affect image contrast. In our live courses we take students through our front screen comparison tests with our customer screen comparison setup so they can visually understand what the numbers mean.

Summary

Rear projection screen technology is an important part of the total image path from the light source to the human eye. Screens are available in a variety of diffuse reflectivity's/scatter and gains. The selection of the proper screen for use in a specific viewing environment is important for optimal system viewing. It is advisable to watch a variety of digital images on the various screen types in the same ambient lighting level of the planned use to ensure a proper screen selection.

Stay tuned and keep looking for your frequent 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, or even send them a copy, your referral is the kindest compliment we can get to show your appreciation.