

# Underwater Light Reflector Design

Kevin R. Hardy, Mark S. Olsson, Peter A. Weber,  
DeepSea Power & Light, San Diego, CA

## Abstract

The two most important performance parameters for underwater lights are beam control and beam angle, both of which are primarily functions of reflector design rather than lamp type.

LEDs provide unique challenges to reflector design.

Total Internal Reflection optics are a second option for luminaire light control, with their own performance benefits and constraints.

Computer-based design software provides designers new tools to create custom reflectors to match specific lighting requirements.

## Reflectors

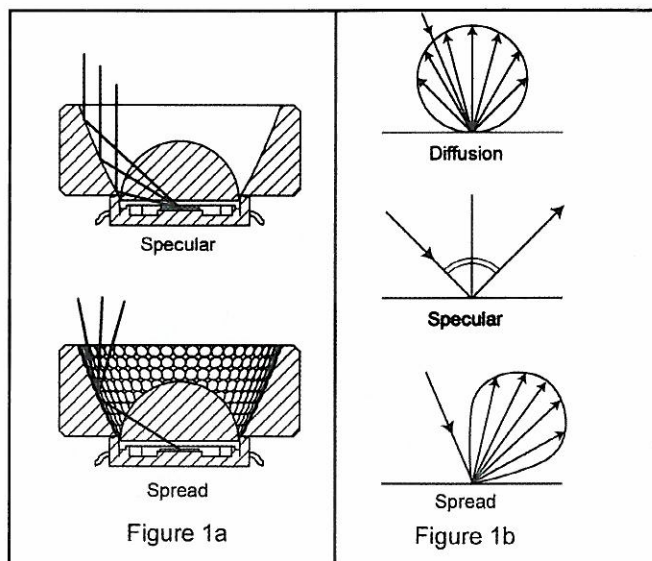
The two most important performance parameters of underwater lights are beam control (minimal stray light, sharp edges, and overall uniformity of field illumination) and beam angle (included angle of illumination), both of which are primarily functions of reflector design rather than lamp type. Within the constraints of this paper, light sources will not be discussed in other than narrow reference.

The third most critical factor, minimizing backscatter, is controlled by the lighting geometry defined by the separation of the luminaire and imager. The key concept of "common volume scattering," was discussed in detail in last month's issue "Optimal Lighting Geometry for Underwater Lights and Cameras." (ONT, September 2008, Vol. 14, No. 6, pp 24-25)

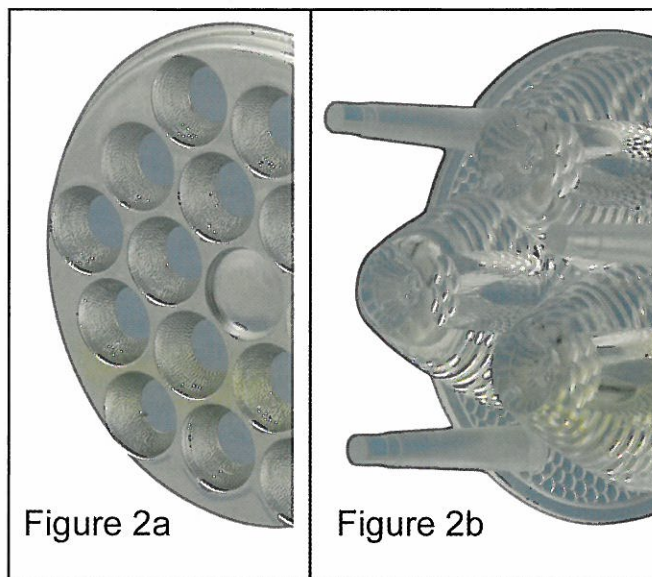
Some reflector designs produce uneven lighting, as evidenced by the presence of hot spots, while many others do not provide a high degree of beam control, as evidenced by broad, but weak, field illumination. The need for high performance underwater illumination suitable for color imaging systems can be addressed by modifying terrestrial lighting technology for underwater use with proper housings and reflectors.

In his seminal work, *Optical Design of Reflectors* (John Wiley & Sons, NY, 288 pp, 1980), William B. Elmer writes, "The optical nature of a reflector is governed by (1) the thermal and spectral nature of the light source to be used, (2) the spatial configuration and intensity distribution of the source proper and its envelope, (3) the character of the reflecting surface, (4) the location of the light source relative to the reflector, and (5) the relative nature and configuration of the lighting task."

There are two general classes of reflectors, specular and diffuse (see Figure 1). Specular reflector surfaces are either smooth or textured, and appear metallic or mirror-like. Diffuse reflectors have a matte surface that is white in color. All reflectors involve some component of both specular and diffuse reflection. Still, highly polished metallic surfaces are almost perfectly specular, while matte, flat white surfaces are nearly perfect diffuse reflectors. Smooth specular reflectors allow a high degree of light control and precise redirection of light. Smooth reflector surfaces, however, can also reflect and project lamp features, such as hot spots or shadows. Spread Specular Reflectors are textured by means such as etching or peening. They offer slightly less edge control but allow the reflector designer to produce an even beam free of hot spots (see Figure 1a). White, diffuse reflectors offer no edge control, but produce broad even beams inexpensively.



**Figure 1a.** Affect on light reflection with specular and spread surfaces.  
**Figure 1b.** Different types of reflection (adapted from Elmer, 1980).



**Figure 2a.** Multiple reflectors in a single molded part (DSPL).  
**Figure 2b.** Multiple TIR lenses in a single molded part (Fraen Corp).

The amount of light control possible from a specular reflector is proportional to the relative size between the light source and the reflector. Extremely compact sources, such as LEDs, allow the use of small reflectors, while larger light sources, such as HID lamps, require proportionally larger reflectors to achieve the same degree of beam control.

Profile shapes of the specular reflector determine beam forming. Parabolic shapes gather emitted light and redirect it as parallel light rays leaving the reflector, providing a tight spot light pattern. Aspheric profiles direct light in wider angles, providing general flood lighting. The aspheric profile may be tailored to produce a medium, or wide flood. An ellipsoidal profile takes light from one focus point and redirects it to another. The convergence of the light beam at the second point permits a small window for the light to escape a housing, as DSPL does in



one of its Thru-Hull SeaLites®. Other profile shapes include anamorphic, hyperbolic, and isoradiant.

The depth of the reflector must be enough to capture the direct light emitted at angles greater than the desired beam angle, as measured off the centerline of the light emitter.

Wide flat emitters, such as high brightness LED arrays, produce light rays from a larger number of positions than do point source emitters, such as halogen bulbs, making individual reflectors for each LED a more effective means to control light in an LED luminaire (Figure 2a).

Diffuse reflectors, known in photography and film as board reflectors, plane reflectors, "flats," or bounce boards, are normally located independent of a light source. A diffuse reflector generally shows lower reflectivity, which can vary with surface texture, coating, and color.

The most important aspect of perfectly diffuse reflectors is that the angle of the reflected light is independent of the angle of incidence, according to Lambert's Law (see Figure 1b). The apparent brightness of the surface is the same in all directions. A flat diffuse reflector can be imagined as a glowing surface, whose brightness varies as the inverse square of the distance between the lamp and the reflector surface. Diffuse reflectors have the advantage of producing even areas of light generally free of hot spots over large beam angles. The direct beam may have some slight spottiness due to refractive effects from the lamp and envelope. The details of the shape of a diffuse reflector have a very minor effect on the beam.

Diffuse reflectors are only appropriate for wide flood beams. "No diffuse reflector can be prudently applied where the required beam is much below 90 degrees" (Elmer, 1980). Diffuse reflectors produce stray light out to a full 180 degree beam angle unless other means, such as cowls or baffles, are provided to absorb or redirect the light falling outside the beam perimeter.

Both specular and diffuse reflectors have been used extensively underwater. In general, specular reflectors have been used for narrow beam lights and diffuse reflectors have been used for wide flood lighting applications. Traditionally, specular reflectors are generally used in a dry mode enclosed inside of a watertight housing, though examples of their use as free flooding shrouds are seen, as with DeepSea Power & Light's powerful 1200 W HMI.

Particular attention to reflector surface quality is extremely important. All surfaces exposed to long term immersion in seawater are subject to some form of corrosion attack and fouling which can significantly degrade efficiency. This is equally true of transparent port and envelope surfaces. Maintenance will be required and should be anticipated; both specular and diffuse reflectors need to be kept clean. White reflectors need to be recoated or repainted periodically. Antifouling coatings can improve endurance somewhat, but must be very white or highly transparent. The apparent reflectance of both white and mirror-like specular surfaces can be deceiving. The difference in reflectance between a "reflector" (pure) white and off-white is very significant in terms of beam efficiency, but only slightly different in appearance. Likewise, a highly polished stainless steel or chrome surface has a reflectance of only about 55 percent, whereas reflector aluminum has a reflectance of over 90 percent.

Near field and far field targets require different lighting solutions. Once, ROV designers tended to install a single system of wide flood lamps mounted on either side of the cam-

era(s) at the front of the vehicle. The entire area in front of the vehicle is flooded with a relatively low level of light. This type of lighting system can provide good illumination in front of the ROV at a distance about equal to lamp spacing, and may permit viewing all the way up to the camera port. This suits general area surveys. If no maximum viewing distance can be defined and close up viewing is a requirement, this is a reasonable solution. Such lighting systems perform poorly at distance, or even at moderate ranges in murky water. Some optimization may be achieved by lowering brightness in close while increasing brightness farther out. If viewing distance needs to be increased, a preferred solution is to add a second system of high power narrow beam lights for penetration forward of the ROV.

### TIR

Total Internal Reflection occurs when light passing through a uniformly transparent body, such as optically clear glass or plastic, strikes a boundary surface at an incidence angle causing internal reflection. This will occur if the refractive index is lower on the other side of the boundary, as with air, allowing no light to pass through. The highest angle, measured with respect to a line normal to the surface, is called the "critical angle." Optical fibers are based on this physical phenomenon.

Optics based on TIR are referred to as "TIR lenses," something of a misnomer as lenses are defined by principles of refraction, not reflection.

TIR lenses may be molded from polycarbonate or acrylic. They are readily available from multiple manufacturers including Fraen and Dialight. With investment in injection mold tooling, custom assemblies with multiple lenses or reflectors may be molded as a single part.

A downside to TIR lenses is the transmissivity, or ability to pass light, through plastic is slightly less than air, and losses of 2-4% may be expected. Improperly blended materials or surface finishes can produce chromatic aberrations. On the plus side, when used with LEDs, the LED emitter dome may be placed fully within the TIR lens body, assuring all emitted light will be captured. In addition, the Max OD of the TIR lens may be made smaller, allowing higher density placement of LEDs, creating a smaller overall light fixture (Figure 2b). Secondary optics may be placed over the face of a TIR lens, using prisms or fluting to diffuse the emitted light into a more uniform pattern.

### Computer-aided engineering

Complex optical engineering and lens design has been made simpler with the advent of computer software that allows today's designers to put away the spherical drafting board, and play with ray trace algorithms that plot positional (illuminance) and directional (luminous intensity) output. TracePro®, ReflectorCAD®, and FRED® Optical Engineering Software are three examples. TracePro® has the additional advantage of providing a design bridge to SolidWorks®, a popular parametric solid modeling program.

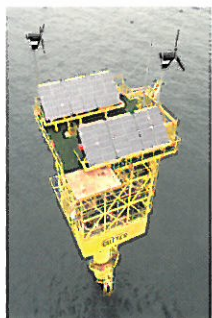
### Conclusion

Reflectors optimize the placement of light to execute a specific task. "The variety of forms in which reflectors can be easily produced frees optics from the spherical straightjacket imposed by lenses, and opens optics to the sophisticated world of infinite beam variety" (Elmer, 1980).





"United We Stand"



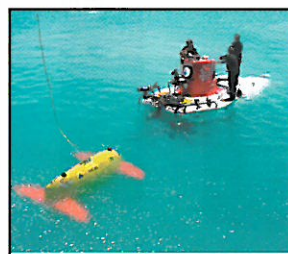
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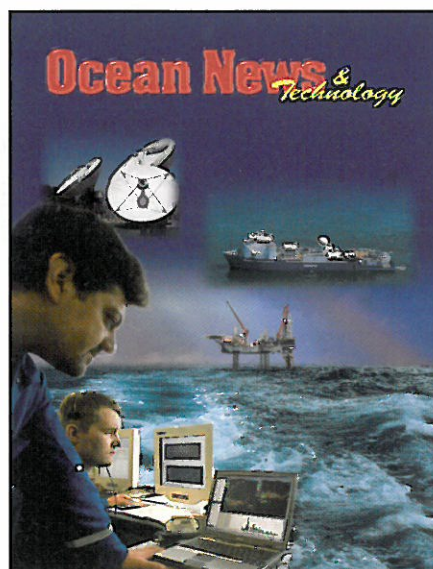
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