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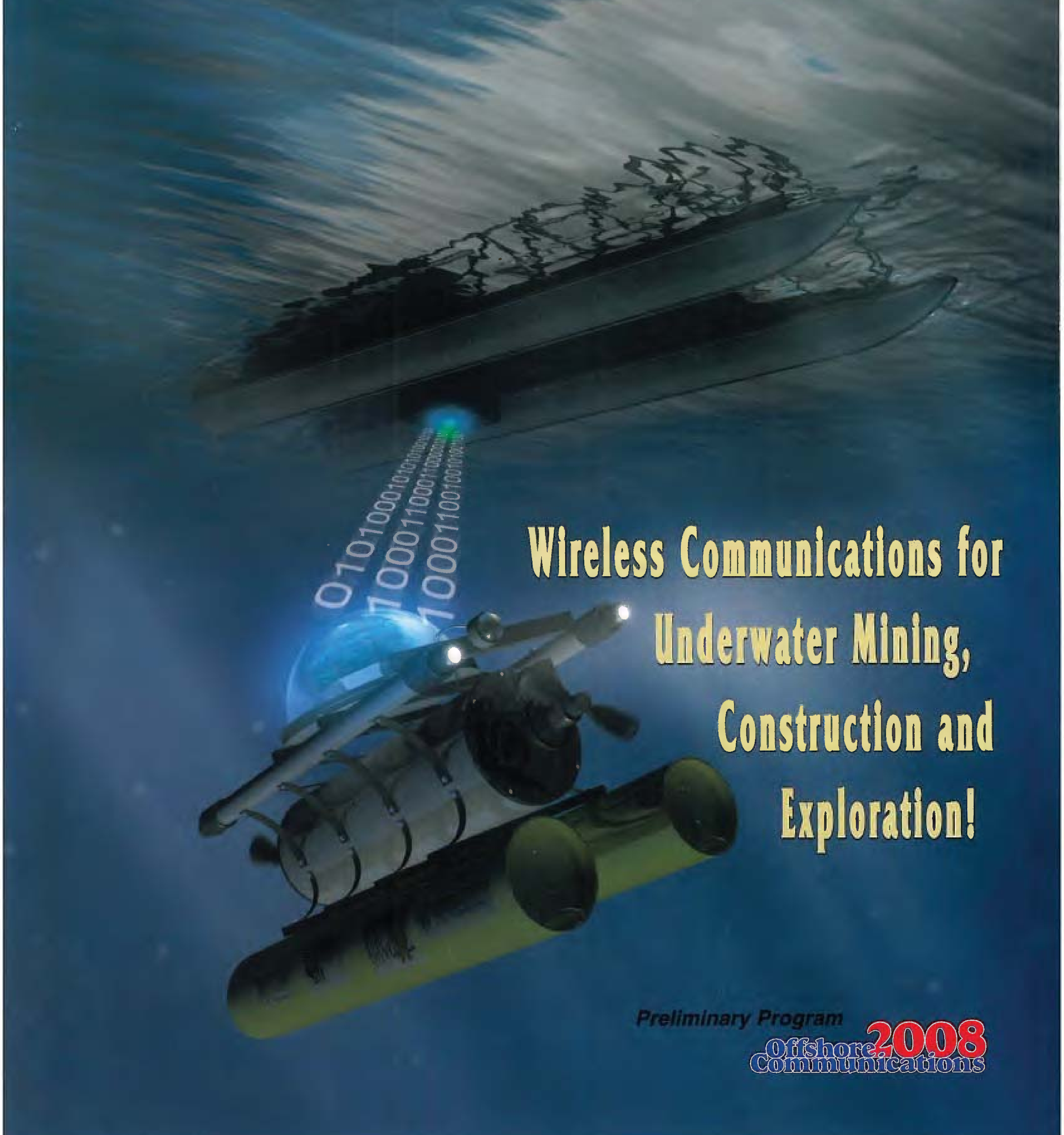

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Optimal Lighting Geometry for Underwater Lights and Cameras—Part 1

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Abstract

Following ideal reflector design, the placement of an underwater light, or "luminaire," relative to the camera will have the greatest affect on image quality, due to "Common Volume Scattering," which can result in backscatter in the presence of suspended particles or organisms.

Background

In order to evaluate a proposed underwater lighting system, it is useful to establish a set of performance standards for the lights themselves. These performance criteria are based upon general underwater applications; specific applications will prioritize some parameters differently. In the authors' opinion, the ordered ranking of performance criteria for an underwater light is:

1. Beam Control (Spill Light, Edge Control, Uniformity of Illumination)
2. Beam Angle (Angle of Illumination)
3. Color (Spectral Power Distribution)
4. Luminous Efficacy (Lumens/Watt)
5. Size/Weight
6. Lamp Life
7. Electrical Requirements, Voltage, Ballasting
8. Temperature Effect on Operation
9. Vibration and Shock Resistance
10. Starting/Restarting and Warm Up

The two most important performance standards 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 controlled by reflector design, not lamp type. 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.

In practice, underwater lights need to be small in size, lightweight, rugged, and tolerate high pressures. These characteristics compete with other luminaire performance metrics of light output, thermal management, and beam control.

Beam Control

The most important design parameter of an underwater luminaire is beam control. Beam control consists of: 1) limiting stray light falling outside of the projected beam, 2) the reduction of hot spots within the beam, and 3) minimizing backscatter. The first two characteristics of beam control are controlled almost entirely by the reflector, the last by the lighting geometry defined by the separation of the luminaire and imager.

There are two general classes of reflectors, specular and diffuse. Specular reflectors are either smooth with a shiny mirror finish, or spread type, with a patterned or textured mirror finish. Diffuse reflectors have a matte surface that is white in color.

Highly polished metallic surfaces are almost perfectly specular, while matte, flat white surfaces can be nearly perfect diffuse reflectors. Smooth specular reflectors allow a high degree of light control and precise redirection of light. Spread reflectors, which are specular, but etched or peened, offer slightly less edge control, but allow the reflector designer to produce an even beam free of hot spots. White, diffuse reflectors offer almost no edge control, but produce broad even beams inexpensively.

The scattering of light underwater is the dominant factor that affects image quality. Scattering becomes more important as the viewing distance increases, and if the light source is close to the imaging device relative to the viewing distance. For this reason, it is essential to reduce stray spill light falling outside of the desired beam angle. Portions of this stray light will be backscattered in the viewer's direction and act to reduce scene contrast. This is basically a signal to noise problem, where the light returning from the target represents the signal and the backscattered light contributes to the noise of the system. This is called common volume scattering. "Common volume" refers to the volume of water between the object and the sensor that is illuminated by the light source (Figure 1). An ideal underwater luminaire will produce a beam of light that just covers the desired field of view, then abruptly falls to zero just outside this task area. For a given source-receiver geometry, such a light will reduce common volume scattering to a minimum. It is important to note how the use of multiple illumination sources can also reduce backscatter.

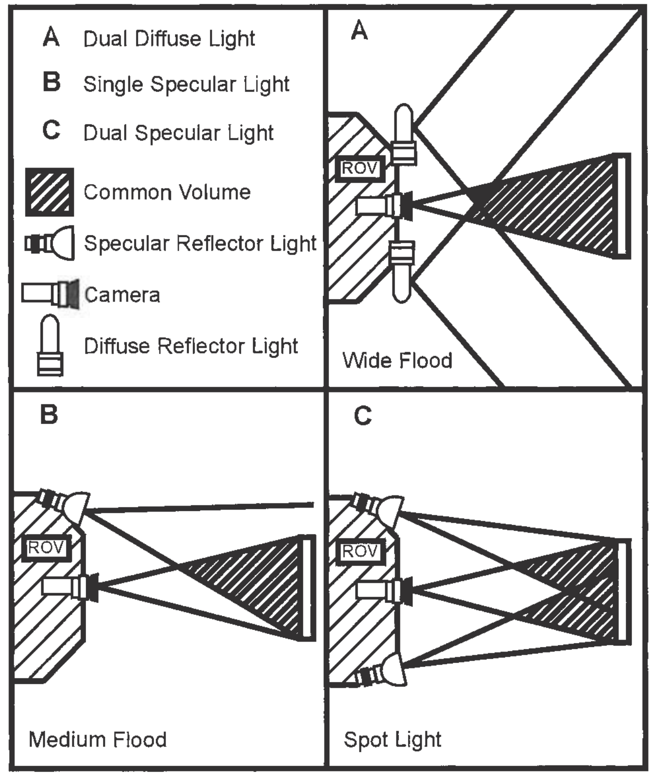

Figure 1 *Common Volume Scattering*

Underwater Vehicle Lighting

Underwater imaging can be either sensitivity limited or backscatter limited. Sensitivity limited imaging occurs in relatively clear water at moderate viewing ranges, and is dependent on camera sensitivity. Color cameras are often sensitivity limited because of their relatively low sensitivity compared to monochromatic imagers. In sensitivity limited situations, additional illumination can provide longer range viewing, better color or contrast rendition, and greater depth of field.

Backscatter limited viewing occurs in turbid water or when using highly sensitive imaging systems for medium range viewing. In backscatter limited situations, beam control and lighting geometry (greater source/receiver separation) are far more important than increased illumination. Improved lighting control and geometry can substantially increase viewing range in a backscatter limited situation.

Long range imaging requires minimizing backscattered light. White light illumination sources will contribute a disproportionate amount of red light to backscatter if the distance traveled by the backscattered light is shorter than the image light travel path. This is due to the selective color filtration effects of water, with the red light contributing more to backscatter than to the useful part of the image. A blue-green filter on the camera may also reduce backscatter and improve contrast rendition.

Some improvement can be achieved by reducing illumination levels in close, while increasing them farther out. This will reduce common volume scattering when viewing at a distance, and yet still provide enough illumination for close in viewing. This is a common situation where the beam characteristics of diffuse reflectors perform well. Performance can be improved if a minimum viewing distance can be established (Figure 1). A lighting system using luminaires that produce beams with sharp edge fall offs can be highly optimized to work at, and somewhat beyond, this minimum distance. The advantages of an optimized lighting system become greater as distance and water murkiness increases. Note the differences in the common volume between the three different lighting arrangements shown in Figure 1. In reality, the beam edges shown are not as sharp as shown, especially with the wide flood diffuse reflectors.

One design approach is to install a single system of wide flood lamps mounted on either side of the camera(s) at the front of the vehicle. On larger vehicles this same lighting system may also be used with a SIT or ICCD camera for longer range imaging. The entire area in front of the vehicle is flooded with a relatively low level of light that provides illumination in most directions. This type of lighting system can provide good illumination in front of an underwater vehicle at a distance about equal to lamp spacing, and may permit viewing all the way up to the camera port. If no minimum viewing distance can be defined and close up viewing is a requirement, then only slight optimization can be achieved with a single lighting system. Such lighting systems perform poorly at a distance, or even at moderate ranges in murky water.

If a range of viewing distances must be accommodated, the recommended approach is to install two lighting systems, one optimized for close range, the other for more distant imaging. On pan and tilt systems, the lights should follow the camera if possible. This allows the use of much more highly controlled lights, and provides a higher level of scene illumination in the direction that the camera is pointing. Good camera to light separation is usually difficult to maintain using a single pan and tilt unit, and this approach is only advantageous for very close range viewing, unless a second paired unit is available for the lights. A variation on this theme would be to swivel lights on either side of the camera as the viewing distance changes, varying the intersection point to suit the minimum viewing distance for the subject.

In some applications, such as pipeline inspection cameras, it is necessary to integrate the light source, typically LEDs, into the same housing as the video camera module. This size reduction comes at the expense of both sub-optimal reflector design and increased common volume scattering. A hot spot free, uniform beam with a sharp cut off at the beam edge is difficult to achieve efficiently in small pressure-resistant enclosures, exacerbating the common volume scattering problem.

Conclusion

Placement geometry of underwater lights with respect to the imager is a crucial element of illumination design for underwater vehicles.

Part 2 in this series will feature an article on "Underwater Light Reflector Design". For more information, visit the DeepSea Power & Light Web site at www.deepsea.com.