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Design Considerations for Laser.Based Underwater Optical Systems

K. O. G. VARUGHESE
Instruments Research and Development Establishment Dehra Dun-248008

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Abstract. Certain typical design requirements of laser based underwater receiver optical systems are dealt with. Some of their special features which are to be considered while designing these systems are highlighted. Optical schemes, which can be used as underwater receiver optics, are also explained.

1. Introduction

In laser based optical systems for underwater operations, the laser transmitter is usually mounted on an airborne platform and the energy emitted by it is picked up by an optical system placed at a certain level below the ocean surface. A typical example is the satellite to submarine communication set-up. When the laser beam is incident on the surface of the ocean, most of the energy is transmitted into the volume of the sea. The beam first spreads at the interface, depending on the ocean surface roughness. As it travels down the sea, additional spreading of the beam occurs due to bulk scattering. As a result of these spreadings and also due to absorption losses in seawater, the laser energy gets considerably reduced as the depth increases[1]. 'The receiver optics can also pick up energy from extraneous sources and back-scattered laser radiation thus adding to the noise of the system. These factors call for certain special design requirements for the receiver optical systems.

2. Requirements on Receiver Optics

The laser energy gets dissipated as it travels down the volume of the sea and the irradiance at the receiver optics will be usually very small. In order to collect sufficient energy in such situation, the receiver optics should have larger collecting apertures. This is one of the main design requirements of underwater receiver optical systems. The collecting aperture for each system will have to be worked out taking into considerations, the laser source, the location of the receiver optics and the noise equivalent power of the detector. It is not uncommon to find receiver optics with **20** to **30** cm diameter for this application.[2] The situation is analogous to that of passive night vision objectives, where the apertures must be made as large as possible to collect more signal photons in order to reduce the noise.

In underwater operations possibility exists of radiations from extraneous sources as also the backscattered radiations of the laser source itself reaching the detector and adding to the noise of the system. This background noise is a function of the optical efficiency and as the receiver aperture increases the background noise also gets increased. The reduction of this noise by preventing the stray radiations from reaching the detector is another important design requirement of these systems. As a first step in this direction, the field of view of the system is to be restricted to as small a value as is absolutely essential. Depending on the detector size and the field of view, the focal length of the system can be worked out by the well known formula.

$$f = \frac{d}{2 \tan \theta}$$

where f is the focal length, d is the diameter of the detector and θ is the semifield angle. The focal length thus calculated will ensure that only radiations from the required field of view will be focussed onto the detector. However, radiations from outside the field of view can enter the optical system and after getting reflected from the walls of the lens housing may fall on the detector and degrade the function of the system. To prevent these radiations from reaching the detector, the internal walls of the housing must be suitably baffled.[3] Baffles are diaphragms having definite sizes, orientations and locations. The procedure for determining their sizes and locations in a simple set-up is shown in Fig (1). The key to successful use of baffles lies in ensuring that the detector does not see any part of the internal housing that is directly illuminated. To achieve this, various possible ray directions within the housing will have to be ascertained and for each optical system the baffle design is to be separately carried out. The procedure becomes quite complex and elaborate as the complexity of the system increases. This type of baffling is very expensive, but will have to be resorted to in optical systems of the type under consideration to get better signal to noise ratio.

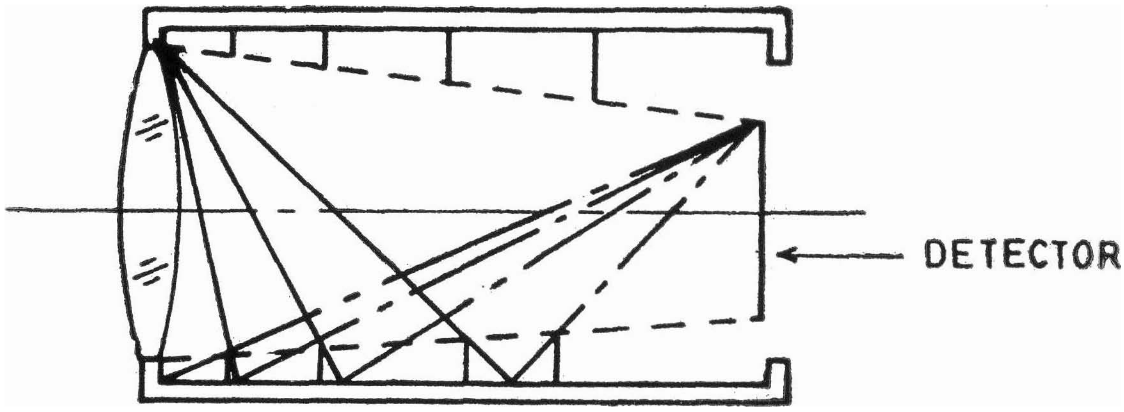

Figure 1. Straylight elimination by baffles.

While the baffles can cut out radiations from outside the field of view, once the extraneous sources are within the field, their radiations must be prevented from getting focussed on to the detector. For this, narrow band interference filters are to be used in the optical system. These filters will ensure that radiation of the required wavelength only will be transmitted to the detector. When these are placed just ahead of the detector in convergent beam, they must be of the wide angle type.[4] However, the maximum full cone angle that a wide angle filter can cover is generally around 25^0 only. This corresponds to a relative aperture of about $f/2.3$. The wide angle filters can be used if the relative aperture of the receiver optics is not better than this value. When faster optical systems are to be used as receiver optics, normal interference filters, which are designed to be used in collimated beam are to be incorporated in them. To get collimated beam within the receiver optical system to match the size of normal interference filters an afocal attachment is necessary. This attachment will ensure the placement of reasonably sized narrow band interference filters in fast receiver optical systems.

Underwater optical systems are normally provided with a transmitting window which also makes the system water-proof. This window can affect some of the system parameters and characteristics. When a plane window is used, the field of view

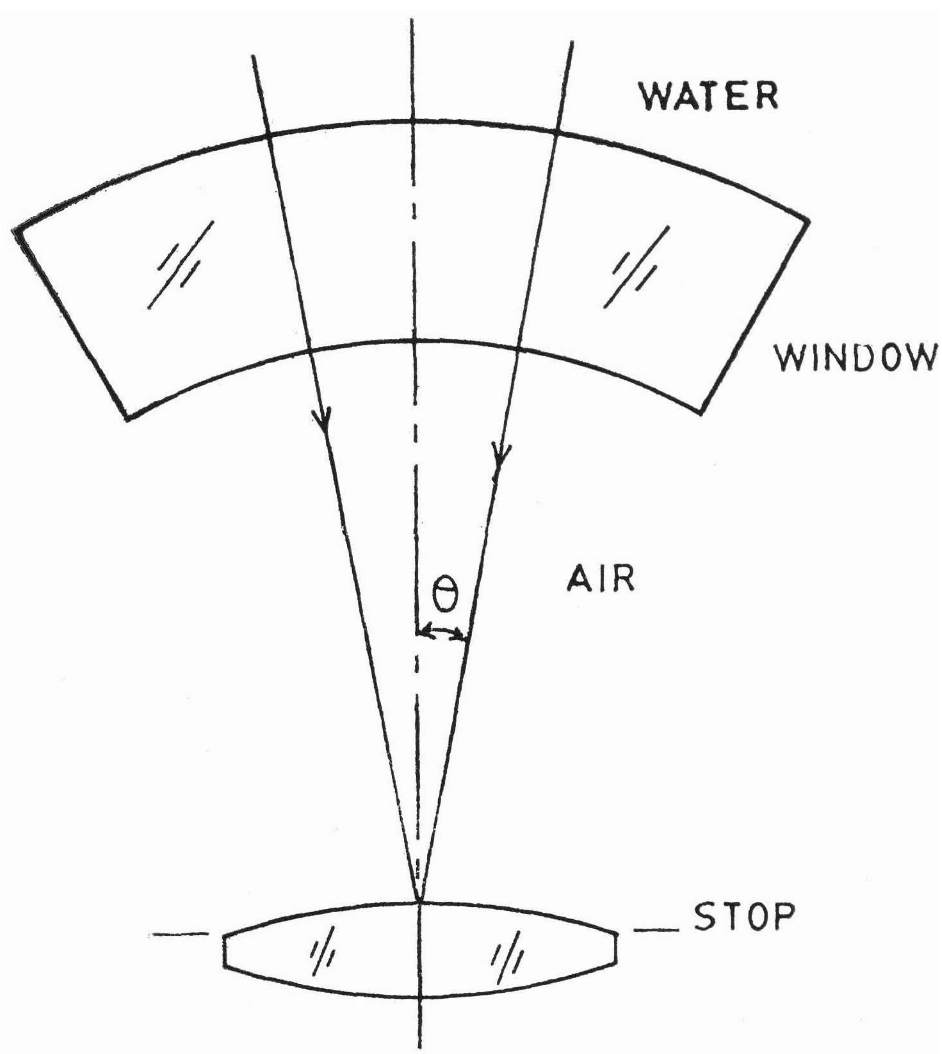

Figure 2. Concentric optical window.

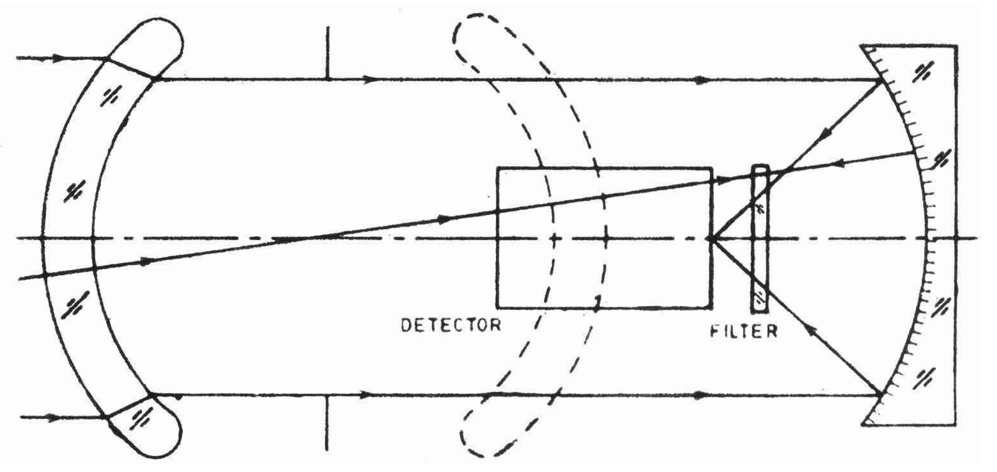

Figure 3. Receiver optics configuration (for low speeds)

presented to the optical system will be more than the actual field due to refraction at glass-air surface. Hence the optical system will have to be designed to cater to a larger field of view than what is actually required. In order to keep the field of view unaffected, one can use a window with concentric inner and outer surfaces and the stop at the common centre of curvature as shown in Fig (2). In this situation the chief rays are all normal to the surfaces and the field of view remains unaffected. An added advantage of this set-up is that the concentric window can be treated as an additional optical element and may be effectively used in controlling spherical aberration of the overall system. However, the concentric window can contribute significantly towards Petzval curvature especially in high aperture systems as the Petzval contribution increases with thickness in a concentric lens. Since the stop is at the common centre of curvature, no other monochromatic field aberration will he introduced by the concentric window.

3. Sample Receiver Optical Systems

If the relative aperture requirement of the receiver optics is not better than about $f/2.3$, wide angle interferance filters can be used in front of the detector in convergent beam. The receiver optics in such cases can be similar to the famous Bouwers[5] concentric system as shown in Fig (3). It consists of a primary mirror and a corrector lens concentric with the mirror, with the stop placed at the common centre of curvature. When the corrector lens and the mirror are placed on both sides of the stop as shown in Fig (3), the corrector can also act as a concentric window. This arrangement will keep the field of view unaffected. Further, the under-corrected spherical aberration contribution by the primary mirror can be effectively compensated by the concentric window. As the stop is at the common centre of curvature no off-axis monochromatic aberration other than Petzval curvature will be present in this system. For limited field of view the Petzval curvature may not pose any serious

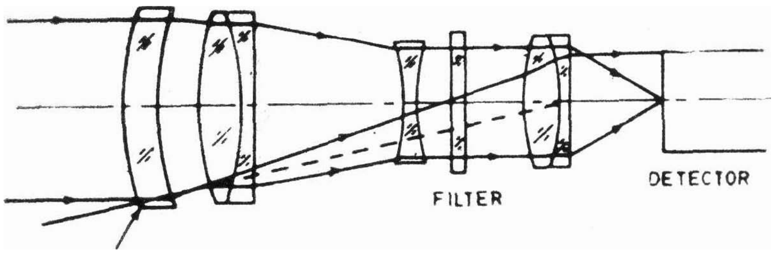

Figure 4. Receiver optics configuration (for high speeds)

problem. A well corrected receiver optics is possible in this configuration with the interference filter placed in convergent beam in front of the detector.

When the relative aperture required is better than about $f/2.3$, as has already been mentioned, an afocal attachment may be incorporated in the receiver optics to facilitate the use of normal interference filters in collimated beam. A possible optical configuration with such an attachment is shown in Fig (4). This set-up has certain interesting characteristics. The afocal system is of the Galilean type. In this set-up the entrance pupil, which is virtual, is located well behind the negative element of the optical system. As the common centre of curvature of the concentric window is to be located at the entrance pupil, the window can be brought very close to the front lens and the system becomes compact. The filter is placed at the exit pupil of the afocal system where the beam is collimated. In this position the filter housing can also act as a glare stop thus cutting out stray radiation. The expensive baffling as explained earlier can be avoided in this set-up. This set-up is amenable to a very high degree of aberration correction for large aperture and reasonable field of view.

4. Conclusion

The main requirement in the design of laser based underwater optical systems is collection of as much laser energy as possible and cutting out of background radiation to get better signal to noise ratio. Aspects like placement of narrow band interference filters and the front window also play crucial roles in the selection of possible optical schemes to be used as receiver optics. The sample systems described can meet the essential requirements significantly.

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References

1. Manzo, P.R., *SPIE* Ocean Optics, 160, (1978), 148
2. Kim, H.H., *Appl. Opt.* 16 (1978), 46
3. Smith, W. J., 'Modern Optical Engineering' (McGraw-Hill Inc., New York), 1966, p. 128
4. Pidgeon, C. R. & Smith, S. D., *J. Opt. Soc. Am.* 54 (1964), 1459
5. Rouwers, A., 'Achievements in Optics' (Elsevier Tnc.. London), 1950, p. 25