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Underwater Imaging and Photography

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Abstract. The problem and various techniques for underwater imaging have been reviewed. The effect of various design parameters like pulse shape and duration, etc. has been brought out. System design considerations for underwater photography have also been discussed.

1. Introduction

The search and recovery of sunken ships, submarines, lost atmoic bombs has historically been a tedious, time consuming and expensive task. Using underwater imaging and photography, not only the above tasks but also monitoring tasks such as laying cable, amplifiers and pipe lines in safe positions could be simplified. A combined sonar/TV re-entry system for the offshore oil industry is much useful. The combination of television and sonar images on board the drilling vessel provide immediate and exact positioning information for guidance in the re-entry procedure. The present day side locking sonar system is inherently prone to data interpretation problems leading to a high false target rate and the corresponding necessity of later optical verification of the target contacted. Various techniques have been developed and used with advantage for underwater imaging and photography[1-4]. The paper reviews the various techniques used for the purpose.

2. Problems of Underwater Viewing

There is not enough natural light for viewing at depths below 125 m. even under good conditions at sea. A system that provides light at the target is necessary but scatter makes this difficult. Viewing under water is like trying to see in a dense fog. The problem of viewing underwater can be summarised as one of attenuation accompained by contrast diluting scatter, The one limits range by cutting signal level while the other adds noise. The solutions to these problems are as follows :-

1. Operation at wavelengths, where attenuation is less.
2. Providing more light and also increasing gain.
3. Removing the contrast-diluting scattered light.
4. Contrast enhancement of images.

Attenuation and scatter can be minimised by working at wavelengths where attenuation is least **i.e.,** by green lights. Television cameras can provide more than enough gain and can improve the signal to noise ratio by integration. The resulting signal can also be processed to increase contrast and to remove some of the uniform signal component due to scattering correction, auto black level and dynamic shading technique in TV system can be used with advantage but normal techniques are of limited value and scatter remains a problem.

The various techniques[5] used to reduce the back scatter are :

(i) Source Receiver Separation
(ii) Range Gating
(iii) Volume Scanning

and (iv) Polarization Enhancement

Conventional underwater optical imaging systems consist of an optical receiver such as a TV or film camera and an artificial light source for illumination. The back scatter encountered is represented in shaded area as shown in Fig I (A). As it can be

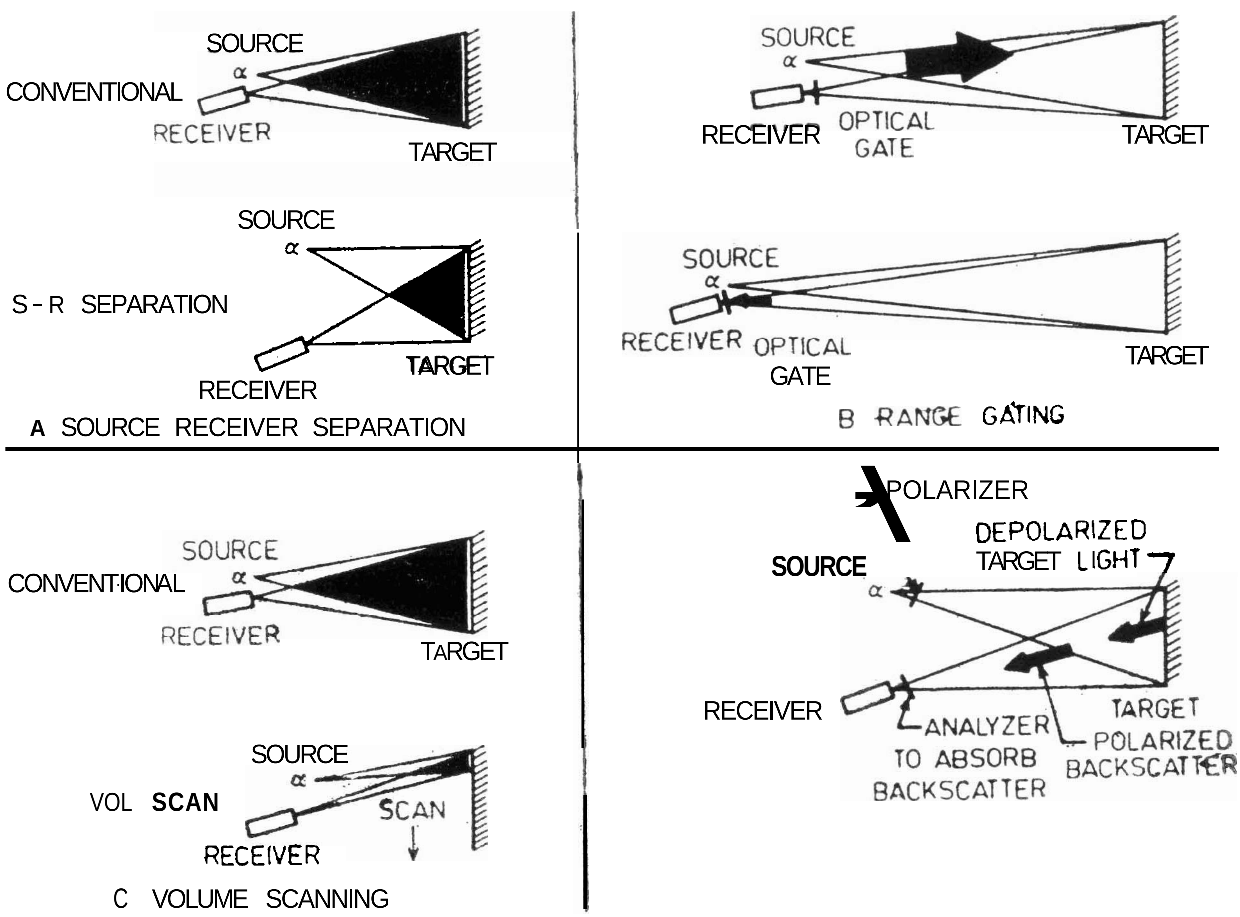


Figure 1. Techniques for reducing back-scatter

seen, separation of the source and receiver can reduce the total volume of back scatter seen by the receiver. On the other hand back scatter can be reduced by the more sophisticated range gating approach shown in Fig 1 (B). The source illuminates the whole targets with a pulse of light. The receiver is gated off with a fast optical shutter during the time the light pulse is travelling to the target and creating back scatter. When the illuminating light returns from the target, the receiver is momentarily gated on. This technique requires light pulses and receiver optical gating equipment capable of responding to durations in the order of few nano seconds. Another equally complex approach is the volume scanning method shown in Fig 1 (C). Here common volume creating the back scatter is reduced by reducing the source beam angle and receiver field of view. The entire picture is then received through a synchronous scan of this smaller beam over the entire target. The complexity of this approach is due to the relatively complex synchronous scanning mechanism necessary for its implementation.

The last technique shown in Fig 1(D) is referred to as polarized enhancement. A polarized light source is used to generate light, which is ideally depolarized by the target yet not affected by the back scatter. The receiver can then reject the polarized back scatter while allowing passage of a greater amount of light from the target. This technique has the advantage of being inexpensive and easy to implement but has the disadvantage of its efficiency being dependent upon the water and target characteristics. It is therefore generally classed as being unreliable.

3. Choice of Technique

All the system described briefly above indeed reduce the effects of back scatter. Choosing the appropriate technique is not an absolute decision but depends upon the specific system application.

There are mainly two type of applications in which user of underwater system is usually interested. He is either interested in seeing the details on a specific object or he is interested in searching a large area to find and classify an object.

Range gating and source receiver separations[6] are techniques which are particularly adaptable to the smaller field of view inspection problem. Range gated light sources are generally not very efficient and narrow fields of view allow a concentration of the resulting limited power over a small target area. Source-receiver separation also works particularly well with small fields of view because the nearest common volume of back scatter is farther from the receiver. Volume scanning on the other hand is of limited use in the narrow field of view inspection problem because of the necessity of dividing up a small area into even smaller elements. The scattering properties of the water will then cause spreading of each resolution element and defeat the goal of high resolution over a small inspection area.

Volume scanning, however, is particularly adaptable to the wide area optical search scenario in which the spot size requirements are not so severe. Both range gating and source receiver separation on the other hand have severe limitations when applied to this situation. If the field of vew is say 120° the range gated system would gate for a small depth of field perpendicular to but would search only half the distance to the bottom along either side leg of the field of view. This would result in a circular arc along the flat target bottom. Trying to overcome this limitation, using a series of range gated receivers would result in a grossly complex imaging system. Simple source receiver separation will do little for the search scenario because of the small improvement it offers for any practical separation distances. However, laser television system handles this problem easily and effectively. Apart from the normal spotlight sources and low light television system, the following are the two laser techniques commonly used by which illumination can be made to appear localized in the vicinity of the object and also the scatter problem can be overcome.

1. Pulsed Range Gating Technique

2. Synchronous Gating Technique

4. Pulse Range Gating Technique

This technique was first described at the High Speed Photographic Conference at Zurich[7,8]. The system uses a pulsed laser with a gated receiving camera.

A pulse of light of 10 nano seconds long (which is about 2 metres in water) is used to illuminate the target, so that the target shall remain illuminated for 10 nanoseconds. If there is only one target then only one pulse will be returned, at this moment the viewing device should also be open in order to detect it. If there are two targets. it is possible to ignore one, using this gated receiver. Thus scatter that is continuous in depth can be removed except in the vicinity of the target. The system discriminates against light appearing to originate in all but the gated volume. A range discrimination better than *2.5* meters can be achived by using pulses shorter than 10 nano seconds.

For efficient operation the shape and duration of light pulses sent out and that of the camera response should be the same. The correlation of these two pulse shape gives the system amplitude response to a target as function of range and also the permissible tolerance on timing in order to pick out a target at a particular range. By suitably choosing the putse shape, the correlation can be made much sharper than the square pulses, giving an improvement in range discrimination. It is seen from the response curve Fig 2 that when transmitter and receiver are. synchronized ($T_t = T_r$) the response is peaked and high. In other cases i.e., $T_t > T_r$ or $T_t < T_r$ the response is not peaked i.e. discrimination is poor. Pulse range gating does not deal with the problem of small angle scatter on the return path. It means that this technique can not achieve better results than the light near the object although large angle scatter is discriminated against.

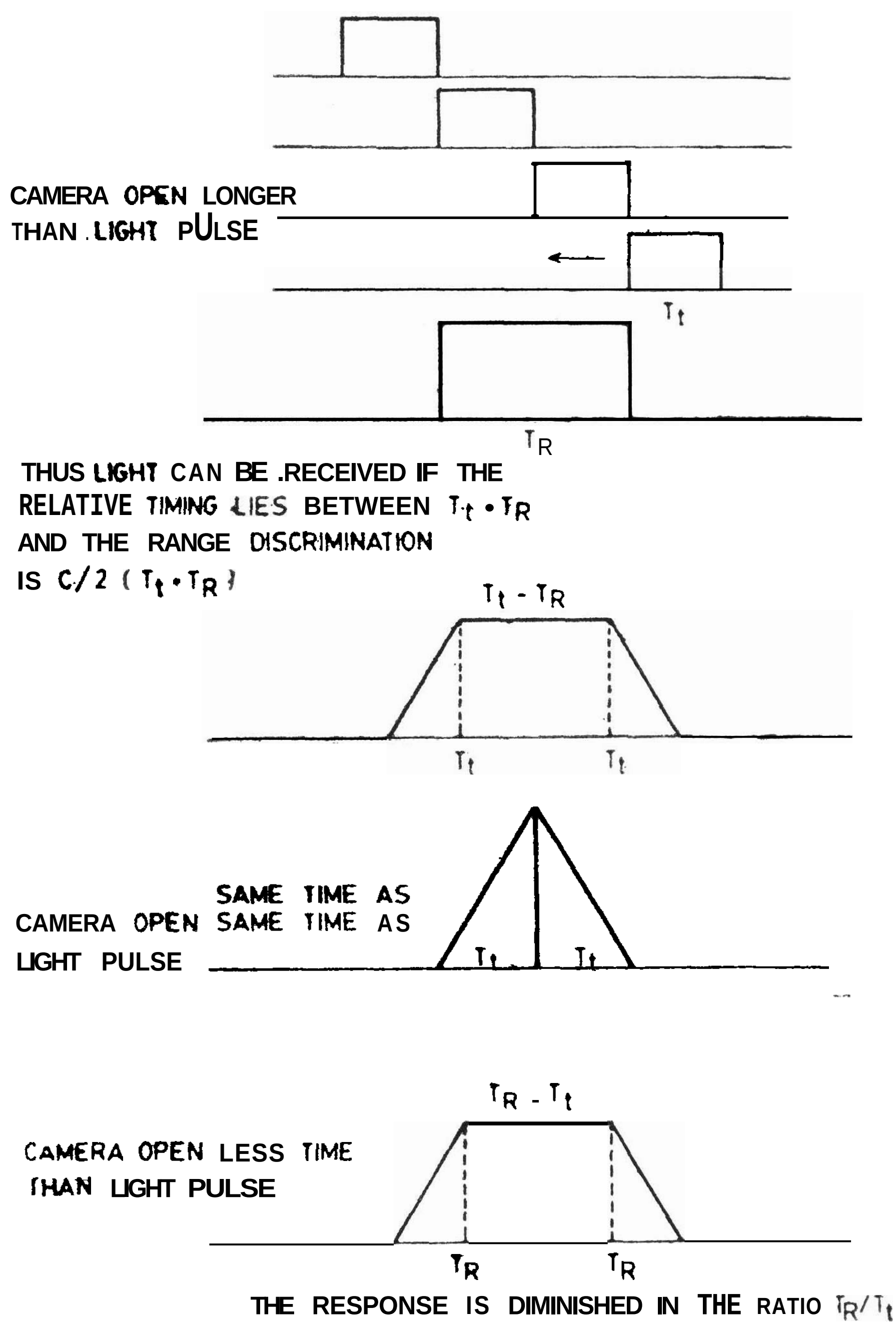


Figure 2. Effect of pulse Synchronisation

5. Synchronous Laser Television Technique

This technique solved the problem of small angle scatter simultaneously. The technique utilizes scanner television system by continuous time gating. **A Sychron-ously** Scanned Television System removes most of the unwanted scattered Light from the receiver channel. This is achieved by a camera which scans the target simultaneously with the laser beam using an identical but suitably delayed raster. For most purposes this effective scanning aperture is obtained using photoelectronic image dissectors. **The** basic configuration of the system is given in Fig **3.**

Let us consider a transmitter and a receiver scanning the **target** simultaneously in accordance with the CCIR standard. Then a line is scanned in 60 micro seconds

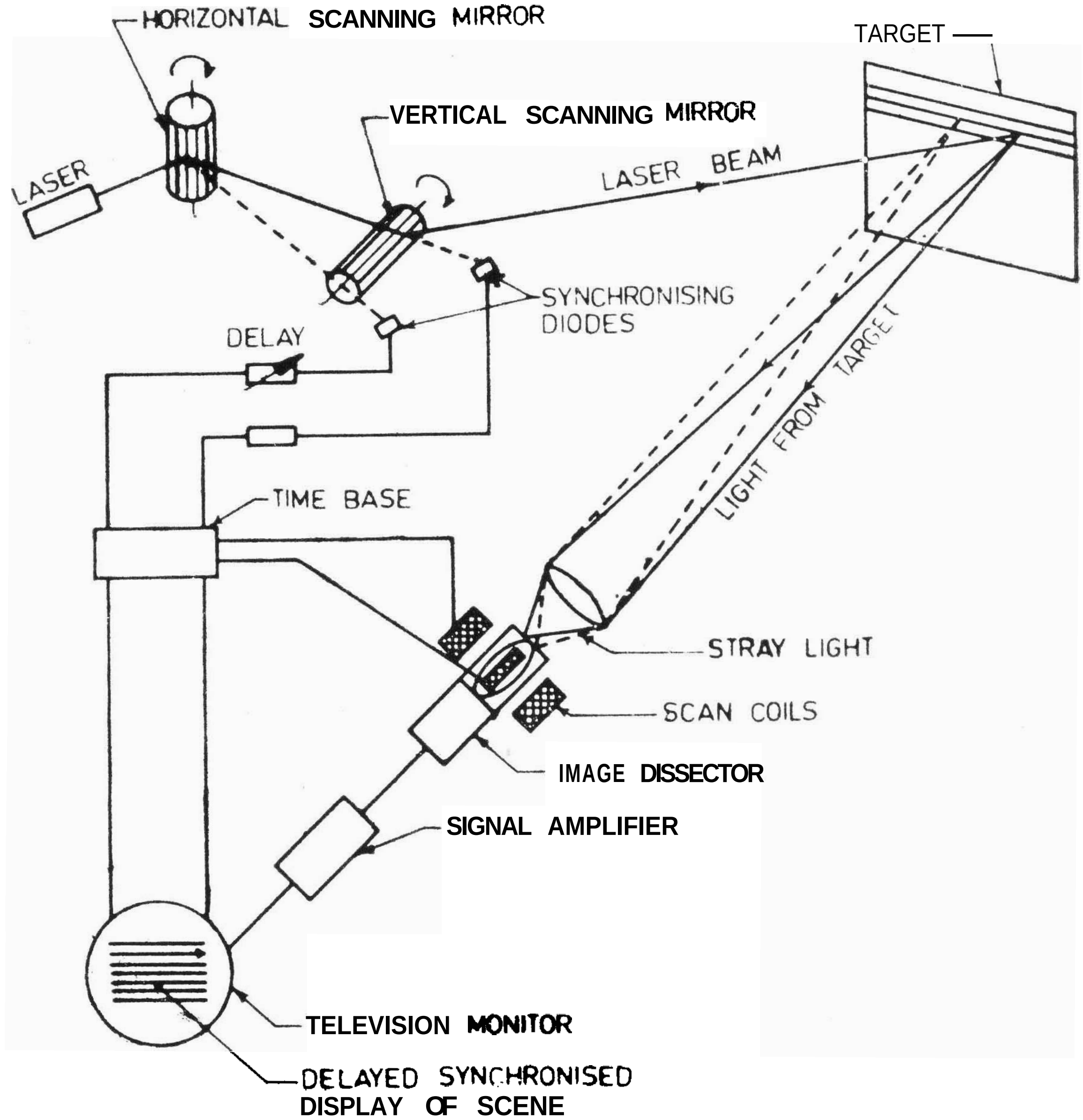


Figure 3. Synchronous laser television

and let the beam resolution diameter be about 1000th of a line length, and any distinguishable point on the scene will only be illuminated for about 60 sec. nano-seconds. Let a point A on scene be illuminated to receive the light from point A as shown in Fig 4, the receiver should also look at point **A.** If the receiver is looking at point *B*, it will not receive the light. It means that both the transmitted and received beams must have the same apparent origin. If the plane to be viewed is at least 13 metres away in water, the transmitted beam will take 120 nano seconds to reach the target and return to the receiver. Then receiver will have to be delayed by 120 aano seconds i.e., equivalent to the spot widths.

It can be seen that with different synchronization, a different plane will be seen. If the delay is three spot width i.e., 180 nano-seconds a point *C*, 7 metres beyond *A* would be seen, there being no light at *A* at the correct time. Similarly, with a delay of one spot width a point *E* would be seen, 7 metres from the receiver. As system

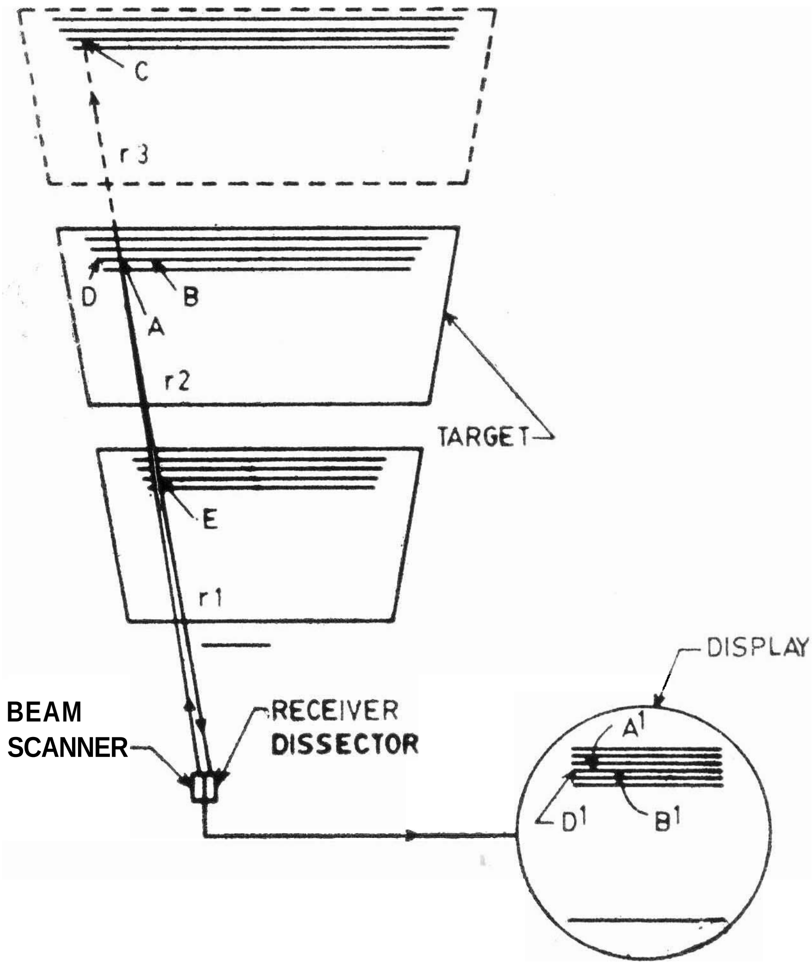


Figure 4. Target discrimination in Synchronous laser television

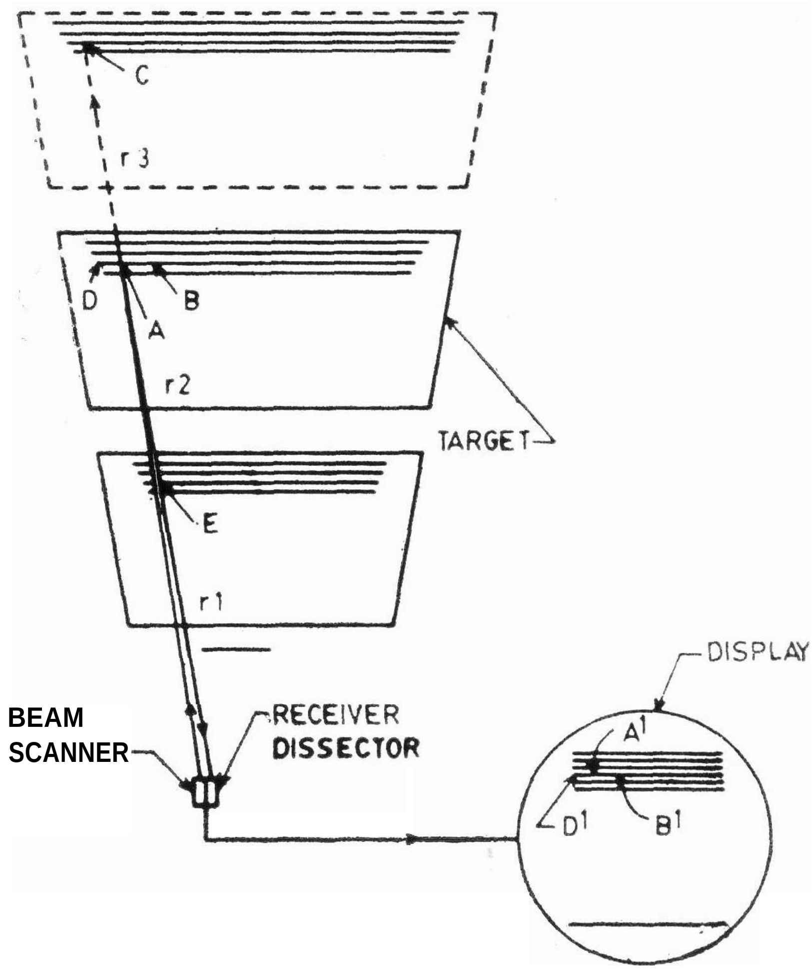
is continuous the raster picks out a plane, but because the effective gating time is finite, a finite depth is seen. In this case *60* nano seconds corr'esponds to 13 metres maximum depth. However, this value decreases with effective aperture and beam profiles, whose time correlation determine discrimination.

By this system, a discrimination of about 5 metres could be achieved. The system is able to remove majority of background scatter, the fluctuation in noise and saturation effects. The reduced fluctuation noise will help background subtraction **and** contrast enhancement techniques in removing the effects of uniform scatter within the discriminated volume.

The system discriminates against all light not appearing to emanate from along the reception cone. Pulsed gating is only the equivalent of localizing the light source in the vicinity of the target, but with this system even the small angle forward scattering of the light returned from *A***,** the target is removed.

6. Underwater Photography

Photography[8] from a constantly shifting sea surface or in an alien, inhospitable under sea environment is immensely more complicated than on solid or dry land. The



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Photography[8] from a constantly shifting sea surface or in an alien, inhospitable under sea environment is immensely more complicated than on solid or dry land. The maintenance of delicate, precise instruments in a region of powerful, moving masses of salt water poses technological problems of a unique nature. The optical transparency[10] in sea water, for example, varies from 0 to over 30 meter visibility. The prediction of visibility, days or even hours in advance, is one of the unsolved problems of oceanographic research. Optical problems arise from multiple refractions at the water, glass and air interfaces. Such phenomena distort the image and make difficult any interpretation of the subject and precise analysis of shapes and sizes. Lighting arrangements are much harder to achieve in the cold, black ocean depths. Colour reproduction is frequently not true as a result of the absorption of short wave lengths in water. For a record of water motion a stationary platform and a reference grid, are required. Obtainig light-weight, compact, easy-to-operate photographic equipment has been a hindrance to research work under the sea surface. Considerable effort has, therefore, gone into the development of unique equipment and techniques in view of the vital oceanographic interest in the photo-optical field as an aid in interpreting and understanding marine phenomena.

A self luminous object can not be seen or photographed at a limitless range through otherwise unlighted water, even if an ample amount of light from it reaches the observer or camera. Beyond a certain distance no image can be perceived, although a bright, diffuse glow may be easily discernible; the object is hidden by some of its own light that has been scattered toward the observer. This occurs even in the clearest water.

The reason for the obscuration is simple : an image is formed by a small amount of light that departs from the object in the exact direction of the eye or the camera lens and arrives there without having been scattered or absorbed. A much larger amount of light also departs from the object in adjacent directions. Some of it is scattered to the lens. This.light does not contribute to the image, but it passes through the lens and floods the image plane. The ratio of scattered light to image-forming light increases rapidly with the distance of the self-luminous object, and at some range it exceeds the contrast threshold of the eye or the camera. The image cannot then be seen; only a glow of scattered light is discernible.

In order to speak about range limitations in a general but quantitative way, let us specify object distance in multiples of the length of water path required to reduce image-forming light by a factor of $1/e$, where $e=2.71828$ and $1/e=0.367879$. Let that path be called the attenuation length, because it is equal to the reciprocal of the well known attenuation co-efficient of water. Attenuation length may exceed 20m in very clear oceans, or it may be 5m in coastal zones and shrink to a few cm in turbid harbours.

The limiting range at which the image of a self-luminous object is visible in unlighted water varies from 15-20 attenuation lengths, depending upon the water's ratio of scattering to absorption. In the day lighted sea ordinary objects can be sighted at 3 to 6 attenuation lengths depending upon the nature of the object and whether the observer looks downward, horizontal or upward. Even shorter limiting ranges are found when same objects are viewed or photographed by means of light from a submerged lamp located near the camera. In fact vision or photography beyond 3 attenuation lenths requires lamp to be separated from the camera, or prevented by a shield from shadding direct light on the path of sight, and/or polarizers be used at both lamp and camera.

The reduction in limiting range from 15 to 20 attenuation lengths for self luminous object from 3 to 6 attenuation lengths in the case ofordinary objects lighted by submerged lamps near the camera is caused by back-scattering throughout the illuminated path of sight. Most of the lost range can be restored by placing the lamp close to the object rather than in the vicinity of the camera. Long time exposures are often used when this is done because a severe loss in total light is imposed by absorption in the long water path.

It has been found that horizontal visibility through day lighted water is closely similar to horizontal visibility through the atmosphere, except for a factor of about 1000 in range. Yet many who have looked and photographed carefully through both media have the impression that resolution suffers differently in water than in air, even after allowing for the factor of 1000 in object distance. It is common practice to attribute resolution losses in either media to density gradients and to imply that water is a poorer optical medium than air.

Experiments with abnormal refractive effects in water have led to believe that neither temperature nor salinity gradients ordinarily found in the oceans attenuate high spatial image frequencies appreciably, even on very long optical paths including tens of scattering lengths. The same is true of normal concentrations of marine biology. From this stand point it appears that scattering length for scattering, ocean water is usually a better optical medium than air, provided that loss of power by absorption can be neglected. This conclusion may not apply, however, where fresh water mixes with ocean water or where major thermal or biological abnormalities exist.

System Design

It has been proved beyond doubt that a **'wet'** flooded camera is the most impractical way for underwater photography due to following reasons :-

(a) The cost and difficulty to calculate design and produce a specialized air lens that would produce a well corrected wideangle picture underwater.

(b) The unwanted extension on the light ray path in water, always increasing the effects of absorption and scattering.

(c) Film manufacturers advise that the coinplex dyes used in film can not stand exposure to salt water, much less even than to tropical humid air.

The modern way of photography is to use a pressure resistant housing where air atmospheric pressure maintains a constant refractive index for maximum lens performance. It is well known today that a plane-parallel window or port hole separating the water environment from an air filled camera housing or submarine hull is not optically acceptable.

The classic plane diopter effect, a direct result of light slowdown when traversing a denser transparent medium converts the flat air-water boundry into a 3.4 diopters convergent lens of the poorest quality causing the full range of all optical aberrations and 34 per cent increase in apparent focal legth. The latter is most bothersome aberration as the dense and scattering medium such as, sea water requires the shortest focal length possible to shorten ray path between subject and lens to the maximum. The simplest possible way of obtaining full correction of all aberrations is to use a correcting port-hole consisting of a strong (—17d) forward negative meniscus lens and re-arward positive (+13.6d) meniscus lens. The result is a total −3.4d negative power correcting the + 3.4 a plane diopter effect. The above design is inexpensive to ground as the two surfaces are flat (Fig. 5).

This design has proved to be most successful so far. This acts as a well recessed clearwater cone substantially improving scattering particle noise in the critical area closest to the lens system.

It is however quite essential to install the correcting lens elements and the primary lens as exactly as possible on the same optical axis. The film plane must also be normal to optical axis. It is of course essential to hold the film plane as flat as possible especially in the larger formats.

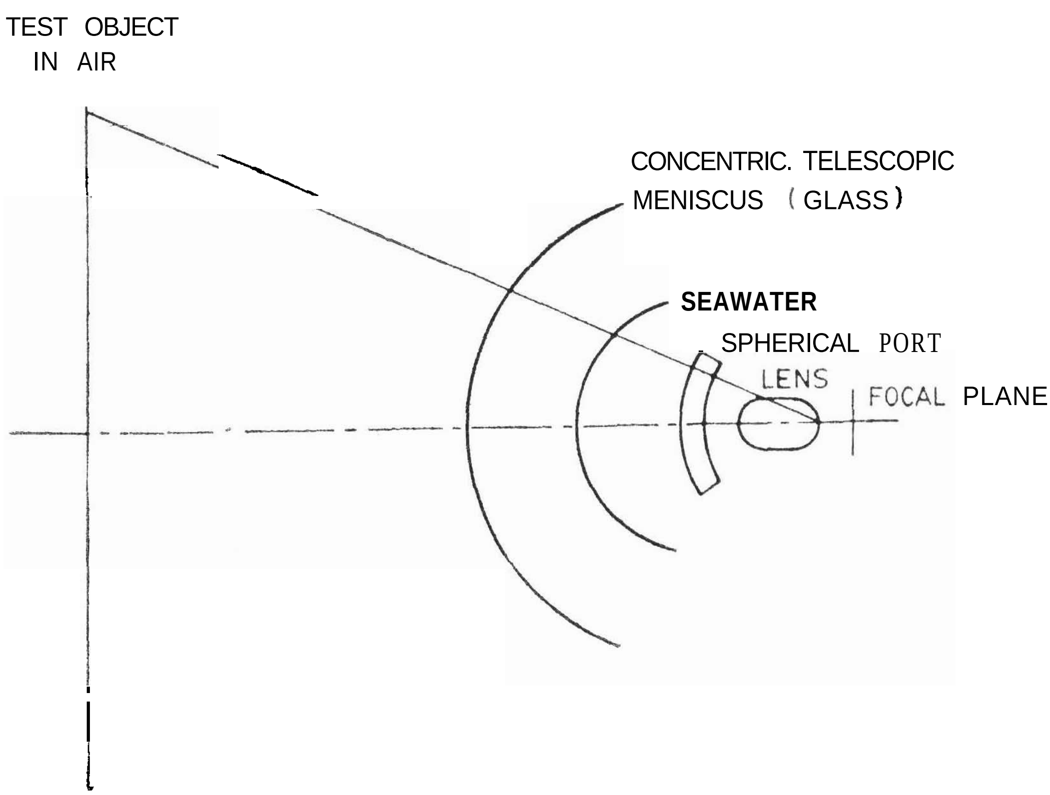

Figure 5. Port hole for underwater camera,

Finally it has been found necessary to fully protect the optical corrected porthole from the water pressure as the latter has been proved to be the cause of major optically unacceptable deformations of pressure resistant front lens. This deformation is supressed by installing a thin flat auxillary window behind the pressure resistant porthole with an identical refraction liquid filling the variable space between both windows. This liquid is being maintained at atmospheric pressure by over flowing into a volume compensating bellows installed inside the pressure housing. Such a device is necessary to achieve constant optical performance regardless of depth, the deformation and extrusion of any transparent porthole under deep sea pressure which is almost unbelievable. The rear surface can be pushed back by 8.5 mm (about 1/3 inch) at 6000 m not as a straight faced element but actually bulging back as strong aspheric convergent lens.

For most general purpose, underwater and deep sea photographic work, the all around work horse remains to be 35 mm or 70 mm automatic pulse camera with large capacity 100, 200 or 400 ft magazines. Jn this pulse means that the camera responds with the shortest possible delay to remote controlled or internally generated electric pulses.

It has been found necessary to supplement the camera system with a practical stable platform. The land techniques of the tripod or tracks fail miserably being completely impractical and particulary unadaptable.

The effective underwater camera system platform must be specially designed and adapted dynamic underwater vehicle such as 1952 'PEGASUS' or 1975 'REMORA'[11] which were both engineered primarily for photography with their unique joystick 3-axis control including full roll capability. It is particularly important both fox precise ranging and framing to control the platform in an extremely precise manner in all 3 to 6 axis of space (3 linear and 3 angular) much in fighter aircraft fashion but workable in undersea environment.

Underwater camera design is an engineering challenge and special skill has to go in its development. Tt is found to be an invaluable tool for oceanographic survey and ocean studv.

Conclusion

The techniques of underwater imaging are still limited in range although problems of back scattering have been solved to a great extent. The range is likely to increase once the high power blue-green lasers are available. The problems in underwater photography are of the development of necessary technology so that the system can work under sea-water environment.

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