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Underwater Ranging

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Abstract. The paper deals with underwater laser ranging system, its principle of operation and maximum depth capability. The sources of external noise and methods to improve signal-to-noise ratio are also discussed.

1. Introduction

Until the first half of this century, the only method of underwater ranging was the acoustic depth sounder. Fessenden is considered to be the discoverer of the acoustic depth sounder. In 1920, Langevin introduced his ultrasonic instrument for depth sounding. Since then, more accurate and reliable sonar systems have been developed. These instruments require surface vessels to carry them, so the speed of coverage of a given area is very low. Moreover, irregularities on the ocean floor sometimes give false returns. To overcome these problems, the concept of an airborne pulsed laser for bathymetry was initially proposed in the late sixties[1]. Pulsed Light Airborne Depth Sounder (PLADS) was introduced by the Naval Oceanographic Office in Washington[2] in 1971. The Weapon Research Establishment, Australia, used the Laser Airborne Depth Sounder[3] (WRELADS) in 1975. This paper explains the basic principle of a laser bathymeter, its maximum depth capability, sources of external noise and methods to improve signal-to-noise ratio to enhance maximum depth capability of the system.

2. Laser Bathymeter — Principle of Operation

The diagram of a basic laser bathymeter is shown in Fig. 1. Details of the laser sources for underwater applications can be found in literature.[4-7] It is well-known that blue-green part of the visible spectrum has maximum transmission in sea-water[8-10]. Frequency doubled *Nd* : YAG laser is the most widely used laser source for underwater ranging, Pulse Transmission Mode Q-Switched Nd : YAG laser is frequency doubled using a non-linear crystal such as deutrated Cesium Dihydrogen

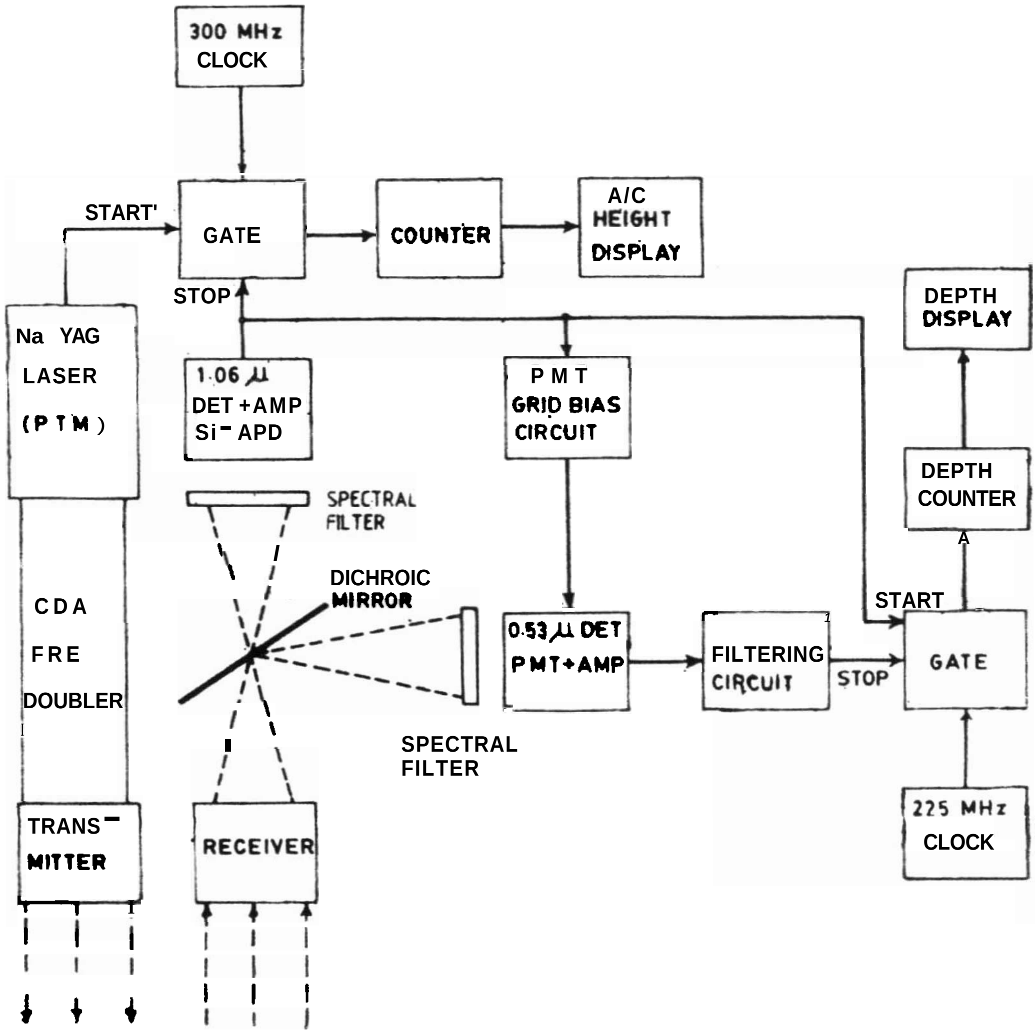

Figure 1. Laser bathymeter.

Arsenate (CDA). The output of the laser transmitter containst wo pulses at different wavelengths; a low energy relatively wide angle infra-red beam of wavelength of 1,064 nm and a high energy narrow angle green beam at wavelength of 532 nm. The infra-red beam provides the surface return, since it has very low transmission co-efficient in seawater. The green laser beam is transmitted through seawater and provides the bottom return. The received laser pulses are collected by the receiver optics and passed through a dichroic mirror. The green signal is directed towards a photo multiplier tube through a narrow band spectral filter to cut out background noise. Similarly the infra-red signal is directed towards a Silicon Avalanche Photo Diode through a narrow band spectral filter. The important characteristics of two typical detectors used for this purpose are given in Appendix 1. The transmitted laser signal is also detected and it opens a gate which is stopped by the IR laser signal reflected from the surface of the sea. Clock pulses are passed to the counter during the interval the gate is open. The clock frequency is chosen such that the desired accuracy is achieved and the display directly gives the height of the aircraft in digital form. With a clock frequency of 300 MHz, ± 0.5 metre height resolution can be obtained. The received IR signal after detection, is also fed to

PMT grid bias circuit for range gating purpose. This signal also starts a gate which is closed by the green signal. The depth counter again counts the clock pulses during interval the gate is open. The clock frequency is so chosen that the sea depth is directly displayed in digital form. The depth resolution of ± 0.5 metre can be obtained with a clock frequency of 225 MHz.

The height H of the aircraft is given by

$$H = \frac{C\,(t_1 - t_0)}{2} \tag{1}$$

and sea depth L is given by

$$L = \frac{C\,(t_2 - t_1)}{n_w \times 2} \tag{2}$$

where

H = aircraft height from sea surface

C = velocity of light in air

t_0 = time of transmission of laser pulse

t_1 = time of arrival of sea surface return IR laser pulse

t_2 = time of arrival of sea bottom return green laser pulse

n_w = refractive index of seawater

The main advantage of using two laser beams as compared to single beam and single receiver is that each sub-system can be optimized. without compromise. for its particular function.

2.1. *Maximum Depth Capability*

The maximum depth capability 'L_{max} of the system is given by[11]

$$L_{max} = \frac{\ln P_{max}/Pb^{1}/^{2}}{a} \tag{3}$$

where

L_{max} = maximum depth capability

P_{max} = maximum detectable laser signal

$P(h)$ = background noise

a = attenuation coefficient of seawater

The background noise Ph at the airborne receiver at a height H above the water surface is given by

$$Ph = \frac{SA\,(s)\ ET\,(Ah)}{h\,c/\lambda} \qquad \exp\,(-KH)\,d\Omega \tag{4}$$

where

S	=	sun and sky radiance at the water surface $(W/\Delta\lambda - cm^2)$
$A(s)$	=	the area sub-tended at the water surface by the receiver having a solid angle $d\Omega$
E	=	efficiency of the optical system
$T(\Delta\lambda)$	=	transmittance of the spectral filter having a pass-hand Ah
h	=	planck's constant
c	=	velocity of light
λ	=	wavelength of radiation

The values of P_{max}/Pb have been determined to be **10,** 10^4 and 10^7 at noon, dusk and night respectively using laser peak power 2 mW, detector PMT noise level of 10^{-10} W and aircraft **height** of 600 m. These values match with the theoretically calculated values. Attenuation **co-efficient** *(a)* for various **seawaters** is taken as **0.03** for **clearest** ocean, **0.09** for continental shelf, 0.16 for coastal water and 0.4 for very turbid **water**[5]. Taking these parameters and **using** Eqn. (3), the maximum depth capability of the system is calculated as shown in Table I. It is seen that during night maximum depth of 268.7 **metres** can be achieved for the clearest ocean water. During day the maximum depth capability reduces due to increase of the background noise. Depths **upto** 30 metres have been practically achieved during day time for clear **water**[3]. If the **background** noise is reduced and low noise level PMT detector is chosen such that the ratio P_{max}/Pb is 10^{10}, the **maximum** depth that **can** be obtained is given in **Table** 2. The **power** received P_{rec} at the airborne receiver is given by

Table 1. Maximum depth capability

Condition	P_{max}/Pb	a (m^{-1})	L_{max} (m)
Noon	10	0.03	38.3
Dusk	10^4	0.03	153.5
Night	10^7	0 03	268.7
Noon	10	0.09	12.8
Dusk	10^4	0.09	51.1
Night	10^7	0.09	89.5
Noon	10	0.16	7.2
Dusk	10^4	0.16	28.7
Night	10^7	0.16	50.3
Noon	10	0.4	2.8
Dusk	10^4	0.4	11.5
Night	10^7	0.4	20.1

Table 2. Maximum depth capability $P_{max} = 10^{10}$

a (m^{-1})	L_{max} (m)
0.03	383.3
0.09	126.6
0.16	71.9
0.40	28.8

$$P_{rec} = \frac{P_t R (1-r)^2 \exp[-2(KH+aL)]}{2\left(H + \frac{L}{n_w}\right)^2} \quad (5)$$

where

P_{rec} = power received per unit area

P_t = peak power transmitted

R = reflectance of the sea floor or targe:

r = reflectance of the sea surface

K = atmospheric attenuation coefficient

H = height of the airborne receiver from the sea surface

a = attenuation coefficient of seawater

L = depth of sea floor or target from seasurface

n_w = refractive index of seawater.

The power received per unit area corresponding to sea depths close to the maximum depth capability is shown in Table 3. The values of R, r & K taken are the experimentally determined values[11]. Having determined the value of P_{rec}, the aperture area of the receiver optics can be calculated.

Table 3. Power received

$R=0.2$, $r=0.02$, $K=0.00017$/m, $n_w=1.33$

P_t (mW)	a m^{-1}	H m	L m	P_{rec} (nW/m^2)
2	0.03	300	260	38.07
2	0.09	300	90	37.75
2	0.16	300	51	40.02
2	0.4	300	20.5	41.80
20	0.03	300	300	30.57
20	0.09	300	102	42.7
20	0.16	300	58	40.8
20	0.4	300	23.5	37.9

2.2. Sources of External Noise *and Methods* to Improve *S/N* Ratio

The following noise components are present at the airborne receiver.

(1) Sun and sky light reflected from the sea surface, bulk water and sea bottom.

(2) Specular surface reflection of the green laser pulses. (This component is not required since the infra-red laser is used to sense the sea surface).

(3) Back scatter due to the propagation of laser light through water.

The following methods can be adopted to improve the signal-to-noise ratio.

(1) Range Gating—This is a technique that minimizes back scattered light by causing a receiver to detect only the light pulse reflected from the target. The receiver must open just as the pulse arrives at the detector, and it must stay open only for the pulse duration. In this way the back scattered light, which arrives at the detector before the reflected pulse, is ignored[4,12].

(2) Use *of* Spectral Filters—Narrow band filters at the laser beam wavelength should be used to reduce background light.

(3) Use of Polarized Laser Light—Polarized laser light can be used to take advantage of the difference in polarization between light reflected from the object and background and scattered light. The utility of a polarized beam is dependent upon the amount of multiple scattering and upon the target reflection characteristics.

(4) Filtering of Low Frequency Components—The low frequency content of back scatter can be eliminated using electronic filters.

(5) Separating *Source and* Receiver—Location of transmitter and receiver with respect to illuminated object partly determines the amount of back scattered light received. In monostatic system the transmitter and receiver are in the same place. In bistatic system they are in different places. A mono-static system is essential when measurements are made from moving vehicles. Range gating can significantly reduce back scatter in such a system. In bistatic systems range gating is not necessary.

3. Conclusion

Airborne laser depth sounding system has definite advantage over sonar system, when high speed of coverage of a given area is required. The speed is increased by using high repetition rate scanning type airborne laser transmitter. However, the maximum depth capability of laser ranging system is limited because of the high attenuation coefficient of seawater and background noise. Attempts should be made to reduce the background noise by optical and electronic means and to develop high peak powder high repetition rate blue green laser sources to enhance the maximum depth capability of the system.

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APPENDIX - I

Characteristics of Detectors

1. 1.06 μ ***Detector (Si APD) Type*** RCA-C 309546

Photosensitive Surface Area	—	0.5 mm^2
Photosensitive Surface Dia	—	0.8 mm
Spectral Response	—	400 to 1150 nm
Reverse Bias Dark Current (Max)	—	200 μA
Forward Current (Max)	—	50 mA
Total Power Dissipation	—	0.1 W
Field of View	—	110 degree
Responsivity	—	36 A/W
Quantum Efficiency	—	36 %
Dark Current	—	50 nA
Capacitance		2 pF
Rise Time	—	2 nS

2. 0.53 μ ***Detector*** (PMT) Type ***RCA*** 7265

Spectral Response	—	S-20 (3000 to 8000 Å)
Wavelength of Max Response	—	4200 ± 500 Å
Photocathode Material	—	*K-Na-Cs-Sb*

Secondary Emitting Surface	—	BeO
Maximum Supply Voltage	—	3000V
Ambient Temp	—	−40° to 55°C
Quantum Efficiency	—	19% at 4000 Å
Cathode Radiant Sensitivity	—	0.064 A/W
Anode Radiant Sensitivity	—	3×10^{6} A/W
Anode Dark Current	—	5×10^{-8} A
Equivalent Anode Dark Current Input	—	1.2×10^{-13} W
Equivalent Noise Input	—	2.1×10^{-15} W
Average Anode Current	—	I mA
Anode Pulse Rise Time (3000V)	—	2.7 nS
Electron Transit Time	—	40 nS
Overall Length	—	19 cm
Dia	—	6 cm
Weight	—	226 g