Airborne Laser Hydrography II

(Blue Book II)

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15th Annual JALBTCX Airborne Coastal Mapping & Charting Technical Workshop
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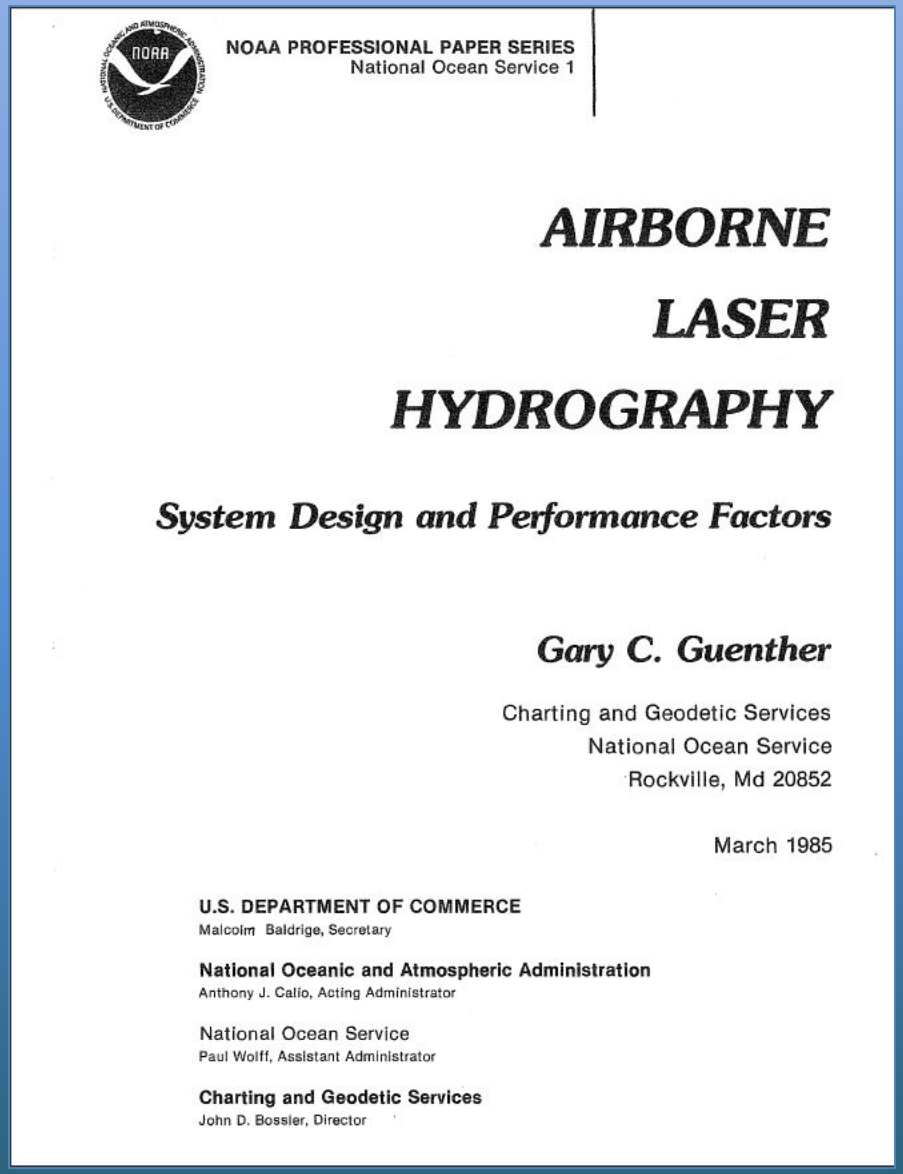


NOAA PROFESSIONAL PAPER SERIES
National Ocean Service 1

AIRBORNE LASER HYDROGRAPHY

System Design and Performance Factors

Gary C. Guenther

Charting and Geodetic Services
National Ocean Service
Rockville, Md 20852

March 1985

U.S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

National Oceanic and Atmospheric Administration
Anthony J. Calio, Acting Administrator

National Ocean Service
Paul Wolff, Assistant Administrator

Charting and Geodetic Services
John D. Bossler, Director

Blue Book I

To the Pioneers
and to those
who kept the Faith

30 Years!

+ 3 months
(& counting)

Blue Book II

	Section	Pages	Lead Authors
1	Preface	~ 2	Gary Guenther
2	Introduction	~ 5	Wozencraft & Lillycrop
3	History and Reference Guide	~ 30	Wozencraft
	3.1. Australia		Sinclair
	3.2. Canada		LaRocque
	3.3. United States		Wozencraft
	3.4. Sweden		Ekelund
4	Environmental Optical Properties	~ 30	Pe'eri et al.
5	Basic Concepts and System Design	~ 70	Feygels, Kopilevich & Kim
6	Basic Problems in Data Processing	~ 35	Feygels, Kopelivich & Kim
7	Performance Evaluation	~ 30	Pe'eri et al.
8	Applications, Ancillary Sensors and Fusion	~ 20	Wozencraft & Reif
9	Epilog: Emerging systems, future directions		
	Appendix A: Acronyms (2 pages)		
	Appendix B: Symbols (15 pages)		
	Appendix C: System Characteristics (4 pages		

Total: 230-250 pgs.

This equation can be solved for $(nKD)_{max,2}$, for desired values of A_2, P_{T2}, and ϕ_2, given knowledge of the parameters and performance of the first system.

For purposes of illustration, the AOL results will be extrapolated to a prospective system. For simplicity, assume $q = 1$, $A_1 = A_2$, and $\phi_1 = \phi_2$. Equation (8-13) then becomes

$$P_{T1}\, e^{-2(nKD)_{max,1}\sec\phi} = P_{T2}\, e^{-2(nKD)_{max,2}\sec\phi} ,$$

and thus

$$nKD_{max,2} = \frac{\ln\left(\frac{P_{T2}}{P_{T1}}\right) + 2(nKD)_{max,1}\sec\phi}{2\sec\phi} . \qquad (8\text{-}14)$$

The peak output power of the AOL was roughly 1 kW (P_{T1}), and the performance to be extrapolated was a nighttime result of $D_{max} = 5.5$ m achieved from a 150-m altitude for $\phi = 11°$, $\alpha = 2.75\ m^{-1}$, $K \cong 0.5\ m^{-1}$, $\omega_0 \sim 0.9$, and $n_1 \cong 1.3$. The predicted "extinction coefficient" for our proposed alternate system is then

$$(nKD)_{max} = \frac{\ln P_T\ (kW) + 7.30}{2.04} . \qquad (8\text{-}15)$$

If we are interested, for example, in predicting penetration with 280-kW peak pulse power, the result would be

$$(nKD)_{max} = \frac{\ln\ (280) + 7.30}{2.04} = 6.3 . \qquad (8\text{-}16)$$

For water with $K = 0.15\ m^{-1}$ ($n \cong 1.19$), for example, this would be achieved at a depth of $D_{max} = 35$ m. It is understood, of course, that a larger receiver field of view is required to maintain $F = 1$ for these deeper depths.

The specific AOL performance cited as an input to this calculation can be used in a more general case with Eq. (8-13) to predict penetration for any shot-noise limited system under similar nighttime conditions given the additional information that for the AOL, $A_R = 730\ cm^2$, and the transceiver nighttime optical efficiency is $\eta = 0.25$.

As a result of beam refraction at the water surface, the sounding beam stationary radiance just below the interface, takes the form $I'_E(s_=, s_\perp; n_=, n_\perp)$ (note that subscript a in the symbol I'_E is omitted and, in view of (5.3.17), the power losses due to Fresnel reflection are taken into account):

$$I'_E(s_=, s_\perp; n_=, n_\perp) = \cos\theta_a \cdot H_s^{-2} \times D\left(\frac{s_{a=}\cos\theta_a}{H_s\Theta_E}, \frac{s_{a\perp}}{H_s\Theta_E}\right) \cdot \delta\left(n_= - \frac{s_{a=}\cos^2\theta_a}{nH_s\cos\theta_w}\right) \cdot \delta\left(n_\perp - \frac{s_{a\perp}}{nH_s}\right) \qquad (5.3.66)$$

Here symbol n (without a subscript) denotes the refractive index of the seawater; "angles" $n_{a=}$, $n_{a\perp}$ reckoned from z_a-axis are related to $n_=$, $n_\perp$ (counted from z -axis, the lidar beam axis in the water) by the following equations:

$$n_= = n_{a=}\frac{\cos\theta_a}{n \cdot \cos\theta_w} \ ; \quad n_\perp = n_{a\perp}\frac{1}{n} \quad ; \qquad (5.3.67)$$

The equations are valid within the context of the small-angle approximation [see (5.3.30)]. This can be demonstrated by applying a Taylor decomposition (Taylor series) to both sides of the equality $\sin(\theta_a + n_{a=}) = N\sin(\theta_w + n_=)$. For small enough $n_{a=}$, $n_=$, the zeroth order term is $\sin\theta_a = N\sin\theta_w$ (the ordinary form of Snell's Law), and the first order term is $\sin\theta_a = N\sin\theta_w$.

Let us rewrite (5.3.68) as

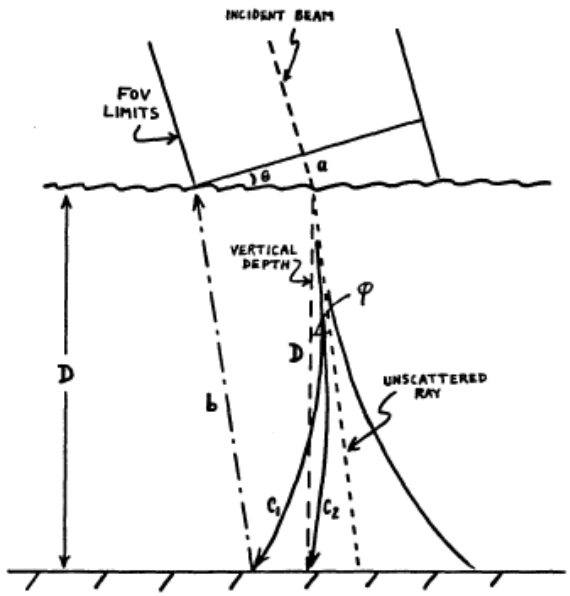
$$I'_E(s_=, s_\perp; n_=, n_\perp) = \frac{n^2\cos^2\theta_w}{H_=^{eq} \cdot H_\perp^{eq}} \times D\left(\frac{s_{a=}\cos\theta_w}{H_=^{eq}\Theta_{E=}^{eq}}, \frac{s_{a\perp}}{H_\perp^{eq}\Theta_{E\perp}^{eq}}\right) \cdot \delta\left(n_= - {s_{a=}\cos\theta_w}/{H_=^{eq}}\right) \cdot \delta\left(n_\perp - {s_{a\perp}}/{H_\perp^{eq}}\right) \qquad (5.3.68)$$

with the new parameters

$$H_=^{eq} = \frac{nH_s\cos^2\theta_w}{\cos^2\theta_a} \ ; \quad H_\perp^{eq} = nH_s \ ; \quad \Theta_{E=}^{eq} = \frac{\Theta_E}{n}\frac{\cos\theta_a}{\cos\theta_w} \ ; \quad \Theta_{E\perp}^{eq} = \frac{\Theta_E}{n} \qquad (5.3.69)$$

The final task is to determine the radiance, $I'_E(z, \mathbf{r}, \mathbf{n}_t)$ in the equivalent geometry; the radiance distribution along the interface plane ("just above" or "just below" has the same meaning in the equivalent problem) must coincide with our model (5.3.68), (5.3.69). In the equivalent problem, the formula coincides with the far-field approximation (5.3.63) of radiance projected on the interface plane by the stationary astigmatic light beam.

Note that, for the beam, the spatial and angular dependences cannot be separated, i.e., function A is a function of both **r** and **n**. Such a beam does not have a "waist" plane, rather, there are two different planes for z=const corresponding to a minimal spot size in one (that is, "=" or "⊥") of the two orthogonal directions:



$$c_1 + b < c_2 + D + a$$

FIGURE 6-2. AIR PATH GEOMETRY

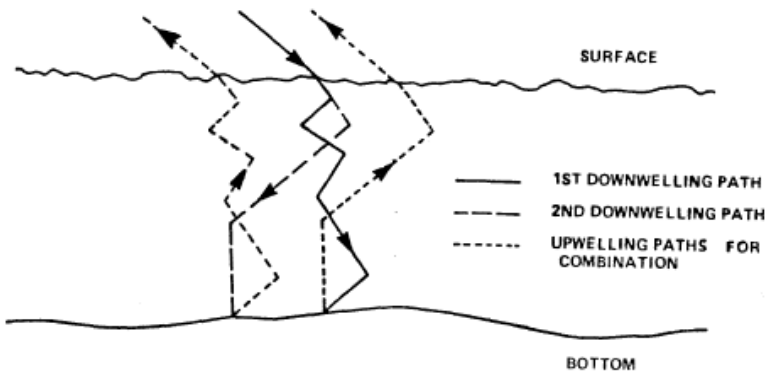


FIGURE 6-3. PATH PAIRING EXAMPLE

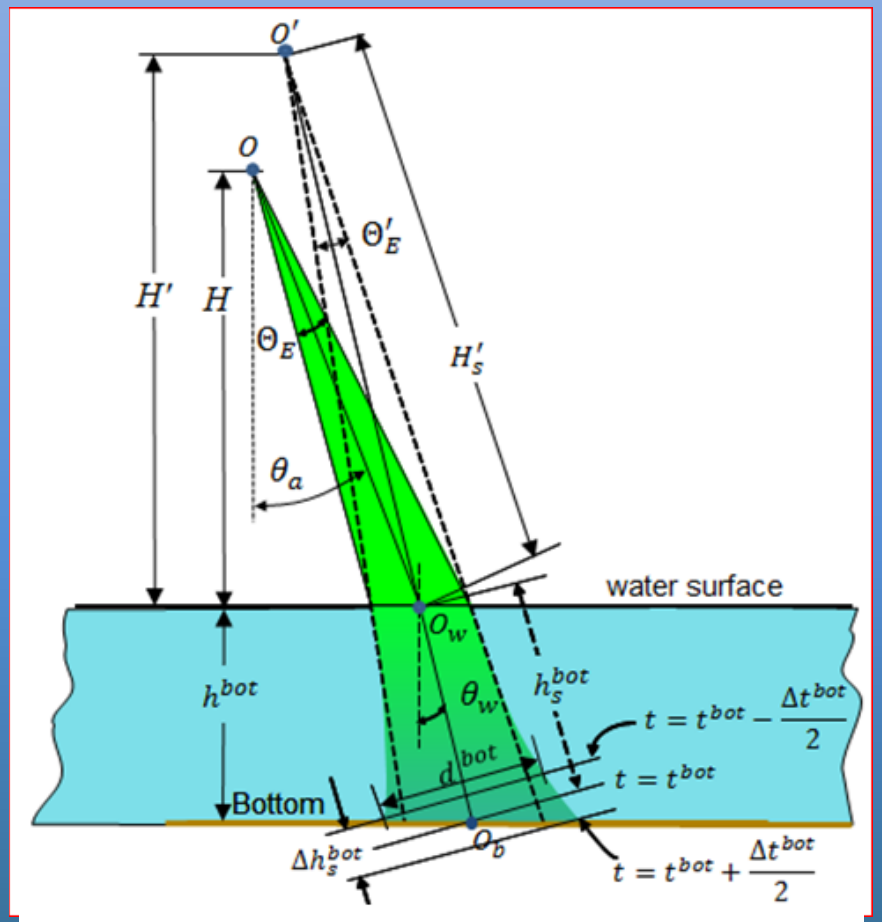


Figure 5.2.4. “Geometric stretch” of bottom-reflected lidar signal and the "equivalent" geometry.

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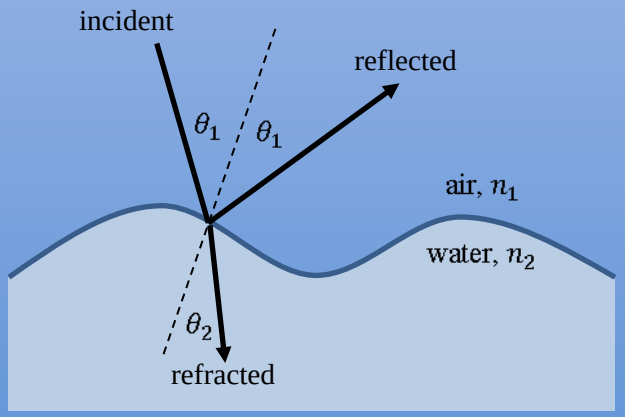
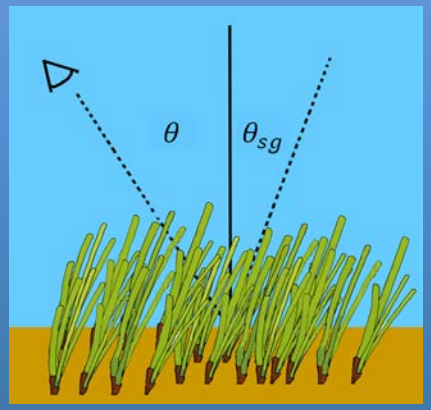
9. Epilog: Emerging systems, future directions





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Transmitter
Scanner
Detector
Auxiliary units

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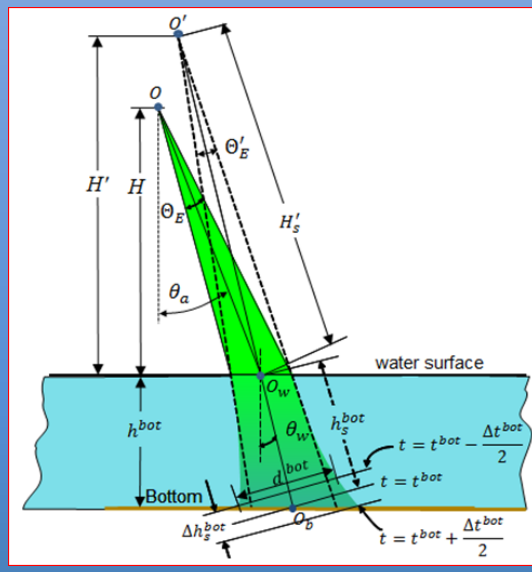
Propagation geometry

Return waveform



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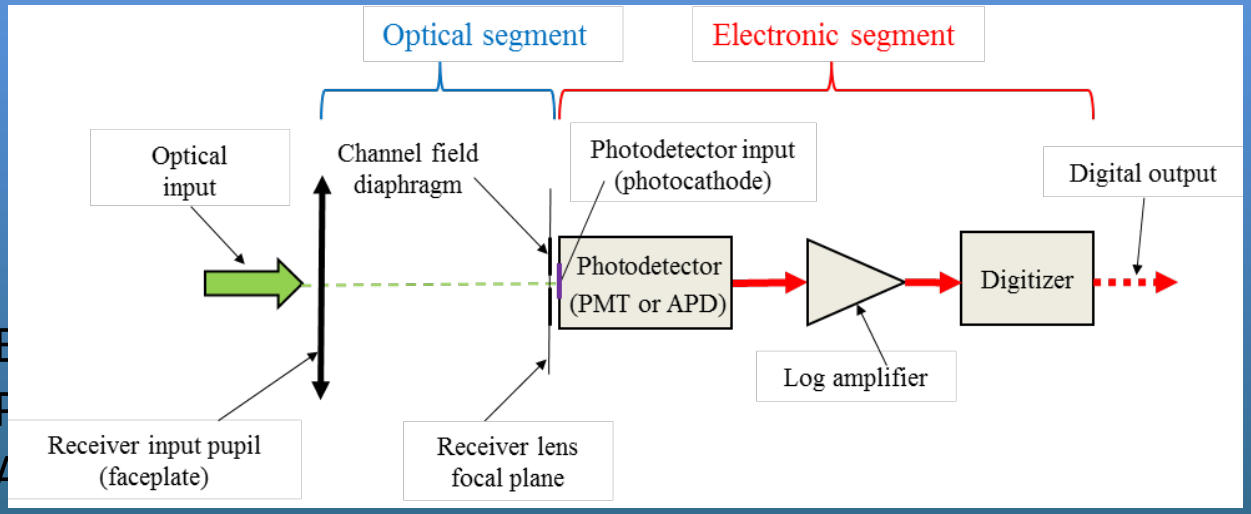
Receiver channel model
Small < scattering approx.
Lidar waveform simulator



6. E
7. P
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Small < scattering approx.

Lidar waveform simulator

$$S_\delta(t) = Q'\Sigma\Omega\frac{c}{2n}\int d^2\,\mathbf{r}\,\gamma(z(t),\mathbf{r})E_E(z(t),\mathbf{r})E_R(z(t),\mathbf{r}), \qquad z(t) \equiv \frac{ct}{2n}\ ;$$

$$E_{E,R}(z,\mathbf{r}) = \widetilde{I}'_{E,R+}(z_0,\mathbf{k},\mathbf{k}(z-z_0))\ exp\{-z(t,r_-)\cdot a_s - a_{bs}(k(z=z_0))\ exp(-i\mathbf{rk})d^2\mathbf{k}\}$$

$$\widetilde{I}'_{E,R+}(z_0,\mathbf{k},\mathbf{k}(z-z_0)) = \frac{1}{(2\pi)^2}\iint I'_{E,R+}(z_0,\mathbf{r},\mathbf{n}_t)\ exp\{i\mathbf{rk} + i\mathbf{n}_t\mathbf{k}(z-z_0)\}\,d^2\mathbf{r}\,d^2\mathbf{n}_t$$

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- Equations:
  - Microsoft Equation editor
- References:
  - RefWorks;
  - Chicago 16th edition;
  - DOI
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- On-line version:
  - video
  - interactive graphics, etc.

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