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MASTER

AUTHOR(S): M. Slatkine, L-9
D. Bensimon, Weizmann Institute of Science, Israel
A. Englander, Weizmann Institute of Science, Israel
S. Shtrikman, Weizmann Institute of Science, Israel
D. Treves, Weizmann Institute of Science, Israel

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STATISTICAL PROPERTIES OF VISIBLE AND INFRARED BEAMS RETROREFLECTED THROUGH A TURBULENT ATMOSPHERE

M. Slatkine*
University of California
Los Alamos Scientific Laboratory
Los Alamos, NM 87545

D. Bensimon, A. Englander, S. Shtrikman, D. Treves
The Weizmann Institute of Science, Dept. of Electronics
Rehovot, Israel

Abstract

Statistical properties of HeNe and CO_2 laser beams retroreflected through a turbulent atmosphere are investigated experimentally for round paths of 1 km and 12 km. Both heterodyne and direct detection are used.

The understanding of the statistical properties of laser beams retroreflected through a turbulent atmosphere is a prerequisite for the proper design of electro-optic systems as remote pollution analyzers. In the following we briefly report on experimental investigation of the statistical properties of He-Ne laser ($\lambda = 0.63\ \mu m$) and CO_2 laser ($\lambda = 10.6\ \mu m$) beams retroreflected through a turbulent atmosphere for round paths of $2L = 1$ km and $2L = 12$ km. (Detailed descriptions of experiments and results are given in Ref. 1, 2.) Both heterodyne and direct detection were used. As a retroreflecting element we used a corner cube of dimensions not larger than the coherence length ρ_0 of the propagating beam. A general schematic of the experimental heterodyne and direct set up for the outdoor optical measurements is brought in Fig. 1.

Histograms of scintillating received radiation were measured and showed a log-normal behavior for unsaturated as well as saturated conditions. It was found that a round path of $2L = 1$ km is still unsaturated for $\lambda = 0.63\ \mu m$ and that a $2L = 12$ km path is only slightly saturated for $\lambda = 10.6\ \mu m$ (Fig. 2). The 7/6 power dependence of log-amplitude variance on wave number, as predicted for unsaturated turbulence by Rytov approximation(3), was confirmed (Fig. 3). The power spectra of the log-intensity fluctuations and of the log-frequency fluctuations induced by the turbulence were found to follow the -8/3 and -2/3 power dependence for the same conditions (Fig. 4,5). The scintillation time correlation was closely proportional to $\sqrt{L}$.

The atmospheric structure constant $C_n^2(3)$ was derived from the scintillations variance by assuming statistical independence of the forward and backward propagations of the laser beam through the atmosphere. The results of the optical measurements of C_n^2 were compared to results of simultaneously in-situ measurements of the temperature structure constant C_T^2 (using fast thermocouples). Good agreement was obtained (Fig. 6).

References

(1) D. Bensimon, A. Englander, S. Shtrikman, M. Slatkine, D. Treves, "Statistical Properties of He-Ne Laser Radiation Reflected Through a Turbulent Atmosphere," submitted to Appl. Opt. (1980).

(2) D. Bensimon, A. Englander, S. Shtrikman, M. Slatkine, D. Treves, "Scintillations of Infrared Beams Retroreflected Through the Atmosphere," to be published (1980).

(3) R. L. Fante, Proc. IEEE, 63, 1669 (1975).

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*This work was done while the author was with the Weizmann Institute of Science, Rehovot, Israel.

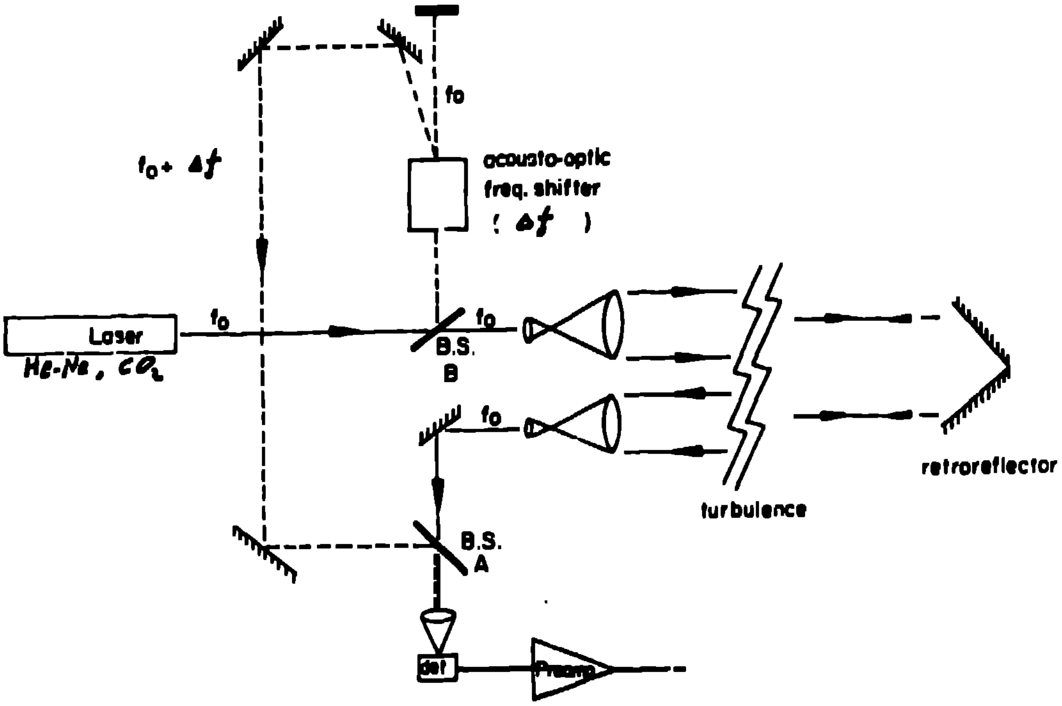

Figure 1. Schematics of the experimental heterodyne setup for studies of the statistical properties of a beam retroreflected through a turbulent atmosphere. The frequency shifted upper beam (40 MHz for He Ne, 500 KHz for CO_2) is a local oscillator collinearly combined with the retroreflected signal to produce an I.F signal through use of a fast Si avalanche photodiode (HeNe) or an M.C.T. photoconductor (CO_2). For direct detection beam splitter A is removed. A reflective optics has been used for the CO_2 laser collimator.

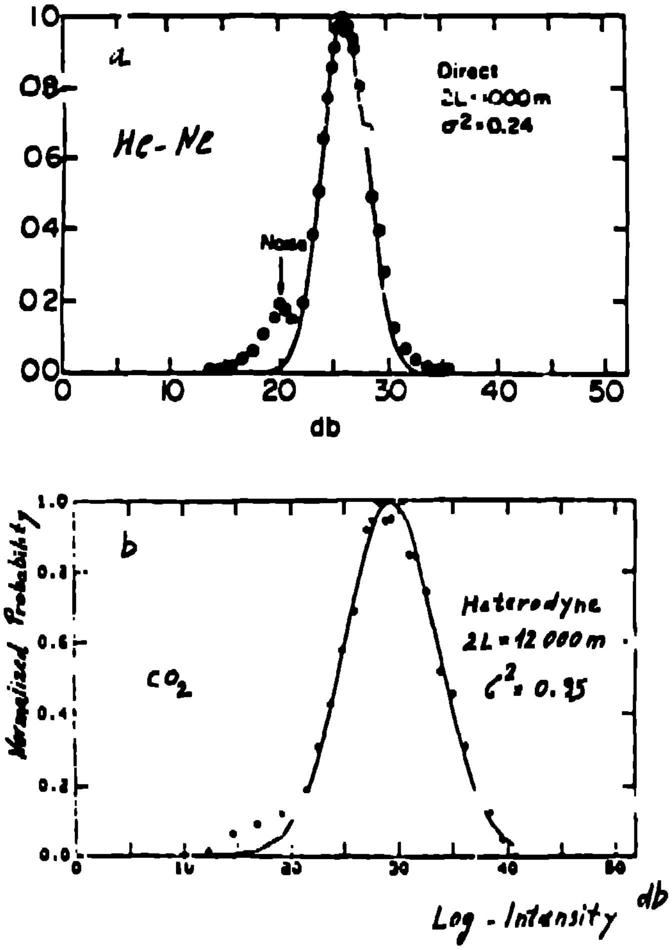

Figure 2. Experimental histograms for 2L = 1 km and 2L = 12 km.
a. He-Ne laser, 2L = 1 km, direct detection.
b. CO_2 laser, 2L = 12 km, heterodyne detection.
Vertical axis: normalized probability.
Horizontal axis: $\log_{10}$ (Intensity), arbitrary reference level.

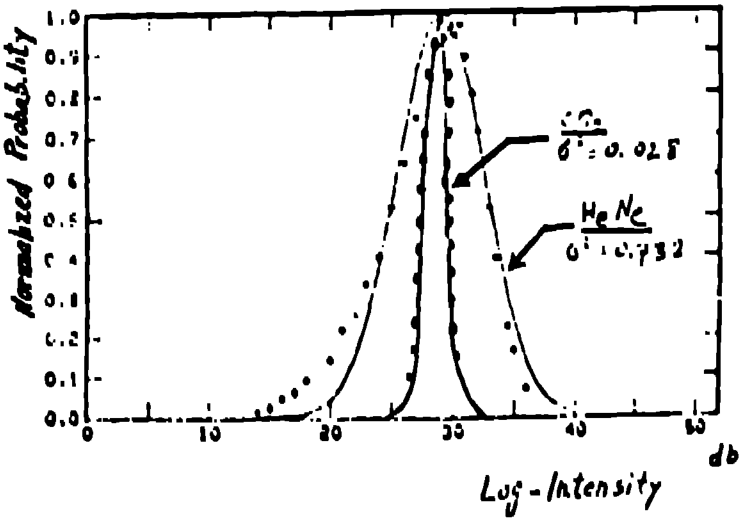

Figure 3. Experimental histograms for 0.63 μm and 10.6 μm radiation. Simultaneous measurements, 2L = 1 km, C_n^2 = 2.5 x 10^{-14} $m^{-2/3}$. The ratio between the standard deviations satisfies the relation σ(HeNe)/σ(CO_2) = [λ(CO_2)/λ(HeNe)]$^{7/6}$.

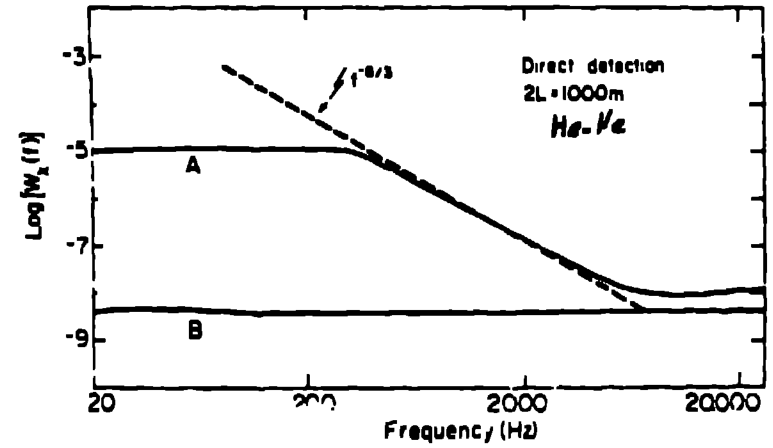

Figure 4. Power spectrum $W_x(f)$ of intensity scintillations.
A - Reflection through the atmospheric turbulence
B - Reflection from a nearby mirror. HeNe laser, 2L = 1 km, direct detection.

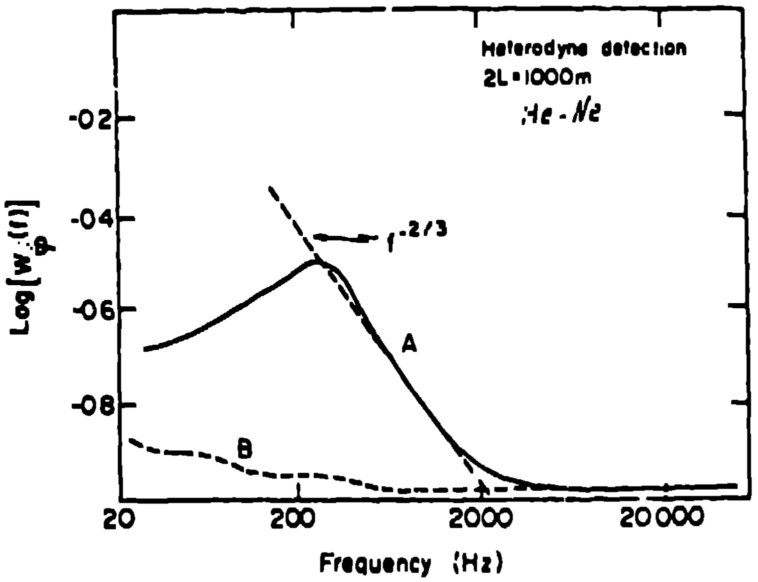

Figure 5. Power spectrum of frequency fluctuations $W_{\dot{\varphi}}(f)$ induced by the turbulent atmosphere.
A - Reflection through the atmosphere.
B - Reflection from a nearby mirror. HeNe laser, 2L = 1 km, heterodyne detection.

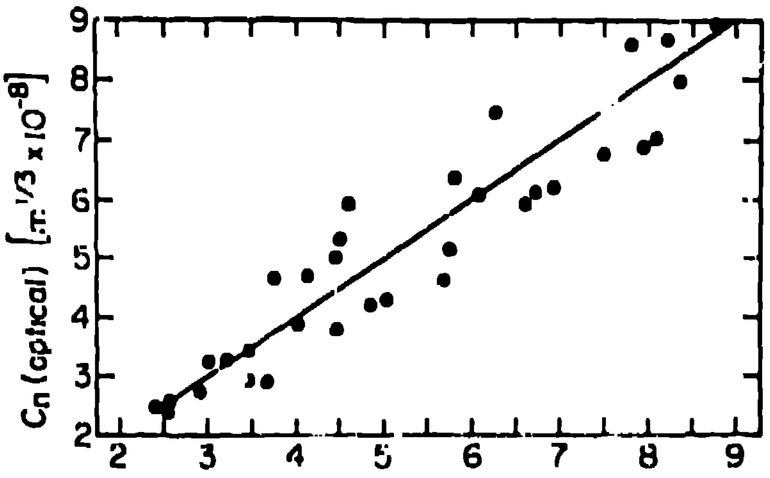

Figure 6. C_n as optically measured through retro reflected intensity fluctuations versus C_n as derived from in situ measurements of temperature fluctuations. Statistical independence of the to and fro beams was assumed in the case of the optical derivation of C_n (from measured histograms).