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Laser Beam Propagation in the Atmosphere

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Preface

When optical waves, whether they originate from starlight, incandescent sources, or lasers, propagate through the clear atmosphere of the earth, they experience distortions due to small temperature variations. The two most common manifestations of this phenomena are the twinkling of stars and the shimmering of "heat" over hot pavement or surfaces. The small temperature variations, on the order of 1° C or less, are related to the sun's heating of the atmosphere and turbulent motion of the air due to winds and convection. The small temperature perturbations cause changes in the velocity of the light as it passes through the atmosphere, which in turn causes distortions in the intensity (twinkling), phase, angle-of-arrival, and displacement (quivering) of the light beam.

With the invention of the laser in 1962 and the myriad of possible practical applications, from lidar (laser radars) to communications, interest in atmospheric effects on optical waves rapidly expanded. In this volume we attempt to cover the latest developments in this field. Earlier monographs on this subject include those of Chernov (*Wave Propagation in a Random Medium*) and Tatarskii (*Wave Propagation in a Turbulent Medium*, and *the Effects of the Turbulent Atmosphere on Wave Propagation*). The emphasis in this volume is on situations where temperature variations in the atmosphere dominate the laser propagation characteristics. Most of the volume is concerned with problems dominated by the earth's atmospheric turbulence, except for the last chapter which considers the case where the laser beam itself is so powerful that it produces the heating of the atmosphere. This volume does not consider effects on laser beams caused by absorption of the light energy by molecules or particles nor does it consider scattering of the light by aerosols or rain or fog.

The first chapter is an introduction and attempts to provide an overview of the subject and the material included in this volume. The second chapter, by S. F. Clifford, presents the classical theory of optical propagation through a turbulent atmosphere including a description of the atmospheric model. This chapter represents the state of the art of the theory until the middle 1960's and is applicable for a wide range of practical problems. The next chapter, by J. W. Strohbehn, attempts to summarize and compare the modern approaches to laser propagation through the turbulent atmosphere, with particular attention to the region where the classical theory has been shown not to be valid. This theory is necessary for laser propagation over long paths and when the strength of the refractive index turbulence is high. Chapter 4 describes the results of a very thorough set of measurements, performed by M. E. Gracheva et al. in 1972, on laser signals in the region where the classical theory breaks down. While the theory in the chapters by Clifford and Strohbehn assumes the initial wave is plane or spherical, Chapter 5, by A. Ishimaru, concentrates on the subtleties of the theory presented by finite-size laser beams which may or may not be focused. This chapter also introduces the problem of using measurements of laser signals to remotely probe atmospheric characteristics such as the strength of the turbulence or the velocity of the wind. J. Shapiro, in Chapter 6, addresses the communications and imaging problems when an optical signal passes through the turbulent atmosphere. Based on the results of the preceding chapters he defines the optimum receiver for communications and analyzes the receiver's performance. Finally, in the last chapter, J. Walsh and P. Ulrich consider the problem known as thermal blooming. In this situation, the intensity of the laser beam is so great that it heats the atmosphere through which it passes. The heated atmosphere distorts the original laser beam so that the beam size is expanded (blooming) and, in the presence of a wind, displaces the position of the beam. These authors give one of the first thorough reviews of this interesting topic.

It is my pleasure to acknowledge some of the debts I have incurred and the inspiration I have received. In particular, I would like to thank A. Waterman, Jr. who got me started on radio-wave propagation, V. I. Tatarskii with whom I had many interesting discussions on the modern theories of laser propagation, and M. G. Morgan who provided an ideal environment in which to work. Besides the contributors, discussions with R. Lawrence, W. P. Brown, D. Fried, R. Fante, and H. Yura materially influenced the direction of this volume. The authors who wrote most of the text have worked hard and patiently to produce high quality manuscripts. Dean C. F. Long generously provided the time and support necessary for the writing and editing of this volume. Janet Brown quickly and accurately typed my contributions as well as Chapter 7, and Cutting Johnson did a superb job with the figures in Chapter 3, 4, and 7. Finally, a special thanks to my children, Jo, Kris, and Carolyn, for cheerfully enduring the many extra hours and late meals while this project was underway—it is to them that my efforts are dedicated.

Hanover, New Hampshire
July, 1978 *J. W. Strohbehn*

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