Sound Transmission through a Fluctuating Ocean*

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ABSTRACT

The effect of sound-speed fluctuations on acoustic propagation is described with emphasis placed on the unique aspects of the ocean environment. The unsaturated region, where intensity flucutations are small, is treated by the Rytov, or supereikonal method. The saturated region, where intensity fluctuations are large, is treated by micro-multipath theory utilizing path integrals. The statistical inhomogeneity and anisotropy of ocean sound-speed fluctuations are specifically treated. Internal-wave rather than turbulence spectra are used. The complications due to the deterministic sound channel are taken into account.

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This report summarizes the work of a number of people over the last four years [1,2,3]. We have made a systematic attempt to connect the known structure of the ocean volume to the results of long-range sound transmission experiments. Our knowledge that the ocean is nonisotropic (the scale sizes in the vertical being much smaller than in the horizontal) and that the strength of the inhomogeneities varies strongly with vertical position, has been taken into account in a basic way, as has the curved nature of unperturbed rays. These effects make the theoretical analysis more complicated, and the results are in many cases fundamentally different from those derived from homogeneous, isotropic turbulence theory.

Our basic theoretical approach to sound transmission can be divided into two parts: first, the Rytov (or supereikonal) extension of geometrical optics valid in regions of weak scattering; and second, a micro-multipath theory capable of treating some aspects of strong scattering, and based on a formulation using path integrals.

The areas of application of these treatments can be understood more fully by referring to Fig. 1; a range-frequency diagram. Transmission of sound in the sea to ranges within the area labelled "absorption" is impractical due to the absorption of sound energy by seawater. Sound with frequencies below 10 Hz will be subject to effects of the surface and bottom acting as wave-guide. Between these two areas, treatments that are basically approximations or extensions to ray theory can apply. Rays in the ocean are restricted to such small angles from the horizontal that the parabolic approximation to the wave equation is universally valid. This approximation is used in most of our theoretical treatments.

The limit of validity of the supereikonal approximation is a function of the strength of sound-speed fluctuations. The line shown is a rough estimate as to the limit of validity in the real ocean; the precise position of the line depends on other factors than range and frequency. The micro-multipath area (also known as the saturated region) is basically that area where a single deterministic path can sporadically change into two or more paths due to the ocean fluctuations. It is important to note that in much of the saturated region there are so many sporadic micropaths between source and receiver that the essential sound characteristics are not altered by the imposition of deterministic multipath as well.

The impetus for past treatments of wave propagation in random media has come from consideration of optical and radio-wave propagation, resulting in almost total concentration on homogeneous isotropic media. The methods developed for these problems have included the Rytov method, the transport equation, and the method of moments. (See, for example, Tatarskii et al., [4] and Uscinski [5].) Results of this sort have been widely applied in ocean acoustics, but their neglect of anistropy and curved rays -- so fundamental to the ocean environment -- has made their results of limited utility. The micro-multipath theory is based on the path-integral method, which provides a formal solution to all the moment equations simultaneously. By use of this method, one can derive many results for the statistics of the wave field in a remarkably simple manner. In contrast to other methods, it has proved possible to extend the micro-multipath theory to account for the complications of the ocean medium; anistropy, inhomogeneity, the background sound channel, and the spectrum of internal waves.

For specific calculations of wave-function statistics, we have used an internal-wave model of the ocean. Our results will be compared in detail with experimental data from the AFAR experiment [6], the Cobb Seamount experiment [7], and the MIMI experiment [8].

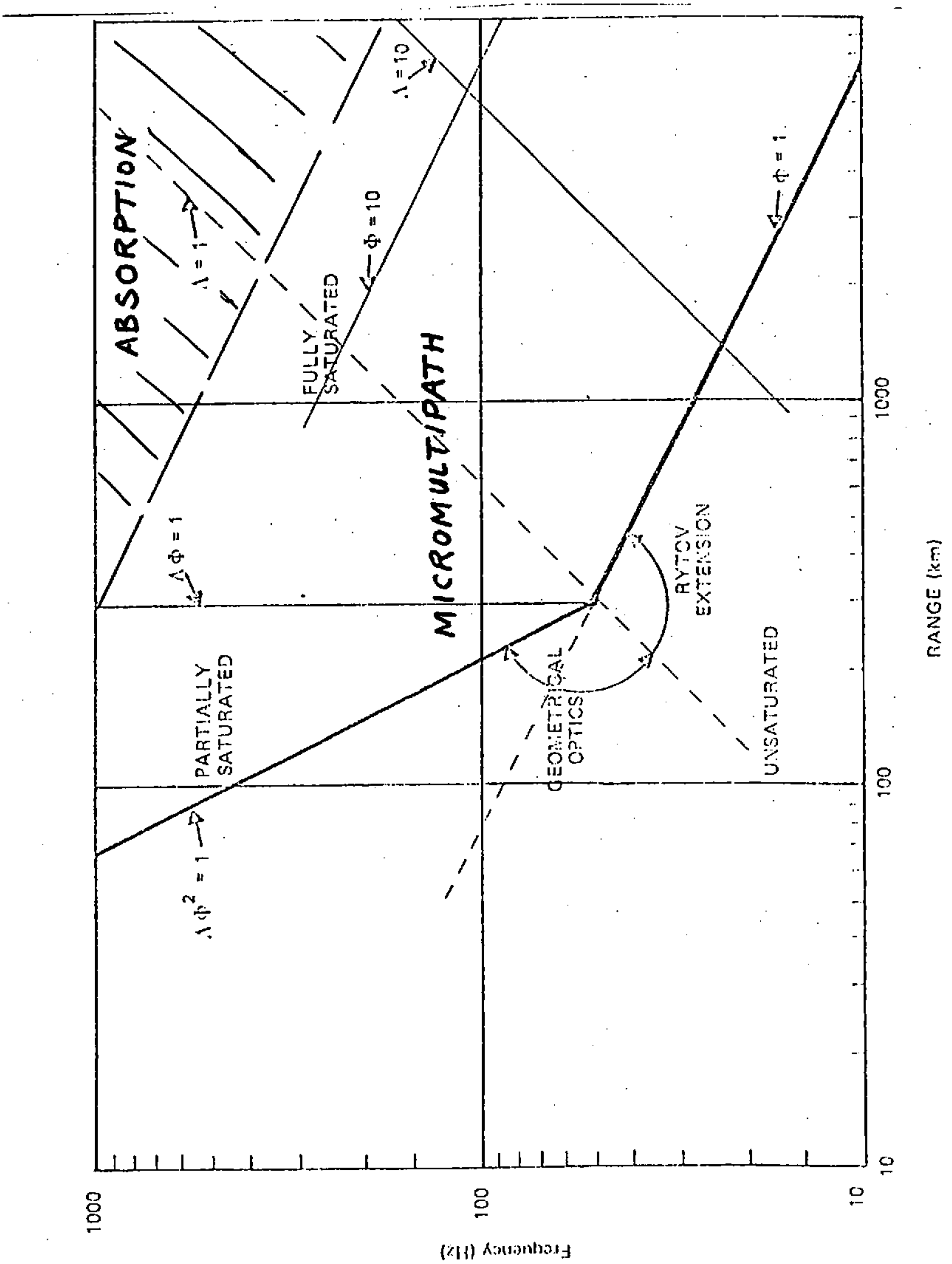

Figure 1

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