PROPAGATION THEORY FOR THE EVAPORATION DUCT

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1. INTRODUCTION

Propagation in radio ducts first attracted attention during the 1940's and was the subject of some notable theoretical studies(1),(2),(3). Recent developments such as the use of the Monin-Obukhov similarity theory(4) to give realistic refractive index models, improvements in theoretical and numerical methods and the need to incorporate other phenomena such as scattering from the sea surface and atmospheric turbulence allow some extensions of the theory. Section 2 of this paper gives a descriptive introduction to duct propagation. Section 3 gives an integral representation which is the theoretical starting point. Section 4 gives the superdiffraction theory and section 5 a sketch of a superrefraction theory. Section 6 applies this to the evaporation duct and gives numerical results. Section 7 assesses the state of the theory.

2. DESCRIPTIVE ASPECTS OF DUCT PROPAGATION

2.1. Characteristics of surface ducts

Generally the refractive index, n, of the troposphere decreases with height, h. This decrease bends rays towards the earth but not sufficiently to overcome the earth's curvature. Instead of using n over a curved earth of radius r_0 it is permissible to use the modified refractive index $m = n + h/r_0$ over a flat earth. Generally m increases with h so that rays bend away from this flattened earth. A radio duct exists where $dm/dh < 0$ within which rays are bent towards the flattened earth. A simple surface duct

A. Zancla (ed.), *Modern Topics in Microwave Propagation and Air-Sea Interaction*

exists when

$$\frac{dm}{dh} \lesseqgtr 0 \quad \text{for} \quad h \lesseqgtr h_d \tag{1}$$

where h_d is the duct thickness. Figure 17 shows some models.

2.2. Ray paths in a surface duct

Used with caution ray optics (zero wavelength limit of wave optics) can give useful insights into duct propagation. Figures 1 and 2 show ray paths for a transmitter, height h_T, which is above and below h_d. Figure 1 shows rays A and B that enter the duct, are reflected by the earth and then leave the duct. By symmetry no direct ray paths can lead to a trapped ray for $h_T > h_d$. The ray E never enters the duct. There is a limiting ray C between those that enter the duct and those that do not which is horizontal beyond D. Rays initially above and below C will diverge beyond D indicating a caustic at the height h_d beyond D in the vicinity of which ray optics breaks down. In figure 2 a ray A is reflected from the earth and leaves the duct and a ray E leaves the duct directly. There are limiting rays C and H which become horizontal at D and I beyond which there are caustics. All rays between C and H, e.g. B, are trapped in the duct.

2.3. Wave aspects of propagation in surface ducts

Within the trapped rays there are preferred directions for which the phase at similar points F and G will differ by multiples of 2π (see eqns.(33) to (35) for a more exact statement) giving constructive interference with maximum energy flow. Figure 3 shows that there are two angles giving rise to similar rays. The energy flowing into the preferred directions forms a mode which form the basis of long distance propagation in ducts. According to figure 3 it is impossible to excite a mode unless $h_T < h_a$. This is not so. Consider, by Huyghen's principle, secondary

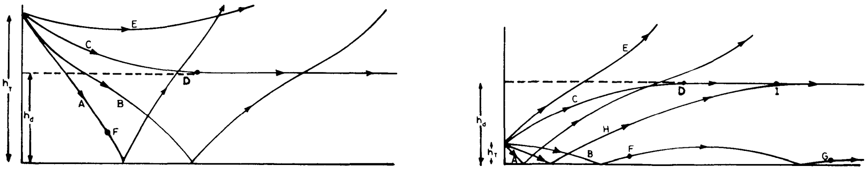

Figure 1. Figure 2.

Ray paths in a surface duct.