THE ROLE OF ELEVATED DUCTING FOR RADIO SERVICE AND INTERFERENCE FIELDS

H. T. Dougherty and E. J. Dutton*

This report categorizes the manner in which atmospheric stratification can complicate the problems of frequency allocation and radio regulation by inhibiting service fields and enhancing interference fields. For the United States and its border regions, preliminary contour maps are presented for those parameters associated with the atmospheric layering (ducts) conducive to the propagation of unusually strong UHF and SHF fields over extremely long distances. The parameters of interest are: the percent occurrence of elevated ducts, a minimum trapping frequency, the modified refractivity lapse, the ducting-layer base height, the duct-base height, and the duct-top height. The role of these duct parameters in the prediction of potential interference fields is detailed by engineering formulas and illustrated by numerical examples. These predictions of duct characteristics from historical (radiosonde) data are necessarily preliminary because of present inadequacies of the data sample. Approaches for improving estimates of duct parameters are described. Appendices detail expressions for duct trajectories and map the variation of duct characteristics.

Key Words: anomalous propagation; atmospheric ducts, layers, or stratification; ducting; interference fields; ray trajectories; SHF; UHF

1. INTRODUCTION

Under the influences of climatological and synoptic weather processes such as subsidence, advection, or surface heating and radiative cooling, there is a tendency for the lower atmosphere to stratify. This stratification can take the form of refractivity layering; i.e., layers in which contrasting refractivity gradients occur. Of primary interest here are those layers:

- o with strong ducting gradients ($dN/dh < -157$ N units/km),
- o immersed within super refractive air ($-157 < dN/dh < -39$ N units/km),

or o overlying a sub-refractive layer ($dN/dh > -39$ N units/km);

the N and h are defined by (2a) and (2b) on page 8. These layers with strong ducting gradients are commonly on the order of ten meters in vertical extent (but often much less), and commonly bounded by layers of localized turbulence. These layers can be horizontally extensive, from tens to hundreds of kilometers in extent, although the thinest layers may be only kilometers in extent [Dougherty and Hart, 1976; Hall, 1980].

* The authors are with the U. S. Department of Commerce, National Telecommunications and Information Administration, Institute for Telecommunication Sciences, Boulder, CO. 80303.

This atmospheric layering in the troposphere is of concern both to system design engineers and to the national or international radio regulators. Ducting layers have the effect of trapping or guiding (ducting) radio wave energy in their vicinity. On short paths and even line-of-sight (LOS) paths, this ducting may intro- atmospheric multipath or be so efficient as to divert energy away from an intended receiving terminal, depressing the received field level to far below the median service field level (fading). Simultaneously, this efficiently diverted radio energy may be directed well beyond the intended service area to cause an otherwise unexpectedly strong interference signal to other co-channel systems or services.

1.1 Degradation of Service Fields

On line-of-sight (LOS) systems, or over the LOS portions of trans-horizon systems (i.e., between each terminal antenna and its horizon), tropospheric layers can degrade system performance. For example, layers near the surface can:

(a) introduce additional propagation paths (which constitute atmospheric multipath and produce fading);

(b) effectively isolate one telecommunications terminal from the other (by diverting the radio wave and attenuating the received signal level);

or (c) diffract the service propagation path, introducing losses (radio holes) due to the proximity of the radio wave trajectory to media boundaries (such as the earth's surface or the base and top of tropospheric layers).

Examples of each of these categories are illustrated by, respectively, Figures 1, 2, and 3 [Dougherty, 1968].

1.2 Enhancement of Interference Fields

For the avoidance of interference as required by radio regulations [ITU, 1976; NTIA, 1979], the terminals of co-channel systems are normally positioned to avoid an efficient inter-system (interference) propagation path. For the usual trans-horizon potential interference path that then results, the available modes of propagation are volume scattering (troposcatter), diffraction, and (in the presence of tropospheric layers) turbulence-layer scatter, reflection, scatter in the presence of rain, and the strongly refracted (ducted) modes of propagation. Their order in the preceding sentence is that of generally increasing efficiency, but of decreasing availability. Figure 4, illustrates the situation: there, the T_aR_a and T_bR_b dash-dot trajectories represent LOS service paths, isolated from one another by their antenna patterns and the intervening terrain, such as at O. The dashed-line

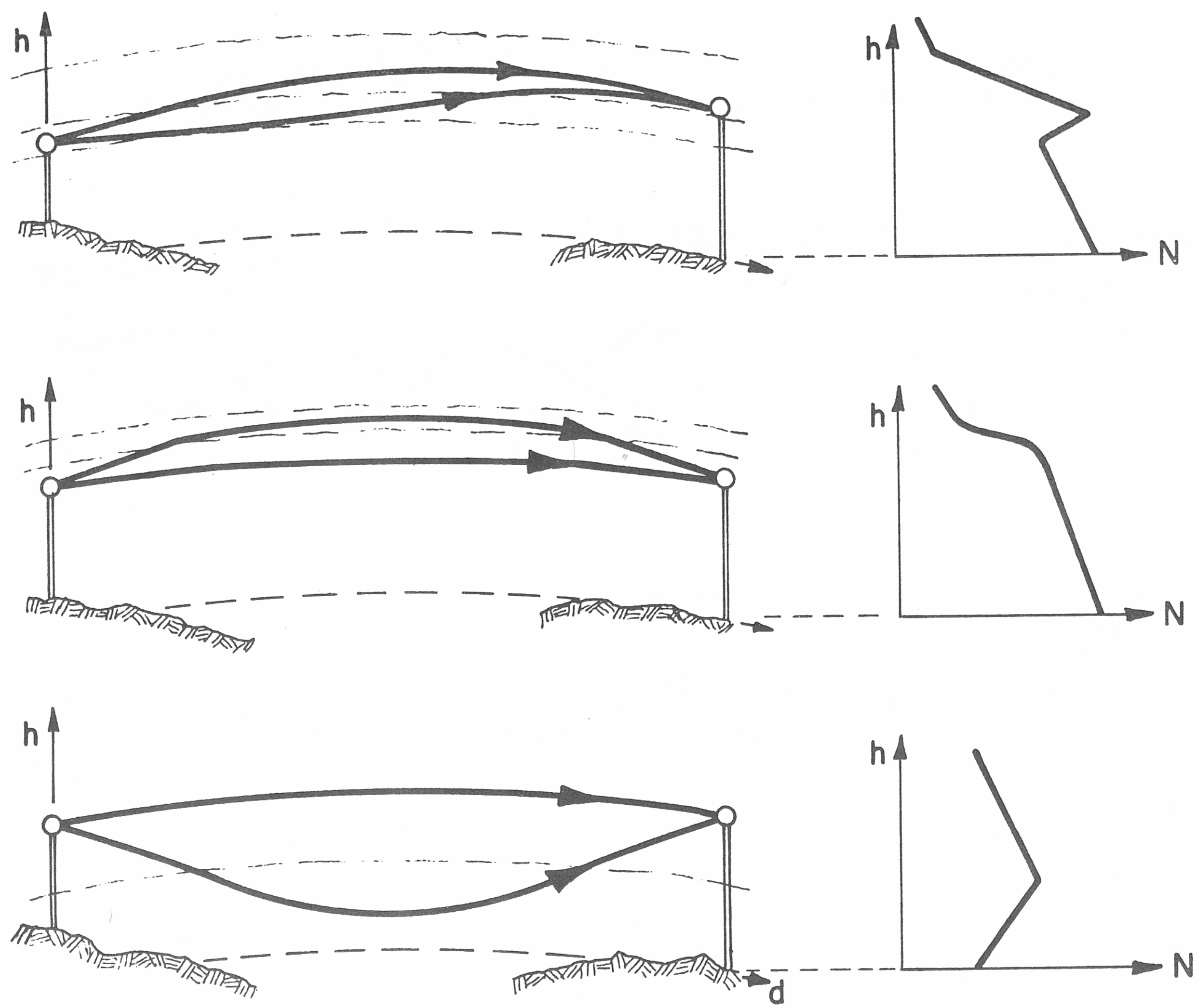

Figure 1. An atmospheric fading mechanism, Multipath [Dougherty, 1968]

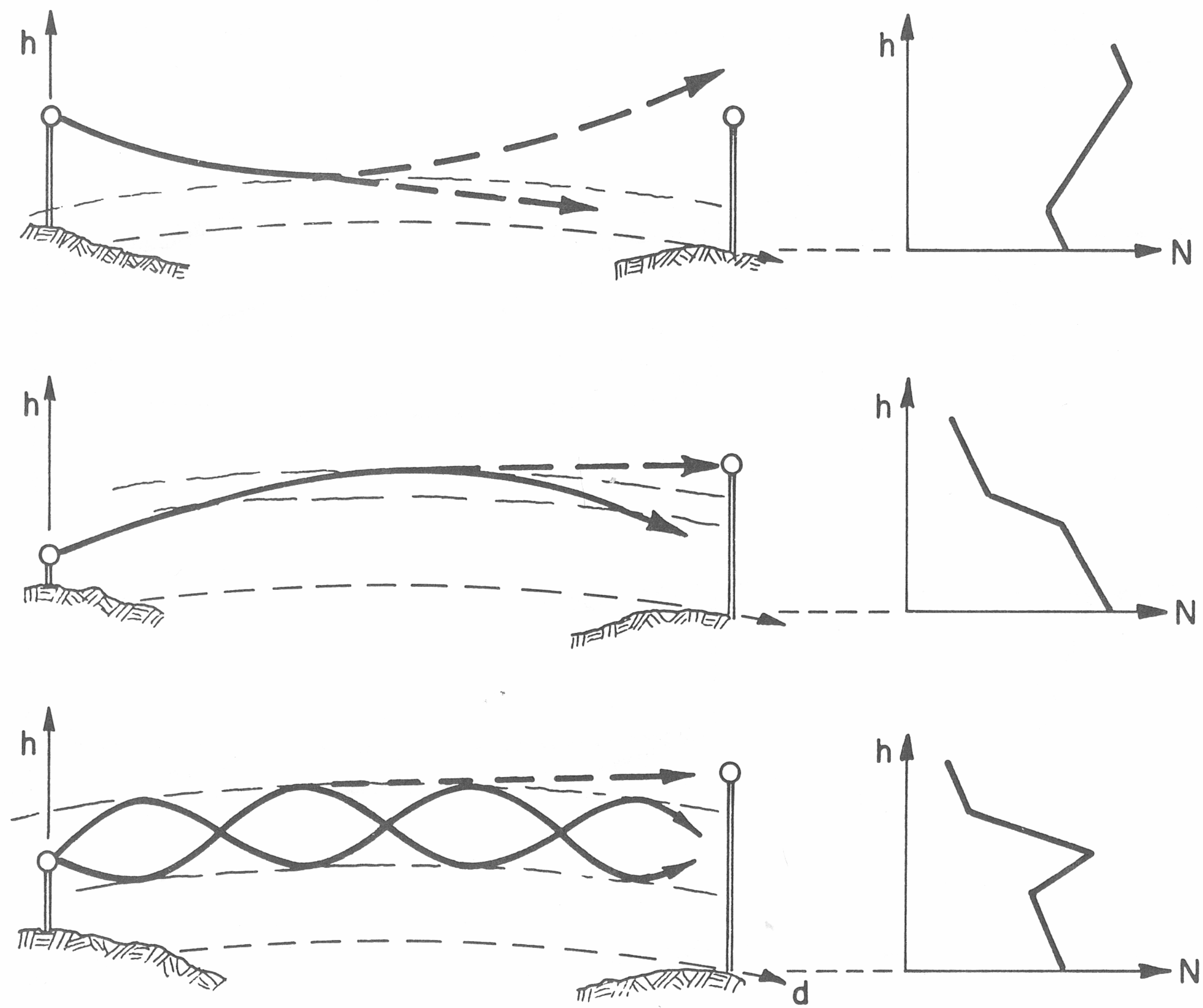

Figure 2. An atmospheric fading mechanism, Isolation. Isolation of terminals, one from another may be caused by atmospheric layers and ducts [Dougherty, 1968].

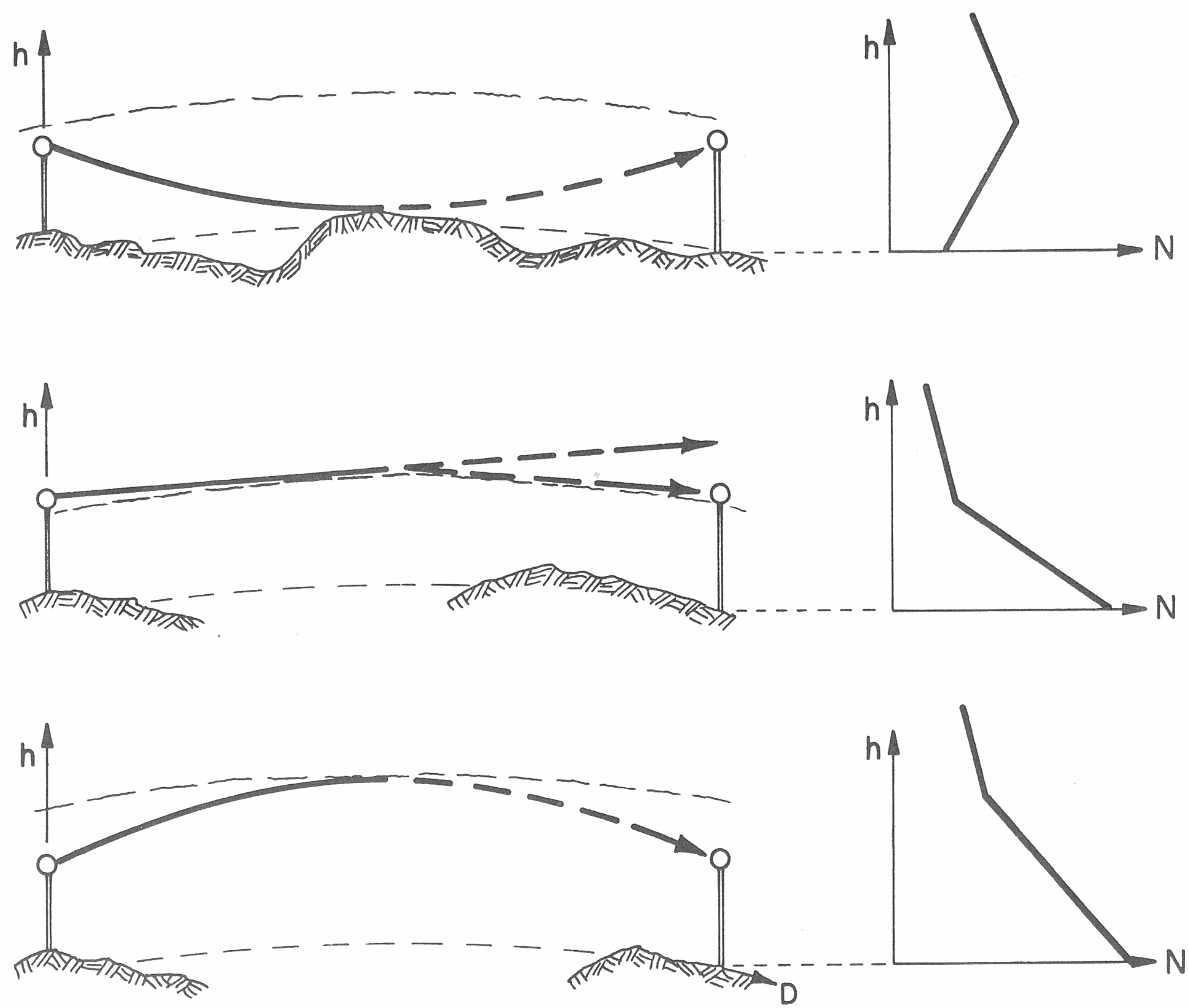

Figure 3. An atmospheric fading mechanism, Diffraction. This loss in a radio hole is encountered whenever the radio wave trajectory approaches too closely to a boundary (such as the earth's surface or the top and base of a layer) [Dougherty, 1968].

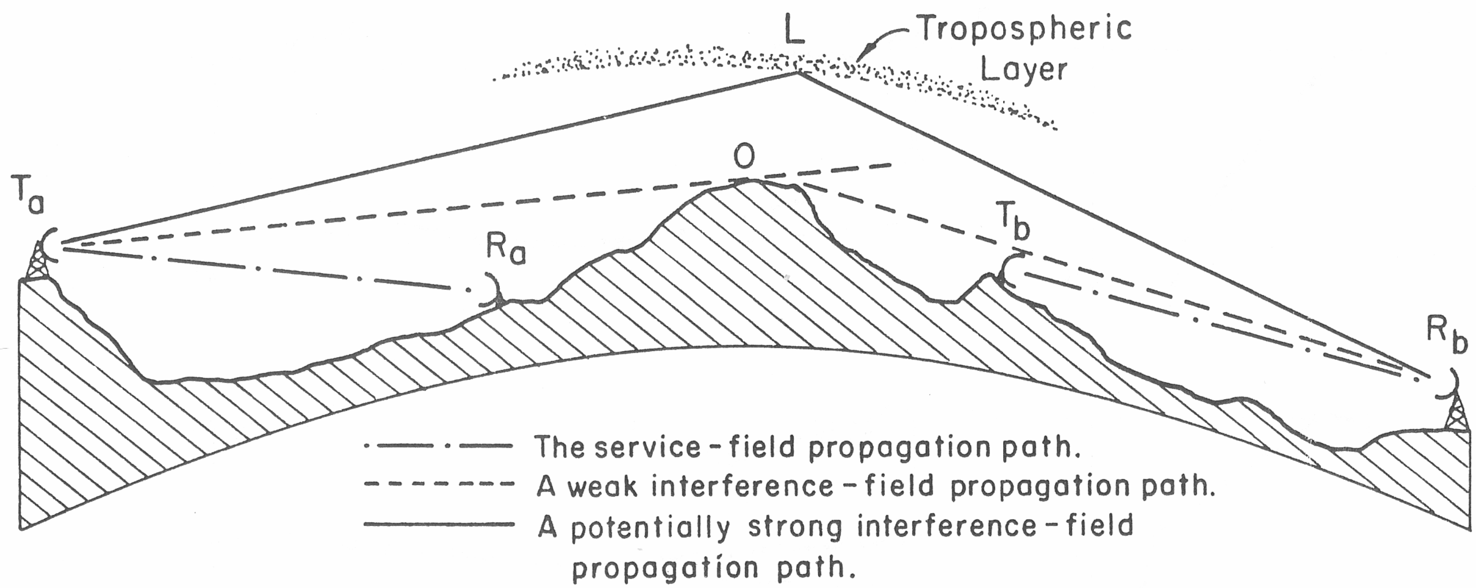

Figure 4. Service and interference propagation paths for two systems.

path T_aOR_b represents a weak (diffracted or troposcatter) interference path [CCIR, 1978a; 1978b], but the continuous-line path T_aLR_b represents a potentially strong interference path, via the ducting layer at L. Of course, additional reflecting layers can provide additional interference path trajectories. Reflection from terrain (between T_a and O or R_b and O) can also provide additional components via the layer at L [Saxton, 1951; Hall, 1968].

Whether a ducting layer causes a radio wave (that is incident upon the layer from below, as in Figure 4) to be scattered, reflected or trapped, depends largely upon the layer's refractivity gradient, the angle of ray incidence measured relative to the layer boundary's tangent, the layer thickness in terms of wavelength and small-scale turbulent fluctuations along the layer boundary. Although detailed descriptions of the relevant parameters are presented in Section 2, we can note here that for critical refraction or ducting by a ducting layer, the grazing angle of incidence from below, θ, must not exceed a critical value θ_c; i.e., ducting occurs for

$$0 < \theta \leq \theta_c \quad . \tag{1a}$$

For larger angles of incidence, the layer will reflect the incident field with a reflection coefficient given approximately by

$$|\rho| \leq (\theta_c/\theta)^2 \Big/ (8\pi\delta \sin\theta) << 1.0, \qquad \theta > \theta_c \quad . \tag{1b}$$

Here, δ is the layer thickness expressed as a multiple of the radio wavelength [Wait, 1964, 1969; Dougherty and Hart, 1976; Hall, 1980]. For a given layer, δ will increase with decreasing wavelength so that the above equation indicates a reflection coefficient that tends to decrease with increasing radio wave frequency. For this reason, layer reflection would be expected to play the more important role in interference at VHF and for paths up to a hundred kilometers or so in length, but become of decreasing importance for increasing radio frequency at UHF and for very long paths. On the other hand, the strong refraction of radio waves by these layers (ducting) tends to become increasingly important at UHF and higher frequencies and particularly for long paths.

The thin turbulent layer that commonly bounds the refractivity gradient layer will also provide a backscatter signal. This has been used as the basis for monitoring the occurrence and motion of tropospheric layers [Bean et al., 1971; Dougherty and Hartman, 1977; Crane, 1980].