

A REVIEW OF TROPOSPHERIC REFRACTION EFFECTS ON  
EARTH-TO-SATELLITE SYSTEMS

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ABSTRACT

Tropospheric refraction effects may seriously limit the performance of communication, navigation and radar systems that operate at low elevation angles. The lower atmosphere has an index of refraction which is slightly larger than unity at the earth's surface and which decreases approximately exponentially with height. As a result, radio waves travel at slower velocity than in free space and as they traverse layers of decreasing index of refraction, they are bent downward. Thus, targets observed from the ground appear to be at higher elevation angle than the true angle and if the range of the target is based on a time delay measurement, the target will appear farther away. In addition, abnormal refractivity gradients may cause radio waves to be trapped within tropospheric layers, thus producing regions through which the waves do not pass: these are called "radio holes".

For some locations and for many applications, refractive corrections based on the surface refractivity are adequate for elevation angles above a few degrees. However, new systems which operate at elevation angles near the horizon often require improved accuracies. In this paper, techniques for obtaining these improved corrections are reviewed.

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## QUESTIONS AND ANSWERS

VICTOR REINHARDT, HUGHES AIRCRAFT COMPANY: Those error figures you had for the range, is that the one way range, or the two way range?

MR.ALTHSULER: One way.

MEL BUCHWALD, LOS ALAMOS NATIONAL LABORATORY: You said that ducting was very unusual except in certain locations where it's common. I think a lot of us are wondering if we live in one of those places.

MR.ALTHSULER: As I understand it, the ducting very often takes place over water. There is a region off of San Diego where they say that ducting occurs on a very regular basis. The ducting is very serious over the Persian Gulf. It is, I think, one of the hottest bodies of water on the earth, and, as you know, there have been all kinds of problems as to whether to put radars on the ground, or up in the mountains. If you put them on the ground, then you have usually serious ducting conditions. If you put them up in the mountains, you have less ducting, but you have other problems. It's a real nightmare.

It is something which is obviously very difficult to measure, but the data that are available indicate that it occurs mostly over water, and there are locations where you can expect it.

MR. REINHARDT: Is there a simple cosecant law that you can use to get the average delay for correction?

MR. ALTHSULER: Thank you for bringing that up. It turns out the distance of the slant path through the atmosphere is a function of the cosecant of the elevation angle, or the secant of the zenith angle, whichever you choose.

For angles typically around four or five degrees you know how the secant behaves. It eventually goes to infinity. But depending upon how much of an error you are willing to absorb, you can get down to eight or ten degrees without any problem. Once you get below eight or ten degrees, you are starting to compromise a little. Of course, I certainly wouldn't try it below four degrees.