Slant Path Absorption Correction for Low Elevation Angles

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Abstract—Slant path attenuation at millimeter wavelengths due to the gases oxygen and water vapor is often estimated by multiplying the zenith attenuation by the cosecant of the elevation angle. This flat-earth approximation is not valid at low elevation angles. The error produced by this approximation is examined. It is assumed that the actual atmosphere can be represented by a uniform surface layer with an effective height such that the attenuation through the layer is equal to that through the actual atmosphere. An expression for calculating this effective height is provided and with the effective height specified, the error produced by the approximation is determined. The percent error is then plotted as a function of effective height for a set of elevation angles above 2°.

INTRODUCTION

Slant path absorption at millimeter wavelengths due to the atmospheric gases oxygen and water vapor, can be measured using the sun as a source [1]. The usual procedure is to make a set of extinction measurements as a function of zenith angle and then infer the zenith attenuation from these data. The slant path attenuation is then calculated by multiplying the zenith attenuation by the cosecant of the elevation angle.

\[ A(\theta) = A(\theta = 90^\circ) \csc \theta. \]  \hfill (1)

However, this flat-earth approximation is not valid at low elevation angles. In this communication, the error introduced by this approximation is examined.

ESTIMATION OF SLANT PATH ATTENUATION

The flat-earth approximation is often used for elevation angles above 8°. In order to calculate the attenuation at lower angles, the height profiles of the absorption coefficients of oxygen and water vapor must be known. Since this information is not usually available, the concept of an effective height is used. The effective height is the height of a surface layer of atmosphere consisting of a uniform distribution of oxygen or water vapor that produces the same total absorption as is produced by the actual atmosphere. If the absorption coefficient decreases exponentially, then the effective height is equivalent to the more commonly referred to scale height, the height at which the absorption coefficient decreases to 1/e of its value at the surface. If the height profile of the absorption coefficient is not known, then the effective height is the ratio of the zenith absorption to the surface absorption coefficient.

Assuming that the absorbing atmosphere can be represented by an effective height, the distance of the slant path through the layer surrounding the curved earth is [2]

\[ d_e = \left[ (a + h_e)^2 - a^2 \cos^2 \theta \right]^{1/2} - a \sin \theta \]  \hfill (2)

REFERENCES


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The slant path distance for the flat earth is
\[ d = h \csc \theta. \]  
(3)

The percentage error by which the flat-earth slant path distance exceeds the curved-earth distance is
\[ \frac{d - d_c}{d_c} \times 100. \]  
(4)

Since the total absorption is directly proportional to the distance through the absorbing layer, the absorption computed from (1) exceeds the true absorption by the percentage computed in (4). This percent error is plotted in Fig. 1 as a function of effective height for a set of elevation angles. It is seen that the percent error increases almost linearly with effective height but much more sharply with a decrease in elevation angle.

The effective height is a weighted average of the effective heights of oxygen and water vapor. Since the absorption coefficients of these gases are a function of frequency, the effective heights are also frequency dependent; however, significant changes only occur near the absorption lines. The effective height of oxygen is relatively stable and has a value of about 5 km. That of water vapor is much more variable with typical values of 2 or 3 km. Based on a set of atmospheres ranging from dry to moist, a weighted effective height in the window regions of the spectrum below 100 GHz can be approximated by
\[ h = 4.94 - 0.50\rho + 0.032\rho^2 - 0.000645\rho^3 \]  
(5)

where \( \rho \) is the surface absolute humidity (gm/m³).

Thus the effective height for a typical atmosphere (\( \rho = 7.5 \) gm/m³) is 2.7 km. From Fig. 1 we see that for \( h = 2.7 \) km and \( \theta = 8^\circ \) the percent error is less than 1 percent so the flat-earth approximation is reasonable for elevation angles above \( 8^\circ \). For lower elevation angles and higher effective heights the correction is more important.

**CONCLUSION**

In summary, slant path attenuation may be estimated at low elevation angles using the following procedure. If the zenith attenuation and surface absolute humidity are known, then attenuation calculated from (1) is decreased by the percentage shown in Fig. 1. If the zenith attenuation is not known, it can be estimated from design curves in International Radio Consultative Committee Report (CCIR) [3]. It is also possible to estimate the zenith attenuation from the surface absorption coefficient; it is simply the product of the absorption coefficient and effective height.

**REFERENCES**


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**Diffraction by a Half-Plane with Two Face Impedances**

**Uniform Asymptotic Expansion for Plane Wave and Arbitrary Line Source Incidence**

**ABSTRACT**

A uniform asymptotic expansion (UAE) of Malizhinaet's exact solution for incident plane wave diffraction by a half-plane with two face impedances has been obtained using Van der Waerden's method. This solution has been further extended to the case of arbitrary line source incidence using a heuristic approach.

**I. INTRODUCTION**

Electromagnetic diffraction by imperfectly conducting half-planes is a subject that has long been of continuing practical and theoretical interest [1]. The exact solution for the case of plane wave incidence on an imperfect half-plane (or, more generally, wedge) was given by Maliuzhinets in the form of a Sommerfeld integral [2]. He also obtained an asymptotic expansion of this solution, similar to Keller's...