2-IV A2

ELECTRO-MAGNETIC PROPAGATION CALCULATIONS USING A FOUR REGION MODEL FOR THE IONOSPHERE

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INTRODUCTION

Radio wave propagation calculations for paths through the ionosphere tend to fall into two categories: rough approximations that can be computed rapidly; or detailed ray tracing that is time consuming. Much of the difficulty with both types arises from the functions used to describe the density of free electrons in the ionosphere; the equations describing the path lengths cannot be integrated analytically. This forces one to use crude approximations for the integrals to obtain rapid solutions, or point to point numerical integration to obtain accuracy.

Parabolic functions have been used to describe the ionosphere in terms of separate layers for the past four decades. The ionograms from vertical sounders are usually interpreted in terms of such layers, such as E, F_1 and F_2, with the assumption of little or no ionization between these layers. Exploration of the ionosphere with rocket borne ion gauges, and top-side sounders on satellites indicates that such "valleys" in the free electron density height profile seldom exist, and are quite shallow when they do occur.

A modification to the parabolic model was suggested by de Voogt in 1953; Croft and Hoogasian developed this into the quasi-parabolic model, described in 1968. Croft and Hoogasian showed that the electron density obtained using the quasi-parabolic (QP) model differed very little from that obtained from a parabolic model at the same height; since the propagation equations obtained from the QP model can be integrated analytically, the calculation of ray paths through a layer can be done rapidly and accurately.

FOUR REGION MODEL FOR THE IONOSPHERE

The ionosphere is assumed to begin at a height of 90 km. with the ionization in this First (E) region described by a QP layer with maximum ionization at 110 km. and a semi-thickness of 20 km. The second region extends from the maximum ionization of the E region to the bottom of the F region. In this intermediate (I) region, the ionization is described by a QP function, with the minimum ionization occuring at the E maximum. The third (F) region extends from the transition from the second region past the height of maximum ionization. The ionization is described by a QP function with the semi-thickness being the difference between the height of maximum ionization and the height of the transition between the second and third regions. In the fourth region, above the F region ionization maximum, the electron density is assumed to vary inversely as the square of the distance from the center of the earth. The functions used are restricted such that the free electron density and first derivative of the free electron density with height must both be continuous, i.e. the transitions between the regions are smooth. The values used for the functions in any particular case are set by data on the ionosphere. These can either be scaled from ionograms, or obtained from predictions of such data, such as the numerical maps published by the Institute for Telecommunication Studies, Boulder, Colorado, USA. when considering only the ionosphere to the F region maximum ionization.

Figure 1 shows the electron density as a function of height, for the ionosphere parameters shown on the figure. Figure 2 is a computed vertical ionogram, based on this distribution.

PROPAGATION CALCULATIONS WITH THE MODEL

For rays returned from the E region, the hop calculations are much like those computed using a parabolic model for the ionization. For rays returned from the higher regions, the hop structure differs from that obtained using a model with two separate layers; either the distance will be greater for a particular take-off angle, or the take-off angle will be greater for the same distance, assuming the same maximum ionization for the two computations.

Detailed hop structure calculations are made, using the ionosphere conditions near the center of each hop to control the hop characteristics. The procedure is to assume a hop structure, compute the total distance a ray following this structure would cover, and use the error to adjust the hop length and take-off angle. A distance error of less than 10 km. is usually obtained with 3 iterations.

Computations for a number of HF paths are compared with measured data for the same paths.

Figure 1.
Computed Electron Density as a Function of Height.
FoE = 2.5 mHz
FoF2 = 10.05 mHz
M-3000 = 3.1
h_o' = 280.0 km.

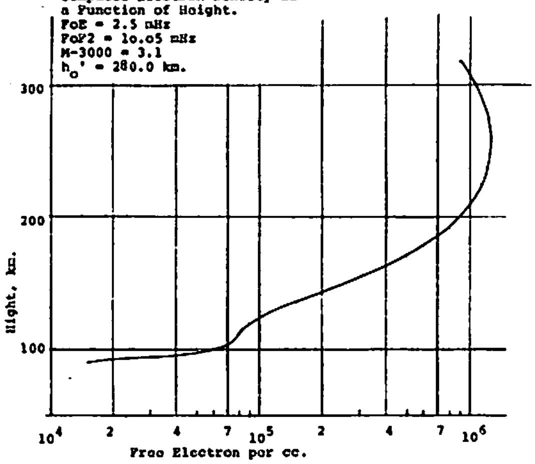

Figure 2.
Computed Ionogram, for ElectronDensity Distribution, Figure 1.