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GENERATION OF IDEALIZED SURFACES FOR THE SIMULATION OF IONOSPHERIC PROPAGATION CONDITIONS

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Introduction

In order to improve the understanding of the radio propagation effects due to wavelike perturbations in the ionosphere, which are associated with the passage of gravity waves in the neutral atmosphere, reflection surfaces were simulated on a computer by means of cylindrical, sinusoidal, moving waves. Although the ionosphere causes a gradual refraction and reflection process for penetrating electromagnetic waves, these perturbations were assumed to be well represented by phase path variations obtained from bistatic continuous-wave Doppler radars.[1] This assumption may not strictly hold.[2] Nevertheless, the simulation study considered a simple, sharply bounded reflector.

Waves in the Ionosphere

Monitoring stable carriers at frequencies of 3.330 and 3.335 MHz two years of data were gathered over an oblique transmission between Time Station CHU, Ottawa, Canada, and AFCRL, Bedford, Mass., separated by 480 km.

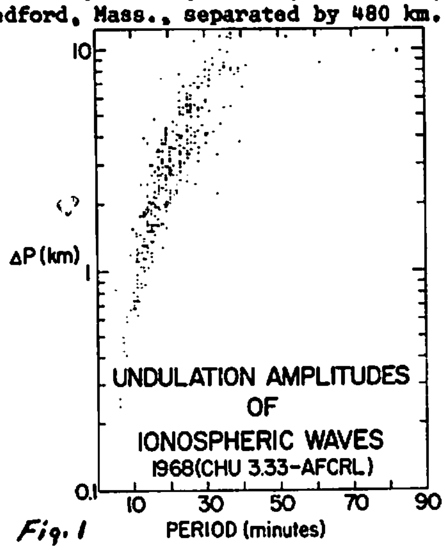

Fig. 1

Fig. 1 shows the nearly linear relationship found between phase path amplitude and period of wavelike perturbation. The most frequent periods occurred between 15 and 20 minutes, close to the natural resonance frequency of the atmosphere in the F region.[3-4] These quasi-sinusoidal undulations were only observed 3% of the time. At other times, interfering waves caused complicated Doppler patterns. For this reason, a more generalized approach to the simulation problem was undertaken.

Simulation of Reflection Surfaces

The reflection surface was represented by the superposition of cylindrical, sinusoidal wave forms as

$$z(x,y,t)=H+\sum_{j=1}^{n} A_j \cos(k_{1,j}x+k_{2,j}y-2\pi\lambda_j^{-1}v_j t-\phi_j)$$

The path length $P=|\vec{r}_{TS}|+|\vec{r}_{RS}|$ from transmitter to surface to receiver was seen as being a function of the position of a contact point on the surface. In order for the contact point to become a solution point the following constraints were initially introduced: (a) the plane T,R,S be perpendicular to the tangent plane at S, i.e. $(\vec{r}_{TS}\times\vec{r}_{RS})\cdot\vec{n}=0$ where $\vec{n}$ is the normal to the surface, (b) the angle between $\vec{r}_{TS}$ and $\vec{n}$ equals the angle between $\vec{r}_{RS}$ and $\vec{n}$, i.e. $(\vec{r}_{TS}\cdot\vec{n})|\vec{r}_{RS}|=(\vec{r}_{RS}\cdot\vec{n})|\vec{r}_{TS}|$. Geometrical criteria were also determined to define a boundary containing solution points.

Finally, the approach used in the generalized case proceeded by deriving a coupled pair of algebraic equations directly from Fermat's principle for the path length P between transmitter, reflection surface and receiver:

$$\partial P/\partial x|_{(\bar{x},\bar{y})}=F_1(\bar{x},\bar{y})=0$$

$$\partial P/\partial y|_{(\bar{x},\bar{y})}=F_2(\bar{x},\bar{y})=0$$

The numerical search for finding a solution point S $(\bar{x},\bar{y})$ could have been conducted over a fine (x,y)-grid. Such an approach was deprecated in favor of using the winding number theorem [5] for a coarse search. The center of the region containing a solution became the initial estimate of a solution point. Care had to be taken not to miss solutions on saddle points in the P domain. The estimate was refined by using the Newton-Raphson iterative technique.[6] Once the solution points were found, the path length P and its derivative were determined. Fig. 2 illustrates the complex behavior of P for the case of two gravity waves traveling in perpendicular directions with a speed of 600 km/h;

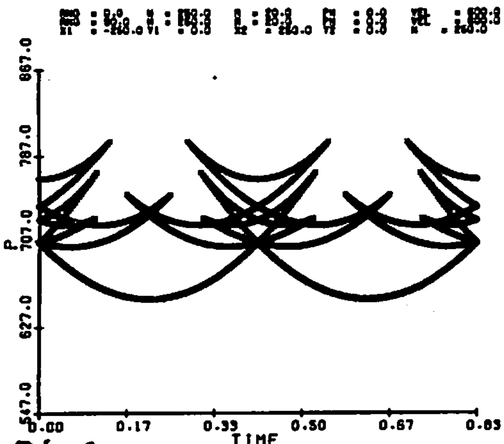

Fig. 2

the amplitudes of the waves are 20 km; both wavelengths are 250 km; waves travel at a mean height H=250 km; one wave travels along the 500 km TR-baseline. Fig. 3 shows the corresponding behavior of dP/dt. It should be noted that patterns of this kind have not yet been identified in the data.

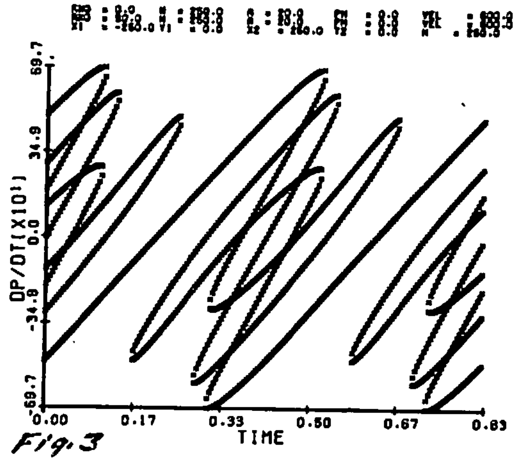

Fig. 3

Conclusion

The simulation approach confirms but also provides new information about the existence and behavior of waves in the ionosphere and their effects on radio propagation parameters. For the case of two interfering waves the search time on a CDC 6600 computer was about 120 sec. This search time increases if higher-order Fourier components are contained in the reflection surface.

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