A NEW METHOD OBTAINING THE IONOGRAMS FROM THE ELECTRON DENSITY AND THE COLLISION FREQUENCY PROFILES IN THE LOWER IONOSPHERE

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Abstract: It is important that apparent heights are obtained from an electron density profile. Up to date, the apparent heights have been estimated by the integration of group delay along the ray path without collision. We suggest a new method giving the apparent heights and the reflection coefficients simultaneously. The apparent heights might be obtained in error by several meters. This method considers the collision using the full wave method, but need not consider the ray tracing. This method is compared with the former one.

1. INTRODUCTION

Ionograms are effective data to know the ionospheric conditions. And the ionograms have information of both apparent heights and reflection coefficients. But, up to date, only the apparent heights have been used for the inversion of the ionograms to estimate electron density profiles[1,2]. Also, collision profiles of the ionosphere have not been used for the estimation. The reflection coefficients might be effective for problems of the D layer and the valley between the Elayer and the F layer. And the calculative apparent heights should include the collision. Recently, the advanced digital ionosonde is to be able to measure echo intensities precisely [3].

In this paper, we introduce a new method to obtain the apparent heights from the ionosphere model with the collision profile on one usage of the full wave method. This method can obtain the reflection coefficients simultaneously. This method is compared with the former one.

2. PRINCIPLE

When the pulse wave transmitted by the ionosonde is received by the same anntena after travelling a time T in the ionosphere, the apparent height h' is

$$h'=cT/2 + Hb \qquad \ldots(1),$$

where c is the light speed and Hb is a bottom height of the ionosphere. The wave separates into two characteristic waves, i.e. an ordinary (O) wave and an extraordinary (X) wave in the ionosphere. These two waves travel at different spead and reflect at different heights. So, we must calculate h' for each wave. Therefore, our interest is mainly to obtain T for each wave by numerical calculations using the ionospheric models, that is, the electron density profile and the collision frequency profile.

Up to now, T has been obtained by integrating small time dT for the wave travelling a small length dl in the directin of the group velocity Vg. As dT is equal to dl/Vg, Eq.(1) is

$$h'= (c/2) \int_{(Hb,0,0)}^{rp} (dl/Vg) + Hb \qquad \ldots(2),$$

where r_p is a reflection point. It is important to estimate V_g and r_p in the ionosphere. For the former method, both V_g and r_p can be estimated according to the ray path theory [4]. But the ray path theory does not include the collision basically. And also, numerical calculation of this integration of Eq.(2) is very difficult because V_g has horizontal components and is close to 0 near r_p.

On the other hand, a principle of the new method is simple. We consider the ionosphere as a black box on the electric circuit theory. The reflection coefficient $R^*\exp(j\phi)$ (R>0) is equal to a transfer function of the circuit. So, a group delay time T is equal to a derivative of ϕ on the angular frequency ω. That is

$$T = | \partial\phi / \partial\omega | \quad ...(3).$$

As this T is equal to the time that the wave traveles in the ionosphere, h' can be obtained easily by Eq.(1). So, if the phase ϕ of the reflection coefficient for each characteristic wave is given precisely, h' can be obtained in no consideration of the ray path theory. This new method solves ϕ directly and obtains T by Eq.(3) by the numerical differential.

In order to obtain the reflection coefficients directly, the full wave method developed Nagano et al [5] is available. On this full wave method, we assume the ionosphere is constructed by homogeneous and thin multi-layers as shown in Fig. 1. So, the ionosphere is like stairs of step size d. We consider an injected wave as a plane wave with an incident angle 0 [deg] in this case. First, we estimate horisontal electromagnetic components in each thin layer using characteristic solutions of qj1,qj2,qj3 and qj4 that are the Appleton-Hartree formular. Next, after deriving transition matrix for each thin and flat layer, we multiply the transition matrix from the top to the bottom of the ionosphere. Finally, we can estimate the reflection coefficients $R^*\exp(j\phi)$ for both the O and X wave preceisely using conditions on the top and the bottom of the ionophore.

The echo intensity A(f) of the ionogram echo on the frequency f is represented,

$$A(f) = Po + Gt(f) + Gr(f) + 20\log R(f) - 20\log Dp(f) \ [dB] \quad ...(4),$$

where Po is the power of the transmitter,
Gt is the antenna gain of the transmitter,
Gr is the antenna gain of the receiver and
Dp is the propagation distance.

As we can measure Po, Gt and Gr from the settled ionosonde, A(f) gives us ionospheric information which combine R with the fifth term in Eq(4). In order to know Dp precisely, we have to use the ray path theory. But if Rp differs from Hrp by only several km in the horizontal direction, Dp may be twice Hrp because A(f) is only a little larger than an inconsiderable one. Therefore, the new method may not use the ray path theory to calculate the ionograms from the ionospheric model.

3. AVAILABILITY OF THE NEW METHOD

In order to test the new method, we use a standard electron density profile of the International Reference Ionosphere 1990 as shown in Fig.2. This profile is made noon, Oct.15 during high solar activity at London, Canada. The bottom height is 65[km]. And the effective collision frequency profile in Fig.2 is used. We calculated h' for $f \geqq 1$ [MHz] from Eq.(3) using the 3-point approximation method with df=10 [Hz].

For the frequency 5.03 MHz, Fig.3(a)(b) shows the reflection coefficients versus the step size d of the stairlike ionosphere, normalized by the wave length λ in the free space. If $d < \lambda/5$, R for both modes are nealy constant as shown in Fig.3(a). But the phases ϕ change in order of degree though $d<\lambda/200$ (25[cm]). This means that it is very difficult to know the true phases for the smooth ionosphere. When $df = 10$ [Hz], phase error 1 degree is nearly equal to apparent height error 21 [km]. It appears impossible to obtain the apparent heights. So, this new method seems to have been no acceptance till now. But we found out that each calculated phase ϕ in Fig.3 is exact for the stairlike ionosphere. And as for the same stairlike one, the numerical differential of Eq.(3) should give the group delays exactly. Fig.3(c) shows h' of the O and X waves for the stairlike ionospheres. It is clear that h' is constant in error of several meters if $d < \lambda/20$ (2.5 [m]). This means the new method is available. After this, we calculate the apparent heights with the step size 0.5 [m] for the purpose of making ionogram at the frequency range between 1 and 25 [MHz].

Fig.4 shows h' and R for the frequency range, and also shows h' for the former method of Eq.(2). The O trace for the new method nearly fit with the former O trace in the E and F layers. But the X trace is different in the lower frequency region where R are very small, as shown in Fig.4(b). We discuss about this though it will matter little that the X trace for this frequency region will not be observed in actuality. In this case, the new ones are wrong because the new method does not treat with a pulse wave but a continuous wave. A received wave is summation of a regular reflected wave, partial reflected waves and a coupling wave from another mode. Here, the X wave for the lower frequency is much more attenuate in the D layer during daytime than the O wave. So, the major received wave is a little coupling from the downgoing O wave because of high collision frequency in the D layer. The apparent heights are, therefore, same as the O wave. The new method can take away this coupling component by moving the top of the ionosphere in Fig.1. But if we can simply measure the echo waves of the condition $R \geq -50$ [dB], Fig.6 is obtained. It is clear that the X trace for the new method nearly fit with the former X trace in the F layer, too. And the new method shows higher apparent heights in the F layer than the former method.

4. CONCLUSION

we suggest the new method to obtain the apparent heights from the ionosphere model with the collision profile on one usage of the full wave method. As this method can obtain the reflection coefficients simultaneously, we can make the theoretical ionogram including the echo intensities. As the result of comparison with the former method, the new method is very avairable and shows higher apparent heights in the F layer than the former method.

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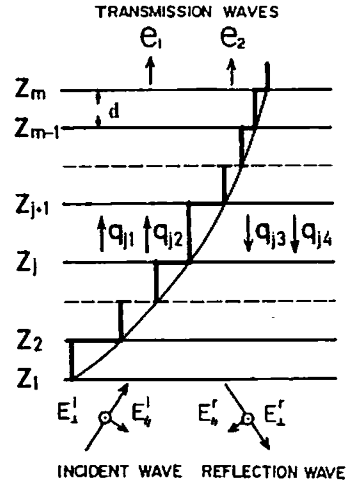

Fig.1 The full wave method developed Nagano et al [5].

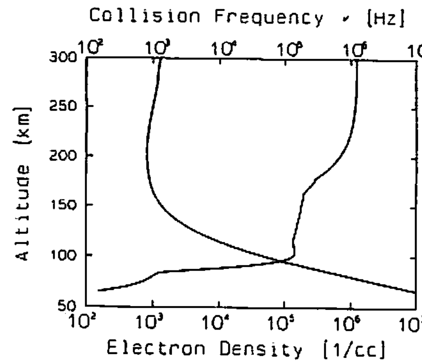

Fig.2 The ionospheric model.

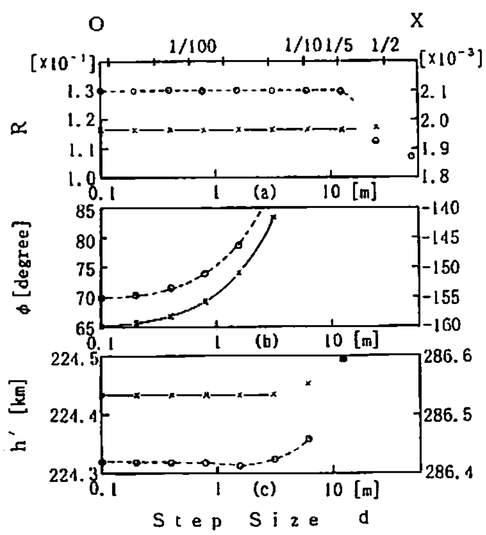

Fig.3 R, ϕ and h' versus step size d (f=5.03MHz).

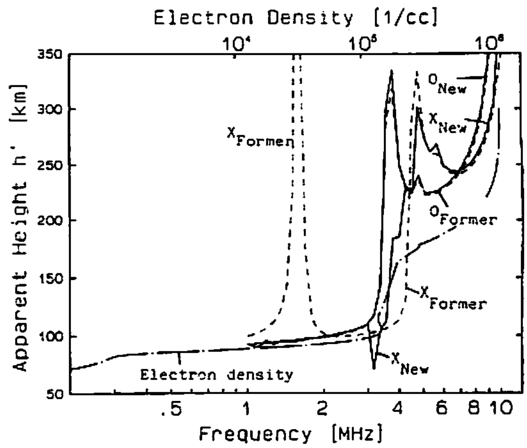

Fig.4(a) h' curves versus frequency.

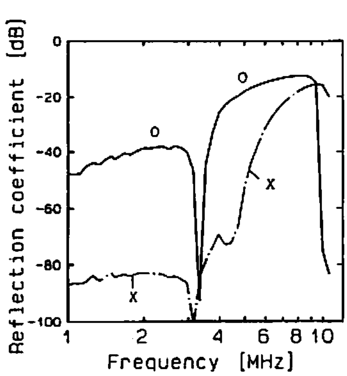

Fig.4(b) R versus frequency.

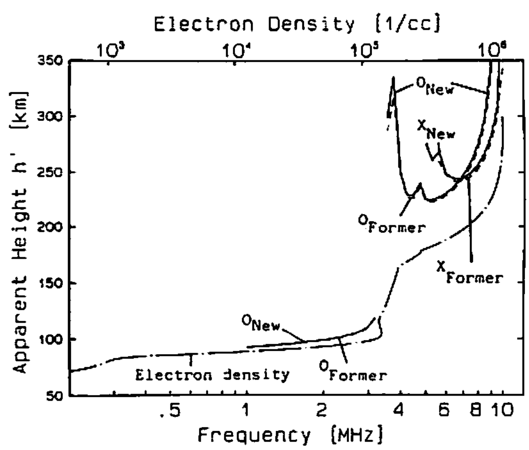

Fig.5 Theoretical ionogram traces.