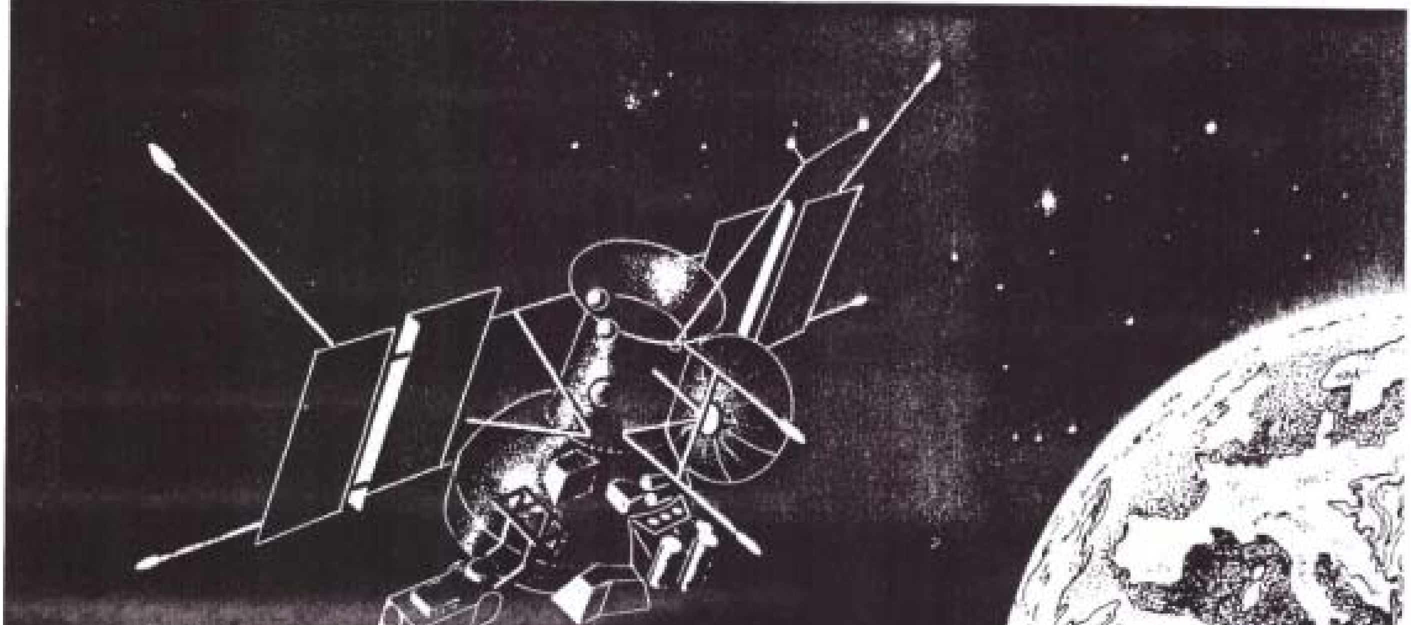
VOLUME 60 NUMBER 10, 11, 12 2003

ISSN 0040-2508

TELECOMMUNICATIONS AND RADIO ENGINEERING



Published by Begell House, Inc.

Telecommunications and Radio Engineering, **60**(10, 11, and 12), 2003

Development of the Method of Determining the Electron Molecule Collision Frequencies in the Ionospheric D-Region by the Partial Reflection Technique

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The classic method of determining the electron-neutral collision frequencies by the partial reflection technique in the ionospheric D-region is developed in the case of using the experimental data obtained with measurement errors.

1. Introduction

Knowledge of height variations of electron-neutral collision frequency profiles $\nu(z)$ in the lower ionosphere (z is the height above the Earth surface in km) is important for solving both the scientific problems and application in the radio communications, radio navigations, forecastings, etc. At present in the literature there is no single opinion about the changes of the $\nu(z)$-profiles in the ionospheric D –region. Some researchers (see, for instance [1]), suppose that $\nu(z)$-variations do not exceed ±30%, however in [2-6] there is noted the presence of both seasonal and latitudinal changes of $\nu(z)$ in the ionospheric D-region. There are not many directional experimental investigations of $\nu(z)$ in the ionospheric D-region, they is separated and difficult yield to the systematizations. It is conditioned in the first place, by difficulty of conducting experimental measurements and by absence of reliable methods of determining the electron-neutral collision frequency profiles with the accuracy required.

Usually the $\nu(z)$ profile in the ionospheric D –region is calculated using the atmospheric pressure models $p(z)$ from the known dependence

$$\nu(z) = k \cdot p(z). \tag{1}$$

The coefficient k is supposed known and k-values are used as: $k = (6-9) \cdot 10^5$ N m^{-2}sec^{-1}. Sometimes k-values are found using rocket experiments. The error in determination of $\nu(z)$ in this case can be essential because the atmospheric pressure models are imperfect, which ignored or take scantily into consideration both regional features and a number of other peculiarities (for instance, presence of different global and local disturbances in the ionosphere and other peculiarities).

Often, the $\nu(z)$- profile in the ionospheric D –region is defined using the amplitude measurements of partial reflection (backward scattered) radio signals at frequencies f=2-2.5 MHz by the partial reflection technique (PR) [1, 4-7]. In this case one most often, one uses two main methods of determining the $\nu(z)$-profile.

The first of them is based on simultaneous experimental measurements height-temporal dependences of the ratio of average (during the measurements of ~ 10 min) quadrates of amplitudes of partially reflected signals of the extraordinary ("x") and ordinary ("o") polarizations $a(z) = < A_x^2(z) > / < A_o^2(z) >$ and the correlation coefficient $\rho_{A_o^2 A_x^2}(z)$ [7].

The second method [6] is based on the fact that in the lower part of the ionospheric D-region (as a rule, the heights of $z <$ 70 km), the differential absorption of magnetic ionic component is small and the approximate

ISSN0040-2508

equation $a(z) \cong R(z)$ being valid. Here $a(z)$ is measured in the experiment, $R(z)$ is the theoretical function depending on the sounding frequency ω and on the longitudinal component of the electron gyro-frequency along the ambient magnetic field direction ω_L (in the middle latitude experiments, the value of ω_L is assumed to be equal 1.35 MHz) and $\nu(z)$.

In the first case, simultaneously with ν one obtains the electron density, N ; in the second case, only the values of $\nu(z)$ for the lower part of the ionospheric D-region are obtained. Other methods of obtaining the $\nu(z)$-profile are developed and analyzed in [5, 8, 9].

The methods considered (particularly the method considered in [7]) are sensitive to the errors in measurements of $A_{o,x}$.

As the practical experience suggests, there is usually used the second method, based on the approximate equation $a(z) \cong R(z)$. In this case, the transcendental equation is solved related to ν of the following type:

$$\frac{< A_x^2 >}{< A_o^2 >} = \frac{[(\omega+\omega_L)^2+\nu^2]}{[(\omega-\omega_L)^2+\nu^2]} \cdot \frac{(\omega-\omega_L)^2 K_\varepsilon^2\left(\frac{(\omega-\omega_L)}{\nu}\right)+\nu^2 K_\sigma^2\left(\frac{(\omega-\omega_L)}{\nu}\right)}{(\omega+\omega_L)^2 K_\varepsilon^2\left(\frac{(\omega+\omega_L)}{\nu}\right)+\nu^2 K_\sigma^2\left(\frac{(\omega+\omega_L)}{\nu}\right)}, \qquad (2).$$

Here K_ε, K_σ are the kinetic coefficients accounting for the kinetic effects on the permitivity ε and the conductivity σ of the lower ionosphere [10]. The dependences $K_\varepsilon(x)$ and $K_\sigma(x)$ can approximated with an error of an order a few percents by the relations

$$K_\varepsilon(x) = 1 + \frac{a_1}{b_1 + x^2}; \quad a_1 = 0.155, \; b_1 = 0.075; \quad 0.05 \le x < \infty,$$

$$K_\sigma(x) = 0.89 + \frac{a_2}{b_2 + x^2}; \quad a_2 = 0.027, \; b_2 = 0.053; \quad 0 \le x \le 3.5,$$

$$K_\sigma(x) = 1; \quad 3.5 \le x < \infty;$$

where $x = (\omega + \omega_L)/\nu$ for the ordinary mode, and $x = (\omega - \omega_L)/\nu$ for the extraordinary mode, $\omega_L = 2\pi f_L$.

In this method one usually supposes experimental data on $a(z) = < A_x^2(z) > / < A_o^2(z) >$ to be unauthentic when the signal to noise ratio is smaller than 2.

In Kharkiv National University there is accumulated a bank of experimental data having the signal to noise ratio of more than 2 (the number of experimental data is more than 10^3). They correspond to the different helio-geophysical conditions and sounding frequencies f. The largest number of the experimental data is obtained within the height interval of z= 60-75 km and frequencies f = 2.0-2.5 MHz for Solar zenith angles χ = 27^0- 97^0 with an approximately regular distribution, which allows – with high statistical confidence – to investigate a question of possible dependences of the electron/neutral collision frequencies on the Solar zenith angle over rather a wide height interval in the ionospheric D-region.

The z-, f- and χ- distributions for these experimental data are characterized by the histograms in Fig. 1 (the number of experiments is n = 421).

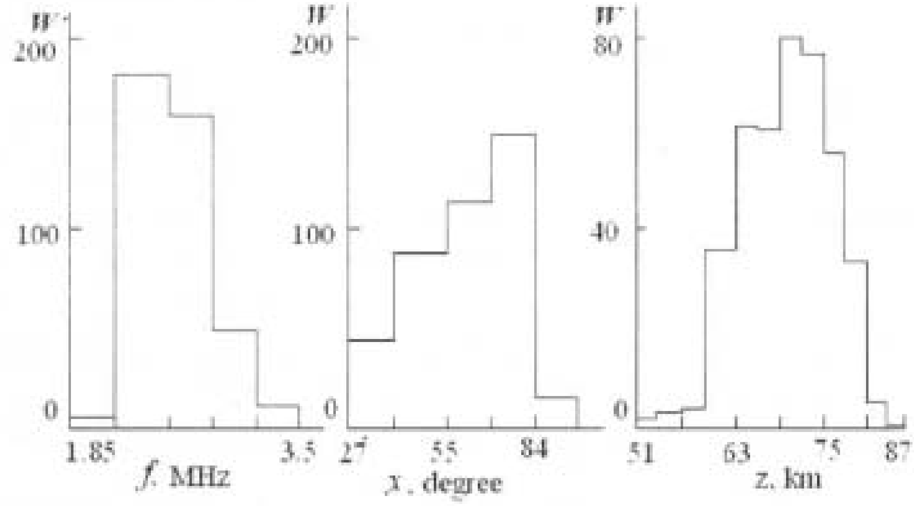

Fig.1. The histograms of the z-, f- and χ- distributions for the experimental data

Analysis of a large number (more than 10^4 experiments carried out under different helio-geophysical conditions) of the experimental $a(z)$ data has showed that under the fixed f and z values they are subject to essential fluctuations, mainly, conditioned by the errors in the $A_{O,X}$ measurements. The classical method of determining $\nu(z)$, considered above, does not take into account such fluctuations.

In the paper the classical method of determining $\nu(z)$ is developed for using the real experimental data having the measurement errors.

2. Main part

The analysis of the experimental data has showed that the errors in the measurements of $a(z)$ may be supposed to be distributed according to the normal law. In this case, as it is well known from the theory of statistical data processing, at each selected height z, a regular value of ν can be determined using a minimum of the dependence

$$D(\nu_j) = \frac{1}{n-1}\sum_{i=1}^{n}\left[a_i(f_i) - a_t(f_i,\nu_j)\right]^2 \qquad (3)$$

in the given interval of $\nu_{min} - \nu_{max}$.

Here $\nu_j = \nu_{min} + \Delta\nu$, $\Delta\nu = (\nu_{max} - \nu_{min})/k$, $j = 0, 1, 2, \ldots k$; k is a number of discretization intervals; $a_t(f_i, \nu_j)$ is the theoretical function equal to the right part in equation (1) and calculated for the given values of $f_i = \omega_i / 2\pi$ and ; $a_i(f_i)$ is the separate experimental value of $a(z)$ obtained at the frequency of f_i.

The minimum value, $D_{\min}$, of function (3) is determined with the help of two iterations. At the first step, an approximate value of $D_{\min}$ for $k = 10$ is determined. For the case of $D = D_{\min}$, the value of index $j = p$ will be marked .

In the second iteration, we make the value of $D_{\min}$ more exact, supposing $\nu_{\min} = (p-1)\cdot\Delta\nu\cdot\nu_{\min 0}$, $\nu_{\max} = (p+1)\cdot\Delta\nu+\nu_{\min 0}$, where $\nu_{\min 0}$ is the initial value of $\nu_{\min}$. The discretization of ν-values becomes 10 times smaller. In the first iteration, the limiting values of ν are supposed to be equal for z = 60-66 km– $\nu_{\min} = 5\cdot 10^{6}$ sec^{-1}, $\nu_{\max} = 3\cdot 10^{7}$ sec^{-1} and for z = 68-75 km $\nu_{\min} = 10^{6}$ sec^{-1}, $\nu_{\max} = 2\cdot 10$sec^{-1}. These values of ν are chosen proceeding from the model dependences of $\nu(z$ and from the analysis of the experimental data of $\nu(z$ known in publications. In this case, the impementation error, conditioned by the discretization, does not exceed 1%.

The main error of the calculation of ν-values is conditioned by the dispersion of the $a(z)$ values, caused by the errors in their measurements and by the limited sample of the n-value.

The confidence intervals (under the confidence probability of 90%) are determined using known formulas:

$$D_{\min,\max} = \frac{(n-1)D_{\min}}{\chi^2_{n-1,\alpha/2}}$$

$$D_{\min,\max} = \frac{(n-1)D_{\min}}{\chi^2_{n-1,1-\alpha/2}}$$

where $\chi^2_{n-1;\alpha/2}$, $\chi^2_{n-1;1-\alpha/2}$ is the percentiles or 100% - points of the χ^2-distribution with $(n-1)$ freedom degrees. The values of $D_{\min\max}$ allow to estimate the confidence intervals of the ν values determined.

In order to do it, using the formula (3), as a result of the iterations are defined those values of ν_j under which $D(\nu_j) = D_{\min\max}$. The minimum confidence limit of the ν-value is calculated by the iteration process beginning in the interval of the $(\nu_{\min}-\nu)$-values. The searching of the maximum confidence limit of the ν-value is carried out in the $(\nu-\nu_{\max})$-values interval.

This method was realized as a kind of program on the Paskal language for IBM PC. The preliminary calculations of the ν-values were made for z = 60-66 km. The total number of the $a(z)$-realizations used for calculating the $\nu(z)$-values was 170. The calculation result conducted for two seasons of year are given in the table (here ν_1 and ν_2 are averaged using the all the registrations of the values of the collision frequencies for the summer and winter conditions, respectively, $<\nu>$ is the average value of ν_1 and ν_2).

Table

The experimental average values of collision frequencies for summer and winter conditions

z, km	ν_1 (summer)	ν_2 (winter)	ν_1 / ν_2	$<\nu>$
60	0.403 10^8	0,274 10^8	1.47	0,339 10^8
63	0,250 10^8	0,154 10^8	1,62	0,202 10^8
66	0,174 10^8	0,164 10^8	1,07	0.169 10^8

Conclusion

The statistical analysis of the amplitudes of the partially reflected signals, measured under characteristic helio-geophysical conditions, has showed that the account of amplitude measurement errors must be taken of when determining a regular height distribution of the electron/neutral molecule collision frequency in the ionospheric D-region.

The classic method of determining the electron/neutral molecule collision frequencies by the partial reflection technique in the ionospheric D -region is developed in the case of using the real experimental data with errors in measurements.

For all the experiments there were also calculated the $\nu(z)$-values by using the classical method. They were compared with the calculation results by the method given in this paper. Using this method has allowed to make the $\nu(z)$-values more accurate on an average 20-50%. The given calculation results $\nu(z)$ are similar to those used in [11] for calculating the electric fields in the lower part of the ionospheric D-region. They confirm the presence of seasonal changes in $\nu(z)$ in the lower part of the ionospheric D-region (see, for instance, [3,4] as well).

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