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A SIMPLE CORRECTION TO ABSORPTION THEORY IN THE REGION OF QUASI-TRANSVERSE PROPAGATION OF RADIO WAVES THROUGH THE IONOSPHERE

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ABSTRACT

This paper presents a simple model correction to absorption theory in the quasi-transverse region of propagation of radio waves through the ionosphere using the Appleton-Hartree equation. It is shown that if the computations of the refractive index are done as derived here and applied in the expression for absorption coefficient for attenuation of HF radio waves traversing an absorption regime, then the total absorption can be determined to a reasonably high degree of accuracy and may be relevant at different strata of the ionosphere, for HF signal prediction purposes.

1. INTRODUCTION

The practical significance of absorption of radio waves in their passage through the ionosphere cannot be over emphasized. Extensive theoretical and experimental results are available in literature [3,5], but most of the work had been limited to the case of non- deviative absorption where the real part of refractive index is approximately equal to unity. All these attempts have been made in order to improve the understanding of the fundamental processes that govern the electron density in the ionosphere through the analysis of the absorption phenomenon.

Our concern in this paper is on model correction to the absorption theory in the region of quasi-transverse propagation of radio waves through the daytime D-region of the ionosphere. The correction has been carried out by considering in details, the imaginary component in the equation for refractive index with a view to attaining an expression for the absorption coefficient κ in terms of some variables. The results are compared with that obtained from the magneto-ionic theory, originally postulated by Appleton and Piggott [1].

2. THEORETICAL BACKGROUND

The Appleton-Hartree magneto-ionic theory (2) is the basis for explaining the various ionospheric phenomena. If the complex refractive index of the ionosphere is denoted by n, the theory shows that for a quasi-transverse propagation of radio waves in the ionosphere the absorption index κ is given by

$$\kappa = \frac{e^2}{2\varepsilon_o mc} \cdot \frac{1}{\mu} \cdot \frac{N\nu}{\omega^2 + \nu^2} \quad (1)$$

where e is the electron charge, m is the mass of the electron, c is the speed of light in vacuum, N is the electron density, ν is the effective electron collision frequency and ω is the angular frequency of the exploring wave.

At the magnetic equator, it is suggested that the Chapman D-layer is centered at a height where electron collision frequency at the height of maximum of ionization of the layer, $\nu_o \approx 12 \times 10^6 \text{ sec}^{-1}$. It is generally believed from experimental work that the D-region contributes about 80 – 90% of the absorption in the ionosphere [6].

Under quasi-transverse approximation, namely

$$4Y_L^2 << \left| \frac{Y_T^4}{(U-X)^2} \right| \quad (2)$$

wherever

Y_L = longitudinal component of the earth's magnetic field,

Y_T = transverse component of the earth's magnetic field,

$$U = 1 - j\frac{\nu(h)}{\omega}$$

$$X = \frac{N(h)e^2}{m\varepsilon_o\omega^2} = \left(\frac{\omega_p}{\omega}\right)^2$$

ε_o = permittivity of free space(8.85 X 10^{-12} Farads m^{-1})

ω_p = angular plasma frequency.

ν = collision frequency of the electron with air molecules, a function of the height, h the ordinary wave trace, may be shown to be

$$n^2 \approx 1 - \frac{X}{U} \quad (3)$$

After simplifying (3) we obtain

$$n^2 \approx 1 - \frac{\omega_p^2(\omega + j\nu)}{\omega(\omega^2 + \nu^2)} \quad (4)$$

When collision becomes imperative, the refractive index of ionosphere is usually complex.
We may write it as

$$n = \mu - j\chi \tag{5}$$

where μ is the real part, χ is the imaginary part and $j = \sqrt{-1}$. Squaring (5) we obtain

$$n^2 = \mu^2 - \chi^2 - 2j\mu\chi. \tag{6}$$

In order to separate the real and imaginary parts, we compare (4) and (6). The real component is

$$\mu^2 - \chi^2 = 1 - \frac{\omega_p^{\ 2}}{\omega^2 + \nu^2}. \tag{7}$$

The imaginary component is given by

$$2\mu\chi = \frac{\omega_p^{\ 2}\nu}{\omega(\omega^2 + \nu^2)},$$

from which we obtain

$$\mu = \frac{1}{2\chi}\left(\frac{\omega_p^{\ 2}\nu}{\omega(\omega^2 + \nu^2)}\right). \tag{8}$$

To express χ in term of plasma angular frequency, angular signal frequency and collision frequency of the electron with neutral molecules, we square (8) and adopt the result into (7), then multiply through by χ^2. The result is

$$\chi^4 + \left(1 - \frac{\omega_p^{\ 2}}{(\omega^2 + \nu^2)}\right)\chi^2 - \frac{1}{4}\left(\frac{\omega_p^{\ 2}\nu}{\omega(\omega^2 + \nu^2)}\right)^2 = 0. \tag{9}$$

Only the solution with the positive sign is valid. The solution is

$$\chi^2 = \frac{1}{2}\{\left(\frac{\omega_p^{\ 2}}{\omega^2+\nu^2}-1\right)+[\left(1-\frac{\omega_p^{\ 2}}{(\omega^2+\nu^2)^2}\right)^2+\left(\frac{\omega_p^{\ 2}\nu}{\omega(\omega^2+\nu^2)}\right)^2]^{\frac{1}{2}}\}. \quad (10)$$

Finally the expression for χ can be written as

$$\chi = [\frac{1}{2}\{\left(\frac{\omega_p^{\ 2}}{\omega^2+\nu^2}-1\right)+[\left(1-\frac{\omega_p^{\ 2}}{(\omega^2+\nu^2)^2}\right)^2+\left(\frac{\omega_p^{\ 2}\nu}{\omega(\omega^2+\nu^2)}\right)^2]^{\frac{1}{2}}\}]^{\frac{1}{2}}. \quad (11)$$

The corrected version of coefficient of absorption is given by

$$\kappa^* = \frac{e^2}{2m\varepsilon_o c}.\frac{1}{\chi}.\frac{N\nu}{\omega^2+\nu^2}. \quad (12)$$

3. DISCUSSION

Due to collisions between electrons and other particles such as molecules, the ionosphere absorbs energy from the passing electromagnetic wave. One difficulty that tends to arise in ground-based absorption studies is deciding between the deviative and non-deviative contributions, which may be imposed in quite different parts of the ionosphere [4]. The present derivation in this paper has resolved this problem.

Comparison of the two forms of index of absorption: theory (1) and the corrected model (12) show that the results obtained for corrected version is in agreement with experimental results. The result of absorpton index with frequency is reported in Fig. 1.Typical values of standard error in mean are also indicated in the figure (about 1%). The cause of this variation is attributed to unpredictable variability in ionospheric characteristics [7]. One of the consequences of absorption is that it limits the efficiency of communications radar and navigation systems, which employ HF radio waves.

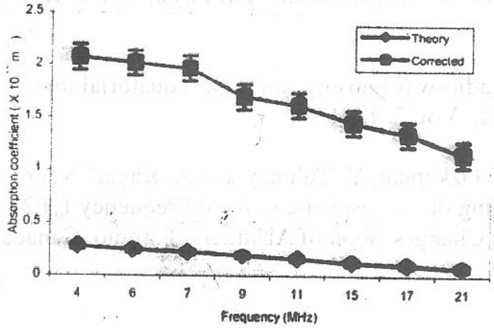

Fig. 1 Comparison between theory and corrected values.

4. SUMMARY

In this work we have presented an incredible model of the magneto-ionic theory for absorption. It is shown that absorption index varies significantly with frequency. However, it is established that the proposed version can be used for prediction purposes especially in HF communications. The result may be applicable at different strata of the ionosphere.

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