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The Analysis of Variation of Electromagnetic Wave Propagation in D- and F-Layers of Ionosphere

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ABSTRACT

The analysis of variation of electromagnetic wave propagation in the D- and F-layers of the ionosphere has been carried out. It studies both time and spatial variation of propagation of electromagnetic radiation in the D and F region of ionosphere. The most important region in the ionosphere for long distance, high frequency (HF) radio communications is the F region, which is the highest region of the ionosphere, at altitudes greater than 160km (100 miles); it has the greatest concentration of free electrons. The charged particles in the F region consist primarily of neutral atoms split into electrons and charged atoms. The wave equation of electromagnetic waves propagating in the layers of ionosphere was solved by method of separation of variables to get solution. The following parameters were determined; propagation constant, phase constant, and attenuation constant of propagation of Electromagnetic wave (EMW) and the variations of plasma frequency and the refractive index in regions of ionosphere during propagation of EMW. Electromagnetic waves are not completely affected by the ionosphere, but they are able to propagate through it with minimal distortion. This is because electromagnetic waves have a wide range of frequencies which interact with the ionosphere in different ways and shown that the refractive index of a plasma and hence the ionosphere, is frequency-dependent.

Keywords**:** Electromagnetic wave, Propagation, Ionosphere, D- and F- layers, plasma frequency, EMW frequency, Refractive index, electron and charged atoms

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1. INTRODUCTION

Electromagnetic waves are radiations that are created as result of vibrations between electric and magnetic field. Electromagnetic wave has the following properties, which ranges from the ability to travel in vacuum at the speed of light, oscillate periodically and inherit the property of a transverse wave, refraction, interference and diffraction. Electromagnetic waves propagation is important for the purpose of transmission of energy but at the same time, over exposure to electromagnetic waves can also be harmful to nature. Generally, there are three modes of propagation of EM waves, which are as follows; ground waves, sky waves and space waves by (Ginzburg, 1964). Ground waves also known as surface waves that have a frequency range between 3 MHz to 30 MHz, they generally work in low or medium frequency ranges over local range communication, and are also used from land to the ionosphere for communication. Space wave work in a frequency range from 30 MHz to 300 MHz, it iscalled tropospheric propagation. The space waves travel through the atmosphere from transmitter antenna to receiver antenna directly or after being reflected from the ground. Sky Wave has the ability to pass through the Earth's atmosphere. The ionosphere reflects the majority of these rays. Its frequency ranges from 2 MHz to 30 MHz, the highest frequency reflected by a sky wave by the ionosphere is known as the critical frequency (Hojo & Mase, 2004). The electromagnetic radiation formed as a result of changes in electric fields that create changes in magnetic field which consist of range of frequencies and their corresponding wavelength. These electromagnetic radiations include Radio wave, microwaves, visible light, infrared, ultraviolet wave, X-rays and gamma rays. Depending on their wavelength, frequency and penetrating power, they propagate in different media such as dielectric medium, good conducting media, and plasma medium and in Earth's atmosphere, especially in ionospheric layers.

Atmospheres are gases that envelop a planet, and are held in place by gravity of the planetary body (Liddell *et al*, 2015). They are seven layers or regions of atmosphere which are different from each other, in terms of temperature, pressure, humidity level & the natural events that occur in them and they are named as follows; troposphere, stratosphere, ozonosphere, mesosphere, thermosphere, exosphere and ionosphere, covering a distance of about 3000km from earth towards sky. Each layer plays an important role ranging from the formation of rain clouds, prevention of harmful radiations reaching on the Earth, reflecting radio waves (Geeta & Yadav, 2014). Ionosphere is the uppermost region of earth's atmosphere, which extends from about 50 km altitude to about 600 km, where the air, are sufficiently ionized by both electromagnetic radiations and particles coming from the Sun. It is a continually changing area of the atmosphere, mainly affected by certain natural phenomena's like solar flare, sunspot, magnetic storms and sudden ionospheric disturbances. Due to this ionization, the Earth's upper atmosphere (ionosphere) gets consist of free electrons and ions. As a result of this, different layers are formed, which are called as D, E and F layers, each layer has a different characteristic and profile (Sean, 2006). Ionization exists over the whole of the ionosphere, its level varying with altitude. The concept of the distinct D, E, and F layers is a convenient way of picturing the structure of the ionosphere, which is not exactly correct. There is also a C region below the others, but the level of ionization is so low that it does not have any effect on radio signals and radio communications, and it is rarely mentioned by (Carl, 2000). The ionosphere significantly affects radio waves below 40 MHz, primarily because the ionosphere effectively reflects radio waves in this frequency range. For frequencies beyond 40 MHz, the wave tend to penetrate through the atmosphere versus being reflected (Sean, 2006).

Peter, (2016) reported that Heinrich Hertz was the first researcher who had successfully sent and receives radio waves. James Clerk Maxwell had mathematically predicted their existence in 1864. Between 1885 and 1889, he produced the electromagnetic waves in the laboratory and measured their wavelength and velocity.

Sean, (2006) worked on the ionospheric propagation highlighting the major usefulness of the ionosphere, that the reflections enable wave propagation over a much larger distance than would be possible with line-of-sight or even atmospheric refraction effects. This was further enhanced by multiple reflections between the ionosphere and the ground, leading to multiple skips. This form of propagation allows shortwave and amateur radio signals to propagate worldwide. Since the D layer disappears at night, the best time for long-range communications is at night, since the skip distance is larger as the E, and F regions are at higher altitudes in his evaluation he developed equation which explains why signals can propagate so much farther at night when the D layer disappears, since it has the lowest virtual height.

Geeta & Yadav, (2014) reported that radio waves interact with ionosphere, how their refraction takes place, and what and the conditions necessary for radio communication. It was observed that radio wave is an electromagnetic wave and it reaches in the ionosphere then, refraction, reflection or absorption takes place depending on the properties of the radiation. Refraction is caused due to the abrupt changes in the velocity of upper part of radio wave as it enters in a new medium. The refraction of radio wave depends upon the following factors. (1)

The ionization density of Ionospheric layer. (2) The frequency of radio wave. (3) The angle at which the wave enters the Ionospheric layer.

Peter & Ratcliffe, (2016) reported how the radio waves propagate in the ionospheric plasma, they exhibit different behaviors related to their wave frequency, oscillation frequency of the electrons in the plasma medium and the refractive index of the medium. Depending on these behaviors, the wave is refracted, reflected or attenuated by absorption from medium. Radio-wave damping is due to movements in the ionosphere of electrons and ions are caused by collisions with other particles. Due to the increase of collisions, absorption increases and field strength of the radio wave decreases. Because of this, amplitude of the radio wave propagated in the ionosphere will decrease because of the absorption. Thus, the real part of the refractive index effects to the phase velocity and the imaginary part of the refractive index is associated with spatial attenuation of the wave. In accordance with the above information, in order to obtain the relation of the attenuation, amplitude of the wave, such as the electric field strength, is need to be expressed depending on the refractive index of the medium

Liddell et al (2015) developed a novel method of measuring the time taken by the signal group to reach the ionosphere and then to come down to the receiver. A pulse of very short duration is transmitted and received at a moderate distance from the transmitter. Both the ground wave and the reflected wave are received on the same calibrated time axis of the cathode ray oscillograph. The sharp and regular echo received on the oscillograph screen points towards the existence of a reflecting layer.

Schunk, & Nagy, (2000) reported that the time of day causes some very significant changes in the state of the ionosphere as the level of ionization falls at night. However,many other factorshave an effect on the ionosphere as well. The main one is the Sun itself, but other factors include the season, and the position on the globe.

Carl, (2000) reported that typically the F1 layer is found at around an altitude of 300 km with the F2 layer above it at around 400 km. The combined F layer may then be centered, around 250 km to 300 km. The altitude of the all the layers in the ionosphere layers varies considerably and the F layer varies the most. As a result, the figures given should only be taken as a rough guide. Being the highest of the ionospheric regions it is greatly affected by the state of the Sun as well as other factors including the time of day, the year and so forth. The F layer acts as a "reflector" of signals in the HF portion of the radio spectrum enabling worldwide radio communications to be established. It is the main region associated with HF signal propagation. Breamer, (2004) reported that due to the variations of the ionosphere through time and day, a long-term and short-term trend can provide information on the variation of the ionosphere. He also investigated the parameter of the ionosphere from the E layer and F layer and his study showed that the trend of the E layer is in qualitative agreement with the increasing greenhouse effect from the lowering of virtual height of the E layer.

Chaman, (1997) explained that in the equatorial region, the electromagnetic wave radiation in the UV EUV range does not appear for maximum F2 layer ion density because of the fountain anomaly effect. The ionospheric research in equatorial region is different due to solar wind contribution to F2 layer ionization.

Srijibendu (2011) reported that the X-ray produced due to the solar flare increases the ionization in the lower region of ionosphere (D layer). This change in the electron profile of ionosphere is known as Sudden Ionospheric Disturbances (SID).

Geeta (2014) reported that the D region attenuates signals because the radio signals cause the free electrons in the region to vibrate. As they vibrate the electrons collide with molecules, and at each collision there is a small loss of energy. With countless millions of electrons vibrating, the amount of energy loss becomes noticeable and manifests itself as a reduction in the overall signal level. The amount of signal loss is dependent upon a number of factors. Carl, (2000) reported in just the same way that the amount of heat places on the Earth receives varies with the seasons, so does the amount of radiation received by the ionosphere. This results from the fact that in summer the radiation received spreads over a smaller area as the Earth's surface is closer to being at right angles to the direction of the radiation. In winter, the Earth's surface is at a greater angle and the radiation has to spread over a larger area. As a result the ionosphere receives less radiation in winter than summer. The D and E regions respond as expected with lower levels of ionization in winter than summer, and the F1 region also follows a similar pattern.

Schunk, *et al*. (2004) reported that the levels of ionization are also affected by the position on the globe. There are naturally variations arising from the latitude where Polar Regions that receive less radiation and the equatorial regions enjoy much higher levels of radiation. Broadly, this results in higher levels of ionization for the D, E and F1 regions in equatorial areas than towards the poles. The F2 region has a number of other factors that affect its level of ionization including the Earth's magnetic field and it also receives ionization from other sources. As a result of these it is found that the levels of ionization are higher around Asia and Australia than they are over the western hemisphere, including Africa, Europe, and North America.

Rishbeth, & Mendillo, (2001) reported that F2 region has other influencing factors and it responds in a different way. For the F2 region, the heating effect of the Sun plays a crucial role in the way it responds. The temperature during the winter is much less than in the summer as a result of the heat from the Sun is spread over a larger area because the sun is lower in the sky. In summer the gas temperature rises in the F2 region so the activity in the air rises and a greater number of molecules rise higher up into the atmosphere. In winter as the temperature falls, so the heavier molecules fall, leaving the lighter atoms to rise to the top. This means that in winter there are higher proportions of atoms at the higher altitude of the F2 region.

Atoms are easier to ionize than gas molecules, and so the number of suitable targets for the radiation to ionize also rises. As a result, the levels of daytime ionization are actually higher in winter than they are in the summer. The overall effect is that the peak daytime levels of ionization rise higher in winter than summer, but they fall away to a lower level as the Sun's radiation is present for a smaller proportion of the time. Tsai *et al*, (2000) reported that the level of ionization is also very important. The higher the level of ionization, the greater the number of electrons, that vibrate and collide with molecules.

Kunitsyn, *et al*, (2003) researched the third main factor frequency of the signal. As the frequency increases, the wavelength of the vibration shortens, and the number of collisions between the free electrons and gas molecules decreases. As a result, signals lower in the radio frequency spectrum are attenuated far more than those, which are higher in frequency. Even so high frequency signals still suffer some reduction in signal strength. In practical terms, it is found that the level of attenuation is sufficient to prevent signals in the MF portion of the spectrum from reaching the higher layers. However, at night when the ionization in the D region falls away, they are able to reach the higher layers and signals from further away may be heard. This is evident on the medium wave band and higher frequencies where the signals are absorbed by the D region. Signals at higher frequencies that are "reflected" by higher regions in the ionosphere will also be attenuated to some extent, although this will be dependent upon the frequency. It is worth noting that for each reflection the signal will need to pass-through the D region twice, being attenuated each time. Therefore, signals that are reflected multiple times can suffer significant degrees of attenuation.

Mitchell, *et al*, (1997) showed that one factor is the number of gas molecules that are present. The greater the number of gas molecules, the higher the number of collisions and hence the higher the attenuation. At the altitude where the D region exists, there is still a relatively high level of gas molecules and hence there is sufficiently large number of ion-molecule collisions to absorb a large amount of the energy under many circumstances.

Reigber *et al*, (2000) reported the results of the ionosphere monitoring obtained by means of GPS measurements on board the current geo research satellite mission Challenging Mini-satellite Payload (CHAMP), where the German CHAMP satellite was successfully launched on 15 July 2000 into a near polar orbit (inclination 87°, altitude 450 km). The satellite is equipped with a dual frequency ''Black Jack'' GPS receiver which enables not only the analysis of the 0.1 Hz sampled navigation data but also the use of GPS radio occultation measurements in the limb sounding mode.

Danielle et al. (2022) reported that electromagnetic wave is located in one cell, whose initial center frequency is 3Hz and whose duration time is 1s. The reason for choosing 3 Hz is that the frequency of a natural earthquake ranges from 1.25 Hz to 10 Hz. As mentioned above, it takes an EM wave 0.155s to circle the Earth in the model. Therefore, it was difficult to discern the periodic propagation regulation of the EM wave from the simulation results due to a natural earthquake's long duration.

Mushtak & Williams, (2002) showed through illustration the variation of the electric field at different latitudes with time after fixing heights and the longitude position, where (a) corresponds to a height of 20 km and a longitude of 155°E; and (b) corresponds to a height of 60 km and a longitude of 155°E. The electromagnetic wave first appears near latitude of 21°N at 0.01s, and then arrives in the north and south poles at 0.03s and 0.05s, respectively. After reaching the north and south poles, the electromagnetic wave crosses the poles and appears at a longitude of 25°W. Meanwhile, waves from a longitude of 25°W appear at 0.05s and 0.13s in the north and south poles and converge near latitude of 21°N at 0.18s. After comparatively analyzing the subfigures, we found that the diffusion and propagation processes of the electric field are roughly similar at different heights, while the amplitude at 20 km and 60 km is approximately equal, which is coherent with the conclusion that the electric field does not attenuate below a height of 60 km.

Gao, & Hu, (2010) reported, using the Pride Equations, derived the Green function of the electric and magnetic fields in order to calculate the wave fields induced by the double couple source in infinite space. And he also obtained the analytical expressions of the electric field and magnetic field in the frequency domain.

Sisir, &Annapurna, (2006) reported that the radio signal is to be transmitted from one station to the other side of the globe; considerably large distance will have to be spanned by the signal. This world-spanning propagation requires several reflections in between the earth's surface and the ionosphere. When a radio signal returns to Earth from the ionosphere, the Earth's surface acts as a reflector and returns the signal back to the ionosphere, where it is reflected back to Earth yet again. In this way signals can travel around the globe.

Hargreaves (1969) researched when a radio wave enters the D layer, it loses some of its energy to the free electrons. If these free electrons do not collide with gas molecules of low energy, then most of the energy lost by radio wave is reconverted into electromagnetic energy and the wave continues to propagate with little change in its intensity. However, if these high-energy free electrons collide with other particles (molecules, ions or electrons) then most of the energy is lost, resulting in absorption of energy from the wave and this is manifested as a loss in the strength of the signal.

Attila K., (2015) reported the effect of the ionosphere on electromagnetic waves propagation and described it partially by simple dispersion. To adequately describe the complete behavior of radio waves in the ionosphere, it is important to realize that the "ionosphere is a partially ionized, spherically stratified plasma with a wide spectrum of non-uniformly spaced irregularities, upon which is imposed a non-uniform magnetic field".

Before the discovery of ionosphere, the electronic communication was not possible at a distance greater than 100 km due to the curvature of Earth; but after its discovery, the ionospheric wave propagation made possible the electronic communication at even more than 3000 km via reflection of radio waves through ionosphere. The ionosphere is electrically neutral, ranging from 50 to 1000 km in altitude and outer limit can exceed to 3000 km depending upon the geo-magnetic activity. High frequency radiations and charged particles from the Sun are the major source of ionization in ionosphere. The disappearance of the lower regions (below or near 100 km) in night is due to the fast recombination rate of molecular ions: nitric oxide (NO^+), oxygen (O_2) and nitrogen (N_2), while atomic oxygen (O) is dominant at higher altitude (120 km or above) with longer life time making the presence of F2 layer at night (Muhammad, 2018).

Sabirin, (2011) reported his observations of F-Region Critical Frequency Variation over Batu Pahat, Malaysia, during Low Solar Activity. In his work, his analyses dependence of the fcduring the solar minimum of Solar Cycle 23. Finally, the median fc value is used to develop a model using regression and polynomial approaches because it is more accurate than using average values.

Adeniyi & Radicella, (2002)showed the parameters used to identify the variability of the ionospheric region in Malaysia. In order to contribute to the development of a model of ionospheric variability, the behavior of the ionospheric critical frequency, foF2 was analyzed on diurnal variation basis at different solar activity conditionsand during earthquake occurrence. The observation data was obtained from the Ionogram that has been stationed in WARAS Centre, UTHM. Overall, the solaractivity can affects the value of critical frequency at the daytime more than during nighttime. Other than that, the relationship between the Earth's movement and the variation of the critical frequency in the ionosonde data can be determined. Senguttuvan & Sanavullah, (2009) reported that you can use partial reflection-drift experiment, to determine the horizontal-drift velocity of ionized irregularities in the ionosphere. In their findings, if a point radio source is used, the stratified irregularities produce a diffraction pattern over the ground. By sensing this diffraction pattern with a minimum of three antennas the horizontal-drift velocity can be computed. To determine the horizontal-drift velocity of the ionosphere it is necessary to illuminate the ionosphere with a single radio-wave point source. When this is done, a diffraction pattern is formed from the ionosphere irregularities in the D-region. They also studied the E and F region of ionosphere, using the ionospheric data from archives of ionospheric station. The ionospheric data were used for training neural networks (NNs) topredict the parameters required to produce the final profile. The NNs have been trained to predict the individual ionospheric characteristics and coefficients that were required to describe the profile.

Nguyen, *et al*, (2015) reported that a stochastic finite-difference time-domain (S-FDTD) algorithm is presented for electromagnetic-wave propagation in anisotropic magnetized plasma. This new algorithm efficiently calculates in a single simulation not only the mean electromagnetic field values, but also their variance as caused by the variability or uncertainty of the electron and ion content of the ionosphere. The structure of the ionosphere is often too variable and uncertain for electromagnetic-wave propagation problems to be solved using a deterministic formulation, particularly during space weather events. For these cases, the S-FDTD ionospheric plasma algorithm will serve as an important tool. For example, it could be used to determine the confidence level at which a communications or remote sensing or radar system will operate as expected under abnormal ionospheric conditions

Zernov & Gherm, (2015) explained a review of the analytical techniques for treating various effects of the high-frequency wave field propagation in the inhomogeneous ionosphere with local variations of the electron density, and the results of their numerical modelling based on the approaches, developed by them. The background ionosphere is considered to be inhomogeneous and isotropic, and the effects of the Earth's magnetic field are solely present by the anisotropic shape of the local variations of the electron density of the ionosphere. Some of the effects of local inhomogeneities are considered in the deterministic statement, others require stochastic treatment. The problems of propagation in the HF ionospheric reflection channel and higher frequency propagation in the transionospheric stochastic channel are discussed. The consideration is confined by the case of forward scattering approximation.

Chen, (2018) researched based on the two-fluid magneto-hydrodynamics (MHD) theory, the advanced finite-difference time-domain method have been conducted to successfully simulate the variability in the electric field, magnetic field and plasma number density during the parametric decay instability (PDI) process driven by electromagnetic (EM) waves. As a result, the mode-conversion process of Langmuir waves excited by ordinary mode EM waves was visualized at the turning point at the millisecond timescale, which is an important characteristic of the PDI process. It was found that the ionospheric electron number density rapidly oscillates with the high-frequency (HF) Langmuir waves. Ionospheric ion density depletion was also observed at the cutoff altitude and two ion density peaks were simultaneously observed on both sides of the EM wave reflection region. These results are of benefit to understand the nonlinear interaction between EM waves and the ionosphere.

Xie *et al*, (2021) explained that releasing easily ionized metal vapor, such as barium, strontium, lithium, cesium, or samarium, can form an enhanced electron density region, which can affect radio wave propagation significantly. The high-frequency (HF) radio wave propagation effects caused by chemical releases in the ionosphere have been investigated. Ray tracing techniques have been used to successfully model HF radio wave propagation path. The results show that the new propagation paths of HF radio wave are established by the artificial plasma cloud, and the lower the frequency is, the more complex the propagation path becomes. Up to four new propagation paths are created for 10MHz wave propagating 500km. For 15MHz and 20M Hz wave propagating 500 km, there is a new propagation path, which is inexistent without artificial plasma cloud, in other words a new radio link is created.

Tereshchenko *et al*, (2019) showed that based on the experimental studies on measuring the controlled source signals in the near zone under different geophysical conditions, it is established that the amplitude of the field experiences variations in the lower part of the ELF band and at lower frequencies. At the same time, variations in the VLF range are absent. For identifying the factors responsible for this peculiarity in the behavior of the field, excitation of the ELF and lower frequency electromagnetic field in the Earth-ionosphere waveguide with different conductivities of the Earth and the ionosphere is considered. The theoretical calculations are proposed showing that at low conductivity of the Earth, the effect of the ionosphere in the near zone can be significant.

In this paper, we studied both time and spatial variation of propagation of electromagnetic radiation in the D and F layers of ionosphere; Propagation of electromagnetic waves in the atmosphere is influenced by the spatial distribution of the refractive index of ionosphere. The electrons oscillate in phase, but there is no polarization charge. Hence, the plasma frequency is the frequency at which electrons oscillate about their equilibrium positions in the absence of a magnetic field. This similarly sets the limit for propagation through Earth's ionosphere at approximately 10MHz. the following parameters were determined; propagation constant, phase constant, and attenuation constant of propagation of Electromagnetic wave (EMW) in ionospheric layers, variation of plasma frequency and refractive index in ionospheric layers during propagation of EMW.

2. MATERIAL AND METHOD

The sources of data for this study was gotten from Maxwell Equations, downloaded journal papers, wave equations,

$$\nabla^2 E_{(r,t)} = \frac{1}{c^2}\frac{\partial^2 E_{(r)}}{\partial t^2} \qquad (1)$$

2. 1. Method

The Wave equation, equation (1) wassolved by method of separation of variables to get solution to the wave equation of electromagnetic waves propagating in the layers of ionosphere.

The solution to wave equation (eqn 1) of propagation electromagnetic wave (EMW) in ionosphere is of this form;

$$E_y(z) = E_o e^{-\alpha z}\cos(\omega t \pm \beta z) \tag{2}$$

2. 2. Theoretical Procedure

In solving equation 1 by using method of separation of variables; let assume that the solution in equation (2) of the form is

$$E(r,t) = Z(z)T(t) \tag{3}$$

where Z(z) represents the spatial part and T(t) represent the temporal part then we have;

$$\left(\frac{1}{Z(z)}\right)\frac{\partial^2 Z(z)}{\partial Z^2} = \left(\frac{1}{(C^2T(t))}\right)\frac{\partial^2 T(t)}{\partial T^2} \tag{4}$$

Since the left hand side depends on Z only and the right hand side depends on T only, we apply a constant value, which is $-k^2$.

$$\left(\frac{1}{Z(z)}\right)\frac{\partial^2 Z(z)}{\partial Z^2} = -k^2 \tag{5a}$$

$$\left(\frac{1}{(C^2T(t))}\right)\frac{\partial^2 T(t)}{\partial T^2} = -k^2 \tag{5b}$$

$$\frac{1}{Z(z)} X \frac{\partial^2 Z_{(z)}}{\partial Z^2} = -k^2 \tag{5c}$$

Rearrange the equation

$$\frac{\partial^2 Z_{(z)}}{\partial Z^2} + k^2 Z(z) = 0 \tag{6}$$

The solution to this equation (6), can be written as;

$$Z(z) = A_1 e^{kz} + A_2 e^{-kz} \tag{7}$$

Equation 5b is re-arranged to equation;

$$\frac{\partial^2 T(t)}{\partial T^2} + k^2 C^2 T(t) = 0 \tag{8}$$

The solution to equation 8 is;

$$\mathrm{T(t)} = \beta_1 \cos(\omega t) + \beta_2 sin(\omega t) \tag{9}$$

where $\omega = kc$

Combining the spatial and temporal parts, then, $E_o = A, B, \& \, b = x = \sqrt{k^2c^2 - \alpha^2}$.

Then the general solution to the wave equation propagating in D, F, and E layers of ionosphere is given by;

$$E(r,t) = E_o e^{-\alpha z} \cos(\omega t \pm \beta z) \tag{10}$$

Similarly,

$$H(r,t) = H_o e^{-\alpha z} \cos(\omega t \pm \beta z) \tag{11}$$

where, α is the attenuation constant which controls how quickly the wave decays, and β is phase constant, which controls how quickly the wave oscillates in space, as it is decaying. Time-harmonic electromagnetic waves will decay when they pass through a material with non-zero conductivity, E_o is amplitude of electric field, (r,t) electric field potential, ωelectromagnetic wave frequency.

The variation of plasma frequency, refractive index, in ionosphere layers was shown graphically for statistical interpretation using relation;

$$\eta = \sqrt{1 - \frac{\omega_p^2}{\omega^2}}. \qquad (12).$$

where η is refractive index, ω_p is plasma frequency, ω is electromagnetic waves frequency.

3. RESULTS AND DISCUSSION

3. 1. Variation of Plasma and Electromagnetic Wave Frequencies

The variation of plasma frequency, and electromagnetic wave frequency were explained using equation (12) in chapter 3; the generated values, of the variations are shown in Table 1 below. The graph of electromagnetic frequency against refractive index in ionospheric layer is shown in Fig. 1, while the graph of electromagnetic wave frequency & plasma frequency against refractive index in ionospheric layer is shown in Fig. 2 below.

Table 1. Variation of plasma frequency, and electromagnetic wave frequency.

S/N	η	η^2	ω	ω^2	ω_p	ω_p^2
1	1.00	1.00	300	90000	0	0
2	1.10	1.20	250	62500	25	625
3	1.20	1.40	200	40000	40	1600
4	1.30	1.70	150	22500	45	2025
5	1.40	2.00	100	10000	40	1600
6	1.50	2.30	50	2500	25	625
7	1.60	2.60	30	900	18	324

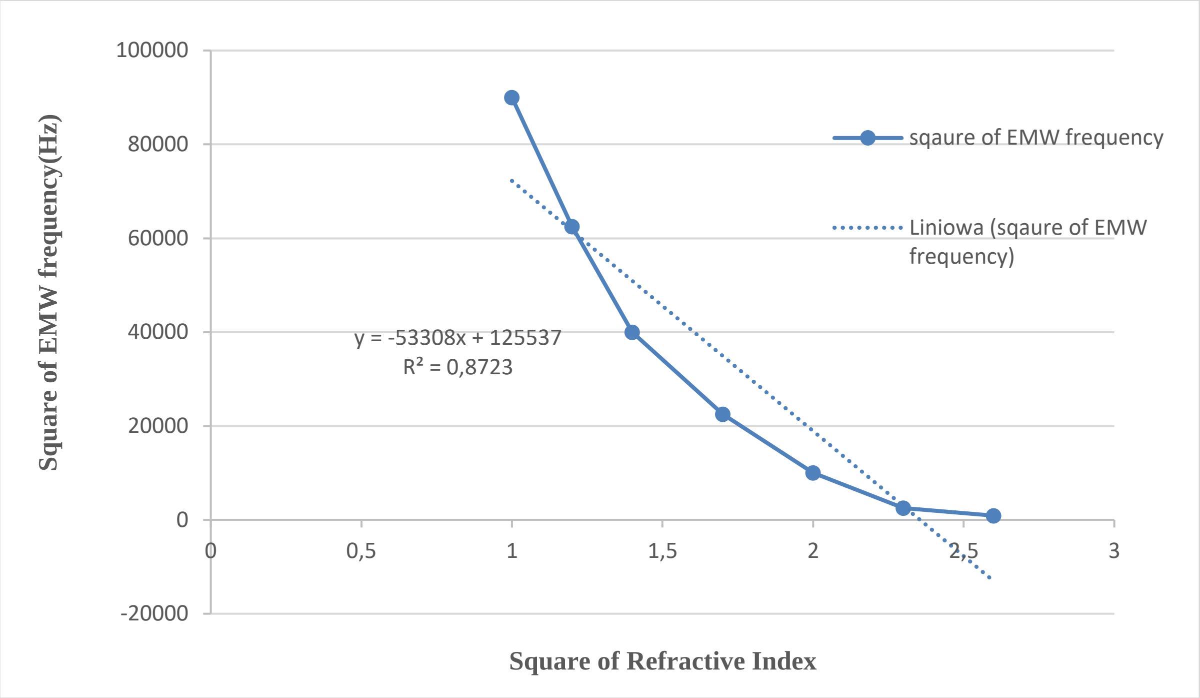

Fig. 1. The graph of electromagnetic frequency against refractive index of Ionospheric layer.

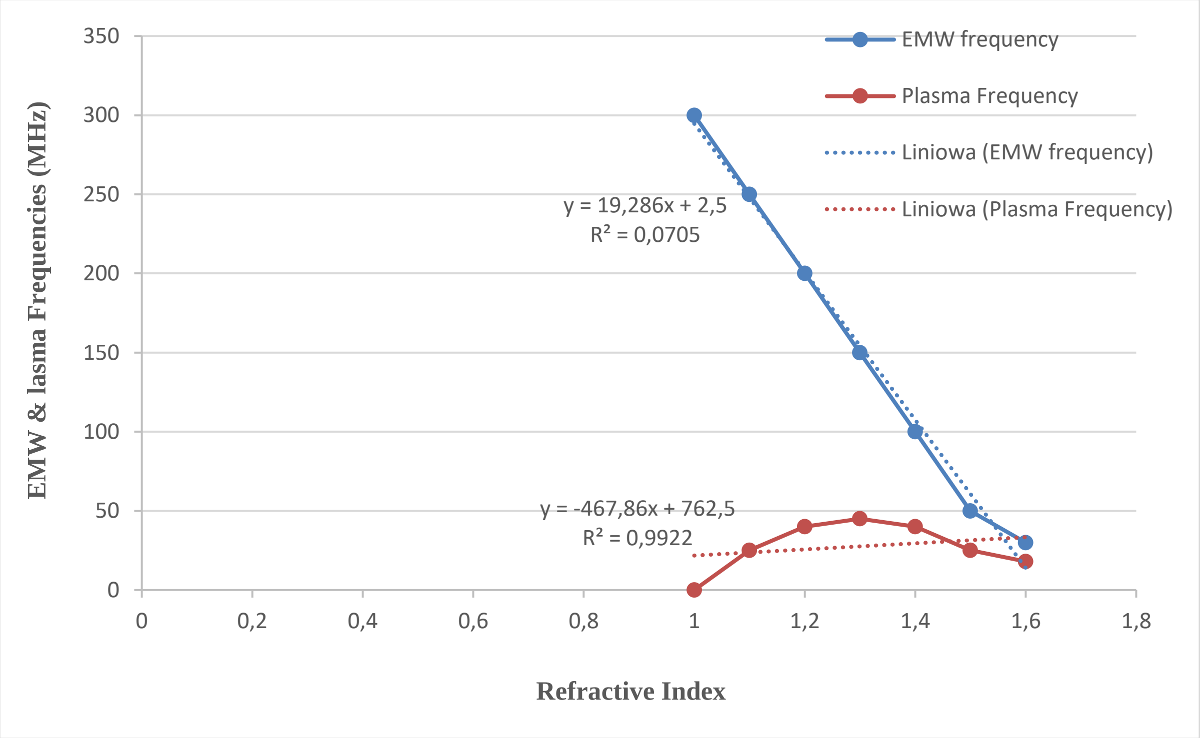

Fig. 2. The graph of electromagnetic wave frequency & plasma frequency against refractive index of Ionospheric layer.

In the Table 1 above, at $\eta = 1$, EMW frequency is far greater than plasma frequency ($i, e\ \omega \gg \omega_p$, that leads $\frac{c}{v} \approx 1$ and $c = v$), which implies that electromagnetic wave is unaffected by the ionosphere, which agrees to (Sean, 2006). Therefore, radio signals follow the techniques for satellite communication by making electromagnetic frequency greater than plasma frequency. At $\eta < 1$,it implies that the wave is propagating faster than the speed of light, which is not possible. At $\eta > 1$, the refractive indices of a medium is inversely proportional to speed of light in the medium.

The ratio of the refractive indices of two different media is inversely proportional to the ratio of the light's propagation speed in each one. As the refractive indices, approaches 1 for higher frequency suggest that radio waves will penetrate into ionosphere for a long distance and return to earth. Hence, higher frequency is more appropriate for satellite-based communication.

In Fig. 1 above shows the graph of electromagnetic wave frequency against refractive index in ionospheric layer. As the frequency of the electromagnetic waves decreases, the refractive index in the ionospheric layer also increases. This means that the speed of light in the ionospheric layer decreases as the frequency increases. This phenomenon is known as dispersion, which agrees to (Attila, 2015).

The graph typically showed a positive correlation between the frequency and the refractive index. This relationship is due to the interaction between the electromagnetic waves and the charged particles in the ionospheric layer. The higher the frequency, the more interaction occurs, leading to a higher refractive index.

In Fig. 2 above shows the graph of the relationship between refractive index, electromagnetic waves, and plasma is quite interesting. Refractive index is a property of a material that describes how light propagates through it. When an electromagnetic wave, such as light, passes through plasma, its speed and direction, can be affected due to the interaction with the charged particles in the plasma. The refractive index of plasma is typically greater than one, meaning that the speed of light in plasma is slower than in a vacuum. The plasma frequency depends on the density of charged particles in the plasma and their masses.

4. CONCLUSIONS

Electromagnetic waves are not completely unaffected by the ionosphere, but they are able to propagate through it with minimal distortion. This is because electromagnetic waves have a wide range of frequencies, and different frequencies interact with the ionosphere in different ways. At lower frequencies, such as AM radio waves, the ionosphere can reflect and refract the waves, causing them to bounce back to Earth's atmosphere or be bent in different directions. This is why AM radio signals can travel long distances, especially at night when the ionosphere is more active.

The variations in the D and F layers of the ionosphere can have a significant impact on electromagnetic wave propagation. These layers are responsible for reflecting and refracting radio waves, which affects their propagation characteristics. Changes in the electron density and ionization levels in these layers can cause variations in the refractive index of the ionosphere, leading to changes in the path and speed of electromagnetic waves. Additionally, the presence of irregularities or disturbances in these layers can cause scattering and absorption of electromagnetic waves, further affecting their propagation.

Recommendation

I recommend that the study of influence of ionospheric irregularities on wave propagation and how these irregularities affect the propagation of electromagnetic waves in the D and F layers as well as their impact on communication systems.

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Certification

This is to certify that this research project titled: The Analysis of Variation of Electromagnetic Wave Propagation in the D- and F-Layers of Ionosphere, has been submitted to the Department of Physics, University of Calabar, PMB 1115, Calabar Cross River State, Nigeria, an authentic record of work carried out by Eronna Benjamin Ojichukwu under my supervision and guidance.

References

[1] Adeniyi, J. O. and Radicella, S. M. (2002). Variability in foF2at anequatorial station and the influence of magnetic activity. *Proceeding of the IRI task force activity* 2002. 27-37.

[2] Bremer, J. (2004). Investigations of long-term trends in the ionosphere with world-wide ionosonde observations. *Advance in Radio Science*, 2. 253-258

[3] Carl F. G. (2000). Ionospheric layers. European Organization for Nuclear Research

[4] Chaman L., (1997). Contribution to F2 layer ionization due to solar wind. *Journal of Atmospheric and Solar-Terrestrial Physics*, Vol. 59, N0. 17, pp. 2203-2211

[5] Chen J. (2018). Simulation Study of the Interaction Between Electromagnetic Waves and Ionosphere During Parametric Decay Instability (PDI) Process, *2018 12th International Symposium on Antennas, Propagation and EM Theory (ISAPE), Hangzhou, China*, 2018, pp. 1-4,

[6] Danielle J. Edwards, Manuel A. Cervera, Andrew D. MacKinnon, High Frequency Land Backscatter Coefficients Over Northern Australia and the Effects of Various Surface Properties, *IEEE Transactions on Antennas and Propagation*, 10.1109/TAP.2022.3161534, 70, 7, (5819-5830), (2022)

[7] Gao, Y.X & Hu, H.S. (2010) Seismoelectromagnetic waves radiated by a double couple source in a saturated porous medium. *Geophys. J. Int*, 181, 873–896

[8] Geeta R. & Yadav M. K. (2014). The Ionosphere and Radio Propagation. *International Journal of Electronics and Communication Engineering & Technology* Volume 5, pp. 09-16.

[9] Ginzburg, V.L. (1964). The Propagation of Electromagnetic Waves in Plasma, Pergamon Press, Oxford.

[10] Hargreaves J.K. Auroral absorption of HF radio waves in the ionosphere: A review of results from the first decade of riometry. *Proceedings of the IEEE*, vol. 57, no. 8, pp. 1348-1373, 1969.

[11] Hojo, H. & Mase A. (2004). Dispersion relation of electromagnetic waves in one-dimensional plasma phonic crystals, *J. Plasma Fusion Res.* Vol. 80: 89-90.

[12] Komjathy, A. (2014). Ionospheric Effects on the Propagation of Electromagnetic Waves. In: Njoku, E.G. (eds) Encyclopedia of Remote Sensing. Encyclopedia of Earth Sciences Series. Springer, New York, NY. https://doi.org/10.1007/978-0-387-36699-9_72

[13] Kunitsyn, V. E., E. S. Andreeva, S. J. Franke, and K. C. Yeh (2003), Tomographic investigations of temporal variations of the ionospheric electron density and the implied fluxes, *Geophys. Res. Lett*. 30 (16), 1851, doi:10.1029/2003GL016908.

[14] Liddell, Breit and Tuve (2015). A Greek-English Lexicon. Perseus Digital Library. *Archived from the Original. Phys. Rev*. 28, 554.

[15] Mahammed Atiq (2018), Historical Review of Ionosphere in Perspective of Sources of Ionization and Radio Waves Propagation. *Research & Reviews: Journal of Space Science & Technology* 7(2), 28

[16] Mitchell, C. N., L. Kersley, J. A. T. Heaton, and S. E. Pryse (1997c), Determination of the vertical electron-density profile in ionospheric tomography: Experimental results, *Ann. Geophys*. 15, 747-752

[17] Mushtak, V.C & Williams, E.R. (2002) ELF propagation parameters for uniform models of the Earth–ionosphere waveguide. *J. Atmos. Sol.-Terr. Phys*, 64, 1989–2001.

[18] Nguyen B. T., C. Furse and Simpson J. J. (2015), A 3-D Stochastic FDTD Model of Electromagnetic Wave Propagation in Magnetized Ionosphere Plasma, *in IEEE Transactions on Antennas and Propagation*, vol. 63, no. 1, pp. 304-313

[19] Peter S. (2016). The legacy of James Clerk Maxwell and Herrmann von Helmholtz, Faculty Book & Manuscript. 1.

[20] Peter Skiff and Ratcliffe J. A. (2016). The Magneto-Ionic Theory and its Applications to the Ionosphere. Cambridge University Press,

[21] Reigber, C., H. Lu¨ hr, and P. Schwintzer (2000), CHAMP mission status and perspectives, *Eos Trans. AGU*, 81 (48), Fall Meet. Suppl., F307

[22] Rishbeth, H. & Mendillo, M. (2001). Patterns of F2-layer variability, *J. Atmos. Solar-Terr. Phys*. Vol. 63(15), pp. 1661-1680

[23] Sabirin Bin Abdullah (2011), Observations of F-Region Critical Frequency Variationover Batu Pahat, Malaysia, During Low Solar Activity. Universiti Tun Hussein Onn Malaysia: UTHM,.

[24] Schunk R, & Nagy, A. (2000) Ionospheres: Physics, Plasma Physics, and Chemistry, Cambridge Universiry Press. New York.

[25] Schunk, R. W, Scherliess, L. Jan, J. S., Donald, C. T., David, N. A., Mihail, C., Cliff, M., Timothy, J. F., Roderick, A. H., Marc, H., and Bruce, M. H., (2004). Global Assimilation of Ionospheric Measurements (GAIM). *Radio Sci*. 39, RS1S02, doi:10.1029/ 2002RS002794

[26] Sean Victor Hum (2006). "Radio and Microwave Wireless Systems. *ECE422*

[27] Senguttuvan P and M.Y. Sanavullah (2009), STUDY OF D, E AND F REGIONS OF IONOSPHERE. *Journal of Computer Applications*, Vol II, No. 2.

[28] Sisir K. Das, & Annapurna Das (2006). Antenna and wave propagation. Tata McGraw Hill Education Private Limited. ISBN-10: 1259097587

[29] Srijibendu Bagchi, (2004). Cognitive Radio: Spectrum Sensing and Performance Evaluation of Energy Detector Under Consideration of Rayleigh Distribution of the Received Signal. *International Journal of Electronics and Communication Engineering & Technology* Volume 2, Issue 1, 2011, pp. 17-23

[30] Tereshchenko E. D., Tereshchenko P. E., and Sidorenko A. E. (2019), The Relationship Between the Variations in the Low-frequency (0.1–10 Hz) Near-zone Electromagnetic Field of a Controlled Source and the State of the Ionosphere. 2019 Russian Open Conference on Radio Wave Propagation (RWP), Kazan, Russia, 2019, pp. 71-74, doi: 10.1109/RWP.2019.8810324.

[31] Tsai, W. H; Huang L. F; Chen, M. F., & Liu C. H. (2000), A tomographic study of seasonal variations of the equatorial anomaly in the Asian sector, *Terr. Atmos. Oceanic Sci*., 11, 337 – 348.

[32] Xie S., Ren G., Xue K., Zhao H., Xu Z. and Zheng Y. (2021). HF Propagation Effects Caused by Artificial Plasma Cloud in the Ionosphere. 2021 13th International Symposium on Antennas, Propagation and EM Theory (ISAPE), Zhuhai, China, 2021, pp. 01-03,

[33] Zernov N. N., and Gherm V. E. (2015), On the techniques for solving the problems of high-frequency wave field propagation in the inhomogeneous ionosphere with local variations of electron density, 2015 1st URSI Atlantic Radio Science Conference (URSI AT-RASC), Gran Canaria, Spain, 2015, pp. 1-1