

Applications of Ionospheric Phenomena in Radio Communication - A Review

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Abstract: The ionosphere and its role on radio wave propagation have been studied with the objective to review the various phenomena going on in the region and how they affect the propagation of radio signals. Some wave effects of these electromagnetic signals considered in the review are reflection and refraction. Basic information on ionisation, recombination and plasma motion in the ionosphere including the refractive index of the ionosphere and some other parameters related to it such as radio wave angular frequency (ω), plasma frequency (ω_p), plasma collision frequency (ν), background magnetic field (B_0) and the angle between the magnetic field and the wave propagation direction (θ) have also been reviewed. It is observed that solar radiations and radiations of cosmic ray origin are the cause of the ionisation in the ionosphere and that the earth's magnetic field influences the plasma motion within the ionosphere and affects low frequency radio wave propagation.

Key words: Refractive Index • Pulses • Plasma • Refraction • Signal

INTRODUCTION

Radio signals are classified as electromagnetic waves in terms of the way they travel. They exhibit the same characteristics as they interact with objects and the media through which they travel. The effect of these interactions may result in reflection, refraction or diffraction of the signals. It can lead to a change in their direction causing them to get to areas that would not have been possible if the radio signals were made to travel in a direct line [1-3].

The ionosphere is a region of the atmosphere at an altitude of several hundred kilometres whose defining feature is the presence of free electrons stripped from atoms by solar ultraviolet radiation [4, 6-8]. It refracts the broadcast high frequency (HF) radio wave by an amount proportional to the total electron content (TEC) along its path and as a function of the signal frequency [9-13].

The properties of the ionosphere govern the way in which radio communications, particularly in the HF radio communications bands take place and as a result, the ionosphere is considered as an important region in the atmosphere with regards to radio signal propagation. The ionosphere is widely known for affecting radio signals on

the short wave radio bands where it “reflects” signals as mirror reflects light, enabling this radio communications signals to be heard over vast distances [14-16].

The ionosphere is characterized with the existence of positive ions and free electrons which are very important for radio signals. These free electrons affect radio waves and radio communications. Worldwide radio communications coverage have long been provided by radio stations making use of the properties exhibited by the ionosphere [17-20].

Ionisation in the Ionosphere and Ionospheric Layers: The ionization in the ionosphere is caused mainly by radiation from the Sun. Solar radiation encounters the Earth's atmosphere with a power density of 1370 watts per m^2 [21]. This value is known as the solar constant.

By ionization, the Sun emits vast quantities of radiation of all wavelengths and this travels towards the Earth, first reaching the outer regions of the atmosphere. Solar radiation at ultraviolet and shorter wavelength is considered to be ionizing since photons of energy at these frequencies are capable of dislodging an electron from a neutral gas atom or molecule during a collision as shown in Fig. 1: [22-25].

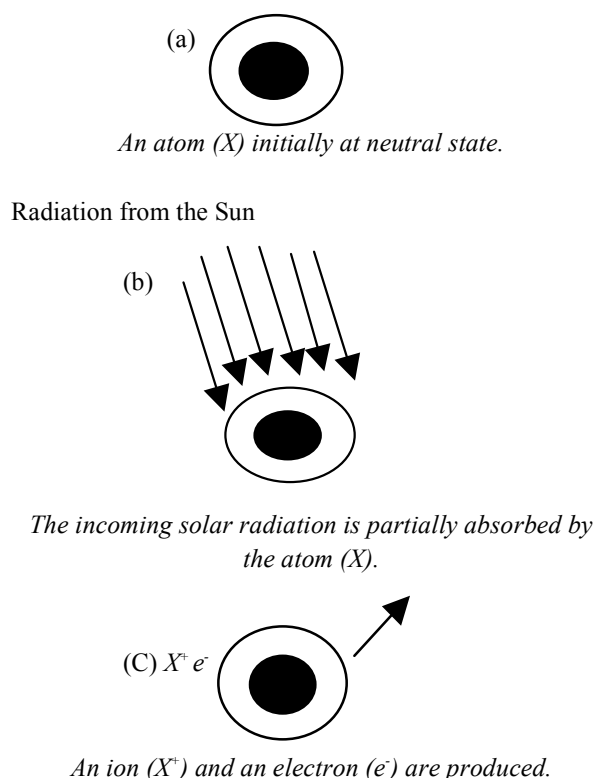
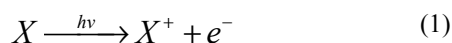


Fig. 1: Ionization process of a neutral atom.

A picture of the ionization of a neutral atom is shown in Fig. 1(a-c).

The photo-ionization reaction is given as



Where X represents the atom or molecule, $h\nu$ is the photon energy, X^+ is the ionized atom or molecule and e^- is the released electron.

Apart from solar radiation and high energy particles, ionization is also produced by cosmic rays (ultra-high energy particles of cosmic origin which can penetrate deep into the atmosphere and lead to ionization of the lower ionosphere) and high temperature in the atmosphere which can cause ion and electron production through chemical processes such as excitation, dissociation and ionization [26-28]. These processes apart from ionization caused by solar radiation are relatively low and of minor effect.

The level of ionization in the ionosphere also changes with time. It varies with the time of day [29-32], time of year and according to many other external

influences. One of the reasons for the variation of electron density is due to the fact that the Sun which gives rise to the ionization is only visible during the day. Accordingly, the level of ionization is dependent on the rate of ionization and recombination [33-35]. This has a significant effect on radio communications.

According to Obasi, (2004) [20] when using HF bands, the ionosphere is observed to reflect the transmitted radio signals. The signals return to the Earth's surface and can be received after being reflected in the ionosphere. As radio waves get to the ionosphere, the electric field in the wave forces the electron in the ionosphere into oscillation at the same frequency as the radio wave [21].

The blanket of gases in the ionosphere is like nature's satellite [5], making High Frequency radio communications possible. As radio waves strike the ionized layers, depending on frequency, some are completely absorbed, others are refracted so that they return to the Earth and still others pass through the ionosphere into outer space. At lower frequencies, the absorption tends to be greater and increases as the degree of ionization increases [7].

Sky wave enters the ionosphere with an angle known as incident angle. The size of this angle is determined by the wavelength and the type of transmitting antenna. A radio wave reflects from the ionosphere at the same angle it hits it just like a billiard ball bouncing off a rail. As a result, the incident angle is an important factor in determining communications range [7]. The incident angle needs to be relatively large when communication is intended on a station which is relatively far and relatively short to communicate with a nearby station. A radio wave will pass through the ionosphere without being refracted back to Earth if the incident angle is too nearly vertical. The incident angle is critical for the radio wave to be refracted back to Earth [35].

The ionosphere is made up of a number of different layers and each of these layers affects radio communication in slightly different ways, (which are the D, E, F1 and F2 layers).

The D region is the lowest of the regions within the ionosphere that affects radio communication signals to any degree. It is present at altitudes between about 60 to 90 km and mainly has the effect of absorbing or attenuating radio communication signals particularly in the low frequency (LF) and medium frequency (MF) portions of the radio spectrum [10]. Its effect reduces with frequency.

The E region exists at altitudes between about 90 and 125 km. Instead of attenuating radio communication signals, it refracts them, often to a degree where they are returned to Earth. However, this layer still acts as an attenuator to a certain degree [9].

The most important region in the ionosphere for long distance radio communications is the F region. During the day- time when radiation is being received from the Sun, this layer splits into two, the lower one being the F1 region and the higher one, the F2 region. The F1 region is more of an inflection point in the electron density curve and it generally only exist in the summer. The F1 region is found at an altitude of about 300 km with the F2 region above it at about 400 km. The combined F layer may then be centred at about 250 to 300 km. The altitude of all the layers in the ionosphere varies considerably and the F layer varies the most. At night, the D, E and F1 regions become very much depleted of free electrons, leaving only F2 region available for communication. The F2 region is the most important region for HF radio propagation [14].

This is because it is present 24 hours of the day, its high altitude allows the longest communication paths and it reflects the highest frequencies in the HF range.

Radio Reptractive Index of the ionosphere and Related Parameters: The passage of electromagnetic wave from one medium to another involves a change in the direction of propagation of the wave with specific angle which occurs according to medium's refractive index [30]. The refractive index, n is a property of the medium. The ionospheric refractivity is expressed by the refractive index, n . It depends on collision frequency, plasma frequency, angular plasma frequency, magnetic field and total electron content (TEC) variations, [19]. The general expression of refractive index, known as Appleton Hartree formula is derived from Maxwell equations and the general wave equation and is given by:

$$n^2 = 1 - \frac{x(1-x)}{1-x - \frac{1}{2}Y^2 \sin^2 \theta \pm (\frac{1}{4}Y^4 \sin^4 \theta + Y^2 \cos^2 \theta (1-x)^2)^{1/2}} \quad (2)$$

where X and Y are normalized plasma frequency and normalized gyro frequency, respectively, (Budden, 1985). The Appleton-Hartree formula can also be written in the form:

$$n^2 = 1 - \frac{x}{1 - iz - (\frac{Y_T^2}{2(1-x-iz)}) \pm (\frac{Y_T^4}{4(1-x-iz)^2} + Y_z^2)^{1/2}} \quad (3)$$

$$x = \frac{\omega^2 N}{\omega^2}, \quad Y_L = \frac{\omega_B \cos \theta}{\omega}, \quad Y_T = \frac{\omega_B \sin \theta}{\omega}$$

$$z = \frac{\nu}{\omega}, \quad \omega_N = \frac{N_e e^2}{\epsilon_0 m_e}, \quad \omega_B = \frac{|e| B_0}{m_e}$$

The refractive index, n depends on θ , the angle between wave propagation direction and geomagnetic field (B_0), on ν , the electron collision frequency, on ω_N , the plasma frequency and ω_B , the electron gyro frequency [35].

Instruments and Methods of Observing the Ionosphere:

The most important feature of the ionosphere in terms of radio communications is its ability to reflect radio waves. As the case may be, only those waves within a certain frequency range will be reflected.

Various methods have been used to investigate the ionosphere but the ionosonde has served as the most widely used instrument for the purpose. An ionosonde is a high frequency radar which sends very short pulses of radio energy vertically into the ionosphere [4].

A technique for determining the height of the reflecting region was devised in the United States in 1925 by G. Breit and M. A. Tuve. They transmitted a short pulse of radio waves upward and by means of an oscilloscope, determined the time taken for the pulse to be reflected back to the receiver a few miles away on Earth's surface [11].

A number of propagation prediction computer programs have been developed. Two widely used and effective programs are Ionospheric Communications Analysis and Prediction (IONCAP) and Voice Of America Coverage Analysis Program (VOACAP), which predict system performance at given times of the day as a function of frequency for a given HF path and a specified complement of equipment [15].

In the use of the ionosonde, the time delay between transmission and reception of pulses over a range of different frequencies is recorded. If the radio frequency is not too high, the pulses sent by the ionosonde are reflected back towards the ground. Echoes appear first from the lower E region and subsequently, with greater time delay, from the F1 and F2 regions [17]. At night, echoes are returned only from the F region since the E region is not present.

Today the ionosphere is “sounded” not only by signals sent up at vertical incidence but by oblique sounders which send pulses obliquely into the ionosphere with the transmitter and receiver separated by some distance. This type of sounder can monitor propagation on a particular circuit and observe the various modes supported by the ionosphere [4]. Backscatter ionosondes transmit energy obliquely which is refracted from the ionosphere and reflected off the ground before returning to the receiver, which may or may not be at the same site as the transmitter [5].

Radio Wave Propagation: Radio signals when radiated from a transmitting source into various parts of the atmosphere behaves in different ways. The behaviour of the radio waves as they are transmitted is known as radio propagation [1]. Radio waves propagate at the speed of light denoted by c and given as

$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}} = 3 \times 10^8 \text{ m/s} \quad (4)$$

where ϵ_0 and μ_0 are permittivity and permeability of free space respectively.

Radio propagation is affected by the daily changes of water vapour in the troposphere and ionization in the upper atmosphere due to the Sun. Understanding the effects of varying conditions on radio propagation has many practical applications, from choosing frequencies for international short wave broadcasters, to designing reliable mobile telephone systems, to radio navigation and to operation of radar systems.

Several other factors that affect radio propagation are determined by its path from point to point. This path can be a direct line-of-sight path or an over-the-horizon path aided by refraction in the ionosphere. Factors influencing ionospheric radio signal propagation can include sporadic E, spread F, solar flares, geomagnetic storms, ionospheric layer tilts and solar proton events [32].

Modern radio technology had its birth with the publication of James Clerk Maxwell’s Treatise on Electricity and Magnetism in 1873, setting forth the basic theory of electromagnetic wave propagation. But the first radio waves were actually detected 15 years later [11]. In 1888, Heinrich Rudolph Hertz demonstrated that disturbances generated by a spark coil showed the characteristics of Maxwell’s radio waves. His work inspired Guglielmo Marconi’s early experiments with

wireless telegraphy using Morse code. By 1896, Marconi had communicated messages over distance of a few kilometres [31].

CONCLUSION

The ionosphere is of much importance in communication engineering since the phenomena observed in the region affect radio communications and human life in general. The properties of the ionosphere are used to provide worldwide radio communications coverage by radio stations. These properties also affect the method used to investigate ionospheric propagation by reflecting pulses sent back to the earth from the ionosphere and are worth studying.

Recommendation: Owing to the vital role of the ionosphere in radio communication and in the light of the recent global advancements in information and communication technology, the need for further studies in this area of research cannot be over-emphasised. It is therefore recommended that more researches be carried out in this region of the upper atmosphere for improvement in information and communication technology.

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