# Ionosphere and Radio Communication

*Saradi Bora*

**The Earth's ionosphere consists of plasma produced by the photoionization of thin upper atmospheric gases by UV rays and photons of short wavelength from the sun. The upper ionosphere is used for radio communication and navigation as it reflects long, medium, as well as short radio waves. Since solar radiation is the main cause of the existence of ionosphere, any variation in the radiations can affect the entire radio communication system. This article attempts to briefly introduce the readers to the study of ionosphere in the context of its use as a radio reflector, with particular reference to India.**

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## 1. Introduction

The ionosphere starts at an altitude of about 60 km above the Earth's surface and extends up to about thousand kilometres. It consists of plasma which is produced by the photoionization of thin upper atmospheric gases by UV rays and photons of short wavelength from the sun. The distribution and dynamics of the plasma is dependent on the coupling between the neutral atmospheric winds, solar heating, photoionization, electrical conductivity, and interactions with the magnetic field of the Earth. In addition to solar radiations, the particles precipitated from the magnetosphere due to collisional ionization are another cause of ionization; particularly in high latitude regions.

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The ionosphere has vertical layers denoted as D, E and F layers based on variations in the atmospheric neutral composition and the rate of ionization with altitude. In D and E regions, the predominant ions are $O_2^+$, $N_2^+$ and $NO^+$. The F region is further subdivided into three sub-layers. In the lowest $F_1$ layer, ionization is caused due to photoionization and it disappears through

**Keywords**
Ionosphere, plasma, radio communication.

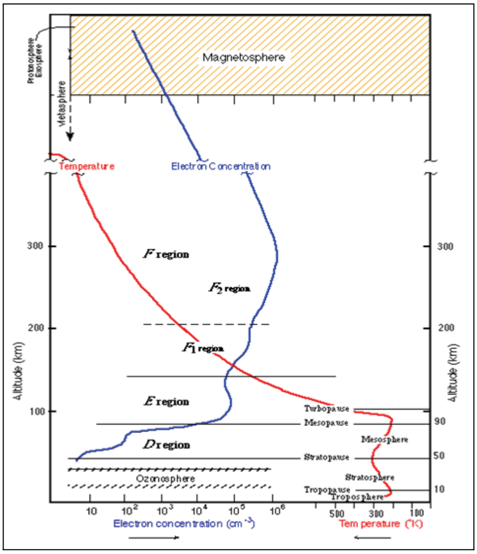


**Figure 1.** Altitude profile of ionosphere layers and thermal structure of the atmosphere.

recombination with electrons. The next sub-layer where chemical to diffusion transition occurs is called the $F_2$ layer, and here the electron density is the maximum. Above this layer, diffusion dominates and we call this layer as topside of the ionosphere. However, in addition to the variation of the plasma density with altitude (*Figure* 1), the ionosphere also shows significant variation with longitude, latitude, solar activity, geomagnetic activity, and seasons along with time of the day. The plasma temperature also changes with the changes in the plasma density.

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The ionosphere has been studied extensively during the last century because of its great importance in radio communication[1]. But there is still a great deal to know about its physical and chemical properties.

[1] R S Dabas, Ionosphere and its Influence on Radio Communications, *Resonance*, Vol.5, No.7, pp.28–43, 2000.

## 2. Methods for Studying the Ionosphere

The available techniques for observing the geospace can be divided into three, *viz* – direct, indirect and remote sensing. In the direct sensor method, an instrument is placed in the medium to measure the properties of its immediate surroundings, and they respond only to that which is to be measured. Artificial satellites, rockets or balloon-borne measurements comprise the direct method. In the second method, an indirect sensor is placed within the medium but is not instrumented with a detector. The properties of the medium are monitored from afar by observing the motion of the sensor. In the remote sensing method, however, no instrument is placed in the medium. The properties are derived from observations of waves that have traversed the medium or those emitted from it. The most commonly used remote sensing techniques and devices for studying ionosphere are – ionospheric sounding, transionospheric propagation, VLF propagation, whistlers, partial reflections, coherent scatter radar, incoherent scatter radar, MST radar, etc.

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Plasma probes are used for the measurement of plasma density, temperature and electric fields. These probes are simple devices based on current measurements when the potential is applied to the sensor. One of the most extensively used plasma probes is the Langmuir probe in which plasma parameters are determined from the current–voltage characteristics. The other probes are the impedance probe and the resonance probe. If two probes are used floating in the medium with a separation of few meters, the electric field is measured from the potential difference which in turn is approximated from the difference in the current collected by the two sensors. Such probes are called double probes.

Ion traps are the devices that collect ions. If additional grids are applied to select electrons or ions in a particular energy range, then the device is called an analyser. Retarding potential analyser (RPA) is used extensively from satellites to measure ion density and temperature. The ion drift velocity measurements are done by drift meters.

Mass spectrometers are used to determine the masses of ions or neutral particles. Different types of mass spectrometers are magnetic deflection mass spectrometer, Bennett–high frequency mass spectrometer and quadrupole mass spectrometer.

Various kinds of techniques are used to observe and measure the properties of ionospheric plasma!

Magnetometers are used to explore the magnetic fields in the neighbourhood of the atmospheric dynamo at 100–130 km and in satellites to explore the electric field in the neighbourhood of the magnetopause [2]. In recent times, the study of the interplanetary magnetic field has become important due to the role of space weather in radio communication. Various types of magnetometers include – proton precession magnetometers and alkali (rubidium vapour) vapour magnetometers.

[2]The outer termination of the geomagnetic field is called magnetopause.

All these devices are used to study the ionospheric parameters such as plasma density, temperature, ion composition, current, neutral winds, etc. One basic problem associated with these is that as soon as a space vehicle is sent to the ionosphere, it can disturb the neutral atmosphere and the ionospheric plasma. To avoid such disturbances and the resulting contamination of the atmosphere by the gases emitted from the measuring equipment, they are usually degassed, and sealed up in a vacuum before launch. The seal is broken only when they reach the desired height.

## 3. Role of Ionosphere in Radio Communication

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The ionosphere plays a great role in broadcasting, ship and aircraft communication and navigation by reflecting the radio signals back to the receivers. However, its effectiveness depends on the frequency of the transmitted signal. This is critical because the behaviour of the ionosphere often shows marked differences during day and night. Moreover, it is known for changing its behaviour during different seasons. What is relieving, however, is that the variations are regular, and they may also be predicted. These predictions help in the planning of radio services. The propagation of the radio signal is influenced by the dispersive nature of the ionospheric plasma and refraction of a signal depends on the wave frequency. The ionospheric refractive index as represented by the Appleton–Hartree equation is,

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$$n = \left(1 - \frac{f_p^2}{f^2}\right)^{\frac{1}{2}} \approx 1 - \frac{1}{2}\frac{f_p^2}{f^2} = 1 - \frac{1}{2}\frac{f_p^2}{f^2} = 1 - \frac{40.30N}{f^2} \qquad (1)$$

Where $f_p$ is the electron plasma frequency in Hz, $N$ is the electron number density in $m^{-3}$. It can be seen from this equation that the refractive index of the ionosphere is less than unity and depends on the frequency of the wave. At a certain frequency, it becomes zero while at the lower frequency it becomes negative.

From (1), the magnitude of the phase velocity can be derived as,

$$v_{\mathrm{p}} = \frac{\omega}{\kappa} = \frac{c}{n} = c\left(1 - \frac{40.30N}{f^2}\right)^{-1} \approx c\left(1 + \frac{40.30N}{f^2}\right) \quad (2)$$

As the refractive index is less than unity, phase velocity exceeds the velocity of light in free space. It also depends on the frequency. When the information is modulated with the radio wave, it travels with the group velocity which is always less than the velocity of light. The group velocity can be obtained by the equation,

$$V_{\mathrm{g}} = \frac{\partial\omega}{\partial\kappa} = \frac{c}{(\partial(nf)/(\partial f)} = c\left(1 + \frac{40.30N}{f^2}\right)^{-1} \approx \left(1 - \frac{40.30N}{f^2}\right) \quad (3)$$

From these equations, it can be seen that the propagation speed of radio waves varies along their path through the ionosphere as the refractive index varies with the plasma density and the radio wave frequency. When the velocity of the wave varies with the frequency, the medium is known as a dispersive medium. Because of this dispersion, the idea of group velocity is introduced to represent the velocity of the crest of a group of interfering waves, where the component waves have different individual frequencies and phase frequencies.

When a radio wave enters and interacts with the ionosphere, some amount of energy of the radio wave is transferred to the electrons and ions of the ionosphere, resulting in the oscillation of the interacting particles at the same frequency as that of the radio wave. As a result, the radio wave is attenuated when passing through the ionosphere. Attenuation is more in the D region where neutral particle density is more as compared to the upper regions. Moreover, the collision frequency of the electrons with

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the neutral particles is inversely proportional to the square of the frequency of the radio waves. As a result, attenuation is greater as the frequency is lower or wavelength is longer. Accordingly, when radio signals pass through higher levels of the ionosphere, the signals suffer little loss of strength.

Furthermore, from (1) it can be seen that for a given frequency, the refractive index decreases while passing from a medium of lower to higher electron density. Hence a beam of radio wave going upwards will be refracted downwards. Now let us consider a radio wave of frequency $f$. At first, the electron density $N$ in (1) is small and the velocity of the wave is nearly equivalent to that of light in free space. But as altitude increases, $N$ also increases and phase velocity must increase while the frequency remains the same. Consequently, refractive index decreases, and at a certain condition, it becomes zero. At this condition, the electron density is called the 'critical electron density', and the radio wave can no longer be propagated in the upward direction and is reflected back to the earth. In this way, the ionosphere is being used for long distance radio communication in the HF band.

In the case of satellite and space-based communication systems, inhomogeneities in the refractivity occur due to the presence of ionospheric irregularities between 200–1000 km altitudes. The signal amplitude and phase of a radio wave propagating through the ionosphere fluctuates, and the phenomenon is known as 'scintillation'. The ionospheric scintillations can also disturb satellite communications, global positioning systems, radar systems and astronomical observations. In this context, proper study of scintillation is very important.

The equatorial and low latitude ionosphere have been studied by many ground and space-based experiments as it has many unique features which are not found elsewhere.

The equatorial and low latitude ionosphere have been studied by many ground and space-based experiments as it has many unique features which are not found elsewhere. The ionospheric electric field plays a dominant role in low latitude electrodynamics. The effect of neutral winds, together with diurnal and semi-diurnal tidal components in the atmosphere causes currents at an altitude of 100–130 km, which is known as the $S_q$ current system in the E region. This current system results in an eastward electric field at low latitudes. In the equatorial E region, the east–west electric field drives the equatorial electrojet, which is a narrow band of enhanced eastward current flowing in 100–120 km altitude region within $\pm 3^{\circ}$ latitudes of the magnetic equator during the daytime. Another prominent feature seen at the equatorial low-latitude ionosphere during daytime is the equatorial ionization anomaly (EIA) or the Appleton anomaly. It is distinguished as a depression in plasma density or trough at the geomagnetic equator and two peaks at about $\pm 10^{\circ}$ to $\pm 15^{\circ}$ magnetic latitudes. The EIA is formed as a consequence of EB upward plasma drifts associated with the eastward electric field ($E$), and a northward horizontal magnetic field ($B$). As the plasma is lifted to greater heights, it diffuses downward along the geomagnetic field lines due to the gravitational force and the plasma pressure gradient. This results in ionization enhancements on both sides of the magnetic equator. This physical phenomenon is generally known as the 'plasma fountain'. *In situ* measurements of plasma density in the F region of ionosphere provides useful information about the location of the EIA, its spatial and temporal extent, and variability with the season and solar cycle. Besides these, equatorial temperature and wind anomaly (ETWA), equatorial spread F, plasma bubble, etc., are the common features of the equatorial low latitude region. The equatorial ionosphere also promptly responds to solar activities including extreme disturbances leading to unexpected variations, which are unfavourable to present day communication/navigation systems. Therefore, ionospheric research over the Indian equatorial and low latitude ionosphere have great importance.

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## 4. Importance of Indian Equatorial and Low Latitude Ionosphere

Ionospheric research in India started with the pioneering works of Sisir Kumar Mitra[3] at Calcutta University in the year 1930 when he with his coworkers obtained the first experimental evidence of the E region in the ionosphere. Mitra's group announced the reception of regular echoes from heights around 55 km and named

[3] Mrinal Kumar Das Gupta, Professor Sisir Kumar Mitra - As I Remember Him, *Resonance*, Vol.5, No.7, pp.92–99, 2000.

it as the D layer. The same had been reported by Appleton in 1928. Another important work of Mitra was his explanation for the Appleton ionization anomaly. Under his influential leadership, a full-fledged Department of Radio Physics and Electronics was created in the Calcutta University. Later it became the Institute of Radio Physics and Electronics[4]. Mitra's laboratory participated in the second International Polar Year (IPY2-1932) which can be regarded as the first entry into organized international scientific research. He established the first ionospheric field station at Haringhata near Calcutta in 1950. An ionosonde[5] was installed in the station which started round the clock observation of the ionosphere by 1955. S K Mitra's research was carried forward by his successor A P Mitra who was the main driving force behind the Indian programme of the International Geophysical Year (IGY)1957–58, and the International Quiet Sun Year (IQSY) 1964–65. In 1970, A P Mitra introduced radio research in the tropospheric region for its applications in radio communication.

[4] P K Basu, Institute of Radio Physics and Electronics, *Resonance*, Vol.5, No.7, pp.100–104, 2000.

[5] An ionosonde is an apparatus which records the echo time of a radio wave, emitted from a sending point and reflected back from the ionosphere. The record is called the ionogram.

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It is worthwhile to quote here the contributions of K R Ramanathan. As a senior scientist at the India Meteorological Department, Ramanathan's research work covered a wide range of subjects like solar and atmospheric radiation, spectrum of the night sky, meteorological optics and acoustics, atmospheric ozone, terrestrial magnetism, seismology, the Indian monsoon circulation and depressions, cyclonic storms of Indian seas, and general circulation of the atmosphere over India and its neighbourhood. His major contribution was the diagram showing the vertical thermal structure of the Earth's atmosphere all over the world. He became the first director of the Physical Research Laboratory (PRL)[6], Ahmadabad where his work was mainly concerned with the studies of atmospheric ozone, night glow, ionospheric and space physics and solar galactic influence on the ionosphere. Ramanathan was associated with many observatories like Colaba and Alibag. He with Vikram Sarabhai[7] was closely associated with the establishment of the Thumba rocket launching facility and the Space Science and Technology Centre at Trivandrum. The contributions to ionospheric physics and remote sensing by K R Ramanathan and

[6] *Resonance,* Vol.6, No.1, pp.100–101, 2001.

[7] *Resonance*, Vol.6, No.12, 2001.

his colleagues like P R Pisharoty, R G Rastogi, Satya Prakash, and their numerous students at PRL, over a period of nearly thirty years have been outstanding.

Significant contributions have been made by many Indian researchers using orbiting satellite electron content data in the late sixties and seventies, and a coordinated total electron content (TEC) measurement campaign was undertaken in 1975 using beacon transmissions from the ATS-6 geostationary satellite. The receiving stations under this campaign extended in latitude from the magnetic equator to low-mid latitude along $75 \pm 2^{o}$E meridian and covered the longitude span of $75^{o}$E to $95^{o}$E. Characteristics of the equatorial and low latitude ionosphere such as the EIA, evening enhancement, noontime bite-out, winter anomaly, and day to day variability were studied using the TEC data obtained for the low solar activity period of September 1975 to August 1976. After ATS-6, a number of satellites such as ETS-II, Symphonie, etc., were used to retrieve TEC over a number of locations such as New Delhi, Calcutta and Visakhapatnam. The Indian middle atmospheric programme in the 1980s saw extensive use of balloons and rockets to carry equipments up to ionospheric levels. In the 1990s, two world class efforts were made – MST radar and SROSS satellite. The radar was installed at Gadanki which enabled exploration of a very substantial part of the atmospheric environment from near the surface to around 100 km. The Indian satellite SROSS C2, launched in 1994 into an orbit of 630 km by 430 km, had two RPAs on-board for the measurement of electrons and ions separately. The satellite provided an extended database, for the first time, over the Indian longitude sector, for the study of electron density and temperature variations for a period extending from solar minimum (1995) to solar maximum (2000) during solar cycle 23. There is also a National Balloon Facility at Hyderabad jointly supported by TIFR and ISRO.

ISRO in collaboration with the Airport Authority of India (AAI) has launched a project termed GPS Aided Geo Augmented Navigation (GAGAN) for the development of GPS aided navigation systems for aircrafts in India. This is in principle similar to the

Wide Area Augmentation System (WAAS) of USA. With increasing demand on transionospheric communication systems used in the navigation of space-borne vehicles such as satellites, aircrafts as well as surface transport systems, knowledge of the total electron density distribution, both in the temporal and spatial domain, has become quite essential. A total of 18 dual frequency GPS receivers were installed at $5^o \times 5^o$ latitude-longitude intervals within India in 2003 and have been in continuous operation since then. The primary objective for the establishment of this chain of receivers is to measure the TEC and scintillation ($S_4$ index) to develop a high precision model of TEC, suitable for implementation of the Space Based Augmentation System (SBAS).

Ionospheric tomography is an effective way of investigation of spatio-temporal variability of the ionospheric processes. For the study of ionosphere–thermosphere region over Indian longitudes, a payload called Radio Beacon for Ionospheric Tomography (RaBIT) on-board the YOUTHSAT satellite was launched in 2011. RaBIT enables measurement of TEC which is used to study the structure and dynamics of the equatorial ionosphere over the Indian region using tomographic techniques. A network of digital ionosonde systems, dual frequency GPS receivers and tomographic receivers for extensive measurements of critical frequency of F2 region ($foF_2$), peak height of F2 region ($h_mF_2$), TEC and VHF, UHF and L-band scintillation for developing ionospheric models have been established by the National Physical Laboratory (NPL), New Delhi, across the country at various stations.

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## 5. Conclusion

Today ionospheric research has reached a critical stage. Scientists are looking for other possible implications of ionospheric variations and its coupling with other atmospheric layers. Using different techniques, a number of scientific communities around the globe are now predicting the ionospheric weather routinely. Many models are being developed for studying thermosphere and ionosphere, and their coupling with the magnetospheric solar wind. On the other hand, recent findings have opened up new avenues for studying ionospheric variations to forecast earthquakes, as disturbances in the TEC of the ionosphere have been reported as short-term precursors to earthquakes in many regions. The hunt, at present, is for a seismo-ionospheric coupling that will lead to a possible system of ground and satellite-based measurements for regional and global monitoring, and a possible prediction system of devastating earthquakes.

## Suggested Reading


[1] H Rishbeth, O K Garriot, *Introduction to Ionospheric Physics*, Academic Press, New York and London, 1969.

[2] M C Kelley, *The Earth's Ionosphere: Plasma Physics and Electrodynamics*, Elsevier, New York, 1989.

[3] J K Hargreaves, *The Solar Terrestrial Environment*, Cambridge University Press, 1995.



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