Chapter I

Introduction

1.1 Historical Perspective

The ionosphere is the region of the earth’s upper atmosphere lying approximately between 100 km and 1000 km altitude where x-rays and EUV-radiation from the sun create ionized particles. Most of the critical interactions between earth and the sun take place in the upper atmosphere. This partially ionized ionosphere acts as a sort of coupling medium between the earth's neutral atmosphere and sun's fully ionized atmosphere. It can be considered as a transition region in a dynamical system that begins at the sun and ends deep in the earth's interior. The regular variations in the daily observations of earth's magnetic field at the end of the 18th century indicated the existence of an electrically conducting region in the upper atmosphere. Gauss (1839) had shown that these variations might be induced from outside the earth by currents flowing high in the atmosphere, and later this idea was further developed. In order to explain the reception of radiowaves at greater distances, Kennelly and Heaviside in 1902 proposed independently that the upper atmosphere might be partially ionized and capable of conducting electricity.

In 1924, the existence of the Kennely-Heaviside layer was experimentally proved by Appleton and Barnet (1925) in England using FM-CW radar. In 1925 experiments were conducted in the USA by Breit and Tuve (1926) using the pulse radar system and confirmed the existence of an ionized layer in the upper atmosphere. Sir Watson-Watt (1929) coined the term ionosphere for this reflecting region.

The experiments of Prof. J C Bose with microwaves a century ago marked the beginning of Radio Science research in India. But the ionospheric research began in India only after the lapse of a quarter century. The University of Calcutta,
under the stewardship of Prof. S K Mitra became the cradle of ionospheric research in India. In accordance with the programme of International Polar Year, the first systematic measurement of ionospheric parameters was carried out in Calcutta.

The decade of 1950 saw the initiation of Ionospheric Research at AIR under the supervision of Prof. S N Mitra. At the same time an Ionospheric Research group was set up at Ahmedabad. The magnetic observatory at Kodaikanal was restarted in 1949 and a C2 model Ionospheric Sounder was also established there. The 1950s also saw the establishment of an ionospheric research group at Andhra University under the leadership of Prof. B Ramachandra Rao. Dr. A P Mitra initiated ionospheric prediction service which still continues, and coordinated the ionospheric research work at Delhi. The commissioning of Thumba Equatorial Rocket Launching Station (TERLS) in 1963 by the Department of Atomic Energy (DAE) marked the beginning of rocket experiments in India. At Thumba both ground based and rocket based probing are done. Apart from the above mentioned institutions, routine ionospheric measurements such as absorption by A1 method, ionospheric drift measurements with spaced receivers, satellite radio beacon measurements and LF wave propagation are being regularly made by many research groups spread all over India.

The introduction of satellites and incoherent scattering techniques provided very powerful tools for ionospheric research. Apart from the study of the production and loss mechanism of ions and electrons, ion density, and geomagnetic field variations, the new techniques reliably probed the dynamics of ionosphere realizing the fundamental role played by electric fields. An important branch of Physics, namely Plasma Physics, itself blossomed along with ionospheric research.

With a large number of laboratories and research groups spread across the nation, the Indian contribution falls mainly into the areas of morphological studies, observational results from ground based experiments and rocket based experiments besides theoretical work. The ground based observations have provided useful results on horizontal drifts, ionospheric irregularities, the vertical
drift measurements of ionospheric layers, total electron content, ionospheric scintillation, equatorial spread-F and geomagnetic disturbance effects in the equatorial ionosphere.

Among the RF techniques described elsewhere, the HF Doppler technique which is used extensively in India is used to probe the bottomside of the F-layer of the equatorial ionosphere to understand the dynamics of the equatorial F-region of the ionosphere, and related phenomena. The installation of an HF Doppler radar at the University of Kerala, Trivandrum, being situated at magnetic equator, provided an excellent location for studies on equatorial ionosphere and hence this study.

1.2 Structure of the Ionosphere

The ionosphere may be defined as part of the earth's upper atmosphere where ions and electrons are present in quantities sufficient to affect the propagation of radio waves. Typical profiles of temperature and plasma density of the earth's atmosphere is given in fig.1.1. The earth's atmospheric structure can be represented by a temperature profile, while the ionosphere is more sensibly organized by the number density of the plasma. The atmosphere is nearly uniform in composition up to about 100 km from the earth's surface, but beyond that the constituents begin to separate according to their masses. The temperature also rises to very high values above 80 km, and can go well above 1000 K. This portion of the atmosphere is called thermosphere and the ionosphere belongs to this region also.

The process of ionization can be explained as due to the EUV rays in the solar radiation incident on the neutral atmosphere that increases in density with decreasing altitude. As the EUV rays come down the atmosphere their intensity decreases and hence the ionization rate also decreases. Considering the nocturnal plasma-density profile (dashed curve) - the plasma density near the
Fig. 1.1 Typical profiles of neutral atmospheric temperature and ionospheric plasma density with the various layers designated (adapted from Kelly, 1987).

F-peak is reduced in magnitude but not as drastic as at the lower altitudes. This is because at lower altitudes, the molecular ions dominate, and their density is sharply reduced at night. But at F-region altitudes, the dominant component is O$^+$ ions and its density is sustained through the night.

The altitude range of 150-1000 km is termed the F-region and the altitude of maximum density is termed F-peak. The F-region at day time can be considered to be constituted of two layers F1 and F2. The layer F1 coalesces with F2 at night forming a single F-region. The plasma below 150 km is mainly constituted by NO$^+$ and O$_2^+$ and the F-region is dominated by O$^+$ ions which correspond to the high concentration of atomic oxygen in the neutral gas. The altitude range 90-150 km is called the E-region and the ionization below 90 km is
termed as D-region. At high altitudes the hydrogen becomes the dominant ion and the region is called protonosphere.

The sunset and sunrise effects are very dramatic at lower altitudes, but are almost nonexistent in the F-region. From the figure, it is clear that the plasma density near the F-peak is reduced in magnitude in the night but not nearly as dramatically as in the density at lower altitudes. This difference mirrors the distinction between the composition of the two regions. In the lower regions, the molecular ions dominate the density during the day time get drastically reduced during the night. On the other hand, the O+ plasma density of the F-region is sustained through night.

In the F-region an electric field parallel to the magnetic field can easily move the ions and electrons along field lines, which will tend strongly to become equipotential lines. An electric field at right angle to both the electric and magnetic field will produce bulk plasma motion at right angles to both the electric and magnetic fields. The plasma drift along a field line can be caused by the component of neutral drift in that direction. A neutral gas wind in the F-region blowing through the plasma at right angles to the magnetic field will cause electrons and ions to separate and produce a current perpendicular to both.

1.3 Motions of the Equatorial Ionosphere

The ionospheric wind system is the result of the action tidal forces together with the magnetic field-generating currents and electrostatic fields which drive the neutral gas and the plasma. The tidal forces of solar origin are much larger than those of lunar origin, and are due to the thermal energy absorbed in the ionosphere. The neutral gas may be dragged along with bulk plasma movements due to the potentials in the E-region conducted up the magnetic field lines to the F-region. Plasma motions in north or south direction can be caused by the wind movements along magnetic field lines resulting from pressure differences in the ionosphere. Gravity waves also have been suggested as a major influence on...
motions of the ionosphere. Other types of waves or interactions which cause ionospheric movements are hydromagnetic waves and incidence of high speed cosmic particles causing local heating and ionization.

Dynamo theory was proposed to explain the movements in the ionosphere which chiefly cause the anomalous behavior of ionospheric F-region. According to dynamo theory atmospheric movements drag the conducting ionosphere across the earth's magnetic field, so that voltages are induced and currents flow. The interaction of ionospheric wind system with the magnetized conducting ionospheric plasma, produces through dynamo action, electric fields that drive currents and plasma-transport. The ions and electrons are constrained to move along the terrestrial magnetic lines of force. This motion has in general, a vertical component except at the magnetic equator. But even at magnetic equator, vertical ion and electron drift can occur if a horizontal electric field exists; such field must exist if the dynamo theory of magnetic variations is valid. The vertical drift of ions and electrons can be considered as due to the polarization field developed by the motion of the ions and electrons across the magnetic field. The permanent magnetic field of the earth not only influences the direction and magnitude of the plasma movement, but also exerts a force on it and causes it to move. The electric field in the equatorial region is maintained by the ionospheric winds. A prominent movement of the equatorial ionosphere is the pre-reversal enhancement of the vertical drift occurring during all epochs and seasons studied except for the solar minimum summer solstices. The effect of this brief-duration, large, vertical drift can be quite significant since the F-region plasma is often driven to very high altitudes where recombination is slow and collisions are rare.

At any point the drift velocity has diurnal, seasonal and annual periods, and the effect of the drift velocity on the night-time F-region is independent of recombination effects. The motions in the F-region causes the production of different types of irregularities. From the irregularity movements the motions of F-region can be obtained. The close-spaced-antenna method developed by Mitra
(1949) is the most useful and simple method of measuring ionospheric drifts by observing the motions of plasma irregularities.

1.4 Equations of the Ionosphere

The local and global properties of many of the equatorial phenomena such as coupling between the neutral winds and the plasma drifts, the relation between the ambient plasma drifts and the spread-F irregularity drifts, the effect of evening vertical plasma drift on the zonal neutral winds, and the importance of gravity waves are yet to be studied in detail. Also most of the general characteristics of the equatorial, F-region plasma drifts during quiet conditions are well known, but the understanding of the electric fields and plasma drifts during magnetically disturbed times are limited due to the measurement difficulties. There are no fully consistent theories which take all the plasma driving processes into account. The equatorial ionosphere is a small but significantly interesting part of the space plasma environment of the earth. The main features and phenomena of the equatorial ionosphere can be explained on the basis of the plasma electrodynamic processes arising from the specific equatorial geometry of the electric fields which are orthogonal to the nearly horizontal geomagnetic field lines. The ions, electrons and neutrals can be considered as three interpenetrating fluids coupled by collision. The gas of ions and electrons, taken together, is often referred to as plasma in ionospheric studies:

Consider a volume element small enough to be treated as a differential volume, still microscopically contains many particles colliding in a random fashion, which can be statistically used to describe the temperature, density and mean flow velocity. The rate of increase or decrease of mass inside a volume element can be expressed using the law of conservation of mass. The continuity equation for an incompressible fluid, can be written as,

$$\frac{\partial \rho}{\partial t} = -(\mathbf{U} \cdot \nabla \rho) \quad \ldots \ldots \ 1.1$$
This can be used as the continuity equation for the neutral atmosphere with mass density $\rho$ and velocity of the neutral atmosphere $U$.

In the case of partially ionized medium, if $P_i$ denotes the rate of production of ions (and electrons) per cubic meter per second and $L_i$ the rate of loss, then the mass conservation equation for each of the ionized species is,

$$ \partial_t \rho_i + \nabla \cdot (\rho_i \mathbf{V}_i) = (P_i - L_i) M_i \quad \ldots \ldots \quad 1.2 $$

$M_i$ is the mass of each species and $V_i$ is the velocity of the charged particles.

Since the electric charge is a conserved quantity, it must be the case that the total number of electrons gained or lost equals the sum of all the different types of ions gained or lost. Also we can ignore the negative ions since their formation is unimportant above 80 km altitude, as is the case with the loss of neutral particles which is negligible. For an ideal gas, the mass density and pressure $(p_i)$ are related by,

$$ p_i = \rho_i k_b T_i / M_i = n_i k_b T_i \quad \ldots \ldots \quad 1.3 $$

This can be substituted for the equation of state for each of the fluids we consider (ions, electrons and neutrals) and we relate the mass density $\rho_i$ to the number density $n_i$ through $\rho_i = n_i M_i$ and $k_b$ is the Boltzmann constant.

For the description of the fluid to be complete, the equation of state and equation of continuity must be supplemented by a dynamical equation relating the fluid velocity to the forces acting on the fluid. This can be derived from the conservation of momentum, which requires that the change of momentum per unit time within a volume be equal to the sum of the pressure gradient force, the total external force field ‘$F$’ acting on the material inside the volume, and the momentum flux carried across the surface bounding the volume by viscosity, advection or wave flux. Taking into consideration the viscous force, the gravitational force, the frictional force (or ion drag) and the upward flux of
momentum due to waves, we can write the equation for the conservation of momentum as,

$$\rho \frac{d\mathbf{U}}{dt} = -\nabla p + \rho \mathbf{g} - \rho \nu_l (\mathbf{U} - \mathbf{V}_l) - \nabla \cdot \pi_m + \eta \nabla^2 \mathbf{U} \quad \ldots \ldots \ 1.4$$

Where, $\eta$ is the coefficient of dynamic viscosity and $\pi_m$, the momentum flux density tensor due to waves in the medium. By considering the rotation of the earth, this equation must be transformed into a rotating frame with angular velocity $\Omega$. Thus the time derivative of the velocity must be replaced by,

$$\left( \frac{d\mathbf{U}_l}{dt} \right)_I = \left( \frac{d\mathbf{U}_l}{dt} \right)_R + \Omega \times \mathbf{U}_l \quad \ldots \ldots \ 1.5$$

and the velocity vector,

$$\mathbf{U}_l = \mathbf{U}_R \times \Omega \times \mathbf{r}$$

Where $I$ and $R$ represents the inertial and rotating frames respectively. If we assume $\Omega$ is constant and by putting $d\mathbf{R} / dt = \mathbf{U}_R$ we have,

$$\left( \frac{d\mathbf{U}_l}{dt} \right)_I = \left( \frac{d\mathbf{U}_R}{dt} \right)_R + 2\Omega \times \mathbf{U}_R + \Omega \times (\Omega \times \mathbf{r}) \quad \ldots \ldots \ 1.6$$

The second term is the Coriolis force. The last term is equal to $r\Omega^2 \cos \theta$, where $\theta$ is the latitude and have components both radially inward and equatorward. This term may be considered with $\mathbf{g}$ to describe an effective gravitational field. Therefore, by using $\mathbf{g}$ for this combined term and by moving the Coriolis term to the right hand side of equation of momentum yields the following equation of motion of the neutral atmosphere in a rotating frame.

$$\frac{d\mathbf{U}}{dt} = -\nabla p + \rho \mathbf{g} + \eta \nabla^2 \mathbf{U} - \nabla \cdot \pi_m - 2\rho (\Omega \times \mathbf{U}) - \rho \nu_l (\mathbf{U} - \mathbf{V}_l) \quad \ldots \ldots \ 1.7$$

In the case of geophysical plasma analysis the velocity dependent magnetic force is very much greater than the Coriolis force, hence the latter can be neglected. In
the case of ionized constituents the important forces which must be included in equation other than gravitational term are (1) Electric: $\eta_j q_j E$ and (2) Magnetic: $\eta_j q_j (V_j \times B)$ where $q_j$ is the charge of the species and $E$ and $B$ are the electric and magnetic fields. In the case of plasma the frictional force on each species may be written as,

$$F_j = \sum_{k} \rho v_k (V_j - U_k)$$

Therefore the momentum equation for each ionized species is,

$$\rho_j \frac{dV_j}{dt} = -\nabla p_j - \rho_j g + \eta_j q_j (E + V_j \times B) - \sum_{k} \rho_k v_k (V_j - V_k) \quad \ldots \quad 1.8$$

Hence, for the neutral atmosphere:

the equation of continuity is,

$$\frac{\partial \rho}{\partial t} = -\nabla \cdot (\rho \, U) \quad \ldots \quad 1.9a$$

The equation of momentum can be written as,

$$\rho \frac{dU}{dt} = -\nabla p + \rho \, g + \eta \, V^2 U - \nabla \cdot \pi - 2\rho \, \Omega \times U - \rho \, n_i (U - V_i) \quad \ldots \quad 1.9b$$

and the equation of state is,

$$p = n \, k_B T_n \quad \ldots \quad 1.9c$$

subscript 'n' stands for neutrals.

The corresponding equations for the ionized species are,

$$\frac{dp}{dt} + \nabla \cdot (p \, V_j) = (P_j - L_j) M_j \quad \ldots \quad 1.10a$$
respectively.

Since the ionosphere is under the influence of electric and magnetic fields a combined set of dynamic and Maxwell's electrodynamic equations are necessary to represent the equatorial ionosphere. In most of the analysis the magnetic field $B$ used is earth's main field and hence we may take $\partial B / \partial t = 0$ and hence $\nabla \times E = 0$. i.e., the electric field is derivable from a potential function $\Phi(r,t)$, or $E = -\nabla \Phi$. Also in an ionized medium, very small charge differences create large electric fields. Thus a plasma must nearly exhibit charge neutrality. This implies, $\nabla \cdot J \approx 0$. Therefore the Maxwell's equations for the plasma are,

$$E = -\nabla \Phi \quad \ldots \quad 1.11a$$

$$\nabla \cdot B = 0 \quad \ldots \quad 1.11b$$

$$\nabla \times B = \mu_0 J \quad \ldots \quad 1.11c$$

$$\nabla \cdot J = 0 \quad \ldots \quad 1.11d$$

Now, to find out the steady state fluid velocity of each species, set the time derivative of the momentum equation for the charged species to zero and specify the force fields and pressure distributions. For the ionosphere, the gyrofrequencies of both the electrons and the ions far exceed their respective collisional frequencies. Hence, in the ionosphere for a collisionless regime the particles are moving at right angles to the electric field and the velocity is identical for ions and electrons and which is equal to,

$$V_j = E \times B / B^2 \quad \ldots \quad 1.12$$
It is seen that an electric field parallel to the magnetic field can easily move the ions and electrons along the field lines and an electric field perpendicular to the magnetic field will produce bulk plasma motion at right angles to both the electric and magnetic fields.

1.5 Equatorial F-Region Instabilities

Plasma instability phenomena occurring in the equatorial F-region ionosphere are grouped under the generic name Equatorial Spread-F (ESF). This term nowadays refers not only to the spread in range or frequency but also to all the processes which contribute to non-thermal F-region plasma scatter. In the coherent, radar scatter echoes the irregularity layer moves up or down with time rather periodically, and is occasionally interrupted by a period of intense backscatter signal which extends to very high altitudes. These towering, echoing features have been termed ‘plumes’. The large depletions of plasma in the F-region called `plasma bubbles’ and the plume structures are the main features of ESF as seen by the radars. The plumes can be considered as the upwelling of the plasma bubbles which are probed by ‘in situ’ measurements (Woodman and Lahoz, 1976; Rino et. al., 1981; Tsunoda et.al., 1982). The study of ESF which proceeded at snails pace for well over 50 years, received a boom with the advent of modern devices and techniques like high power radars, rocket soundings, satellite measurements and fast computers during the last quarter century.

Considerable work is done in explaining and modeling different physical processes which can give rise to the spread-F irregularities and plasma bubbles (Singleton, 1963; Balsley et.al., 1972; Ossakow & Chadurvedi, 1978; Edward, 1978; Booker, 1979; Tsunoda et al., 1979; Ossakow, 1981; Maruyama, 1988; Chou & Kuo, 1996; Maruyama, 1996; Sahai et al., 1998). The earliest of these theories is the Generalized Rayleigh Taylor (GRT) instability process originally proposed by Dungey (1956). This theory has been able to explain a number of properties of ESF (Farley et al., 1970). But gravity is not the only destabilizing influence of the equatorial ionosphere. The neutral wind and ambient electric field
can also be included. An eastward electric field will have a destabilizing effect and a westward field will have a stabilizing effect on the bottomside F-layer. The general condition for instability is that the electrodynamic drift caused by the ambient field be parallel to the plasma density gradient. Since the large scale neutral winds blow perpendicular to the vertically stratified ionosphere, they cannot contribute to the generation of ESF which requires a component parallel to the density gradient of the ionosphere. But during the course of any given observation period, we can consider a horizontal component of density gradient by assuming that the layer can be tilted with respect to the vertical. The GRT theory is to be modified taking into account the above considerations, to a generalized RT to account for the instability mechanism of equatorial ionosphere and it explained many of the observations on ESF (Tsunoda, 1981; Kelly et al., 1981). Based on linear and non-linear theories the possible contributing processes of ESF of different ranges of observed structure can be explained. The possible contributing processes are (Kelly, 1987) as,

- Gravity wave seeding and electrodynamic uplift (l > 200 km)
- Shear effects (200 km > l > 20 km)
- The generalized RT instability (0.1 km < l < 20 km)
- Low frequency drift waves (1 m < l < 100 m)
- Lower hybrid drift waves (l < 1 m)

To explain fully the morphology of ESF, one must include the diurnal, seasonal and solar cycle effects on the electric field, on the neutral density, temperature and wind patterns, and on the conductivities of E and F-regions. This is necessary to explain why certain seasons are preferred at certain locations for the occurrence of ESF and the hitherto question of the need of seed perturbations. The roles of neutral winds and electric fields in controlling and triggering ESF, and the nature and extent of E-region influence on the ESF are yet
to be studied in detail. With this view, such a study has been carried out and presented in the subsequent chapters.

1.6 Measurement Techniques

At any given frequency the upgoing radio wave penetrate a region of increasing electron density. The ambient electrons in the plasma are forced to oscillate in response to the alternating electric field impressed by the radio waves. This oscillation creates an additional electromagnetic field that advances the phase of the radio wave and retards its group velocity. Owing to the repulsion between like charges, an electron displaced from its mean position will attempt to vibrate about that position like a pendulum with frequency $f_p$ (known as plasma frequency) given by $f_p = \frac{9}{\sqrt{N_e}} \text{ Hz}$, where $N_e$ is the electron concentration per cubic meter. As the radio waves approaches the altitude at which its frequency becomes equal to the plasma frequency, an additional electric field begins to approach the amplitude of the incident field and the wave is slowed down and finally reflected. This property of the electromagnetic waves is the basic principle of different radio wave measuring techniques.

As noted, the pulse echo technique of Breit and Tuve (1926) was gradually improved by the development of a better transmitter and receiver that permitted the experiments to be performed at will over a wide range of frequencies. In the earlier days, echoes were photographed from an intensity modulated oscilloscope to obtain a plot of the height of the reflection versus the frequency of the sounder. Instruments capable of making such recordings automatically, are called vertical incidence sounders or ionosondes and such instruments are largely used to prepare large volumes of ionograms all over the world.

With the invention of modern computers, the ionosondes were modified to take advantage of the digital techniques. The modern ‘digital ionosondes’ are called dynasondes and were first described by Wright (1969). Another digital sounder for measuring the three dimensional motion, velocity, shape, size and lifetime of irregularities is the Kinesonde (Wright, 1969; Wright and Pitteway,
1979). Vertically transmitted frequencies above the plasma frequency penetrate through the ionosphere and hence ionosonde was not usable to gather data above the F-peak. If there is a dense E-layer, it can block the F-layer completely. In order to circumvent these problems, ‘incoherent scattering radars’ were developed which operates with frequencies greater than 50 MHz (Kelly, 1987). When plasma instabilities are present in the ionosphere, the amplitudes of the fluctuations in the medium can grow to values much greater than the thermal level. Such large fluctuations can be detected by coherent radars which are smaller than incoherent scatter radars. In this case the Doppler spectrum received, is representative of the phase velocity of non-thermal waves rather than of the bulk motion and temperature. Wave vectors of the fluctuations must be perpendicular to the earth’s magnetic field for the detection of instabilities. Coherent scatter can occur at all elevations at the magnetic equator but at higher latitudes the perpendicularity requirements place severe constraints on the location of the radar.

Another important RF technique for Ionospheric studies is the Trans-Ionospheric Sounding (TIS). It is a method which combines ground based and satellite ionospheric sounding so that information on the ionospheric structures is obtained from frequencies on both side of the penetrating frequency. TIS applies to radio wave frequencies at the boundary of the radio frequency penetration range. The high frequencies are not used in methods involving radio wave reflection such as vertical sounding, oblique incidence sounding and topside sounding from satellites. TIS combines the registration of TS ionograms using radio wave reflection at less than critical frequencies, with ionospheric signals propagating between the moving satellites and ground based stations at frequencies exceeding the cut off (Avdyushin et al., 1988). These, together with TS ionograms we obtain ionograms for the oblique incidence of signals passing the ionosphere called trans-ionograms.

With the launching of Canadian built Aloutte I satellite by NASA which is solely dedicated for the systematic exploration of the upper atmosphere down to the F-peak, the probing of the space started as an established technique for
ionospheric investigation. The launching of satellites opened the scintillation studies of radio waves using satellite beacons. The scintillation data will yield information of a number of irregularity parameters such as height, thickness, percentage deviation in density, spectral distribution and also the temporal variation of them.

Shortly after the launch of Alouette I, Canada and the United States entered into a continuing programme of satellite studies of the ionosphere [International Satellites for Ionospheric Studies ISIS]. These programmes are conducted cooperatively with countries other than USA and Canada with each participating country supplying necessary resources for its share of the programme, but having access to all the data produced.

Apart from satellites, the ionosphere is probed by balloons and rockets. Baver and Nagy (1975) reviewed the direct ‘in situ’ techniques used on sounding rockets and satellites to measure ionospheric parameters. Direct ‘in situ’ instrumentation is defined as an experiment which measures the parameters in the immediate vicinity of the vehicle carrying the instrument. The different instruments and measurement techniques are illustrated in this paper.

HF Doppler technique is an adaptation from the ‘phase path technique’ described by Findlay (1951) to measure the ionospheric movements. Thus in this method, the phase of the signal reflected from the ionosphere is compared with that of a local oscillator signal of high frequency stability. A beat frequency of a few hertz is produced and is recorded in a strip chart, magnetic tape or in a computer. It is then analyzed by standard spectral techniques. An advantage of this technique is that it permits the various components of the composite Doppler signal to be separated and identified. The HF Doppler radar of University of Kerala described elsewhere makes use of phase coherent receiver with quadrature channels to detect Doppler shifted received signal. The complex time series of the Doppler shifted signal can be analyzed to obtain the Doppler spectra of the received signal.
1.7 Scope of the Study

Most of the features of the equatorial ionosphere are the result of the orthogonality of the almost, horizontal geomagnetic field lines and electric fields threading the ionosphere in the vicinity of the dip equator. Even though many experiments and theoretical studies were carried out, the observations were not sufficient to understand fully the dynamics of the equatorial ionosphere. Immense work is yet to be done to verify the role of the various ionospheric parameters which contribute to the equatorial spread-F. For this, the measurement of various ionospheric parameters with different techniques at different locations is to be stressed.

The present work studies systematically the F-region at the magnetic equatorial station of Trivandrum (8.33° N, 77° E, dip 0.5° N) using HF Doppler radar. The F-region drift measurements were done with the spaced receiver configuration, with the intention of finding the east-west and north-south components of the plasma drift. The east-west component along with vertical drift determine the complete electric field vector while the north-south component yields the meridional neutral wind.

The history of ionospheric studies with special mention to the Indian scenario, the basics of ionospheric electrodynamics and experimental techniques for probing the ionosphere have been reviewed as part of the work. Zonal and meridional winds are the two mutually perpendicular components of horizontal winds in the equatorial ionosphere. A systematic attempt has been made to understand the nature of horizontal plasma drifts at the magnetic equatorial station, Trivandrum. The present work is also aimed at understanding the characteristic features of equatorial F-region electric fields. The final aspect addressed is the ESF. The ionosphere is a vital part of the solar terrestrial system and has great importance in space and terrestrial communication. Even though the basic mechanisms of the ionosphere appear to be known, surprises are possible in any living and active area of science like ionospheric science.