CHAPTER - I

INTRODUCTION

The equatorial ionosphere has many characteristic features some of which arise due to the presence of the earth's magnetic field which is nearly horizontal. The author has studied some of the special features of lower region of the equatorial ionosphere i.e. upto 180 kms.

The lower ionosphere is mainly due to the ionisation of the neutral particles through ultraviolet radiations, X-rays and particle radiations from the sun and the cosmic rays. Near the equator only particles with energies greater than 15 Bev can reach the lower ionosphere and hence the equatorial ionosphere is mainly due to ultraviolet radiations and X-rays from the sun. This makes the interpretation of the phenomena occurring near the equator much easier than that at high latitude.

The interaction of charged particles with the horizontal magnetic field leads to various geomagnetic and ionospheric phenomena, unique to this region. The enhanced conductivity at 100 km associated with the special magnetic field configuration at the equator results in a strong daytime equatorial electrojet current. Even during night time when electron density is comparatively very small a weak current flows in the reverse direction. In the equatorial E-region we encounter various types of plasma instabilities
which are difficult to simulate in the laboratory. This region can be effectively used to study some of the plasma instabilities not yet detected and explored.

The author has carried out a study of equatorial D and E regions over Thumba using a modified Langmuir probe. A plasma noise probe was developed to make in situ measurements of irregularities of sizes as low as 1.0 meter in the D and E regions of the ionosphere. Amplitudes as low as 0.05% were measured for small scale irregularities in the range 1 meter to 15 meters. This enables the study of irregularities spectrum. Some of these irregularities in scale size of 3 meters have been studied by other workers using backscatter techniques at Jicamarca, Peru, near the magnetic equator.

The following describes some of the important features of the lower ionosphere near the vicinity of the equator.

1.1 The equatorial D region: It is usually considered the lowest portion of the ionosphere and ranges in altitude from about 50 to 85 km. The region below 60 km is sometimes called the C region because of its cosmic ray origin. Over equator the C region is almost absent due to a large reduction in the high energy particle flux. In the D region the motion of the electrons is dominated by collisions with neutral particles giving rise to a large radiowave absorption. This absorption provides a powerful tool for making measurements
of the D region electron density by radiowave technique. It is generally believed that during solar quiet period the ionisation in the D region is produced due to ionisation of nitric oxide by Lyman alpha (1216 Å). However, during periods of increased solar activity the flux of kilo volt X-rays (2-8 Å) increases by an order of magnitude, while the Lyman alpha flux remains essentially constant. Above some level of activity it can be expected that the production of D region ionisation by solar X-rays will exceed the Lyman alpha nitric oxide contribution. At any given time however it is difficult to evaluate the relative importance of these two ionising sources because the nitric oxide concentration is not known with certainty.

1.1.1 D-region irregularities: D region irregularities have been observed by Clemsha (1963) during day light hours. As the neutral density is very large compared to electron density the dynamical properties of D region irregularities are governed by the motion of neutral constituents. Clemsha has observed that between 80 to 90 km altitude region there is no tendency for field alignment while there is a slight tendency for field alignment above 90 km. These irregularities are discussed in detail in the Chapter II.

1.2 The day time equatorial E region: The E region extends from 85 to 150 km. Unlike D region the radio wave absorption in this region is low as the collision frequency
of electron with neutrals is small. In E-region the electron density follows closely the \((\cos \phi)^{1/2}\) law where \(\phi\) is the solar zenith angle and is called a Chapman layer.

The equatorial E layer is similar to that of temperate latitude E region except the presence of electrojet current. The electrojet gives rise to irregularities which are not observed in the mid-latitudes. These irregularities are responsible for non blanketing type equatorial Es (Bowles and Cohen 1962).

1.2.1 The night time equatorial E region: During the night time the E region electron density as high as \(10^4\) ele/cc have been observed both over the coast of Peru (Aikin and Blumle, 1968) and over Thumba (Satya Prakash et al 1970) in the height range 95 to 115 km. A valley in 120 km region with electron density around \(10^2 - 10^3\) ele/cc has also been observed. Such high electron densities around 100 km can't be explained on the basis of scattered Lyman \(\alpha\) and Lyman \(\beta\) radiations (Ogawa et al 1966).

1.3 The equatorial electrojet: The equatorial electrojet is an enhanced current system within a narrow belt of a few degrees of the geomagnetic latitude. This enhanced current arises due to enhanced electrical conductivity in the 100 km region. In the presence of a primary east-west electric field and horizontal magnetic field directed northward, a vertical polarisation field is set up due to the disparity between the
electron and ion mobilities. This polarization field known as Hall field is responsible for enhanced conductivity.

The westward drift of electrons during day time is believed to reverse the direction during night time. The experimental evidence of the night time flow direction was given by Balsley (1966, 1969a, b).

During the early periods the primary experimental evidence for the existence of the equatorial current system was obtained from the observations of daily variation in the earth's magnetic field by ground based magnetometers, situated in the vicinity of geomagnetic equator. The direct measurements of the electrojet were carried out by Singer et al (1958) using rocket borne magnetometers. The extensive measurements for the vertical, latitudinal and longitudinal behaviour of the electrojet were carried out by many workers. [Haynard (1965), Davies et al (1966), Sastry (1968)]. Recent measurement of the current density at the height of maximum flow is \( \approx 5 \text{ amp/km}^2 \) over Thumba and \( \approx 10 \text{ amp/km}^2 \) over the coast of Peru.

1.3.1 Equatorial electrojet model: Sugiyama and Cain (1966) derived the electrojet model as the difference of current which will explain the deviations from the normal magnetic field. This is expressed in terms of 48 coefficients and the corresponding Legendre terms. Other related parameters being taken from standard atmospheric models.
The value of primary east-west electric field was calculated to be 2.4 mv/meter. In addition to that they have shown that conductivity values for Indian zone is lesser by 60% to that of American zone. This may explain the observed current density which is nearly twice over American zone as compared to Indian zone if it is assumed that primary east-west field is same for both the places.

Various problems of Sq current systems and the equatorial electrojet have been reviewed by Onwumechilli (1967). It was thought earlier that the electrojet is a simple intensification of the world wide Sq current system, near the geomagnetic equator. Recently OGBEHI et al (1967) have shown that all the experimental results can't be explained by this model of electrojet.

Untiedt (1967) introduced a model of equatorial electrojet involving meridional currents. This model yields stronger currents and gives larger width of electrojet compared to previous models.

1.4 The electric field in the equatorial E region: The electric field around 100 km altitude have been estimated from the measurement of the horizontal drift velocity of irregularities embedded in the equatorial electrojet (Balsley 1967, 1969b). Balsley suggests that during certain periods the velocity of the irregularities is a measure of electron drift velocity which in turn can be related to the east-west
electric field through the following expression given by Suguira and Cain,

\[ E_y \approx -10^{-6} V_e, \text{ Volts/meter} \]

A drift velocity \( V_e \) of electrons of the order of 300 m/sec will correspond to an electric field \( E_y = 0.3 \text{ m V/m} \).

The observations of Balsley (1969 b) show that during the night time the electron drift velocity is comparable to those during the day time and is of the order of 300 m/sec. This favours the theoretical calculation of Maeda et al (1963), that the driving electric field has comparable magnitude during the day time and night time. Although the direction of the field during the night time is opposite to that during the day time.

The electric field measurements carried out over Thumbe around 200 km altitude during evening twilight using Barium cloud technique. Haerendel et al (1968) gives the value of about 0.5 mV/meter for east-west field and 2.8 mV/meter for vertical field.

1.5 The equatorial electrojet irregularities: It has been realised for some time that certain scatter echo configurations noted on conventional ionograms near the vicinity of the equator were associated with the electrojet current variations, (Matshushita 1962). These configurations are due to irregularities embedded in the electrojet and are known as equatorial 'sporadic E'.
The irregularities of sizes 3 meters have been studied by backscatter radar at Jicamarca (dip 1°N). Rocket borne Langmuir probes and plasma noise probe were flown over Thumba to make in situ measurements. The sizes studied lie in the range 1.0 to 15 meters (Satya Prakash et al 1968, 1969 a, 1969 b, 1970). As shown by backscatter radar study, these irregularities have been found to be associated with field aligned plane waves having their wave fronts oriented parallel to magnetic field lines and velocity vector perpendicular to it, (Cohen and Bowles 1967).

These waves are presumed to be of small amplitude, so that many waves moving in variety of directions and having a variety of wave lengths could be present in the same volume simultaneously. The density amplitudes of the order of 3% has been estimated by Weinstock (1968) from the coherent backscatter measurements from these irregularities.

Two types of irregularities are known to exist in the equatorial electrojet (Balsley 1967). Type one which occurs when electron drift velocity exceeds the ion thermal velocity. Farley (1963) developed two stream instability theory to explain their production mechanism. While the type two exist during most of the periods.

1.6 Necessity of the present study: Many of the phenomena in the lower ionosphere over equator have not been
completely understood. Some features which require further study and in situ measurements are given in the following text.

In addition to those measurements carried out by rocket borne probes, it becomes necessary to study the disturbances produced by a moving rocket if the results of the in situ measurements are to be interpreted correctly.

1.6.1 The equatorial E region irregularities: The equatorial E region irregularities have been studied at Jicamarca for quite some time with backscatter radar. Only recently in situ measurements of these irregularities were made by Satya Prakash et al (1969 a) over Thumba. The radar measurements have shown that strong irregularities are present in the 100 km region most of the time. These are plane waves with their wavefronts mostly aligned along the magnetic field lines. The horizontal movements of these irregularities depend on the time of the day and have been observed to be in westward direction during day while mostly in eastward direction during most of the night time, (Balsley 1969 b). The radar operating at a single frequency resolves the one fourier component of irregularities whose sizes are about half the wavelengths of exploring e.m. wave. The above conclusions are based on the study of scale sizes of the order of 3 m. The irregularities of
different scale sizes can't be studied by the radar technique, as many radars operating at different frequencies would be required for such a study. Even to study one scale size the backscatter technique is quite complicated. If various sizes are to be studied then the system will become too cumbersome and expensive.

The spectrum of these waves and its relationship with other ionosphere parameters has now been studied with rocket borne probes in order to examine their production mechanism. Plasma noise probe incorporated with Langmuir probe has proved very useful tool for such studies and is complementary to the backscatter radar studies. While the rocket borne plasma noise probe enables the study of the spectrum of the irregularities, the coherent backscatter radar gives the direction of the motion of irregularities and the large scale structure.

The presently known mechanisms responsible for the electrojet irregularities are the cross-field instability, the two stream instability and the plasma turbulence. The conditions and the time at which different irregularities are likely to operate are as follows.

1. The two-stream instability operates when the velocity of the stream of electrons exceeds that of the ion acoustic waves in the medium. This condition is likely
1. The present knowledge of these irregularities is based on the ground based measurements. However in situ measurements of the secondary irregularities like those discussed in this thesis will greatly help in establishing the importance of various mechanisms responsible for the generation of these instabilities.

A few rocket borne plasma-noise probes have been flown from Thumba during different periods of the day and night. The spectrum of ionospheric irregularities have been studied by the author in the scale size \( \frac{V_R}{f} \) where \( V_R \) is rocket velocity and \( f \) is the frequency, ranging from 70Hz-1KHz.

1.6.2 D region irregularities: A few ground based experimental measurements suggest that D region irregularities can give rise to the scattering of V.H.F (30 MHz to 100 MHz) radio wave, (Davies 1965). Due to small electron densities in this region and relatively large absorption, the D region irregu-
larity measurement with ground based radio techniques are quite difficult. Langmuir probe and plasma noise probe are recently employed to study D region irregularities over Thumba by the author, (Satya Prakash et. al 1969 a, 1970). Thus the study of D region irregularities and their spectrum will reveal about the nature of forces responsible for D region irregularities and will indirectly help in locating the region where such forces are operative.

1.6.3 The equatorial E region: Unlike the study of the E region at high latitude the study of the equatorial E region can't be carried out with the conventional ground based techniques. This is mainly due to the presence of the equatorial type of $E_s$ for most of the time of the day and night. The in situ measurements are therefore necessary for the study of E region.

One of the problems which still remain unsolved is the night time source of ionization for the E region. Electron densities as high as $10^4 \text{ electrons/cc}$ around 105 km have been observed both at high latitude and at equator. Also a valley around 120 km with an electron density as low as $10^2/\text{cc}$ has been observed in both the regions.

These observations indicate that a similar mechanism is operative during night time hours over the equator as well as over the mid-latitude. The night time fluxes of scattered Lyman alpha and Lyman beta radiation can't account
for the observed high electron density. Vertical downward drift from the F region into the E region has also been suggested as a possible mechanism. However, this mechanism has not been studied on a quantitative basis due to lack of sufficient data (Aikin & Blumle 1968, Smith 1966, Satya Prakash et al 1970).

During evening twilight periods a valley around 125 km just starts developing and occasionally an E₂ layer is also observed around 135 km (Satya Prakash et al 1968). The above authors pointed out that this layer is due to high electron temperatures and some more studies are necessary to establish the source of such high electron temperatures. It was also pointed out that the higher electron temperature in this region is likely to be due to electric currents present in the altitude region during evening twilight.

Electron temperature measurements over equator are very few, (Satya Prakash et al 1968, 1969). Electron temperature measurements are necessary at different periods of the day as well as during night to study the nature of heat sources.

1.6.4 Study of the disturbances produced by moving rocket or satellite: The interaction of a moving body with a low density plasma (ionosphere) needs to be studied if the results of measurements by a
variety of direct measurement devices on space vehicles are to be correctly interpreted. This problem has been the subject of number of theoretical studies. On the other hand, ground based measurements of these irregularities have yet been carried out. Singer and Walker (1965) Alpert et al (1965) have carried out theoretical investigation of the effects produced by moving rocket or satellite in the earth's ionosphere. However, no adequate theory is yet available which can explain the nature of these disturbances taking into account the rocket velocity, the body potential and body dimensions. Gurvich and Pitovskiy (1965) have shown that in the wake region of moving satellite ion acoustic waves are generated with frequencies lying in the range 0.1ωc to 1.0ωc where ωc is the ion plasma frequency in radians.

The first systematic measurements of these ion acoustic waves produced by a moving rocket using a Langmuir probe and plasma noise probe, in the frequency range around 1 KHz, during evening twilight hours were made in the range 155 to 175 km by Satya Prakash et al (1969 a). It is necessary to study the spectrum of these waves and thus correlate the experimental results with the existing theories, for various probe geometries and probe potentials. The author has studied the spectrum of these waves by rocket borne Langmuir probes and plasma noise probes. These oscillations
were observed near rocket apogee when the probes were able to record these fluctuations due to the subsonic motion of the rocket. The results are presented in this thesis.

The study presented in this thesis is based on the following measurements carried out over Thumba using modified Langmuir probe and plasma noise probe.

1) D region electron density profile and irregularities during afternoon hour and evening twilight hours.

2) The electron density and the electron temperatures of equatorial E region at midday evening and midnight hours.

3) The spectrum of the electron density irregularities in the 100 km and 145 km altitude region during midday, evening and midnight.

4) The spectra of plasma ion acoustic waves due to disturbance from the rocket motion observed near the rocket apogee.

1.6.5 Synopsis of the thesis: The thesis is organised in 7 chapters. The first chapter describes some of the special features of equatorial ionosphere between 50 to 150 km region.

Pertinent mechanisms for the generation of equatorial electrojet irregularities are treated in Chapter II. The cross-field instability, the two-stream instability and the
plasma turbulence in a collision dominated low density magnetic ion media are treated in some detail.

In Chapter III the various techniques to study lower ionosphere are described. The basic principles of Langmuir probe in regard to the electron density and the temperature measurements are discussed. A brief review of various forms of Langmuir probe is also given. The principles of the plasma-noise probe capable of studying the irregularities of scale sizes as low as one meter and amplitude as low as 0.05% of background electron density are described. The disturbances created by moving rocket are also discussed.

Chapter IV deals with the development and instrumentation of modified Langmuir probe and Plasma noise probe. Various circuits including sweep circuit, electrometer amplifier, audio frequency amplifier, subcarrier oscillators and band-pass filters are described. The prelaunch checking and testing of the whole payload are described in detail. The results of electron density, electron temperature and Plasma irregularities are presented in Chapter V.

Chapter VI includes discussion of results described in Chapter V in relation to presently known theories. The inadequacies of the presently known theories have also been discussed. In the last Chapter VII, conclusions drawn from the above studies are presented.