PART II

STUDIES ON EQUATORIAL F REGION PLASMA DRIFTS
CHAPTER V

THE HF DOPPLER SYSTEM FOR F REGION PLASMA DRIFT MEASUREMENTS

5.1. Introduction

5.2. Important Techniques for Ionospheric Drift Observations

5.3. The HF Doppler System

5.3.1. Principle of the HF Doppler System

5.3.2. Transmitting system

5.3.3. HF Phase coherent receiver

5.3.4. Frequency synthesizer

5.4. Statement of the Present Study
5.1. Introduction

The study of plasma motions in the equatorial ionosphere assumes special significance as they are intimately connected to many ionospheric phenomena such as the equatorial anomaly, the maintenance of nighttime ionosphere, the nighttime enhancements in total electron content as well as equatorial spread F and scintillations. The plasma drift measurements conducted in the F region at the magnetic equator permit to resolve the electrodynamic and neutral wind induced components of the plasma motion because of the unique magnetic field configuration. While the field aligned plasma motion provides the NS component of the thermospheric neutral wind, the transverse EW and the vertical components determine the total electric field vector. As such, a clear understanding of the plasma drifts in the equatorial region is essential for the proper understanding of the ionospheric dynamics at low latitudes. The following sections present (1) the important techniques used for ionospheric drift observations (2) a detailed description of the HF Doppler system used in the present study and (3) a statement of the present investigation.
5.2. Important Techniques for Ionospheric Drift Observations

**Ionosonde technique:** This is based on the pulse sounding technique of Breit and Tuve (1925), which is still a basic tool for ionospheric research. An ionosonde can be viewed as an HF sweep frequency pulsed radar which receives the signal from a height where the transmitted frequency matches the electron plasma frequency. A detailed description of the conventional ionosonde technique and data analysis were presented by Rishbeth and Garriott (1969). Ionograms were conveniently used to determine the vertical plasma drift velocity in the equatorial F region during the evening hours (Abdu et al., 1983; Sastri, 1984). At these times the measured vertical drift velocity has been shown to correspond to the actual plasma drift velocity provided the reflection level is above 300 km (Bittencourt and Abdu, 1981). In addition to the vertical plasma drifts, it is possible to study the horizontal motions of the large scale ionospheric disturbances using widely spaced ionosondes (eg., Cooper and Cummack, 1986). The new generation digital ionosondes, which allow computer analysis of the ionograms have been proven to be very valuable for studying ionospheric irregularity drifts (eg., Argo and Kelley, 1986).
HF phase path and Doppler techniques: These techniques involve the measurement of changes in the phase path $P$ of a radio wave reflected from the ionosphere. The phase path is defined as $P = \int_{p}^{\infty} \nu \, ds$ where $\nu$ is the phase refractive index and $p'$ is the ray path. The derivative of $P$ with respect to time provides a measure of Doppler frequency shift of the received signal. Two different techniques have been developed relating to phase path and Doppler measurements. The first one proposed by Findlay, (1947) and adopted by many workers (e.g., Findlay, 1951; Reddi and Rao, 1967, 1971; Krishna Murthy et al., 1976; Subba Rao and Krishna Murthy 1983) uses pulse transmission and can measure simultaneously the changes in phase path and group delay. The second technique, making use of continuous waves transmitted from a distant or nearby stable frequency transmitter, can measure the Doppler frequency shifts (Watts and Davies, 1960; Davies et al., 1962; Chan and Villard, 1962; Waldock and Jones 1986). The HF phase path and Doppler techniques have contributed greatly to the information obtained on ionospheric motions, particularly on travelling ionospheric disturbances (e.g., Reddi and Rao, 1971; Waldock and Jones, 1986).

Spaced-receiver technique: When a radio wave is reflected from an irregular ionosphere, it produces an irregular
diffraction pattern or shadow pattern on the ground. If the irregular ionosphere is moving, there will be corresponding motion of the diffraction pattern on the ground as well. By observing the amplitude fading of the received signal at a number of points on the ground, it is possible to derive information on the horizontal drift and spatial properties of the irregularities themselves. The simplest and earliest method of measuring horizontal plasma drifts was developed by Mitra (1949). This method is based on the principle of similar fades of the ionospherically reflected signals obtained using three spaced-receivers arranged about one wave length apart in the configuration of a triangle. For an accurate determination of the horizontal drifts, the fading records are to be subjected to a correlation analysis (Briggs et al., 1950; Briggs and Spencer, 1954; Phillips and Spencer, 1955). The spaced-receiver technique has been used by several investigators to measure the horizontal ionospheric plasma drifts (e.g., Chandra et al., 1970; Rastogi et al., 1972).

**Backscatter radar technique:** The earth's ionosphere has been extensively studied with radar systems operating at frequencies of 40 MHz and above. Since the transmitting frequencies are appreciably above the maximum plasma frequency of the ionosphere, most of the transmitted power
is lost in space. Some small fraction of the energy is reradiated by free electrons in the ionosphere. This is the basis of incoherent or Thomson scatter which has been discussed in detail by several authors (e.g., Evans, 1969; Farley, 1971). The measurement of the total scattered power spectrum of the incoherently scattered signals provide information on electron density, electron and ion temperatures, ion composition and plasma drifts. Much of the equatorial plasma drift measurements come from the 50 MHz Jicamarca incoherent scatter radar. The experimental procedure is discussed in detail in a number of papers (Woodman and Hagfors, 1969; Woodman, 1970, 1972). A consolidated review of the Jicamarca drift observations may be found in a review by Fejer (1981).

Radar interferometry and ion cloud release techniques: This technique by Kudeki et al., (1981) has been proved to be a suitable method for the measurement of the plasma drift velocity. In this technique two spaced antennas were used to receive scattered signals from the ionospheric irregularities. This technique was used to measure the East-West drifts in the electrojet region (Farley et al., 1981) as well as in the F region (Kudeki et al., 1981) in the equatorial station of Jicamarca.
The technique of rocket releases of barium vapour to generate artificial ion clouds at ionospheric heights has been proved to be a powerful means to map ionospheric drifts (eg., Valenzuela et al., 1980). These experiments, however, were restricted to narrow time slots around sunrise and sunset hours since the commonly employed optical diagnostics can make observations on the clouds only at these times (eg., Haerendel et al., 1967; Valenzuela et al., 1980; Raghava Rao et al., 1987). The phased array radar described by Thome et al., (1977) could be used to study the motion of ion cloud during other times of the day also, since it does not suffer from the limitations of optical system.

5.3. The HF Doppler System

In view of the importance of plasma drifts to many F region phenomena at the magnetic equator an HF Doppler system has been developed to measure them at the equatorial station of Trivandrum (8.5°N, 77°E, mag. dip 0.9°S). The system is designed to operate in the spaced-receiver mode. The principle and detailed description of the constituent units of the system are presented in the following subsections.

5.3.1. Principle of the HF Doppler system

The HF Doppler radar consists of a pulse
transmitter, a bank of phase coherent receivers, a frequency synthesizer, the associated antennas and recording units. The block diagram of the system is given in figure 5.1. All the frequencies required for the system are generated by a master frequency synthesizer which has a long term frequency stability of better than one part in $10^7$. A 5.5 MHz r.f. wave is modulated by a transmitter pulse having a pulse width of 100 μs and a pulse repetition frequency of 50 pps in the modulator unit. The resulting modulated r.f. pulse is fed to the transmitter, in which the pulses undergo various stages of amplification. The final output is a pulse with a peak power of about 3 kW which is fed to a 600-μ transmission line. The vertically transmitted pulse signal gets reflected from the ionosphere and is received by a half wave dipole, the output of which is fed to the phase coherent receiver through a coaxial cable. The received signal is 5.5 MHz $\pm \Delta f$, where $\Delta f$ is the Doppler frequency. The receiver gives two quadrature channel outputs, $A \cos \phi$ and $A \sin \phi$, where $A$ and $\phi$ are instantaneous amplitude and phase of the received signal. The final quadrature outputs from the receiver are the Doppler signals of low frequency which are fed to a multichannel strip chart recorder as well as to a sense detector that resolves the sign of the Doppler. A gate delay pulse derived from the frequency synthesizer is fed to a delay counter which counts and displays the delay
Figure 5.1. Block diagram of the HF doppler system in spaced-receiver configuration.
with a resolution of 10 μs. From the outputs recorded on strip charts, the amplitude and phase of the signal and their variations with time can be computed.

5.3.2. Transmitting system

The Doppler system employs a wideband pulse transmitter of C₄ type (Parameswaran, 1978), the block diagram of which is shown in figure 5.2. The transmitter can operate over a frequency range of 2 to 20 MHz. The input to the transmitter is a pulse modulated HF signal of 5 V peak to peak, 100 μs width and 50 Hz PRF. The pulsed HF is amplified successively by a preamplifier, an intermediate low power amplifier and a final push-pull configured high power amplifier feeding its output to the transmitting antenna. All the amplifiers are keyed to the transmitter pulse and operate only during the pulse duration. The low level TTL keyer pulse of 5 V is amplified to 120 V in the transmitter before feeding to the various amplifier stages of the transmitter. The transmitting antenna is a three element folded dipole at a height of λ/4 from the ground. The balanced r.f. output (2.5 kW) of the transmitter is fed to the antenna by an open parallel wire feeder line of 600 Ω impedance.

The preamplifier forms the first unit in the transmitter system and consists of three stages of cascaded
Figure 5.2. Block diagram of the pulsed HF transmitter
amplifiers, with the last two stages being keyed. The first two stages make use of 6A67 tubes and the last stage, BEL 125 tube. Necessary keying pulses, derived from the keyer unit, are given at the control grids of the respective tubes. The keyer unit, which supplies all the necessary keying pulses as needed by the respective units, is a conglomeration of cathode followers deriving their input through a common signal bus activated by a pulse amplifier stage. The initial stage of the keyer unit is a pulse amplifier using 6SJ7 with a plate supply of 600 V. The input pulse to this stage is derived from the frequency synthesizer. To supply the necessary parallel inputs to the succeeding stages of cathode followers, a current amplifier or a cathode follower is incorporated. The cathodes are energized with -600 V, whereas the plates of the first two stages are earthed. Hence the output swing can go up to -600 V, and as this is too much for the preamplifier driver, a voltage dropping resistor is included so that the output of the first two cathode followers is limited to -120 V. The remaining stages are identical except that their plates are terminated with 250 V, whereas cathodes are at -600 V. The control grids of these cathode followers receive their keying intelligence from main bus which is driven by the cathode follower of 6J5. Potentiometers are employed to adjust the input levels to the keyer tubes, thus enabling
control over the keying pulse amplitude. The outputs of the keying stage are taken across their respective cathodes in order to realize full cathode swing.

The pulsed output of BEL 125, the last stage of the preamplifier unit, appears at the control grid of the succeeding stage of the intermediate amplifier implemented by 4 PR 60 B. Here also, the control grid is excited by the keyer. It is actually biased well beyond cut off during transmitter 'off' period and is brought out to active region during the 'on' period. The plate circuit has a peaking coil to compensate for the output capacity of the tube on the high frequency side. The output of this driver stage is capacitively coupled to the final amplifier unit.

The final power amplifier stage employs 4 PR 60 B tubes in push-pull combination. But the input to the final amplifier is derived from the single ended driver stage. So the output from that tube is split into two, one being capacitively coupled to one end of the antenna, the other the cathode bifilar wound choke and the ground. Thus the first tube activates the second tube by energising the cathode choke whereas both the control grids are being keyed simultaneously. The plate circuit of the second is also capacitively coupled to the other terminal of the antenna thus yielding a balanced output.
Specifications of the Transmitter

Frequency : 2 to 20 MHz
Pulse length : 100 us
Pulse repetition rate : 50 pps
Maximum output peak power : 3 kW
Input keying pulse amplitude : 5 V
Input RF pulse amplitude : 5 V (peak to peak)
Output impedance : 600Ω (balanced)

5.3.3. HF Phase coherent receiver

The Doppler system uses HF phase coherent receivers (Balan et al., 1979). The receiver is phase coherent in the sense that it is in phase coherence with the transmitter; that is, all the receiver injection frequencies and transmitter frequencies are synthesized from the same frequency standard. The block diagram of the receiver is given in figure 5.3.

Depending upon the ionospheric conditions, the receiver input signal strength may vary from a few hundred microvolts to a few millivolts. In order to compensate for this variation, a panel controlled attenuator which goes upto 40 dB in steps of 10 dB is introduced. The high frequency signal (HFS = f₀ +Δf) is mixed with a local oscillator frequency of (f₀ - 500 kHz) in a converter with a balanced configuration using an IC, CA 3028. The output of
Figure 5.3. Block diagram of the HF space coherent receiver
This mixer is centered at 500 kHz IF with 20 kHz bandwidth. This IF is amplified in an IF amplifier using CA 3028 in a differential configuration and is split into two separate balanced outputs in the secondary of the IF transformer to attain quadrature detection. The IF amplifier attenuation can be varied by 20 dB by means of a panel mounted switch. Each balanced output is mixed with a L.O. frequency of 500 kHz in a product detector using an IC type MC 1496. The two L.O. frequencies of 500 kHz each differing in phase by 90° are obtained through the digital division on a source frequency of 2 MHz using a TTL dual JK master/slave flip-flop of type 7473N. The output of the product detector is coupled to the next stage through a balanced-to-unbalanced amplifier using type 741 IC. A 10 kΩ trimmer potentiometer is introduced at the input of the balanced-to-unbalanced amplifier so that the gains of the two quadrature channels can be adjusted to be identical.

The next stage is a third order low pass active Butter-Worth filter using μA 747 IC. The cut-off frequency of the filter stage is 20 kHz and beyond 20 kHz the output decreases at the rate of 18 dB per octave. The filtered output is fed to a sample-and-hold (S/H) circuit through a voltage follower using 747 IC. The S/H contained an FET input op-amp of type SE 8007. The sampling gate is a 10 µs pulse occurring at the same rate as the transmitter PRF. The
quadrature outputs of the receiver are simultaneously sampled and held for the inter-pulse period. The two quadrature channel outputs provide as function of time the phase and amplitude of the received signal. In practice, the Doppler is obtained mostly by counting the number of cycles on either of the channels for every few seconds of the recorded data. The sense of the Doppler is determined by means of a sense detector and often cross-checked by examining few samples of the recorded quadrature outputs.

The gain and phase characteristics of the two channels of the receiver have been checked by feeding a test signal whose frequency was adjusted to provide a very low frequency (2 to 5 Hz) output signal. The outputs of the two channels are found to be very nearly in phase quadrature and almost equal in amplitude. Whenever necessary, the trimmer potentiometers provided at one of the amplifier stages can be used to adjust the gains of the two channels to be identical.

Receiver specifications:

Supply voltage : +15 V dual
Signal attenuator : 40 dB in steps of 10 dB
Overall gain of the receiver : 80 dB
Maximum output level of active LPF : 2 V (peak to peak)
IF amplifier step-attenuation : 20 dB
Signal-to-noise ratio: 20 dB for the CW input of 0.1 mV (RMS)

Input impedance: 50 ohms

Output impedance: 50 ohms

5.3.4. Frequency synthesizer

The HF Doppler system is based on the principle of phase coherence between the transmitter and the receiver. The desired phase coherence is accomplished by deriving all the signal frequencies including timing pulses required by the system from the same master oscillator source. The basic source from which all the signals are synthesized is a 10 MHz crystal oscillator.

The block diagram of the frequency synthesizer and timing pulse generator (described in details by Reddi et al., 1980) is shown in figure 5.4. The output of the 10 MHz crystal controlled oscillator is frequency divided to get 5 MHz, 2 MHz, 0.5 MHz, 100 kHz, 50 kHz, 5 kHz, 0.5 kHz and 50 Hz. Logic gates, in conjunction with the last two decade scalers giving 500 Hz and 50 Hz, provide the transmitter keyer pulse and the RF gating pulse. The keyer and RF gating pulses occur at the same time but are of opposite polarity. They are of 100 µs duration with a PRF of 50 Hz. The carrier and the local oscillator signals (5.5 MHz and 5.0 MHz CW) are derived from 5 MHz and 0.5 MHz square
Figure 5.4. Block diagram of the frequency synthesizer and timing pulses generator
waves. 5 MHz CW is obtained by filtering the 5 MHz square wave and 5.5 MHz CW is obtained by mixing 5 MHz and 0.5 MHz square waves in a mixer. The output of the mixer is further filtered and amplified by a tuned amplifier.

Any desired frequency other than the 5.0 or 5.5 MHz described here can be used as the operating frequency for the transmitter by generating the required frequencies for the transmitter and the receiver local oscillator by filtering the available frequencies of square waves or suitably adding or subtracting them in conventional mixer stages. Some of the frequencies can be generated by frequency multipliers using harmonic generation and filtering technique.

The quadrature channel outputs, $A\cos \phi$ and $A\sin \phi$, from the receiver are recorded either on an Adept or an Encardio-Rite four channel strip-chart recorder. The Adept and Encardio-Rite recorders have selectable multiple speeds ranging over 2 cm - 10 cm/min and 12 cm - 60 cm/min respectively.

5.4 Statement of the Present Study

The following two chapters deal mainly with the F region plasma drift observations conducted at the equatorial station of Trivandrum by using the HF Doppler
system described above. Chapter VI gives a comprehensive picture of the day-to-day, seasonal, solar as well as magnetic activity variations of the evening vertical plasma drift measurements covering the important evening pre-reversal enhancement period. Preliminary observations of vector plasma drifts for three successive days are also included in this chapter. Chapter VII deals with the simultaneous HF Doppler and ionosonde observations made at Trivandrum and Kodaikanal (10°14'N, 77° 28'E dip 3.5°N) respectively, with a view to examining the relative importance of the various factors such as the height of the F layer, vertical drift velocity and the electron density scale length for the onset of equatorial spread F (ESF).