Chapter 2
Experimental Setup and Other System Description

2.1 Introduction

In the present thesis the amplitude scintillation records of geostationary INMARSAT and FLEETSATCOM satellite signal are analyzed for a study of the long term L-band and VHF amplitude scintillations from Kolkata (22.58°N, 88.38°E geographic; 32°N magnetic dip) over a complete solar cycle 1996-2006. Amplitudes of the L-band carrier signal (1537.528 MHz) from INMARSAT (64°E) (350km-subionospheric point 21.08°N, 86.59°E geographic; 28.74°N magnetic dip) and VHF carrier signal (244.155 MHz) from FLEETSATCOM (72°E) (350km-subionospheric point: 21.10°N, 87.25°E geographic; 28.65°N magnetic dip) have regularly been recorded at the Ionosphere Field Station (IFS) of the University of Calcutta at Haringhata, 50km north of Kolkata, since 1990 and 1980 respectively. Simultaneously, the Signal-to-Noise Ratios (SNR) of the L1 (1.6 GHz) transmissions from the GPS satellites are monitored at Kolkata since 1994. Ion density data of DMSP (Defense Meteorological Satellite Program) satellites are also used in the present thesis to find out the global variation of ion density on a given evening. Ionosonde records of Trivandrum (8.5°N, 77°E geographic) are also studied to find the maximum height of the F layer near the magnetic equator during ESF and non ESF days. Total Electron Content (TEC) data obtained from dual frequency GPS receivers under the program GAGAN (GPS Aided Geo Augmented Navigation) are used to study the day to day variability of TEC from any station. For ESF observation during geomagnetically quiet and as well as for disturbed days, radar backscattered data of Gadanki, Tirupati (13.5° N, 79.2° E, 6.3° N mag lat) are analyzed in this thesis.

Brief discussions on the satellites and the receiving systems are given in the following sections:

2.2 INMARSAT Satellite

INMARSAT (International Maritime Satellite Organization) is an international telecommunications company originally operating as an intergovernmental organization established in 1979. INMARSAT currently operates a global satellite system which is used by independent service providers to offer an
unparalleled range of voice and multimedia communications for customers on the move or in remote locations. The INMARSAT satellites are located in geostationary orbit 22,223 miles (35,786 km) out in space. Each satellite covers up to one third of the Earth's surface and is strategically positioned above one of the four ocean regions of Atlantic Ocean Region – East (AOR-E), Pacific Ocean Region (POR), Indian Ocean Region (IOR), Atlantic Ocean Region – West (AOR-W) to form a continuous 'world-wide web in the sky'. Every time a call is made from an Inmarsat mobile satellite it is beamed up to one of the satellites. There are 3 series of INMARSAT satellites, INMARSAT-2, INMARSAT-3 and INMARSAT4. The amplitude of INMARSAT 3F1 (Figure 2.1) signal is used for the present research work.

![Figure 2.1: INMARSAT-3F1 satellite](image)

The communications payload of INMARSAT-3 operates in the C- and L-band portions of the radio spectrum. The tremendous advantage of the INMARSAT-3 satellites are their ability to concentrate power on particular areas of high traffic within the particular area of the earth. Each satellite utilizes a maximum of seven spot beams and one global beam. The satellites produce up to 48 dBW of EIRP (Effective Isotropic Radiated Power), a measure of how much signal strength a satellite can concentrate on its service area.

### 2.2.1 System set up for recording 1537 MHz of INMARSAT satellite signal

L-band (1537.528 MHz) signal from geostationary INMARSAT is received regularly with a system consisting of a 3 meter dish antenna (Figure 2.2) with a helical feed, preamplifier, and an ICOM wideband R7100 communication receiver. The signal is fed to a Mini-Circuits low noise, broadband, linear pre-amplifier connected to the helix. The Pre-amplifier operating in the 1200-1700 MHz range with a maximum noise figure of 1.5dB and gain of 20dB amplifies the signal before feeding it to the receiver through the Amphenol RG-9B/U coaxial cable.
The power of the pre amplifier is given by a DC 15 Volt power supply. The receiver is operated in AM mode. The detected output of the receiver is simultaneously recorded on a PC-based data acquisition system and a two channel Evershed-Vignole strip chart recorder. The receiver is calibrated at least once a week by a Hewlett Packard signal generator (model HP8648C) following Basu and Basu (1989). The dynamic range of the receiver is ~25 dB, and the sampling frequency is 20 Hz. The block diagram of the receiving system is shown in Figure 2.3.

The sample scintillation patches at L band signal of INMARSAT satellite recorded a) by strip chart recorder b) digitally are shown in the lower panels of Figure 2.4 and Figure 2.5 respectively. The dc impedance of the recorder is 2.2 kΩ. It is operated at a speed of 12 inches/hr. The response time of the pen is 0.1s. Simultaneously digital data recording was started in 1990. The Data Acquisition
System consisted of a PCL-208 A/D Card and a PC-386 machine. The card has 16 single ended input channels with analog input ranges of 0-10V. An industrial 12-bit successive approximation converter (ADC674) was used to convert analog inputs. The maximum A/D sampling rate was 60 kHz in Direct Memory Access (DMA) mode. The detected L-band carrier was connected to the input channel# 0 of the card and was recorded at a 20Hz sampling frequency.

The card was supported by the integrated data acquisition software LABTECH NOTEBOOK with real time data analysis, display and process control from Laboratory Technologies Corp. The output files of the software provide voltage (V) for the carrier amplitudes and the corresponding time (hh:mm:ss.000) for each channel. The PC-386 machine with LABTECH NOTEBOOK was in operation till 2005. After that it was upgraded to Pentium IV with a modified version of Advantech data acquisition GEN1DAQ software USB-4711A. It consisted of a true plug and play data acquisition module. It had 16 analogue input channels with a maximum sampling rate of 100kS/sec and the resolution of 12 bit. The input impedance of the hardware
was 2MΩ/5pF and the input ranges of the voltage were ±10V, ±5V, ±2.5V, ±1.25V and ±0.625 V, out of which ±10volt range was selected for data acquisition. The sampling rate was chosen as 20 Hz and the output files were generated for every 10 minutes. From April, 2009 another data logging system Velleman kit-4 channel recorder/logger (K8047) is installed, replacing the previous one. It consists of four DC coupled input channels so that at a time four different signals can be logged. The hardware has one USB port to connect it to the computer. The input resistance of the recorder is 1 Ω and its maximum sampling frequency is 100 Hz.

2.3 FLEETSATCOM satellite

FLEETSATCOM (Fleet Satellite Communications) is a constellation of American military satellites in geostationary orbit which, together with LEASATs (Leased Satellites), supported worldwide, ultra-high-frequency (UHF) communications between naval aircraft, ships, submarines, and ground stations, and between the Strategic Air Command and the national command authority network. It became fully operational in January 1981 and was gradually replaced during the 1990s by satellites in the UFO (UHF Follow-On) series. Each spacecraft has 23 communications channels and 12 transponders in the ultra-high and super-high frequency bands. Ten of the channels are used by the Navy for worldwide communications over land, sea and air. Twelve of the channels are used by the Air Force as part of the Air Force Satellite Communications System for command and control of nuclear capable forces. The minimum specified EIRP for the narrowband 5 kHz channels is 16.5dBW. During 1980-1992 FLEETSATCOM-2 was positioned in the Indian Ocean (72°E). Later, during 1996, FLEETSATCOM-1 (Figure 2.6) launched in 1979 was placed at 72°E. In the present work carrier amplitude measurement from the transmission of the FLEETSATCOM-1 narrow band channel with center frequency 244.155MHz is used.

Figure 2.6: FLEETSATCOM 1 satellite

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2.3.1 System set up for recording 244 MHz signal

VHF (244 MHz) signal from geostationary FLEETSATCOM is received regularly with a system consisting of a Yagi-Uda antenna and an ICOM wideband R7100 communication receiver since 1981. The linearly polarized antenna (Figure 2.7) has 11 elements with one folded dipole, two reflectors and eight radiators. The signal received by the antenna is fed to the receiver through the Amphenol RG-9B/U coaxial cable.

![Yagi-Uda antenna for receiving VHF carrier signal from FLEETSATCOM satellite.](image)

The detected output of the receiver is simultaneously recorded on the PC-based data acquisition system and the strip chart recorder. This receiver is also calibrated at least once a week by a Hewlett Packard signal generator (model HP8648C) following Basu and Basu [1989]. The dynamic range of the receiver is ~25 dB, and the sampling frequency is 20 Hz.

![Figure 2.8: Block Diagram of VHF data recording system](image)
The block diagram of the receiving system is shown in Figure 2.8. The sample Scintillation patches of VHF signal transmitted from FLEETSATCOM satellite a) recorded by strip chart recorder and b) recorded digitally are shown in the upper panels of Figure 2.4 and Figure 2.5, respectively. The detected output of the receiver is recorded by Velleman kit-4 channel recorder/logger (K8047) data logger with a sampling rate of 50 Hz. There are four input voltage ranges 3 V, 6 V, 15 V and 30 V. Here 15 V range has been selected for the data recording. The output files of the software for each channel provide voltage (V) for the carrier amplitudes and the corresponding time in sec from the starting time of the data logging.

2.4 System Calibration

Calibration is a process through which the signal level at a particular time can be quantified. To do this a steady source of signal is required, so that the full span of the chart record or digital record should be quantified properly on the basis of the signal level from a known source. This is done by a signal generator where desired signal is generated and then the signal is attenuated in 1 dBm steps from the saturated level to the match load level. Figure 2.9 shows sample calibration imparted on the Strip Chart Recorder to the 1537 MHz system on October 09, 2000. Simultaneously, the whole process is recorded digitally. The voltage time plot of the calibration is shown in Figure 2.10 and the time for each dB level in the strip chart is matched with that in the output file of the Data Acquisition System to obtain a Voltage-dB plot shown in Figure 2.11. Figure 2.12 shows sample calibration on Strip Chart Record imparted to the 244 MHz receiving system on the same day. Simultaneously, the whole process is recorded digitally. The voltage time plot of the calibration is shown in Figure 2.13 and the time for each dB level in the strip chart is matched with that in the output file of the Data Acquisition System to obtain a Voltage-dB plot shown in Figure 2.14.
Figure 2.9: sample calibration on Strip Chart Record imparted to the 1537 MHz receiving system on October 09, 2000.

Figure 2.10: voltage time plot of the L band calibration

Figure 2.11: voltage dB plot of the L band calibration
Figure 2.12: Sample calibration on Strip Chart Record imparted to the 244 MHz receiving system on October 09, 2000

Figure 2.13: Voltage time plot of the VHF band calibration

Figure 2.14: Voltage dB plot of the VHF band calibration
2.5 GPS

2.5.1 An overview of GPS

The Global Positioning System (GPS) is a Global Navigation Satellite System (GNSS) developed by the United States Department of Defense. It uses a constellation of 32 Medium Earth Orbit satellites that transmit precise microwave signals, which enable GPS receivers to determine their current location, time and their velocity. The current GPS consists of three major segments. These are the a) space segment (SS), b) a control segment (CS) and c) a user segment (US).

a) Space segment

An example of the GPS constellation is shown in Figure 2.15.

The space segment (SS) comprises the orbiting GPS satellites, or Space Vehicles (SV). The orbital planes are geocentric, not rotating with respect to the distant stars. The six planes have approximately 55° inclination (tilt relative to Earth’s equator) and are separated by 60° right ascension of the ascending node (angle along the equator from a reference point to the orbit's intersection). The orbits are arranged so that at least six satellites are always within line of sight from almost everywhere on Earth's surface.

b) Control segment

The flight paths of the satellites are tracked by US Air Force monitoring stations in Hawaii, Kwajalein, Ascension Island, Diego Garcia, and Colorado Springs, Colorado,
along with monitor stations operated by the National Geospatial-Intelligence Agency (NGA). The tracking information is sent to the Air Force Space Command's Master control station at Schriever Air Force Base in Colorado Springs, which is operated by the 2nd Space Operations Squadron (2 SOPS) of the United States Air Force (USAF). The two SOPS contact each GPS satellite regularly with a navigational update. These updates synchronize the atomic clocks on board the satellites to within a few nanoseconds of each other and adjust the ephemeris of each satellite's internal orbital model. The updates are created by a Kalman filter which uses inputs from the ground monitoring stations, space weather information, and various other inputs.

c) User segment

GPS receivers come in a variety of formats, from devices integrated into cars, phones, and watches etc. The user's GPS receiver is the user segment (US) of the GPS. In general, GPS receivers are composed of an antenna, tuned to the frequencies transmitted by the satellites, receiver-processors, and a highly-stable clock (often an over controlled crystal oscillator). They may also include a display for providing location and speed information to the user.

The three major segments of GPS are shown in Figure 2.16.

![Figure 2.16: 3 major segments of GPS](image)

**Navigation signals**

Each GPS satellite continuously broadcasts a **Navigation Message** at 50 bit/s giving the time-of-week, GPS week number and satellite health information (all transmitted in the first part of the message), an ephemeris (transmitted in the second part
of the message) and an almanac (later part of the message). The messages are sent in frames, each taking 30 seconds to transmit 1500 bits. The almanac consists of coarse orbit and status information for each satellite in the constellation, an ionospheric model, and information to relate GPS derived time to Coordinated Universal Time (UTC).

All satellites broadcast at the same two frequencies, 1.57542 GHz (L1 signal) and 1.2276 GHz (L2 signal). These two frequencies are integral multiples $f_1=1540f_0$ and $f_2=1200f_0$ of a base frequency $f_0=1.023$ MHz. The receiver can distinguish the signals from different satellites because GPS uses a code division multiple access (CDMA) spread-spectrum technique where the low-bit rate message data is encoded with a high-rate pseudo-random (PRN) sequence that is different for each satellite. The receiver knows the PRN codes for each satellite and can use this to reconstruct the actual message data. The message data is transmitted at 50 bits per second. Two distinct CDMA encodings are used: the coarse/acquisition (C/A) code (a so-called Gold code) at 1.023 million chips per second, and the precise (P) code at 10.23 million chips per second. The L1 carrier is modulated by both the C/A and P codes, while the L2 carrier is only modulated by the P code. The C/A code is public and used by civilian GPS receivers, while the P code can be encrypted as a so-called P(Y) code which is only available to military equipment with a proper decryption key. Both the C/A and P(Y) codes impart the precise time-of-day to the user. The C/A code has 1 msec period and repeats constantly whereas the P code is a 7 day sequence.

**Determining satellite to user range**

$U$ is the user receiver's position with respect to ECEF (Earth Centered Earth Frame) system which is unknown as shown in the Figure 2.17.

![Figure 2.17: Position of user and satellite.](image-url)
The User position coordinates are \( x_u, y_u, z_u \). Let \( S \) represents the position of satellite relative to ECEF coordinate system. The Satellite is located at \( x_s, y_s, z_s \). Satellite to user vector \( r = s - u \) or \( r = |s - u| \)

The distance \( r \) is computed by measuring the propagation time \( \Delta t \) required for a satellite generated ranging code to transit from the satellite to the user receiver antenna. Multiplying this propagation time \( \Delta t \) by speed of light the true satellite to user distance can be computed. But satellite and receiver clock are not synchronized. The range determined by this process is denoted as pseudorange \( p \) as it contains: The geometric satellite to user range and an offset between system time, satellite clock and receiver clock.

Geometric range \( r = c(T_u - T_s) = c\Delta t \)

Pseudorange \( p = c[(T_u + t_r) - (T_s + \delta t)] = r + c(t_r - \delta t) \)

where, \( T_s = \) system time at which the signal left the satellite, \( T_u = \) system time at which the signal reached the user receiver, \( \delta t = \) offset of the satellite clock from system time, \( t_r = \) offset of the receiver clock from system time, \( T_s + \delta t = \) satellite clock reading, \( T_u + t_r = \) receiver clock reading, \( \delta t \) is corrected by GPS ground monitoring. So, pseudorange \( p = r + c t_o \)

or, \( p = |s - u| + c t_o \) (as from vector diagram \( r = s - u \))

**Calculation of User position**

To determine the user position in three dimension \((x_u, y_u, z_u)\) and the offset \( t_o \), Pseudorange measurement are made to four satellites. A single pseudorange can be represented by:

\[
\rho_i = (x_i - x_u)^2 + (y_i - y_u)^2 + (z_i - z_u)^2 + c t_o
\]

Solving such equations for four satellites the user position and time can be calculated.

2.5.2 GPS L1 signal recording by GPSMARG receiver

The carrier-to-noise ratio (CNO) of the L1 (1575.42MHz) transmission from the GPS satellites has been recorded by a stand-alone C/A code GPSMARG-9312 receiver at Calcutta from August 1994 through January 2000. A micro pulse airborne antenna is used for receiving the signal. The amplified L1 carrier is fed directly to an 8-channel C/A code Receiver GPSMARG (MODEL-9312), manufactured by M/s Aero Space Limited,
operating at the L1 frequency, through a low loss cable without any down conversion. An external power supply provides 5 and 12V DC to the receiver. The output of the receiver sampled at 0.5Hz is connected to the serial port COM1 of the PC-based Data Logger and data logging is performed through Control and Display Unit Software.

A sample of the GPSMARG-9312 receiver output recorded at 0.5Hz sampling frequency is shown below:

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2.5.3 GPS signal recording by GG24 receiver

The signal-to-noise ratios (SNR) of the L1 (1575.42 MHz) transmissions from the GPS and GLONASS satellites have been recorded at Kolkata from 1999 through 2007 by a stand-alone C/A code Ashtec (model GG24) receiver. The GPS/GLONASS receiver usually tracks 10–15 satellites, simultaneously sampling different sections of the ionosphere at different look angles from the station. An omni-directional patch Antenna with internal LNA is elevated with a vertical extension rod to ensure clear visibility. A Coaxial Cable is connected to the antenna via a TNC connector. The other end of the cable is connected to the TNC female receptacle RF connector of the receiver. One of the serial input/output ports of a multi-function 25 pin connector DB25 has been used to provide 15V DC voltage from an external power supply to the Receiver which consumes a power of about 2.8W. The receiver output is connected to the PC-based Data Logger via a RS-232 port of DB25. The Time and Frequency Division, National Physical Laboratory developed the data logging software. The data is recorded according to user-defined schedules in output files at 1Hz sampling frequency.
A sample of the Ashtec GG24 output file is shown below:

$PASBR,AC3*3D

$PA5BR, TO, 0,10,122559.00,2231.690033,8, 08822.340343,1,-00014.519,, 000.00,000.01, 4000.01,01.5,00.8,01.2,00.7,GG00*0A

$GR

$JPASBR,SOS,0,10,123000.00,2234.689997,H,08822.340324,£,-00014.606,,000.00,000.02,4000.02,01.5,00,8,01.2,00.7, GG0Q*0F

$GPSSA,A,3,30,22,,15,,18,11,16,25,05,01,01.5,00.8,01.2*02

The $SPASHR, POS line denotes the following: Position type (0 for autonomous), Number of satellites used in position computation (10), UTC time of position computation in hours, minutes and seconds (122959.00), Latitude component of user’s position in degrees, minutes and fraction of minutes (2234.690033), Latitude sector ( N for north), Longitude component of user’s position in degrees, minutes and fraction of minutes (08822.340343), Longitude sector (E for east), Altitude in meters above WGS-84 reference ellipsoid (00004.619), the next field is reserved, True track over ground in degrees, Speed over ground in knots, Vertical Velocity in meters per second , Positional Dilution of Precision (PDOP) , Horizontal Dilution of Precision (HDOP), Vertical Dilution of Precision (VDOP) , Time Dilution of Precision (TDOP) , Firmware version ID.

The $SPASHR, SAT line denotes the following: Number of satellites locked (10), PRN of the first satellite locked, Azimuth in degrees of the first satellite locked, Elevation in degrees of the first satellite locked, Signal- to-noise ratio (SNR) in dB of the first satellite locked, Satellite used/not used in position computation (U: Used), the next 45 fields denote the PRN, Azimuth, Elevation, SNR, Satellites used/not used for the remaining nine satellites locked. The $GPGSA line denotes the following: Mode (A: Automatic), Mode (3: 3D), the next 12 fields are GPS satellite PRNs used in position computation,
PDOP, HDOP, VDOP. The GG24 receiver usually tracks 10-12 satellites, simultaneously sampling different sections of the ionosphere at different look angles from the station. When a satellite signal frequently fades to a level less than a threshold value (SNR=25dB), the receiver ignores the particular satellite for navigation solution.

2.5.4 GAGAN GPS data

Indian Space Research Organization (ISRO) in collaboration with Airport Authority of India (AAI) has set up 20 GPS NOVATEL GSV4004B receivers (Figure 2.18) in India to implement a Satellite Based Augmentation system (SBAS) under the program GPS Aided Geo Augmented Navigation (GAGAN). The dual frequency GPS receivers are operating at L1 (1575.42 MHz) and L2 (1227.6 MHz) frequencies. It can derive Total Electron Content along the Slant Ray Path (STEC) (Klobuchar, 1996) by measuring the carrier phases of the two frequencies. The differential carrier phase (Δδφ) is related to TEC by,

$$\Delta\delta\phi = \frac{40.3 \times TEC(1-m)}{c f_i}$$
Where, \(m=f_1/f_2\), where \(f_1\) and \(f_2\) are the two frequencies.

The receiver data contained STEC, azimuth, elevation, satellite PRN number, time, Scintillation index S4 etc at 1 minute interval in Rinex format (Mannuci et al., 1997). From the azimuth, elevation and station's location the 350 km subionospheric point of the satellite signal is calculated. The GAGAN TEC data for different stations are available from 2003 to 2006, out of which the data during 2004-2006 are useable for further analysis.
Figure 2.18: Locations of 20 GAGAN stations in India

The sample data of the GAGAN receiver is shown below.

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</table>

2.6 Indian MST Radar

In the present work the F region Backscattered data of MST radar situated at Gadanki, Tirupati is used for the observation of equatorial irregularities. A short description of MST radar is given below:
Indian MST Radar is a high power, coherent, pulse Doppler radar operating in the VHF band of frequency. It is an excellent system for atmospheric probing in the regions of Mesosphere, Stratosphere and Troposphere (MST) covering up to a height of 100km. It is also used for coherent backscatter study of the ionospheric irregularities above 90km. The block diagram of MST radar system is shown in Figure 2.19. The radar is situated at Gadanki, Tirupati. It operates at 53 MHz with a peak power of 2.5 MW. It is sensitive to backscatter from waves which satisfy Bragg's matching condition. This condition requires that $k_r = k_s + k_m$, where $k_r$ is the radar wave vector, $k_s$ the scattered wave vector and $k_m$ is the wave vector in the medium. Since $k_s = -k_r$ for backscatter, it follows $k_m = 2k_r$. Thus for 53 MHz radar ($\lambda=6$ m) it detects only waves with wave vectors corresponding to a 3 m wavelength. The system specification including those of the intermediate stage of ST mode is given in Table 2.1. The Phased antenna array consists of two orthogonal sets, one for each polarization arranged in 32 x 32 matrixes (Figure 2.20) over an area of 130 x 130 meter. The two sets are collocated with pairs of crossed Yagis mounted on the same set of poles. The array is aligned along the geomagnetic axes to enable the radar beam to be transverse to the Earth's magnetic field for ionospheric backscatter application. The array of either of the polarization is illuminated using 32 transmitters of varying power, each feeding a linear sub array of 32 antennas. The power distribution across the array follows an approximation to modified Taylor weighting in both principal directions. The radar beam can, in principle, be positioned electronically at any look angle within $\pm20^\circ$ off zenith in the East-West and North-South planes. For the spread F observation the radar beam is oriented at $14.8^\circ$ due magnetic north which is the nominal direction looking transverse to the earth's magnetic field at a height of about 333km to satisfy Bragg's matching condition. For the radar half power beam width of $3^\circ$ the condition for the perpendicularity to the magnetic field is satisfied over the height range of 150-550km. It is possible to transmit both coded and uncoded pulses with pulse repetition frequency in the range of 62.5 Hz to 8 KHz, with a maximum duty cycle of 2.5%. Coded and uncoded pulse can be varied from 1 to 32 µs with a baud length of 1 µs providing a range resolution of 150m.
Figure 2.19: Block diagram of MST radar.

Figure 2.20: Antenna array at Gadanki, Tirupati.
Table 2.1: Main specification of the Indian MST Radar.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Gadanki, Tirupati, (13.5° N, 79.2° E, 6.3° N mag lat)</td>
</tr>
<tr>
<td>Frequency</td>
<td>53 MHz</td>
</tr>
<tr>
<td>Average power aperture product*</td>
<td>7 x 10^8 Wm^2 (4.8 x 10^8 Wm^2)</td>
</tr>
<tr>
<td>Peak power*</td>
<td>2.5 MW (80 kW)</td>
</tr>
<tr>
<td>Maximum duty ratio</td>
<td>2.5%</td>
</tr>
<tr>
<td>Number of Yaggi antennas*</td>
<td>1024 (256)</td>
</tr>
<tr>
<td>Beam width*</td>
<td>3° (4.6°)</td>
</tr>
<tr>
<td>Number of beams for automatic scan</td>
<td>7°</td>
</tr>
<tr>
<td>Pulse width</td>
<td>1-32 µs uncoded (in binary steps); 16 and 32 µs coded (1-µs baud)</td>
</tr>
<tr>
<td>PRF</td>
<td>62.5 Hz to 8 KHz (in binary steps)</td>
</tr>
<tr>
<td>Maximum number of range bins</td>
<td>256</td>
</tr>
<tr>
<td>Number of coherent integrations</td>
<td>4 to 512 (in binary steps)</td>
</tr>
<tr>
<td>Maximum number of FFT points</td>
<td>512</td>
</tr>
<tr>
<td>Radar Controller</td>
<td>PC/AC featuring programmable experiment specification file (ESF)</td>
</tr>
<tr>
<td>Computer System</td>
<td>32-bit super mini with vector accelerator</td>
</tr>
</tbody>
</table>

PRF- Pulse Repetition Frequency;

* the specification in parentheses refer to ST mode

+ Zenith in x, y polarizations, ± 20° off Zenith in EW and NS planes, and 14.8° N looking transverse to B field.

2.7 DMSP satellites

The latitudinal variation of ion density for different longitudes can be observed from the ion density plots of DMSP (Defense Meteorological Satellite Program) satellite data. The DMSP is a series of polar orbiting weather satellites at an altitude of about 840 km operated by the United States Department of Defense. The spacecrafts are in circular sun synchronous polar orbits with inclinations of 97.8°, which result in a precession rate of the orbital plane of one rotation per year. These results in keeping the spacecraft's orbit
The space environment sensors of the satellite include the SSIES package (thermal plasma instruments including a Retarding Potential Analyzer (RPA), Ion Drift Meter (IDM), Langmuir probe, and a scintillation meter). Other sensors include the SSJ4 (precipitating ions and electrons monitor (30eV-30KeV), SSJSTAR (penetrating particles monitor (>1MeV), SSM (vector fluxgate magnetometer, SSULI (limb scanning ultraviolet imager /spectrometer) and SSUSI (nadir scanning ultraviolet imager /spectrometer and photometer). It could measure the latitudinal variation of in-situ ion density at 840 km at 4-s resolution. The RPA measures the ion flux entering the instrument as a function of the retarding potential (positive) applied to the incoming ions. From this data the RPA can measure the thermal ion flow speed in the direction of the spacecraft (V_X), the ion temperature (T_i) and the H+, He+ and O+ fractional composition of the plasma (f_{H+}, f_{He+}, and f_{O+}). The IDM has a detector divided into four sections, each of which measures the ion current falling on it. By comparing the differences in the currents and knowing the geometry of the instrument, the arrival angles of the ions and hence the cross-track horizontal ion flow (V_Y) and the vertical flow (V_Z) velocities of the plasma are deduced. The scintillation meter is a simple Faraday cup, which measures the total ion current entering the cup. From that the ion density of the plasma (N_i) are calculated. The Langmuir probe is a sphere on boom 76.2 centimeters (30 inches) away from the spacecraft, which collects electrons from the ambient plasma. Calculations based on the collected current as a function of the bias voltage on the probe allow for the determination of the electron density (N_e) and temperature (T_e).
In the present work spacecrafts used for analysis are F12, F13 and F14. The DMSP spacecraft F13 is in dawn-dusk time orientations where F12 and F14 are in 0930-2130 local time orientations. In the course of a day each satellite made ~12-13 equatorial crossing with the subsatellite point on the earth’s surface shifting ~25° in longitude to the west.

2.8 Ionosonde at Trivandrum

Trivandrum ionosonde is situated at southern most part of India near the magnetic equator. This ionosonde data is used in the present work for the onset time of ESF near the magnetic equator and the maximum height of the F layer during both ESF and non ESF days.

The digital ionosonde system at Trivandrum consists of an IPS-42 ionosonde, a DBD-43 system dedicated to the IPS-42 with pre-programmed software, a double delta antenna and printer. The IPS-42 consists of a transmitter, receiver and all necessary sub-systems. The DBD-43 is used for controlling the operational program of IPS-42 to store and scale the ionograms and to give commands for the printouts.

IPS-42 Ionosonde

The IPS 42 transmits on 576 logarithmically spaced frequencies in the range from 1.0 to 22.6MHz. Transmissions on each frequency consist of three pulses 41.7s long separated by 5.33 ms. Signals reflected from the ionosphere are detected by a receiver which is automatically tuned to the frequency of transmission. The receiver is a triple conversion unit, with intermediate frequencies (IF) at 70.0, 10.7 and 1.6 MHz and has a bandwidth of 25 kHz. Signals from the final IF are passed to an amplifier whose output is a logarithmic function of its input. The output from this amplifier undergoes two stages of signal processing. Firstly the output is integrated over a long period (~500 μs) compared with the transmitted pulse length, and then subtracted from the original output. This separates interference generated by other HF transmissions from ionospheric reflections from its own transmissions. The second stage of processing removes spurious repetitive signals. This is achieved by comparing the virtual height of echoes received from each of the three transmitted pulses on each frequency. Echoes with virtual heights not coincident over all three pulses are rejected.