CHAPTER 3
Experimental Set up, Site & Data

3.1 INTRODUCTION

The experimental measurements on the propagation effects of Ku-band signal have been
Carried out at Kolkata on a continuous basis since June, 2004 at the Institute of Radio
Physics and Electronics, University of Calcutta. The co-polar and cross-polar component
of a satellite signal have been monitored to study the attenuation and depolarization of the
Satellite signal respectively due to atmospheric hydrometeors confronting the earth-space
Communication path. Rain rate and rain drop size distributions are also measured
Simultaneously by an optical rain gauge and a Joss-type disdrometer respectively, co-
sited with the satellite receiving system. A multi-frequency radiometer has been installed
In June 2010 at the same site to obtain the profile of water vapour density and
temperature and also integrated water vapour (IWV) and liquid water path (LWP) in the
troposphere. Measurements of the vertical profile of rain parameters are obtained with
Vertically pointing micro radar (MRR) installed at the experimental site with 1 min time
Resolution and 200 m height resolution.

3.2 CHARACTERISTICS OF THE EXPERIMENTAL SITE

The present measurements have been carried out at the Institute of Radio Physics and
Electronics, University of Calcutta, Kolkata (22°65' N, 88°45' E), located in the eastern
Part of India. The region experiences a tropically wet and dry climate as classified by
Koppen climate classification, depicted in Figure 3.1. The annually averaged temperature
is around 26.8 °C (80º F). The summers are typically hot and wet with temperatures around 30-35 °C and relative humidity often reaching more than 80 % on an average while the winters, which lasts around two and a half months, experiences a dip in temperature reaching around 10-14º C between December and January. The rainy season of Kolkata prevails during June to September with the annual rainfall of 1600-2000 mm as shown in the precipitation map of India in Figure 3.2. The south-west monsoon from Bay of Bengal mainly causes showers in this region of India. During early summer in
Kolkata localized thunderstorms along with heavy rain often occurs. These thunderstorms, accompanied by strong squalls and sometimes by hail are convective in nature and are locally known as *Kal Baisakhi or Nor’westers*.

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3.3 EXPERIMENTAL PROCEDURE

The block diagram of the experimental set up for the measurements is shown in Figure 3.3. A Ku-band signal of frequency 11.172 GHz from the satellite NSS-6 (geostationary at longitude 95° E) has been received with a parabolic dish antenna of about 60 cm in
diameter. The receiving polarizations are both horizontal and vertical and are at 63° elevation of the path. By using a low-noise block converter (LNBC) having noise figure of 0.5 dB, the Ku-band signal is down converted to a L-band signal. The signal is then fed to a spectrum analyzer (model: HP 8590L) operated with zero time span at the peak of the received spectrum of the signal and the video filter output is recorded with a data logger (Agilent 3497 A) and stored in a PC.
The calibration of the satellite signal is carried out using a X-band oscillator (model: HP 8620C) and a rotary vane attenuator. The signal has a low fade margin that can calibrated down to level of 20 dB below which there is no discernible change with the increasing attenuation. The cross-polar component of the satellite signal is monitored using a separate receiving channel with identical components to that used for the co-polar channel. The polarization of the receiving horn antennas of the two channels are orthogonally aligned so that when the co-polar signal level reaches the maximum and the cross-polar level is at the minimum, the separation between the signal levels of the two channels becomes 18 dB. Further, the rainfall rate has been measured by an optical raingauge (model: OSI ORG-815-DA) and recorded simultaneously with the satellite signal. The satellite signal and rain rate are recorded at a sampling interval of 10 sec. Also, rain dropsize distributions (DSD) are measured at the same site using a Joss-type disdrometer (model: Distromet RD-80). The disdrometer is capable of sensing drop sizes in the range of 0.3 to 5.5 mm with 5% accuracy level and with a minimum integration time of 30 sec. Experimental observations obtained since June 2006 have been taken into consideration in the present work.

3.4 DESCRIPTION OF THE SET UP

3.4.1 Satellite Receiving System

The indoor and outdoor sections of the setup are shown in Figure 3.4 and Figure 3.5 respectively. The indoor system consists of several power supply units required for giving power to LNBC of the two dish antennas, two spectrum analyzers to which the
Experimental Set up, Site & Data

Satellite signals are fed, a data logger connected with the video outputs of the spectrum analyzers and a computer where the output data is recorded.

The outdoor unit consists of two parabolic dish Antennas of 60 cm in diameter having Ku band LNBCs of noise figure 0.5 dB.

Fig. 3.4: Indoor section of the set-up for earth-space propagation study

Fig. 3.5: Outdoor set-up for earth-space propagation study
3.4.1.1 New Sky Satellite (NSS-6)

New Sky Satellite is a satellite of a Dutch Organization, SES NEW SKIES with its head quarter at The Hague, The Netherlands. NSS-6, a part of the SES NEW SKIES family of satellites provides the satellite services to the whole of Asia, Australia, Southern Africa and the Middle East as shown in Figure 3.6. In NSS-6 there are six high-performance beams of Ku-band covering the whole of Asia. The major specifications for the New Sky Satellite are given in Table 3.1.

**Fig. 3.6: Coverage map for NSS-6 satellite**
(Ref: www.LyngSat.com)

**Table 3.1: Specifications of New Sky Satellite**

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Lockheed-Martin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbital Location</td>
<td>95° East</td>
</tr>
<tr>
<td>Launch date</td>
<td>December 2002</td>
</tr>
</tbody>
</table>
3.4.1.2 Dish Antenna System

Dish antenna system consists of a parabolic dish antenna of about 60 cm diameters inclined to 62.5°E elevation angle. The Ku-band signal of 11.172 GHz is received through this antenna and is down-converted to a L-band signal by a low-noise block converter (LNBC) having noise figure of 0.5 dB.

3.4.1.3 Spectrum Analyzer

Two analog spectrum analyzers of model HP 8590L have been used in the present experimental set up for receiving the co-polar and cross-polar component of the signal. The L-band signal, obtained after down converting from LNBC mounted on the satellite dish, is fed to a spectrum analyzer that is operated with zero time spans at the peak of the received spectrum of the satellite signal. The output of the video filter of spectrum analyzer is recorded with a data logger and stored in a PC. The following

| Number of Transponders (36 MHz Equivalent) | Ku-band: 60 |
| Saturated EIRP Range | Ku-Band: 44 to 55 dBW |
| Polarization | Ku-band: Linear Ka-band: Linear |
| Frequency Band | Ku-Band Uplink: 13.75 to 14.50 GHz Ka-Band Uplink: 29.5 to 30.0 GHz Ku-Band Downlink: 10.95 to 11.20 GHz, 11.45 to 11.70 GHz, 12.50 to 12.75 GHz |
specifications in Table 3.2 are applied to the spectrum analyzers in this experimental system.

### Table 3.2: Specifications of Spectrum Analyzer

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre Frequency</td>
<td>11.172 GHz</td>
</tr>
<tr>
<td>Amplitude</td>
<td>10dB</td>
</tr>
<tr>
<td>Span</td>
<td>0</td>
</tr>
<tr>
<td>Reference Level</td>
<td>-61.4 dBm</td>
</tr>
<tr>
<td>Scale</td>
<td>log 2 dB</td>
</tr>
<tr>
<td>Resolution bandwidth</td>
<td>1 MHz</td>
</tr>
<tr>
<td>Video Bandwidth</td>
<td>1 kHz</td>
</tr>
</tbody>
</table>

### 3.4.1.4 Data Logger

The data logger of Model Agilent 34970A is used in the present experimental set-up. It consists of a three-slot mainframe with a built-in 6 1/2 digit digital multimeter. It features a built-in thermocouple reference and 20 two-wire channels with both USB and RS-232 interfaces. Agilent BenchLink Data Logger software is included with the device. The software gives a normal Microsoft Windows interface for test configuration and real-time data display and analysis. It is operated to interface the output of the video filter of the Spectrum Analyzer.
3.4.2 Optical Rain Gauge

The Optical Rain Gauge (ORG) is an electro-optical sensor consisting of optics, analog signal processing electronics and a digital microprocessor. It measures rain, snow and applies algorithms to automatically determine the precipitation type, rate and water equivalent accumulation. The ORG is vastly superior to traditional type of sensors and offer reliability and proven performance of the user’s need.

The ORG-815 is presently available in two versions, the standard digital output version that measures both rain rate and snow and an analog version that measures precipitations only. In the present work, the second version of ORG-815-DA has been used. It detects
the optical irregularities which are induced within the sample volume by precipitation particles while falling through a beam of partially coherent infrared light. These irregularities are known as scintillation. By detecting the intensity of scintillations the actual rainfall rate can be determined. Figure 3.7 shows the unit of optical rain gauge operating at the roof top of the measuring site.

3.4.2.1 Specifications of Analog ORG

The electrical specification of the instrument is shown in Table 3.3

<table>
<thead>
<tr>
<th>Electrical Specification</th>
<th>Analog Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage</td>
<td>11-16 VDC</td>
</tr>
<tr>
<td>Current Drain</td>
<td>30 ma w/o heaters, 400-600 ma w/ heaters</td>
</tr>
<tr>
<td>Fusing</td>
<td>User supplied 1 A Slow Blow</td>
</tr>
<tr>
<td>Signal Output</td>
<td>0-5 VDC</td>
</tr>
<tr>
<td>Relay Control Output</td>
<td>n/a</td>
</tr>
<tr>
<td>User Heater Control</td>
<td>Yes</td>
</tr>
<tr>
<td>Transient Protection</td>
<td>All power and signal lines protected by MOV</td>
</tr>
</tbody>
</table>

3.4.2.2 Analog ORG Sensor Operation

The analog ORG-815-DA output is designed to interface with commercially available data acquisition system. The rain signal output of the ORG is a DC voltage that is proportional to the power raised to the “1.87” of the rain rate. The actual output level at the signal output pair caries from 0 VDC to +5 VDC at the extreme limits.

The signal output of the ORG is described by the following formula:
Rain Rate (mm/hr) = 25 \left(V_{out}\right)^{1.87} - 0.15

where $V_{out}$ is the sensor output in volts DC as the rain varies over the range of 0.1 to 500 mm/hr.

### 3.4.3 Micro Rain Radar

The Micro Rain Radar (MRR) operates at a frequency of 24 GHz. The instrument is manufactured by M/s Metek GmbH, Germany. It is a frequency modulated, continuous wave vertically looking Doppler radar. The signal is transmitted into the atmosphere in vertically upward direction and a small portion of this signal is scattered back to the antenna from rain drops or other forms of precipitation. As the scattering volume is large, a statistically stable drop size distribution can be obtained in short period of time which cannot be done with a conventional instrument. It uses frequency modulation of frequency deviation of 1.5 – 15 MHz depending upon the height resolution. The MRR can operate with height resolution of 35 m to 200 m. Other rain integral parameters like rain rates, liquid water content and characteristic falling etc. are derived from DSD. The droplet number concentration is derived from the backscatter intensity for each drop diameter bin using the relation between terminal falling velocity and drop size. The frequency deviation between transmitted and received signal is a measure for the falling velocity of the rain drops. The Doppler frequency is due to the falling velocity of the rain drops relative to the stationary antenna. The drops with different diameters exhibit different falling velocity and the backscattered signal consists of a distribution of different Doppler frequencies. The spectral analysis of the received signal thus gives a spectrum of wide range of lines corresponding to the Doppler frequencies of the signal.
The output signal of the system is transmitted continuously with a linearly decreasing saw tooth modulation of the transmit signal enabling the unit to measure from different vertical heights.

The Radar electronics unit determines this spectrum with a high time resolution of 10 s and sends it to the connected control and data acquisition system. The drop spectrum is then calculated from the Doppler spectrum considering the transfer function of the Radar module. The other correction terms like atmospheric correction and Mie scattering corrections are then applied in the final processing and averaging over 10 - 3600 seconds is performed. If the drop diameter is small compared to the wavelength, then the backscatter cross section of rain drops increases with the fourth power of the droplet diameter in Rayleigh scattering. The height ranges which are quantitatively interpretable at very high frequencies will become limited due to attenuation at moderate and higher rain rates. The attenuation effects may be noticeable at 24 GHz but is weak enough to be rectified with sufficient accuracy. The RADAR antenna is an offset parabolic dish of 60 cm in diameter.

3.4.3.1 Hardware configuration

In MRR, a frequency modulated gunn-diode-oscillator with integrated mixing diode is used as radar front end. MRR uses small transmit power of about 50 mW. The schematic diagram of radar front end is shown in Figure 3.8. The linear polarized RF-power is fed through a wave guide and a horn in form of the feed of an offset parabolic dish. The backscattered signal is also received with the same antenna unit. A mixing diode detects
the received signal in the wave guide between gunn-oscillator and horn. This diode which acts as mixer is biased with a fraction of the transmitted signal. A voltage appears in continuous wave mode at the diode output which depends on the phase difference between the transmitted and received signal (homodyne principle) and is used for further signal processing.

![Diagram of MRR front end electronics](image)

**Fig. 3.8: Diagram of MRR front end electronics**

### 3.4.3.2 Operational principle

For static targets, the range resolution is determined from the frequency shift between the echo and the transmitted signal. A linearly decreasing saw tooth frequency modulation of
the transmit signal is used for this purpose. The echo-frequency is found to be higher than that of the transmit signal, and the difference in frequency is proportional to the range of the target as shown in Figure 3.9. The frequency sweeps linearly from \((f_0 + B/2)\) to \((f_0 - B/2)\) and jumps back to the initial value again. The frequency jump of the echo follows a bit later with the delay of \(t = 2 h/c\), with range \(h\) of the target and \(c\) is the velocity of light. The time interval \(t\) between the frequency jumps of transmit and the receiving signal is not used for the further signal processing. This Interrupt is small compared to \(T\), the time of a full frequency sweep. Its frequency is equal to the constant frequency difference \(f\) between the transmit- and receiving-signal. At each sweep the

![Diagram showing frequency of transmitted and received signals](image)

**Fig. 3.9: Resting point target for MRR: Frequency of echo and transmitted signal along with mixture output**
mixer output is exactly repeated with the period T. Harmonics of 1/T is obtained during a
large number of sweeps in the frequency spectrum.

Let, the transmit signal be \( s(t) \)

\[
s(t) = S \sin(\phi_s(t)), \text{ here } \phi_s(t) \text{ is the phase and given by } \int \omega_s(t) \, dt
\]

Again \( \omega_s(t) \) is given by \( \omega_s(t) = \omega_0(t) - B/T \cdot t \)

Therefore, \( s(t) = S \sin(\omega_0(t) - B/T \cdot t^2) \)

The receiving signal is delayed by \( t_n = 2h/c \).

Now the mixed signal will have two terms, (i) the sum of phases of both \( s(t) \) and \( e(t) \) and (ii) the difference of phases \( s(t) \) and \( e(t) \).

Let us assume that frequency deviation \( (B) \) is smaller compared to the centre
frequency \( (f_0) \), So the 1st term of the mixed signal will be more frequent than the second
term and can be suppressed by a low fass filter of frequency \( 2f_0 \).

The remaining term can be written as \( \phi_m(t) = - \omega_0 \phi_h + 2\pi B/2T \cdot t_h^2 - 2\pi B/2T \).

The echo of a moving target will exhibit an additional frequency shift and
according to the Doppler effect it will be proportional to the velocity. Thus an ambiguity
will be there between range and velocity. However, it can be resolved easily as MRR
provides continuous sweep. The frequency shift observed during one sweep can be
expressed as

\[
\Delta f_{total} = v^2/\lambda + B.2h/cT
\]

Now, as the rain drops are not very fast moving objects, the Doppler term holds
the condition, \(-1/2T < v^2/\lambda < 1/2T\), indicating the correct range gate.
If the Doppler shift exceeds half of the frequency interval of a range gate, the spectral line is associated with the adjacent range gate. This range error limits the maximum allowable Doppler shift, which is also designated as Nyquist frequency shift (corresponding to the Nyquist velocity). As the MRR is only able to see the falling drops, the limit will be \( v_n < \frac{\lambda}{4T} \).

For rain, a large number of drops exist within the scattering volume. The phases of the scattering signals of each drop are statistically independent as the drop position is irregular in space. Therefore, the total power of the echo can be obtained by taking sum of the power of all individual scattering signals. In this case the spectrum within one range gate consists of a distribution of lines corresponding to the velocity distribution of the rain drops.

(a) Estimation of DSD

The spectral power received by the radar is

\[
p(f) df = C(f, h/\Delta h) \Delta h/h^2 \eta(f) df
\]

\( \Delta h \) is the range (height) resolution, \( h \) is the measuring range (height), \( C(f,h/\Delta h) \) is a calibration function, \( \eta(f)df \) is the spectral volume reflectivity and the (height-range dependent) transfer function of the MRR radar receiver.

The derivative of \( v \) with respect to \( D \) can be used to calculate the spectral reflectivity as a function of drop diameter \( D \):

\[
\eta(D) = \eta(v) \frac{\partial v}{\partial D}
\]
The DSD is obtained by dividing the spectral reflectivity by the backscattering cross section of a rain drop of diameter \( D \).

\[
N(D) = \frac{\eta(D)}{\sigma(D)}
\]

As the MRR wavelength is not small compared to all naturally occurring drop diameters, back scattering cross section is calculated according to Mie theory.

(b) Fall velocity

The fall velocity of the drops is calculated by,

\[
v = \frac{\lambda}{2} \frac{\int_{0}^{\infty} \eta(f) f df}{\int_{0}^{\infty} \eta(f) df}
\]

Mean fall velocity is obtained directly from the spectral power related to Doppler frequency as follows,

\[
v_m = \frac{\lambda}{2} \frac{\sum f p(f)}{\sum p(f)}
\]

(c) Liquid water content

The liquid water content is the product of the total volume of all droplets with the density of water, divided by the scattering volume. It is therefore proportional to the 3rd moment of the drop size distribution: 

\[
LWC = \pi/6 \rho_w \sum D^3 n(D)
\]
(d) Rain rate

The differential rain rate $rr(D)$ is equal to the volume of the differential droplet multiplied with the terminal falling velocity $v(D)$. From this rain rate is obtained by integration over the drop size:

$$ R = \pi/6 \sum D^3 v(D) N(D) $$

(e) Radar reflectivity factor

Radar reflectivity factor is 6th moment of the drop size distribution and given by

$$ Z = \pi/6 \sum D^6 N(D) $$

3.4.3.3 Error analysis

(a) Statistical Error of the Spectral Reflectivity:

Due to random internal structure of the target, the resulting spectral power is randomly distributed to the uncorrelated phases of the scattering targets. The standard deviation of the spectral power distribution for each frequency bin is usually equal to its mean value. The MRR has the minimum measuring cycle time of 10 s. The time lag for issuing spectra via the interface is about 4 s. During this time no measurement is possible as interferences can occur from the active data port to the receiving amplifier. Thus a total of 6 s measuring time only is available. As the number of spectra per second calculated is 23, an issued spectrum represents a mean of a minimum of 138 single spectra. By this method statistical fluctuations are reduced to about 9 % of their mean values.

(b) Vertical Wind and Turbulence:

Downwind increases the falling velocity, and it is responsible for overestimation of the drop size. As the scattering cross section depends on the drop diameter, it underestimates
the number concentration. So, the liquid water content and the rain rate are underestimated in presence of down-wind.

Not only the downward vertical wind but also turbulence, the random fluctuations of vertical wind, within the scattering volume or within the averaging time interval can cause a systematic error because the effects of up and downwind cannot compensate each other completely due to their non-linear velocity-diameter relation. It is observed that turbulence leads to an underestimation of LWC and RR.

(c) Radar Calibration:

All the derived integral parameters including volume reflectivity and drop size distribution depend proportionally on the radar calibration constant $C$. The value of the constant can be determined by comparing with in situ rain rate measurements in specific environmental conditions. Its uncertainty is estimated to be 10%.

(d) Air Density

The relation between drop diameter and fall velocities is valid only for the air density at 1013 hPa and at 20 °C. The variations of falling velocity are affected by the change of air density effects. The errors in drop size distribution and integral parameters due to change in air density are up to 3%.

(e) Ice Phase

The complex refractive index of ice very much differs from that of water in the frequency range of 24 GHz. In the melting layer the radar reflectivity is even increased in comparison to the underlying altitudes with rain. The automatic signal analysis of the MRR always assumes the presence of liquid rain drops. As the falling velocity of snow-
flakes is much less in comparison to rain drops, the rain rate and liquid water content is drastically overestimated in snow.

(f) Attenuation

The intensity of radar waves can be attenuated on the propagation path by different ways. Although the absorption by water vapor is relatively strong at 24 GHz (0.2 dB/km for $= 10 \text{ g/m}^3$), it can be neglected on the path lengths considered here. But if high altitudes are considered rain can attenuate significantly at moderate and higher rain rates.

3.4.4. Disdrometer

Disdrometer RD-80 [Disdrometer RD-80 Instruction Manual, 2002] measures the size distribution of rain drops as they fall on the sensible surface of the sensor of the instrument. The range of drop diameters that can be measured ranges from 0.3

![Disdrometer operating at the rooftop of University of Calcutta](image)
mm to 5 mm. Drops smaller than 0.3 mm cannot be measured due to the measuring principle. However, the smaller drops have less contribution towards rain rate estimation. Again the drops of more than 5 mm are also very unstable and their occurrence is statistically insignificant. Figure 3.10 shows the outdoor unit of disdrometer operating at the experimental site.

3.4.4.1 Dropsize Classes

The Disdrometer measures the drop sizes in 127 classes of drop diameter. The final output categorizes the drops in 20 bins according to their diameter and thus reduces the amount of data. This also makes the data statistically meaningful. Over the available range of drop diameters.

3.4.4.2 Theory of Operation

A rain drop size distribution is commonly represented by the function $N(D)$, the number concentration of rain drops with the diameter $D$ in a given volume of air. The function $N(D)$ is highly variable and cannot be given in a simple unique form due to the complicated processes involved in the formation of precipitation. Disdrometer derives the DSD from experimental observation. However, to model the DSD, we need to utilize some mathematical form. Other quantities like rainfall rate ($R$), liquid water content in a given volume ($W$), radar reflectivity factor ($Z$) etc. can be determined from the DSD. These integral rain parameters (IRP) are calculated for a distribution with a time interval $t$ as given in Table 3.4.
### Table 3.4: The Parameters and their formula calculated by Disdrometer

<table>
<thead>
<tr>
<th>Parameters and Dimensions</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>RI Rain rate, [mm/hr]</td>
<td>$RI = \frac{\Pi}{6} \times \frac{3.6}{10^9} \times \frac{1}{F \times t} \times \sum_{i=1}^{20} (n_i \times D_i^3)$</td>
</tr>
<tr>
<td>RA Rain amount, [mm]</td>
<td>$RA = RI \times \frac{t}{3600}$</td>
</tr>
<tr>
<td>RAT Total rain amount since the start of measurement</td>
<td>$RAT = \sum RA$</td>
</tr>
<tr>
<td>W Liquid water content [mm$^3$/m$^2$]</td>
<td>$W = \frac{\Pi}{6} \times \frac{1}{F \times t} \times \sum_{i=1}^{20} \left( \frac{n_i}{v(D_i)} \times D_i^6 \right)$</td>
</tr>
<tr>
<td>Wg Liquid water content, [g/m$^3$]</td>
<td>$W_g = W/1000$</td>
</tr>
<tr>
<td>Z Radar reflectivity factor [mm$^6$/m$^3$]</td>
<td>$Z = \frac{1}{F \times t} \times \frac{1}{10^9} \times \sum_{i=1}^{20} \left( \frac{n_i}{v(D_i)} \times D_i^6 \right)$</td>
</tr>
<tr>
<td>ZdB Radar reflectivity factor [dB]</td>
<td>$ZdB = 10 \times \log Z$</td>
</tr>
<tr>
<td>EK Kinetic Energy, [J/m$^2$]</td>
<td>$EK = \frac{\Pi}{12} \times \frac{1}{F} \times \frac{1}{10^9} \times \sum_{i=1}^{20} (n_i \times D_i^3 \times v(D_i)^2)$</td>
</tr>
<tr>
<td>EF Energy Flux, [J/(m$^2$×h)]</td>
<td>$EF = EK \times 3600/t$</td>
</tr>
<tr>
<td>N$_0$ Number concentration, [1/(m$^3$×mm)]</td>
<td>$N_0 = \frac{1}{\Pi} \times \left[ \frac{6T}{\Pi} \right]^\frac{4}{3} \times \left[ \frac{W}{Z} \right]^\frac{4}{3} \times W$</td>
</tr>
<tr>
<td>$\Lambda$ Slope [1/mm]</td>
<td>$\Lambda = \left[ \frac{6T}{\Pi} \times \frac{W}{Z} \right]^\frac{1}{3}$</td>
</tr>
<tr>
<td>N(D$_i$) Number density of drops of the Diameter corresponding to size</td>
<td>$N(D_i) = \frac{n_i}{F \times t \times v(D_i) \times \Delta D_i}$</td>
</tr>
</tbody>
</table>

Where, $t$ = Integration time, 30 seconds for our measurements. $n_i$ = Number of drops for size class i during the time interval t, $D_i$ = Mean diameter of size class i, $v(D_i)$ = Fall velocity of a drop with diameter $D_i$ and $\Delta D_i$ = Diameter interval of drop size class i.
3.4.4.3 Hardware Configuration

The RD-80 disdrometer for raindrops consists: (A) a sensor which is exposed to the rain and (B) the processor connected to a computer (data storage) as shown in Figure 3.11. In Figure 3.12, the schematic diagram of the electronics configuration of the disdrometer is shown.

![Figure 3.11: Hardware configuration of disdrometer](image)

![Figure 3.12: Schematic diagram of disdrometer electronics](image)
(A) The Sensor

As shown in Figure 3.13 the sensor part consisting of an electromechanical unit and an amplifier module is housed in a common case. A styrofoam body, conical in shape, is used to transmit the mechanical impulse of an impacting drop to a set of two moving coil system in magnetic fields. The styrofoam body and the two moving coils are rigidly fixed together. At the impact of a drop the styrofoam body together with the two moving coils moves downwards resulting an induced voltage in the sensing coil. Now,
a force must counteract the movement of the coils and thus the voltage is amplified and applied to the driving coil. As a consequence it takes very little time for the system to return to its original resting position and to get ready for the next impact of a drop. At the output of the amplifier the amplitude of the pulse is a measure for the size of the drop that caused it.

(B) The Processor

The processor of a Disdrometer performs the following functions:

i) **Power supply to the sensor**: The built in power supply generates regulated DC voltages of +15V and -15 V for powering the sensor and the circuits of the processor.

ii) **Signal processing**: The signal processing circuit has a noise reduction filter, a dynamic range compressor, a signal recognition circuit and a non-linear AD-converter. The noise reduction filter is an active band pass filter and frequency response is designed to give an optimum ratio between the signal from raindrops and the signal from acoustic noise that affects the sensor. The dynamic range compressor has an amplifier with a voltage dependent feedback network which can adjust the amplitude response of the system to the desired characteristic. The signal recognition circuit can differentiate between the signal pulses which are caused by the rain drops hitting the sensor and the more uniform oscillations caused by acoustic noise. It is of course a requirement that the pulses caused by raindrops exceed the oscillations caused by acoustic noise. If this case, a gate passes the pulses to the AD-converter. The analog to digital converter which has an exponential conversion characteristic
generates a 7-bit code at the RS-232 interface of the processor for every drop measured by the sensor.

iii) *Performance testing the of the instrument*: The test circuit consists of an astable multivibrator. The output of the multivibrator is fed directly into the driving coil of the sensor. Signals are generated to indicate the error if the sensor is not properly connected or if any part of the processor is not working properly. In order not to suppress the test signal while the test signal is actuated, the signal recognition circuit is disabled. The test signal is set off with a pushbutton situated on the front panel of the processor unit.

### 3.4.4.4 Error Source

The disdrometer is very sensitive to the acoustic noise. A sensor is essential to put in quiet surroundings, as high acoustic noise levels will affect the measurement of small drops. Though acoustic noise are efficiently handled by the instrument, signals due to rain drops not exceeding the noise level will be submersed in the noise signal. Thus only drop signals which are above the noise signal can be measured successfully. The strong winds which produce turbulence at the edges of the sensor, can also bring in considerable acoustic noise. Transients propagating along the power line to which the processor and the computer is connected can also cause recording of some small drops even in absence of rain. Such transients can be caused by surge currents in the power line, when an electrical device is switched on or off near the processor and the computer.
3.4.5 Multi frequency Radiometer

The multi-channel microwave radiometer has been developed as a technically advanced alternative to the radiosonde for tropospheric temperature and humidity profiling [Frate et al., 1998; Solheim et al., 1998]. The usefulness of ground-based microwave radiometry in retrieving temperature and humidity profiles was proven a few decades earlier [Westwater et al, 1965; Askne and Westwater, 1986]. Microwave radiometer is a low maintenance instrument capable of providing continuous atmospheric profiling with the highest vertical resolution near the ground in the planetary boundary layer.

Fig. 3.14: Multi- frequency Radiometer operating at the experimental site
Experimental Set up, Site & Data

This feature of microwave radiometer may be helpful in evaluating the futuristic high resolution numerical weather forecast models.

3.4.5.1 Introduction

Figure 3.14 shows the radiometer unit operating at the experimental site. Apart from sporadic and expensive in-situ measurements from research aircraft, passive microwave remote sensing provides till date the most accurate measurement of liquid water path column in the vertical direction over the land surface. Two channel radiometers had been proved to achieve high accuracy measurement of LWP as well as IWV over three decades ago [Westwater, 1978]. In the last few years, further improvements to the LWP retrieval have been made by the inclusion of additional microwave channels [Bosisio and Mallet, 1998] and the combination of microwave radiometer measurements with other ground-based instrumentation [Han and Westwater, 1995]. Solheim et al. [1998] suggested the potentiality of multi-channel radiometer in deriving the profile of cloud liquid water content.

3.4.5.2 Specifications of radiometer

The detailed specification of the HATPRO Radiometer is shown in Table 3.5.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humidity profile</td>
<td>Vertical resolution: 200 m (range 0-2000 m)</td>
</tr>
<tr>
<td></td>
<td>400 m (range 2000-5000 m)</td>
</tr>
<tr>
<td></td>
<td>800 m (range 5000-10000 m)</td>
</tr>
<tr>
<td>Experimental Set up, Site &amp; Data</td>
<td></td>
</tr>
<tr>
<td>--------------------------------</td>
<td></td>
</tr>
</tbody>
</table>
| **Temperature profile**         | Vertical resolution:  
|                                 | BL-Mode: 50 m (range 0-1200 m)  
|                                 | Z-Mode: 200 m (range 1200-5000 m)  
|                                 | 400 m (range 5000-10000 m)  |
| **Liquid water profile**        | Vertical resolution:  
|                                 | 250 m (range 0-2000 m)  
|                                 | 300 m (range 2000-5000 m)  
|                                 | 500 m (range 5000-10000 m)  |
| **Channel center frequencies**  | K-Band: 22.24 GHz, 23.04 GHz, 23.84 GHz, 25.44 GHz, 26.24 GHz, 27.84 GHz, 31.4 GHz  
|                                 | V-Band: 51.26 GHz, 52.28 GHz, 53.86 GHz, 54.94 GHz, 56.66 GHz, 57.3 GHz, 58.0 GHz  |
| **Channel bandwidth**           | 2000 MHz @ 58.0 GHz, 1000 MHz @ 57.3 GHz, 600 MHz @ 56.66 GHz, 230 MHz @ all other frequencies  |
| **System noise temperatures**   | <400 K for 22-31 GHz profiler, <700 K for 51.4-58.0 GHz profiler  |
| **Absolute brightness temperature accuracy** | 0.5 K  |
| **Brightness calculation**      | based on exact Planck radiation law  |
| **Retrieval algorithms**       | neural network, linear / nonlinear regression algorithms  |
| **Power consumption**           | <120 Watts average, 350 Watts peak for warming-up (without dew blower heater), blower: 130 Watts max.  |
### Experimental Set up, Site & Data

<table>
<thead>
<tr>
<th>Input voltage</th>
<th>90-230 V AC, 50 to 60 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>60 kg (without dew blower)</td>
</tr>
<tr>
<td>Dimensions</td>
<td>$63 \times 36 \times 90$ cm$^3$</td>
</tr>
</tbody>
</table>

### Hardware Configuration

- The schematic diagram featuring the internal components of radiometer is shown in Figure 3.15. The basic functional blocks of the radiometer are:
- Receiver optics comprising a corrugated feedhorn (encapsulated in thermal insulation) for each frequency band and off axis paraboloid (scanning mirror)
- Two receiver units (22.24-31.4 GHz, 51.3-59 GHz)
- The ambient load as part of the calibration system
- The internal scanning mechanism
- The instrument electronics sections
- Data acquisition system
Fig. 3.15: Internal structure of the RPG-HATPRO radiometer

The optical section of the radiometer has a HPBW (Humidity Profiler Beam Width) of $3.5^\circ$ and TPBW (Temperature Profiler Band Width) of $2.5^\circ$ with side-lobe level less than -30 dB. The optical section actually improves the stability of radiometer and its calibration accuracy by reducing standing wave problems within the quasi-optics. A polarizer wire grid helps in superimposing of the beams of the two profilers. The superimposed beam is reflected back by an off-axis paraboloid mirror as shown in Figure 3.15. All the receivers are integrated with their respective feedhorns and they are thermally insulated in order to achieve a high thermal stability.

3.4.5.3. Theory of Operation

Figure 3.16 shows the atmospheric absorptions of different atmospheric constituents. The green line shows the absorption loss for water vapour, blue line corresponds to liquid...
water content of cloud and the orange one represents the oxygen absorption. The dark black line shows the composite absorption loss for different atmospheric constituents. The frequency bands marked in blue are used by RPG’s radiometers to deduce LWP,

![Graph](image)

**Fig. 3.16:** Atmospheric emission of liquid water, water vapour and oxygen. The frequency bands marked in blue are utilized by RPG’s radiometers to derive LWP, IWV, Humidity and Temperature Profiles (full troposphere and boundary layer)

IWV, Humidity and Temperature Profiles. The information on Atmospheric water vapour profile is derived from frequency channels spanning over 22-28 GHz of the pressure broadened, relatively weak water vapour line.

Additionally, an IR-radiometer along with the humidity and temperature profiler provides cloud base height (CBH) and liquid water profiles (LPR) of atmosphere.
3.4.5.4 Operating Modes

The RPG-HATPRO radiometers [RPG-HATPRO Operating Manual, 2009] supports two temperature profiling modes, namely, full troposphere profiling (frequency scan across the oxygen line) and boundary layer scanning (elevation scan at 54.9 and 58 GHz). Humidity profiling at 22.4 GHz frequency is only available for the full troposphere mode due to the lack of opaque channels on the water vapour line at other frequencies.

In case of boundary layer temperature profiling the elevation scan is done in between 5° and zenith as shown in Figure 3.17. At frequencies 54.9 GHz and 58 GHz the atmosphere is optically thick. The respective weighting functions peak at 500 m at 58 GHz and 1000 m at 54.9 GHz. The receiver stability and accuracy has to be optimized for
small brightness temperature variations in the elevation scanning method. The physical
temperature of the receiver is stabilized to 30 mK over the whole operating temperature
range (-30°C to 40°C) to ensure a high gain stability during measurements (>200 sec).
The receiver noise temperature is minimized to be better than 700 K to reduce the overall
noise level.

3.4.5.5 Error Source

All types of losses in the receiving system are due to increase in temperature. Also, a
significant system noise contribution comes from the receiver optics. Usually, a
corrugated feedhorn which operates at 90 GHz has a typical loss of 0.5 dB. If the physical
temperature of the feedhorn is changed from 0°C to 30°C it leads to a system noise
increase of 3 K which consequently results in an error in the absolute brightness
temperature. Thus it is an essential condition for the receivers to be thermally stabilized
with the antenna.

3.4.6 Radiosonde Data

A Radiosonde is an instrument that measures various atmospheric parameters at different
heights using weather balloons and transmits them to a fixed receiver. Radiosondes
measure temperature with a thermometer, humidity with a hygrometer, and air pressure
with a barometer. The instruments up into the upper atmosphere on balloons twice a day
simultaneously around the world-- at midnight and at noon Greenwich Mean Time
(GMT). Radiosondes take continuous measurements as the balloon rises up in the air.
This information is transmitted back by radio to the ground. There is a tracking
equipment which monitors the movement of the radiosonde which is converted into wind speed and wind direction data. Local Radiosonde data are collected from the India Meteorological Department (IMD). The Radiosonde launches two times in a day at 0000 GMT and 1200 GMT. Different meteorological parameters including temperature, pressure, humidity etc. at different heights are obtained from the radiosonde data. For our study we have taken account of the Radiosonde data obtained at Kolkata (22°65' N, 88°45' E).

3.5 CONCLUSIONS

A fairly elaborate experimental facility has been created at the rooftop laboratory of the Institute of Radio Physics and Electronics comprising of radiometer, micro rain radar (MRR), optical raingauge (ORG), disdrometer, automatic weather station, tipping bucket rain gauge, Ku-band receiving system. The details of their characteristics have been described in this chapter to understand the scopes of investigation possible in the laboratory. It will be helpful to better interpret the results that are presented in the following chapters.