Notes on AWS and ARG

1. Introduction

The observations of weather parameters such as air temperature, relative humidity, atmospheric pressure, rainfall, wind speed, wind direction etc. are being taken in India Meteorological Department at conventional observatories since establishment of the department in 1875. At present a network of 559 surface observatories comprising of departmental and non-departmental observatories caters to the need of operational weather forecasting. For continuous monitoring of weather systems such as cyclones, western disturbances, thunderstorms and monsoon etc. over continental India the conventional network of observatories is not adequate. In view of this a network of automatic weather stations was envisaged so that human intervention can be minimized.

The concept of automation of meteorological observations and their dissemination is not new to the meteorological fraternity. The automation began way back in 1877 when Dutch meteorological instruments designer Olland developed telemeteograph on suggestion of Buys Ballot. Similar attempt was made in Belgium but theconcept could not flourish at that time due to high production and maintenance cost involved. U. S. Navy sponsored development of Automatic Weather Station (AWS) with radio communication in 1940's. This AWS was developed by the U. S. National Bureau of Standards. This perhaps was the first AWS in operation. Since then, development of AWS has undergone phenomenal changes. With the advancement in technology especially with the advent of microprocessor technology in 1960ies the concept of AWS in its modern form brought revolution in meteorological observations.

The history of AWS in India can be traced back to 1974-75 when first experiment was carried out to relay meteorological data through India's first polar orbiting satellite "Aryabhatta". In the year 1979-80, India Meteorological Department (IMD) conducted a pilot experiment with Indian Space Research Organization (ISRO) to operate a small network of Data Collection Platforms (DCP) via polar orbiting satellite "Bhaskara" (SEO). The data transmitted were received at the Earth Station located at Shriharikota Rocket Range. These initial experiments though more of academic interest helped IMD to get insight into the technical detailsof DCPs and experience of operating the network of DCPs in hostile environment. Subsequently, IMD established a network of 100 DCPs across India. Satisfactory performance of DCP installed in oppressive weather conditions of Antarctica was reported. However, due to system design limitations overall network performance was unsatisfactory both in terms of data reception and quality. In 1997, the network of 15 state-of-the-art microprocessor/ microcontroller based AWS was established in Test and Evaluation mode. IMD developed the algorithms for computerized monitoring of performance of this AWS network. The deviations of AWS data from the co-located synoptic surface observatory data were within acceptable limits during 1998-2005 and thus AWS network performance was satisfactory.It was therefore decided to expand and upgrade the network of AWS under the project “Replacement of obsolete DCP network with AWS and establishment ofdata receiving Earth Station at Pune”. In the year 2006-07, the network of 125 AWS has been established across India as depicted in Figure 1. The objectives of AWS network are: (i) To establish network of 125 AWS for measurement of about 8 to 12 meteorological parameters and transmission of these data via UHF transmitter. (ii) To receive the data at receiving Earth Station via a dedicated meteorological satellite and data process, archive and disseminate the data. (iii) To enhance surface observational network of IMD and augment the manned observatory network by providing high temporal resolution data in a cost effective manner.

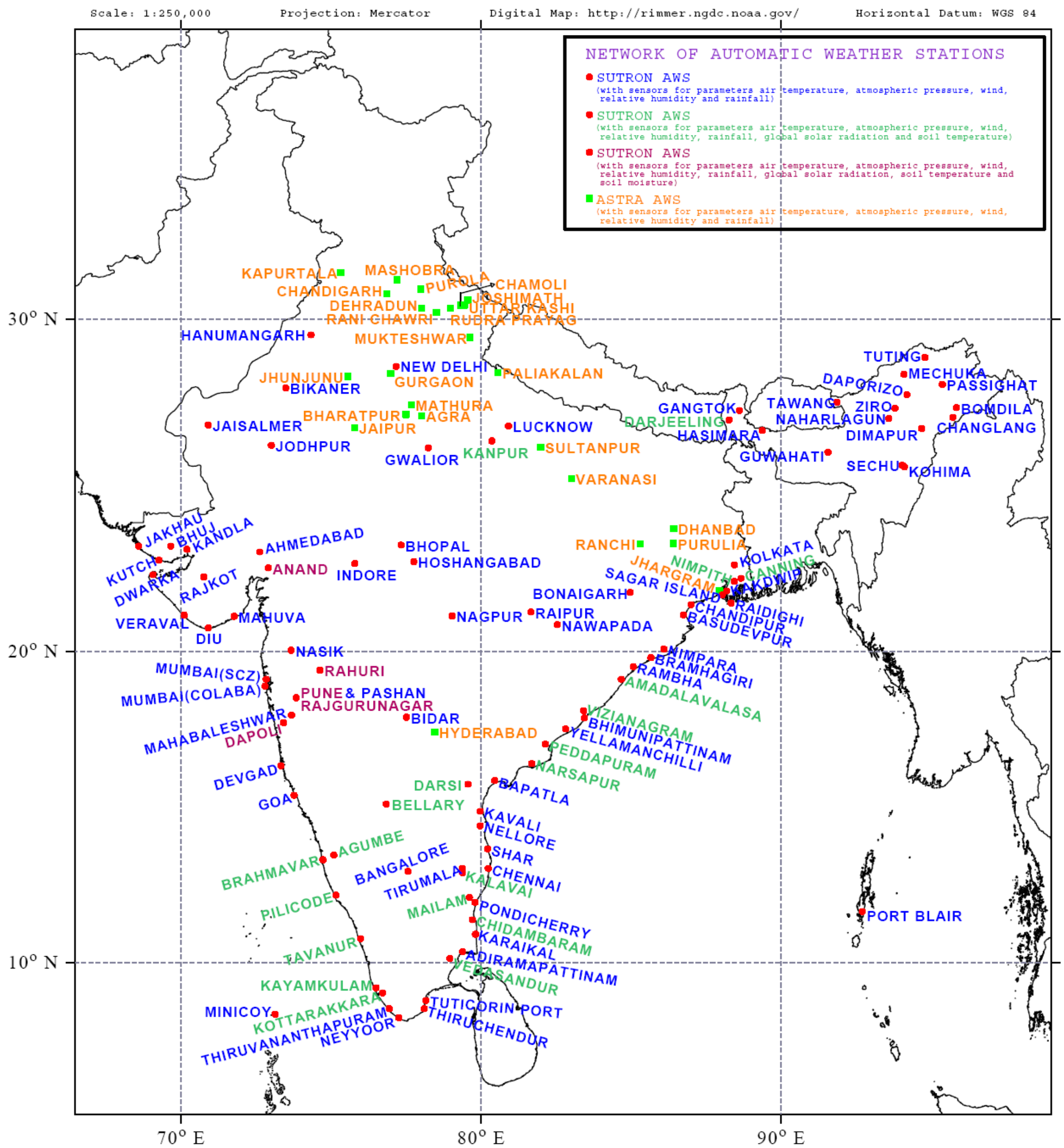

Figure 1: Network of Automatic Weather Stations established during 2006-2007.

A steering committee constituted by the Ministry of Earth Sciences, Govt. of India recommended refurbishment and establishment of various atmospheric observational networks under modernization program for India Meteorological Department (IMD). One of the recommendations of the committee was to establish a network of 1200 AWS and 3600 Automatic Rain Gauge (ARG) stations across India in a phased manner. Initially the AWS network would serve as augmentation of the conventional surface observatory network. Based on the results of network performance, a decision would be taken on installation of additional AWS co-located with conventional manned observatories where measurements of meteorological parameters such as air temperature,relative humidity, wind, rainfall, atmospheric pressure, solar radiation will be taken by AWS and visual observations such as visibility, present weather, cloud cover, height of base of cloud etc by human observers.

The committee made several detailed recommendations for establishment of the network of AWS. All recommendations of the committee could not be accomplished in Phase – I of modernization program. The present network plan is primarily based on three factors, viz., (i) meteorologically unrepresented districts (ii) monitoring of meso-scale systems and (iii) Agro-meteorological requirements.The committee mentioned that by the year 2006, there were 253 meteorologically unrepresented districts in Indo-Gangetic Plains, Himachal Pradesh, Central India and south peninsular India. These districts have been considered on priority for installation of AWS. A uniform network of AWS is now available in India with an AWS in almost all districts of the country. The present manned surface observational network is adequate for monitoring synoptic scale weather phenomena but not meso-scale severe weather generating systems. In order to address this issue for National Capital Region (NCR), a meso-network of 27 AWS has been established in and around NCR. The data of meso-network are being ingested in Numerical Weather Prediction models for generation of forecast with improved skill.

The sensors for parameters air temperature, relative humidity, atmospheric pressure, wind speed, winddirection, rainfall and global solar radiation have been interfaced with each AWS. For better understanding of the processes affecting crop growth, crop yield, incidences of pests and diseases, additional sensors for soil temperature, soil moisture, leaf temperature and leaf wetness have been interfaced with 127 AWS in different agro-climatic zones of India. These stations are called Agro-AWS. The network of 550 AWS comprising of 423 AWS (without sensors for agro-meteorological parameters) is depicted in Figure 2 and network of 127 Agro-AWS is shown in Figure 3.

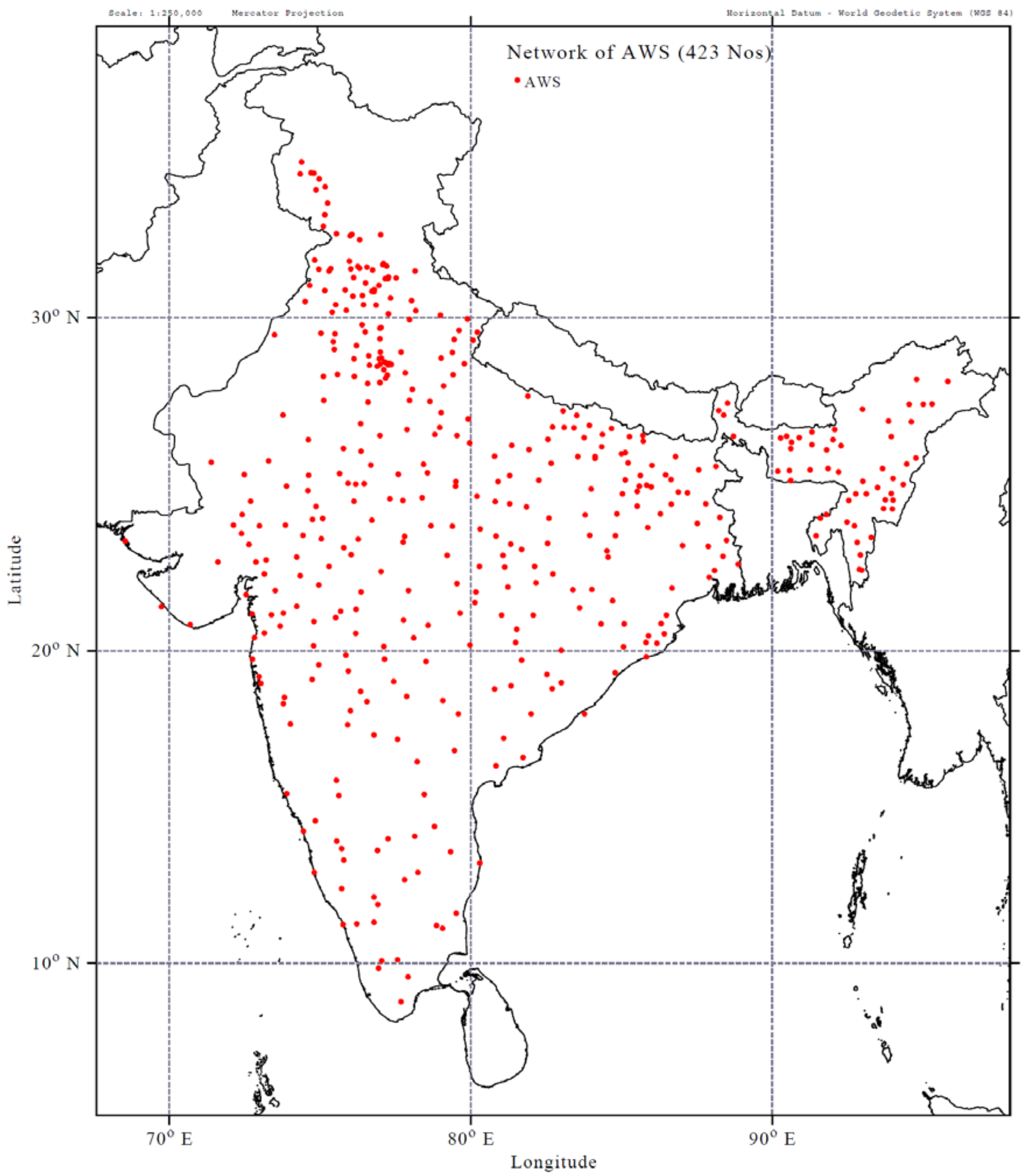

Figure 2: Network of AWS established during 2009-2012.

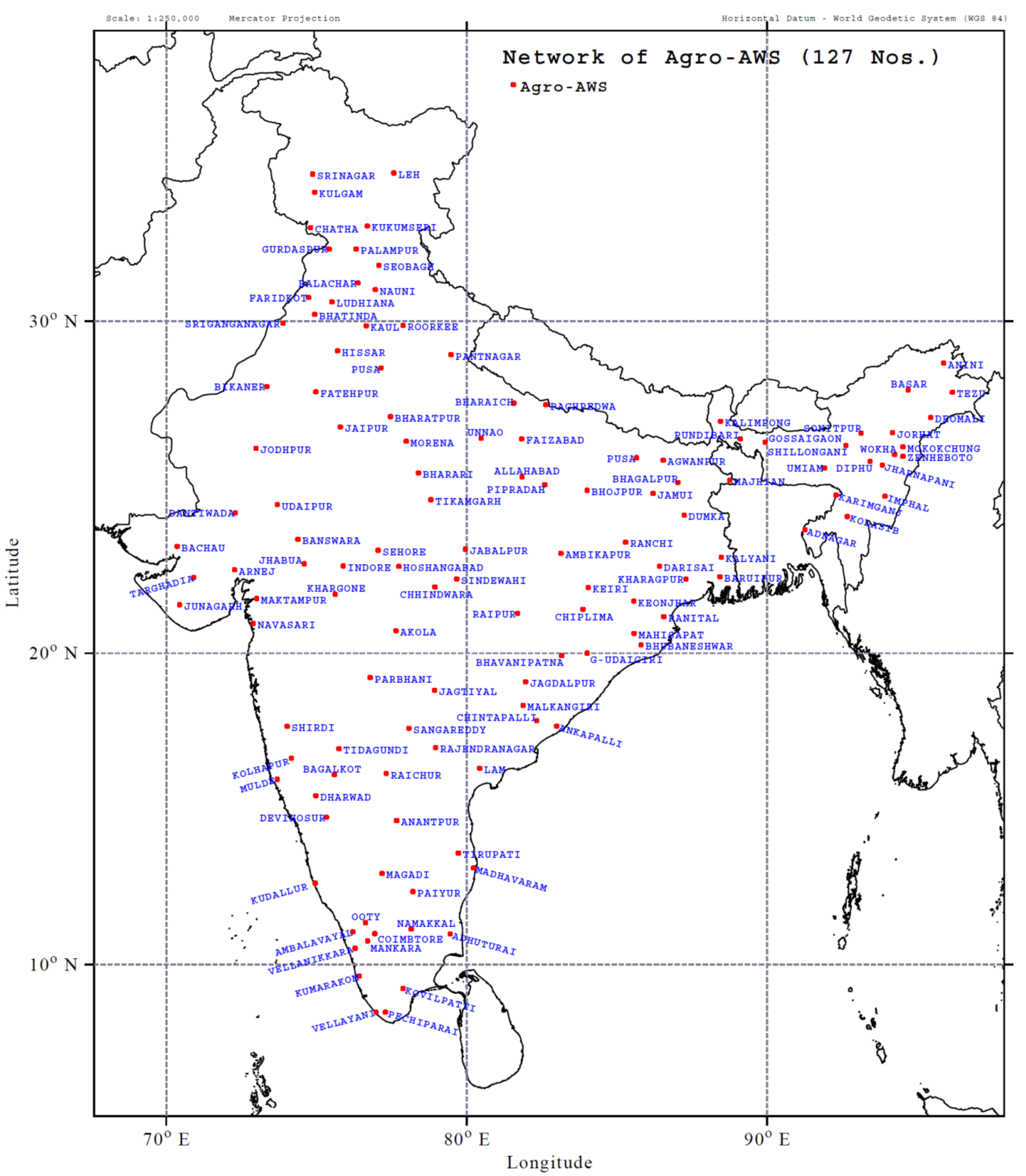

Figure 3: Network of Agro-AWS established during 2009-2012.

The AWS network has diverse applications in operational meteorology such as agro-meteorology, operational forecasting and Numerical Weather Prediction etc. In view of these potential applications, expansion of network of AWS is recommended by the steering committee constituted by the Ministry of Earth Sciences. Network of about 1000 AWS and

3600 Automatic Rain Gauge (ARG) stations will be established across India in phased manner through implementation of modernization programme.

2. Purpose of establishing AWS network

Definition of AWS: According to the World Meteorological Organization(WMO), an AWS is defined as a "meteorological station at which observations are made and transmitted automatically".

Automatic weather stations are used for increasing the number and reliability of surface observations. This is achieved by:

a) Increasing the density of an existing networkby providing data from new sites andfrom sites that are difficult to access andinhospitable.
b) Supplying, for manned stations, data outside the normal working hours.
c) Increasing the reliability of measurements byusing sophisticated technology and modern,digital measurement techniques.
d) Ensuring the homogeneity of networks bystandardizing the measuring techniques.
e) Satisfying new observational needs and requirements.
f) Reducing human errors.
g) Lowering operational costs by reducing the number of observers.
h) Measuring and reporting with high frequencyor continuously.

3. WMO guidelines on Automatic Weather Stations

When considering the introduction of new AWS instrument systems, Meteorological Services should:

a) Introduce into service only those systemsthat are sufficiently well documented so as toprovide adequate knowledge and understandingof their capabilities, characteristics andany algorithms used.
b) Retain or develop sufficient technical expertiseto enable them to specify system requirementsand to assess the appropriateness of thecapabilities and characteristics of such systems and algorithms used therein.
c) Explore fully user requirements and engage users in system design of AWSs.
d) Engage users in validation and evaluation of the new automated systems.
e) Engage manufacturers in the system assessmentand need for improvements in performance.
f) Develop detailed guides and documentationon the systems to support all users.
g) Develop adequate programmes for maintenanceand calibration support of the AWSs.
h) Consult and cooperate with users, such asaeronautical authorities, throughout the processfrom AWS design, to implementation, to operational use.
i) Develop and apply reporting methods fornational use to accommodate both observationsgenerated by traditional and automatedsystems.

4. Types of AWS

A general classification could include stationsthat provide data in real time and those that recorddata for non‐real-time or off‐line analysis. It is notunusual, however, for both of these functions to bedischarged by the same AWS.

Real‐time AWS: A station providing data to users of meteorological observations in real time, typicallyat programmed times, but also in emergency conditionsor upon external request. Typical real‐timeuse of an AWS is the provision of synoptic data andthe monitoring of critical warning states such asstorms and river or tide levels.

Off‐line AWS: A station recording data on site on internal or external data storage devices possiblycombined with a display of actual data. The interventionof an observer is required to send storeddata to the remote data user. Typical stations areclimatological and simple aid‐to‐the‐observerstations.

Both types of stations can optionally be set up with means both for manual entry and for the editing ofvisual or subjective observations that cannot yet bemade fully automatically. This includes present andpast weather or observations that involve highcosts, such as cloud height and visibility. Such astation could be described as partially or semi‐automated.

Based on characteristics of telemetry system the AWS can be categorized into following types

- Pseudo random type: A group of stations is assigned a time window for transmission of data to central receiving system. The user know the time window in which station will transmit the data but exact time of transmission in the time window will be random and not known to user. (PRBS type stations in IMD network.)
- Self-timed type: Each station is assigned a fixed time for transmission of data to central receiving system. (TDMA type stations in IMD network.)
- Interrogative type: The station does not transmit the data to central receiving system. The data are stored in locally the data logger and user retrieves the data by remotely interrogating the station as and when required.
- Alarm type: The station transmits the data only when alarm condition set by the user is measured. Eg. Temperature exceeding 40 Deg. C or hourly rainfall exceeding 50 mm.

5. Setup and configuration of AWS

There are three basic components of AWS namely (i) remote/field station (ii) telemetry system and (iii) data receiving Earth Station.

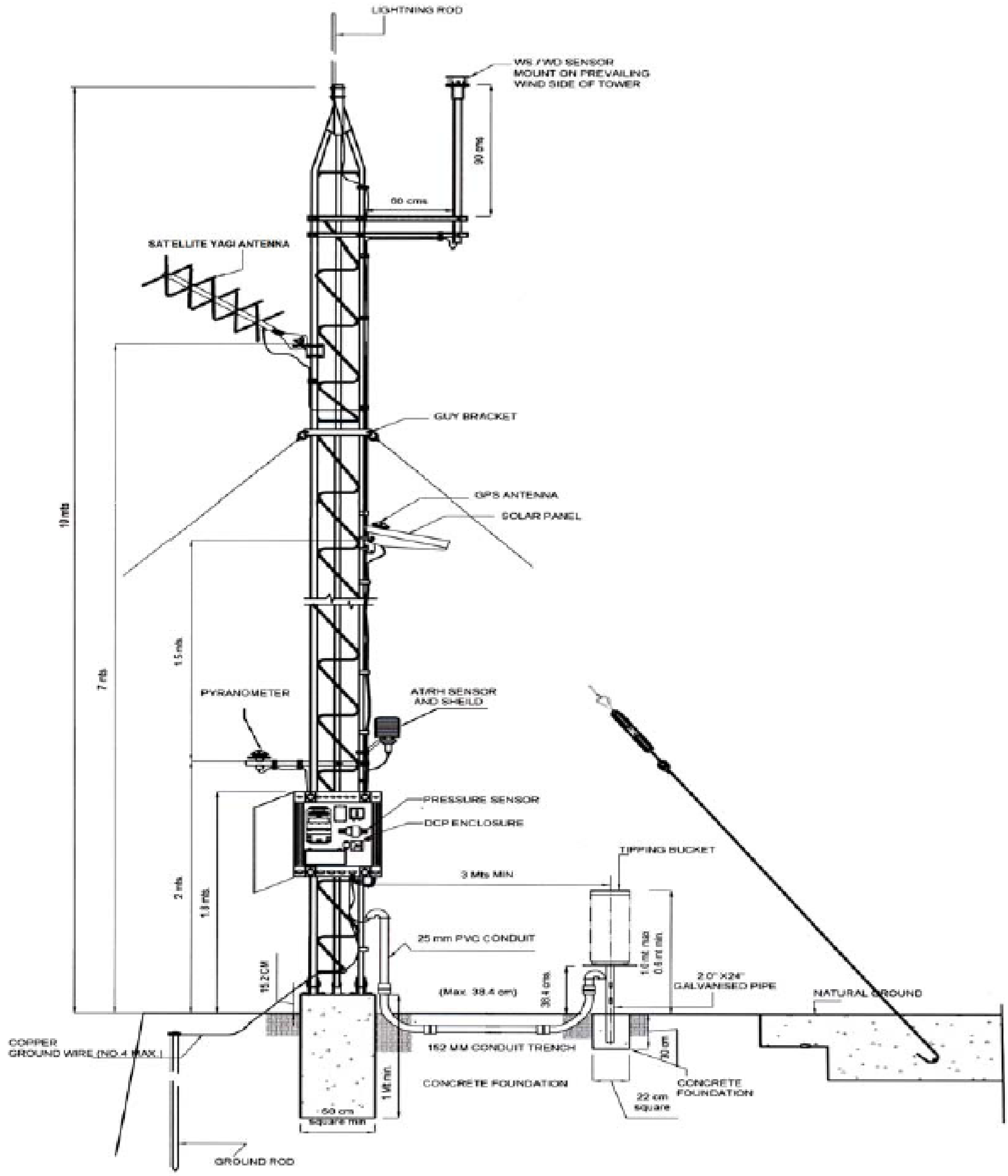

Figure 4: Typical site layout of AWS.

Remote/Field station: The field station comprises of data logger, sensors, transmitter, antenna, power supply system (battery and solar panels, charge controller), 10 m mast etc. A 10 m galvanized iron tower with red oxide coating is used tomount the system enclosure and sensors. The tower is erected on a concrete foundation of 3-5 feet depth depending on site requirement. In addition the tower is supported by three guy ropes. The NEMA – IVstandard enclosure is fixed on the tower at a height of about 1.8 m. data logger, transmitter, battery, charge controller and pressure sensor etc. are housed in NEMA –IV standard enclosure. Wind sensor is mounted on a shaft; at least 3 feet from the tower. The shaft for pyranometer is kept to the south to minimize the effect of tower shadow. The crossed Yagi antenna is installed on a tower at an approximate height of 6-7 m. The antenna elevation and azimuth angle depends on latitude and longitude of the field site and the satellite longitude. For the AWS network the azimuth angle is greater than170 Deg. The antenna is therefore mounted on the tower facing the South. The tipping bucket rain gauge is installed at a minimum distance of 3 m from the tower. The site layout of AWS is shown in Figure 4 below.

6. Data logger transmitters and crossed Yagi antenna

The data loggers used in AWS systems have been procured from different Original Equipment Manufacturers and hence they differ in their functional capabilities. However, both are configured with same sampling and measurement schemes.

The data loggers have sufficient analog (single and double ended) and digital channels (RS232, RS485, SDI-12, RS422, frequency/counter) for interfacing of sensors. The loggers support varied transmission modes such as telephone, satellite, GSM/GPRS, radio modem etc. It is possible to execute customized programs at scheduled interval in Sutron make data logger. UHF satellite transmitter is used for transmission to INSAT series of satellites. The real time clock of the system is synchronized to UTC via GPS at least once in a day. The features of UHF transmitter are given below.

The logger shall have memory to store the data acquired from sensor over a time period as per user application. The logger shall be modular in design and shall be user configurable without requirement of laptop through keys and display.

Crossed Yagi antenna is interfaced to satellite transmitter to transmit data from stations. The antenna polarization is field configurable and can be set either to LHCP or RHCP depending upon the satellite. The mounting arrangements are such that 360 Deg azimuth and 180 Deg elevation angle adjustment are possible. High beamwidth (40 Deg) permits easy pointing of antenna and high gain (minimum 11 dBi) allows operation with AWS transmitting in the range of 3 to 10 Watt.

An antenna is a transducer that converts radio frequency electric current to electromagnetic waves that are then radiated into space. The electric field or "E" plane determines the polarisation or orientation of the radio wave. In general, most antennas radiate either in linear or circular polarisation. A linear polarised antenna radiates wholly in one plane containing the direction of propagation. Circular polarisation is in fact two orthogonal linear polarised waves 90 degrees out of phase. Circular polarisation is most often used in satellite communications. The polarisation of each antenna in a system should be properly aligned. Maximum signal strength between stations occurs when both stations are using identical polarisation. In a circular polarised antenna, the plane of polarisation rotates in a circle making one complete revolution during one period of the wave. If the rotation is clockwise looking in the direction of propagation, the sense is called right-hand-circular (RHC). If the rotation is counterclockwise, the sense is called left-hand-circular (LHC). A circular polarised wave radiates energy in both the horizontal and vertical planes and all planes in between. The difference, if any, between the maximum and the minimum peaks as the antenna is rotated through all angles, is called the axial ratio or ellipticity and is usually specified in decibels (dB). If the axial ratio is near 0 dB, the antenna is said to be circular polarised. If the axial ratio is greater than 1-2 dB, the polarisation is often referred to as elliptical.

The crossed Yagi antenna is used in the AWS field sites for transmission. Just by interchanging the position of the dipoles, it has the facility to transmit with both right hand circular polarisation (RHCP) and left hand circular polarisation (LHCP). It operates in the frequency range of 402.65 to 402.85 MHz, with a centre frequency of 401.8 MHz. The gain of the antenna is 11 dBi with an axial ratio of 0.8 dB. It can sustain winds of severe cyclonic storms. This high gain antenna allows for operation with AWS transmitting at less than 10W with 8.5W typical output. Base of the antenna is installed on a vertical pipe providing 360° azimuth and 90° elevation adjustment range.

7. Sensors and their characteristics

Before going into details of sensors used for measurements of different weather parameters let us first recapitulate definitions of basic terms used in metrology.

Measureable quantity: An attribute of a phenomenon, body or substance that may be distinguished qualitatively and determined quantitatively.
Base quantity: One of the quantity that, in a system of quantities are conventionally accepted as functionally independent of one another.
Example: The quantities length, mass and time are generally taken to the base quantities in field of mechanics.
Derived quantity: The quantity defined, in a system of quantities, as a function of base quantities of that system.
Example: in a system having base quantities length, mass and time, velocity is a derived quantity defined as: length divided by time.

Unit of measurement: Particular quantity, defined and adopted by convention, with which other quantities of the same kind are compared in order to express their magnitudes relatives to that quantity.

Units of measurement have conventionally assigned names and symbols. Units of quantities of the same dimension may have the same names and symbols even when thequantities are not of the same kind.

International System of Units, SI: The coherent system of units adopted and recommended by the General Conference on Weights and Measure (CGPM). The SI is based at present on the following seven base units.

Quantity	**SI base unit**	
	Name	**Symbol**
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

Base unit of measurement: unit of measurement of a base quantity in a given system of quantities. In any given coherent system of units there is only one base unit for each base quantity.

Derived unit of measurement: unit of measurement of a derived quantity in a given system of quantities. some derived units have special names and symbols; for example, in the SI:

Grandeur	**SI base unit**	
	Name	**Symbol**
force	newton	N
energy	joule	J
pressure	pascal	Pa

Value of a quantity: magnitude of a particular quantity generally expressed as a unit of measurement multiplied by a number.

EXAMPLES:

a) length of a rod: 5.34 m or 534 cm;

b) mass of a body: 0.152 kg or 152 g;

c) amount of substance

of a sample of water (H_2O): 0.012 mol or 12 mmol.

True value of a quantity: A value that would be obtained by a perfect measurement. True values are by nature indeterminate. This is a value consistent with the definition of a given particular quantity.
Conventional true value of quantity: The value attributed to a particular quantity and accepted, sometimes by convention, as having an uncertainty appropriate for a given purpose.
Example: At a given location, the value assigned to the quantity realized by a reference standard may be taken as a conventional true value.
The CODATA (1986) recommended value for the Avogadro constant, N_A: 6.0221367 x 10^{23} mol^{-1}.
Measurement: A set of operations having the object of determining a value of a quantity.
Principle of measurement: Scientific basis of a measurement.
Example: The thermoelectric effect applied to the measurement of temperature, The Doppler effect applied to the measurement of velocity, The Raman effect applied to the measurement of the wave number of molecular vibrations etc.
Method of measurement: Logical sequence of operations, described generically, used in the performance of measurement.
Measurement procedure: set of operations, described specifically, used in the performance of particular measurements according to a given method.
Measurand: particular quantity subject to measurement.
Example:Vapour pressure of a given sample of water at 20°C. The specification of a measurand may require statements about quantities such as time,
temperature and pressure.

8. Measuring system and characteristics of measuring system

The complete set of measuring instruments and other equipment assembled to carry out specified measurements is called measuring system.
Example: Apparatus for measuring the conductivity of semiconductor materials, apparatus for calibration of thermometer.
Sensor: Element of a measuring instrument or measuring chain that is directly affected by the measurand.
Example: Measuring junction of a thermoelectric thermometer, Rotor of a turbine flow meter, Photocell of a spectrophotometer etc.
Detector: A device or substance that indicates the presence of a phenomenon without necessarily providing a value of an associated quantity.
Example: Gas leak detector, litmus paper.
Gauge: operation of fixing the positions of the scale marks of a measuring instrument (in some cases of certain principal marks only), in relation to the corresponding values of the measurands.
Example: Tipping Bucket Rain Gauge (TBRG).

Characteristics of measuring system:

ACCURACY OF MESUREMENT: Degreecloseness of the agreement between the result of a measurement and a true value of a measurand."Accuracy" is a qualitative concept.

PRECISION: The degree of scatter in the results.

ERROR OF INDICATION OF A MEASURING INSTRUMENT: Indication of a measuring instrument minus a true value of the corresponding input quantity. (Since a true value cannot be determined, in practice a conventional true value is used.)

DEVIATION: value minus its reference value.

INTRINSIC ERROR OF A MEASURING INSTRUMENT: Error of a measuring instrument, determined under reference conditions.

RAMDOM ERROR: result of a measurement minus the mean that would result from an infinite number of measurements of the same measurand carried out under repeatability conditions. Random error is equal to error minus systematic error. Because only a finite number of measurements can be made, it is possible to determine only an estimate of random error.

SYSTEMATIC ERROR: The mean that would result from an infinite number of measurements of the same measurand carried out under repeatability conditions minus a true value of the measurand. Systematic error is equal to error minus random error. Like true value, systematic error and its causes cannot be completely known.

CORRECTION: The value added algebraically to the uncorrected result of a measurement to compensate for systematic error.The correction is equal to the negative of the estimated systematic error.Since the systematic error cannot be known perfectly, the compensation cannot be complete.

UNCERTAINTY OF MEASUREMENT:parameter, associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand.

BIAS (OF A MEASURING INSTRUMENT): systematic error of the indication of a measuring instrument. (The bias of a measuring instrument is normally estimated by averaging the error of indication over an appropriate number of repeated measurements.)

REPEATABILITY (OF A MEASURING INSTRUMENT): ability of a measuring instrument to provide closely similar indications for repeated applications of the same measurand under the same conditions of measurement.

Repeatability may be expressed quantitatively in terms of the dispersion characteristics of the indications.

The conditions of repeatability include:

- reduction to a minimum of the variations due to the observer.
- the same measurement procedure.
- the same observer.
- the same measuring equipment, used under the same conditions.
- the same location.

- repetition over a short period of time.

REPRODUCIBILITY (OF RESULTS OF MEASUREMENTS): Closeness of the agreement between the results of measurements of the same measurand carried out under changed conditions of measurement. A valid statement of reproducibility requires specification of the conditions changed. Reproducibility may be expressed quantitatively in terms of the dispersion characteristics of the results.

The changed conditions may include:

- principle of measurement,
- method of measurement,
- observer,
- measuring instrument,
- reference standard,
- location,
- conditions of use,
- time.

DRIFT: slow change of a metrological characteristic of a measuring instrument.

RESPONSE TIME: time interval between the instant when a stimulus is subjected to a specified abrupt change and theinstant when the response reaches and remains within specified limits around its final steady value.

Measurement Standard

Measurement Standard etalon: material measure, measuring instrument, reference material or measuring system intended to define, realize, conserve or reproduce a unit or one or more values of quantity to serve as a reference.

Examples:

a) 1 kg mass standard;
b) 100 Ω standard resistor;
c) standard ammeter;
d) Caesium frequency standard.

Primary Standard: The standard that is designated or widely acknowledged as having the highest metrological qualities and whose value is accepted without reference to other standards of the same quantity.

National measurement standard: The standard recognized by a national decision to serve, in a country, as the basis for assigning values to other standards of the quantity concerned.

Reference standard: The standard, generally having the highest metrological quality available at a given location or in a given organization, from which measurements made there are derived.

Working standard: The standard that is used routinely to calibrate or check material measures, measuring instruments or reference materials. A working standard is usually calibrated against a reference standard.

Traceability: The property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties. The unbroken chain of comparisons is called a **traceability chain**.

Calibration: set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system, or values represented by a material measure or a reference material, and the corresponding values realized by standards.

The result of a calibration permits either the assignment of values of measurands to the indications or the determination of corrections with respect to indications.

Sensors interfaced with AWS

The meteorological requirements for sensors used at AWSs are not very different from those of sensors at manual observation stations. The sensors must be robust, fairly maintenance-free and should have no intrinsic bias or uncertainty in the way in which they sample the variables to be measured. In general, all sensors with an electrical / electronic output are suitable. Depending on their output characteristics, sensors can be classified as analogue, digital and "intelligent" sensors.

Analogue sensors

Sensor output is commonly represented by a continuously varying signal and small fluctuations are meaningful as well like voltage, current, charge, resistance or capacitance. Signal conditioning is the process in which the transducer(sensor) analog outputs are converted into voltage levels (for example 0 to 100 % humidity corresponds to 0 to 1 V) for further processing in the data logger.

Digital sensors

Sensors with digital signal outputs have information contained in a bit or group of bits(zeros and ones) and sensors with pulse or frequency output. Rain gauge is a digital sensor.

Intelligent sensors/transducers

Sensors including a microprocessor performing basic data-acquisition and processing functions and providing an output in serial digital or parallel form are called intelligent sensors. The Gill ultrasonic sensor is an intelligent sensor with a microprocessor arrangement mounted in the neck of the sensor which performs the basic data acquisition and processing.

SDI-12: SDI-12 is the acronym for "Serial Data Interface at 1200 Baud". SDI-12 is an asynchronous, ASCII, serial communications protocol that was developed for intelligent sensory instruments. Electrically the protocol is a three wire digital connection - data, ground and 12V. This connectivity is achieved by digital communication along a single serial line. The digital addressing system allows an SDI-recorder to send an address over a single line that is occupied by up to 62 sensors. Only the pre-configured sensor matching that address will respond (handshake). Other sensors on the same line will not respond until called and typically stay in "sleep mode" (low power mode), until called. Advantages of this are the ability to use a single available data channel for many sensors (in many cases a technician may want to set up more sensors, but it is limited by the number of analogue channels that may be available on a particular data logger). This allows more sensors to be used on a limited number of channels, transmit over longer distances and save power. SDI-12 communication has the limiting factor of taking around 20–30 seconds to record a measurement. Sutronaccubar pressure sensor is connected using the SDI-12 interface.

RS485 / RS232: The Electronics Industry Association (EIA), USA has recommended standards(RS) RS485, RS422 and RS232 that deal with data communications to ensure compatibility between units provided by various manufacturers. Electronic data communications between elements will generally fall into two broad categories viz., single-ended and differential. RS232 (single-ended) allows for data transmission from one transmitter to one receiver at relatively slow data rates (up to 20K bits/second) and short distances (up to 5 metres at the maximum data rate). The RS232 signals are represented by voltage levels with respect to a common (power / logic ground). When communicating at high data rates, or over long distances in real world environments, single-ended methods are often inadequate. Differential data transmission offers superior performance in most applications. Differential signals can help nullify the effects of ground shifts and induced noise signals that can appear as common mode voltages on a network. RS-485 are restricted to connections / cable lengths up to 1.5 km.

a) **Ultrasonic Wind Sensor**

Ultrasonic wind sensor is used for measurement of wind. The sensor has no moving part and hence is suitable for use in remote field AWS. The hourly wind speed and wind direction are obtained after taking vector average of samples taken every second starting from three minutes prior to full hour UTC (180 samples starting from 57th minute to full hour UTC).The measurement range is 0-116 knots (0 to 60 mps) for wind speed and 0-359° for wind direction. The sensor operates over the power range 9-30V. The sensor gives two separate outputs for the wind speed and wind direction from 0 to 5 Volt.

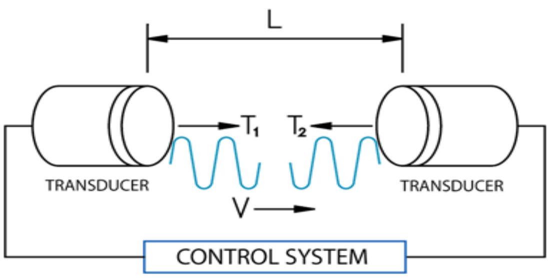

Figure 5: Time of flight theory

The Windsonic measures the time it takes for an ultrasonic pulse of sound to travel from the North transducer to the South transducer, and compares it with the time for a pulse to travel from S to N transducer(Figure 5). The times are also compared between West and East, and

E and W transducers. WS/WD is obtained by determining which way the wind is blowing faster. An arrow is engraved in the sensor which shall be set to point towards north direction. Using a magnetic compass north direction in the station needs to be located correctly and then sensor is to be mounted.

The transducers fire ultrasonic pulses to the opposing transducers. In still air (zero wind speeds) time of flight between the two transducers is same for all pulses, both forward and reverse directions. When the wind blows, it increases the time of flight for pulses travelling against the wind. So from the changes in the time of flight, the sensor calculates the wind speed and direction. For instance if a North Wind is blowing, then the time it takes for the pulse to travel from N to S will be faster than from S to N whereas the W to E, and E to W times will be the same. The wind speed and direction can then be calculated from the differences in the times of flight on each axis. This calculation is independent of factors such as temperature, altitude and humidity. The microcontroller embedded in the neck of the sensor computes the wind speed and direction and reports them to the data logger.

L = Distance between transducer faces, C=speed of sound (The speed of sound is the distance travelled during a unit of time by a sound wave propagating through an elastic medium. In dry air at 20°C (68°F), the speed of sound is 343.2 metres per second), V= velocity of gas flow (here air) T1 = Transit time of ultrasound in one direction, T2 = Transit time of ultrasound in the opposite direction as indicated in the Figure 5.

$$T_1 = \frac{L}{C - V} \quad \text{and} \qquad T_2 = \frac{L}{C - V}$$

Therefore: $V = \frac{\mathrm{L}}{2}\left\{\frac{1}{T_1} - \frac{1}{T_2}\right\} C = \frac{\mathrm{L}}{2}\left\{\frac{1}{T_1} + \frac{1}{T_2}\right\}$

In AWS, vector averaging of wind speed and direction is done from the 180 samples (@ one per sec) for the three minutes prior to the top of the hour, say, 57:00 to 60:00/00:00 at which hourly observations are sampled for all the sensors.

b) Air Temperature – Relative Humidity sensor

Temperature is the condition which determines the direction of net flow of heat between two bodies. Meteorological requirements of temperature measurements primarily related to air near Earth's surface, surface of the ground, soil at various depths, surface level of the sea and upper air.

Air Temperature/ Relative Humidity probe mounted in naturally ventilated radiation shield is used for measurement. Pt100 sensor is used as temperature sensor and relative humidity is measured based on change in capacitance. The hourly air temperature and relative humidity along with hourly maximum and minimum temperature based on samples taken at every minute (60 samples) are transmitted from field station.

The electrical resistance thermometer is a device measuring temperature by the reversible change of electrical resistance of metal wire. The metal's choice depends on sensitivity, reproducibility, linearity. A good metal resistance thermometer will satisfy following requirements:

- Its physical and chemical properties remain same throughout temperature measurement range.
- Its resistance will increase steadily with increasing temperature without any discontinuities in measurement range.
- Its resistance and thermal coefficient should be large enough to be useful in measuring circuits.

  Pure Platinum satisfies these requirements. Practical thermometers are artificially aged before use and are commonly made from platinum alloys. Usually they are hermetically sealed with either glass or ceramic.Their time constant is smaller than liquid in glass thermometers.

The physical law of a resistance thermometer:

$R(T) = \rho(T)\frac{L}{A}$where L is length of wire, A is cross section area, ρ is resistivity.

The use of resistance thermometer assumes stability of sensing element, the law R(T) is known, the sensing element is kept free of contamination.

Humidity measurements at Earth's surface are required for meteorological analysis and forecasting for climate studies and many special applications in hydrology and agriculture.
In general relative humidity is a derived at conventional observatory from hygrometric tables. RH is ratio of vapour pressure in unit volume of air to saturation vapour pressure.Conventionally relative humidity is measured using Psychrometer or hair hygrograph. In AWS, a capacitive humidity sensor is widely used. Sensor consists of a substrate on which a thin film of polymer or metal oxide is deposited between two conductive electrodes. The sensing surface is coated with porous metal electrodes to protect it from contamination and exposure to condensation. The substrate is typically a glass, ceramic or silicon. Incremental change in dielectric constant of sensor is directly proportional to relative humidity.

c) Atmospheric Pressure sensor

Pressure of the atmosphere at any place on the earth is the force exerted on unit area of given surface by virtue of the weight of the air in vertical column extending above it. A solid state pressure transducer is used in AWS for measurement of pressure. A Piezo-electric quartz crystal is used for direct measurement of pressure. A material is said to exhibit piezo electric effect if a mechanical force applied to it produces electric charges. Conversely, when placed in an electric field, there results mechanical strain and distortion.

Strain gauges are essentially devices whose electrical resistance changes when they are strained, by extending or compressing them. The phenomenon of a change in resistivity due to a strain, inducedby a mechanical force, is known as piezo-resistivity and is exhibited by most conductors and semiconductors.

When a metal wire is stretched (strained) it becomes longer and thinner, and its resistance will increase by an amount related to geometry and piezo-resistivity. In this example it can be expressedas:

The gauge factor $k = \frac{dR/R}{dl/l}$

dR: Resistance variation.

dl: length variation due to strain.

R: Resistance.

L: Length.

The gauge factor is very much greater in semi-conductors than in metals –typically 50 times much greater because the piezo-resistive contribution to the gauge factor in semi-conductor is very large. Thismakes them much more sensitive and suitable for use as strain gauges.

d) Rainfall

Rainfall is most important parameter measured by meteorological services. In AWS, rainfall measurement is done using Tipping Bucket Rain Gauge (TBRG). Rainfall enters the funnel inside the collector and is directed to one of two tipping buckets. When one bucket fills it tilts due to its weight and other bucket is in collection mode At the same time a momentary contact closure occurs (reed switch arrangement) this pulse initiates an event accumulation. The water drains through bottom of the instrument.

Figure 6: Tipping Bucket Rain Gauge

e) Solar Radiation sensor

The LI-200SZ Pyranometer has been calibrated against an Eppley Precision Spectral Pyranometer (PSP). The pyranometer is an instrument for measuring solar radiation received from the whole hemisphere. The sensor is a silicon photovoltaic detector which is very stable with a fully cosine corrected miniature head. It can be mounted in any plane without affecting performance. It has anodised aluminum base with stainless steel levelling screws and a weatherproof spirit level. Spectral response is equal from 280-2800nm with sensitivity varying typically as 80 µA per 1000 W m-2. The duration of bright sunshine is derived from the values of global solar radiation.

f) Soil Temperature sensor

The Campbell-Scientific sensor (Model No.CS-107) is used to accurately measure the temperature of a variety of media, most commonly air, water, and soil. The sensor consists of a thermistor encapsulated in cylindrical aluminum housing. The probe measures temperature from -35° to +50°C and is designed for durability and ease of installation / removal. The sensing element is buried 20 cm below ground level and can operate in the range -40 °C to + 50°C with a resolution of 0.1 °C. The sensor is buried 20 cm below ground level.

g) Soil moisture

The Soil Moisture Sensor is a Stevans hydra probe using a SDI-12 output and the unit of measurement of soil moisture is water fraction by volume(wfv). Its accuracy is ±0.03 wfv with a range of 0 to 0.45 and resolution 0.01 wfv. The Hydra soil moisture probe determines soil moisture and salinity by making a high frequency (50 MHz) complex dielectric constant measurement which resolves simultaneously the capacitive and conductive parts of a soil's electrical response.

The capacitive part of the response is most indicative of soil moisture while the conductive part reflects predominantly soil salinity. Temperature is determined from a calibrated thermistor incorporated into the probe head. Each Hydra Probe is serial addressable, allowing for multiple sensors to be connected to any RS485 or SDI-12 data logger via a single cable. The voltages recorded depend on the type of electrical properties of the soil. Onboard software converts the raw voltage to standard units of measurement for each parameter. With a standard database or spreadsheet, managers can view real-time soil snapshots or long-term soil trends.

h) Leaf wetness

The leaf wetness sensor detects the presence of soil moisture. The sensor is an artificial leaf electrical-resistance type. It consists of a sensing grid, low voltage bipolar excitation (3V normal) and conductivity-sensing circuit. The conductivity across the grid is measured in the output voltage range 2.5 to 3V and shown as a moisture level, scaled from 0 to 15 (Dry/Wet threshold is user-selectable). The sensing grid is a gold plated etched circuit on an epoxy-glass substrate. The excitation and sensing circuits are encapsulated in black epoxy. The sensor is mounted in the mast at height of around 2m at a 45° angle to simulate a typical leaf position and to permit runoff of excess moisture.

i) Leaf temperature sensor

The leaf temperature (KDS-161) sensor consists of precision RTD as sensing element packaged in a sensing button for deployment in actual leaf or in the midst of bushes or plants in close proximity to the leaves whose temperature is to be measured.

Thermally, the sensor contains a two component coagulation with one part of higher specific heat but low thermal conductivity and the other a low specific heat but high thermal conductivity. The low specific heat sensing dot quickly establishes thermal equilibrium with the leaf. Using a microprocessor polynomial modelling accurate temperature of the leaf is calculated. The interface with data logger is RS485 using baud rate 9600 bps.

Slope and offset calculation for a linear analog output sensor

Example : If the Air temperature sensor covers the range -40°C to +60°C and the corresponding voltage output is 0 to 1 V(Table 2.3); then -40°C is indicated by 0V and +60°C is 1V as shown in table below.
The range which the sensor covers = 100 °C (Slope)
Offset is the initial value = -40°C
So if the reading Vin = 0.5V then using the equation y=mx+c where
y=converted value, m = Slope, x = original (raw) value, c = offset

Output value (in °C) = Vin (Raw value) * Slope + Offset
= 0.5* 100 + (-40) = 50-40 = 10°C

Volts	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Degrees (Celsius)	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60

9. Battery and solar panel

The AWS are operated with a DC power supply from a 12V / 65 Ah Sealed Maintenance Free (SMF) battery which is float-charged by the solar panel of 30W capacity. In the early DCPs, AC power supply was used but later was discontinued due to various uncertainties. Battery and the charge regulators are placed inside the NEMA enclosure within which the data logger, transmitter and pressure sensor are kept.

The main element of a solar panel is the photo-voltaic cell, a semi-conductor device. The cell absorbs photons when exposed to sunlight (solar radiation) and produces a voltage potential across the junction of the semi-conductor. The most commonly used solar cell is the silicon cell with a PN junction. The open circuit voltage for the 30W solar panel is 21V and short circuit current is 2.4 A.

Solar charge regulators are used to regulate the charging voltage from the solar panel which can be even 18V during day time. The charge regulators ensure that the battery gets only a voltage of up to 14.5V while charging. The charge regulators used in Sutron and Astra AWS are shown in Fig.6.1.

Fig. 6.1 Sutron (left) and Astra(right) solar charge regulators

Since batteries are replaced only once in two-three years, care must be taken to buy good quality SMF batteries for effective performance in field sites. Some batteries bulge and spill acid within the NEMA enclosure under extreme hot weather conditions thereby causing malfunctioning of the system. Hence periodic checks are required. A fully charged battery must be connected at the first instance to support the system. A deeply discharged battery will draw more current and damage the charge regulator. It must be noted that a solar panel cannot charge a completely discharged battery. So the battery must be charged prior to connecting it to the AWS.

Mounting of solar panel

The solar panel is mounted in the southern direction at a height of about 3-4 m from ground level with an inclination angle which is the total value arrived at by adding the numerical value of the latitude of the place to 10 to 15 degrees. This is to ensure that solar panel is oriented towards the sun throughout the year in that place so that at least six to seven hours of sunlight fall on the solar panel at any point of time in a year.

10. Satellite Telemetry system

A dedicated geo-stationary meteorological satellite is used for data transmission to the central receiving Earth Station. Satellite telemetry system is most cost-effective and reliable for a nation-wide network though it has limitation of being one way communication.

Since its inception in 2006-07 to May 2010 the network was operated through Data Relay Transponder (DRT) on board the KALPANA-I located at 74˚E. The KALPANA-I satellite has reached its expected End of Life (EoL) and is now in inclined orbit. In view of this, the DRT traffic on KALPANA-I has been switched over to INSAT-3A (93.5˚E) in the year 2010. With the launch of INSAT 3D (82˚E) the network is now being switched over to INSAT 3D. The use of DRTs on board the satellites is regulated by ISRO and IMD. The regulations include transmission of data on assigned frequency channel (within a band of 402.65 to 402.85 MHz with a channel separation of 10 KHz) and time window at a baud rate of 4800 with 0 and 180 degree Phase-Shift Keyed Non Return to Zero-Manchester (PSK NRZ-M). encoded modulation. The transmission protocol is based on the National Environmental Satellite, Data, and Information Service (NESDIS) protocol. The protocol used for AWS data transmission is given in Table below.

Carrier and Bit Time Recovery	Frame Synchronization $(D8E2)_{16}$	BCH Address	Data for Met. Parameter	End of Transmission	Total Bits
160 bits (100 zeros & 60 ones)	16	31	199	16	422

In this protocol transmitter is required to transmit 160 bits (first 100 bits are zeros and remaining 60 bits are ones) for carrier and bit time recovery. This facilitates bit synchronization in the demodulator. This is followed by a frame synchronization message which is a minimum autocorrelation sequence of 16 bits (Frame sync: 11011000111000102, i.e., D8E216) with number of ones equal to number of zeros.Thirty one bits followed by frame synchronization constitutes station identification and error correction. These 31 bits are referred to as Bose, Chaudhuri, Hocquenghem (BCH) Code. The first 21 bits of this code provide information in respect of user identification, priority of data transmission and platform index. These 21 bits are called information matrix for the platform. Last 10 bits are known as check bits. These bits provide means for error correction and are generated by multiplying the (1×21) information matrix with a well known (21×31) BCH matrix. The product is 1×31 matrix which is known as 31/21 BCH code. This 31/21 bit code provides 2^{21} unique addresses as defined in NOAA Technical Memorandum (NOAA, 1979). The 21 bit information matrix consists of 9 bits for user identification, 2 bits forpriority and 10 bits for platform index. The BCH check bits matrix and procedure to use it is given in table below.

BCH check bits matrix and procedure to use it

Check bits Matrix (BCH Code)

22	=	1	4	6	9	12	13	14	15	17	19	21				
23	=	1	2	4	5	6	7	9	10	12	16	17	18	19	20	21
24	=	1	2	3	4	5	7	8	9	10	11	12	14	15	18	20
25	=	2	3	4	5	6	8	9	10	11	12	13	15	16	19	21
26	=	1	3	5	7	10	11	15	16	19	20	21				
27	=	1	2	8	9	11	13	14	15	16	19	20				
28	=	2	3	9	10	12	14	15	16	17	20	21				
29	=	1	3	6	9	10	11	12	14	16	18	19				
30	=	2	4	7	10	11	12	13	15	17	19	20				
31	=	3	5	8	11	12	13	14	16	18	20	21				

Procedure to use the BCH Matrix:

As an example, take the basic left adjusted 21 bit hexadecimal address 1E806 which in binary mode is

b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}	b_{11}	b_{12}	b_{13}	b_{14}	b_{15}	b_{16}	b_{17}	b_{18}	b_{19}	b_{20}	b_{21}
0	0	0	1	1	1	1	0	1	0	0	0	0	0	0	0	0	1	1	0	0

Thus b_{21} is 0. To calculate b_{22} examine the binary values of (0 or 1) of b_1, b_4, b_6, b_{12}, b_{13}, b_{14}, b_{15}, b_{17}, b_{19}, b_{21} (see the first row of Table above). If the number of "ones" are even in number then b_{22}=0. Conversely, if the number of "ones" is odd in number then b_{22}=1. In abovementioned example, four bits viz. b_4, b_6, b_9 and b_{19} are "ones", so b_{22}=0. Proceed in the same manner to compute b_{23} through b_{31}.

The priority bits are used to categorize the platform as test and evaluation (00), cyclone warning (01), flood warning (10) or snow survey (11). Next 199 bits constitutes AWS data frame which consists of time code, calibration voltages, AWS health and data from 10 sensors as given in Table below.

AWS data frame

Number of bits	Data
5	Time (in UTC)
11	Battery Voltage
11	Hourly Rainfall
11	Hourly Soil Moisture
11	AWS Health
15	Sensor-I
15	Sensor-II
15	Sensor-III
15	Sensor-IV
15	Sensor-V
15	Sensor-VI
15	Sensor-VII
15	Sensor-VIII
15	Sensor-IX
15	Sensor-X

Five bits are provided for transmission of time in full hour UTC (from 00 to 23). Each of the calibration voltages and AWS health has 11 bits arranged in 10 data bits + 1 parity bit form. In 10 data bits the extreme right (last) bit is least significant (LSB). The slots for calibration voltages are now used to transmit sensor data. All health bits are not used extensively. Each sensor data consists of 15 bits arranged in the form of 10 bits (sensor output) + 1 bit (Parity) + 4 bits (sensor identification). Out of the 10 sensor output bits, the bit on extreme right (last) is least significant (LSB).

The transmission is concluded with 16 bit End of Transmission code 1111101011011110_2 i.e. $FADE_{16}$. The total time for transmission of 422 bits is 87.9 msec(422bits at the rate of 4800 bits sec^{-1}).

Each AWS automatically takes measurement of meteorological parameters once every hour at full hour UTC and stores it in system memory. System transmits this data in a self timed Pseudo Random Burst Sequence (PRBS) manner in its allotted time slot within the next 60 minutes before the next measurement. This random multiple access technique is known as ALOHA technique in which the station neither has assigned time stamp as in TDMA nor narrow frequency band as in FDMA. Each station is assigned a time window in which it transmits in pseudo random manner. All the AWS are divided into 6 groups each of 10 minutes duration. These transmission windows are 0-10 min, 10-20 min, 20-30 min, 30-40 min, 40-50 and 50-60 min.Each 10 min transmission window is further divided into 4 sub-slots as shown in Figure 7.

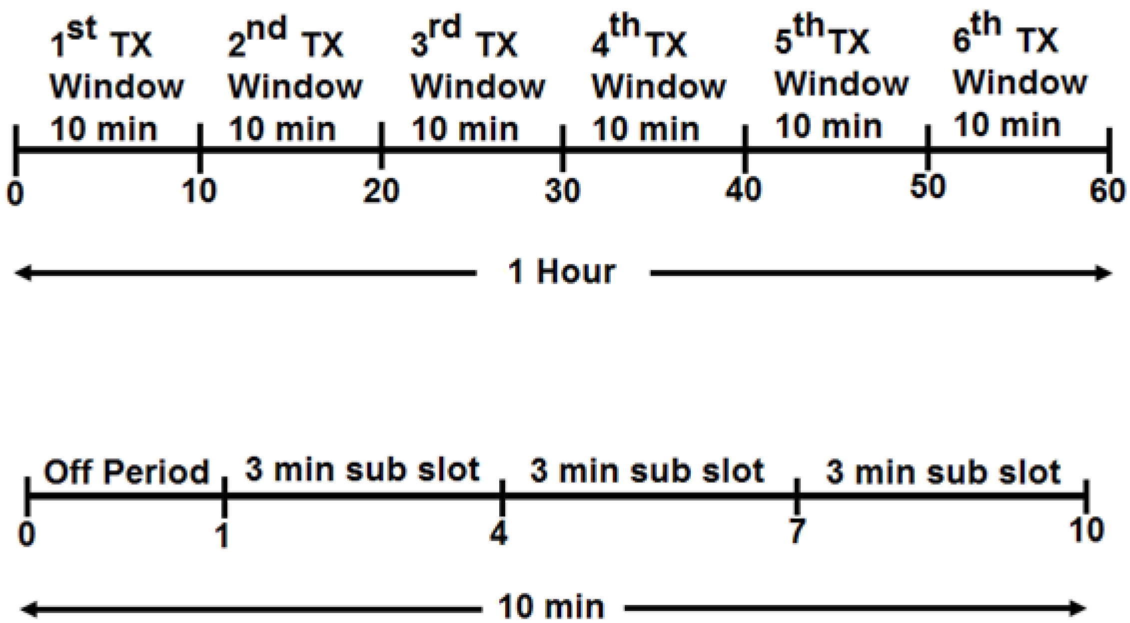

Figure 7: Time windows and sub-windows for transmission in pseudo random manner.

First slot of 1 min duration is off period and 3 sub slots each of 3 minutes duration are for repeat transmission. Every AWS transmits hourly data 3 times within the allotted transmission window once in each 3 min sub-slot in burst mode. This follows from the optimum number of transmission attempts needed to transmit the burst successfully in ALOHA system. Thus, we do know that a station will transmit data in allotted 10 min time window but we do not know the exact time of transmission hence, the name Pseudo Random Burst Sequence. An hourly message is repeated 3 times in order to preclude the loss of data due to (1) satellite communication errors (2) collision of messages transmitted simultaneously by any two AWS.

Time Division Multiple Access

1. Time Division Multiple Access (TDMA) Telemetry Technique

The network uses satellite telemetry system for transmission of data from field stations and reception at central data receiving Earth Station. The transmission technique used in this network is called Time Division Multiple Access (TDMA). A dedicated DRT on board INSAT 3A has been made available by Indian Space Research Organization (ISRO) to relay AWS data. Satellite telemetry system employed for the network is one way communication system. Hence, it is not possible to configure the stations in the network remotely from the central data receiving Earth Station. However, it is a robust system not affected by vagaries of tropical weather.

1.1 Need for TDMA technique

The ALOHA or Pseudo Random Burst Sequence (PRBS) technique has been in use in IMD for AWS data transmission since last three decades. This technique is suitable when number of AWS simultaneously sharing a common frequency channel in a randomized time of transmission mode is not too large (Abramson, 1977). As the number of AWS increases, the loss of data bursts due to collision also increases. It has been shown by Muthuramlingam et al. (2006) and Ranalkar et al. (2012) that maximum number of stations that can be transmitted in an hour using PRBS technique per satellite channel should be restricted to 400 to prevent loss of data due to burst collision.

In view of massive expansion of surface observational network envisaged in near future by various organizations, need for more efficient transmission technique was felt by all DRT users. In order to address this issue Indian Space Research Organization (ISRO) recommended using Time Division Multiple Access Technique (TDMA) for transmission of data through DRTs aboard INSAT series of satellites.

1.2 Features of TDMA technique

TDMA is an open loop system with timings derived from GPS receiver which is a part of AWS. Each AWS is assigned a unique one-second time stamp. The one second time frame is worked out taking into account 20 ms differential propagation delay over coverage area, RTC drift of about 1 ms per day, GPS receiver accuracy of less than 1 µsec and guard time required in receiving Earth Station. The GPS receiver in data logger updates RTC once in every 24 hours to conserve the battery. If RTC update through GPS synchronization is not achieved after 24 hours then GPS receiver in the system tries to acquire signal every hour for next three hours. If the GPS receiver fails to acquire signal even for next three hours the transmission to the satellite from particular station is suspended until GPS receiver acquires the signal.

In TDMA technique, theoretically, 3600 stations can be accommodated for transmission per satellite channel. Although, not essential in TDMA technique, each AWSis configured to send repeat transmission after 30 minutes (i.e. data burst is transmitted two times in an hour) to ensure that data is successfully received at the earth station. This reduces the channel capacity to 1800 stations, which is significantly greater than channel capacity of PRBS technique. Thus, TDMA technique is more efficient than PRBS in utilizing satellite channel capacity. It is now mandatory for all INSAT DRT users to operate future networks using TDMA transmission technique.

1.3 Description of data stream in TDMA technique

The values of meteorological parameters measured by each sensor interfaced to AWS, time and satellite ID are formatted in a data frame of 230 bits. The format of data frame is same as that used in PRBS technique. A detailed break-up of data frame is given in Table 2. The data frame prefixed with Frame Synchronization (FS) code (1101100011100010_2 i.e. $D8E2_{16}$) and appended with End of Transmission (EoT) code (1111101011011110_2 i.e. $FADE_{16}$) is subjected to Cyclic Redundancy Check (CRC).The CRC is a technique for detecting errors in data but not making corrections when data errors are detected. The CRC is calculated for262bits using CRC-CCITT-16 polynomial $X^{16}+X^{12}+X^5+1$ and checksum bits are appended to the message after EoT. The receiver then determines whether an error occurred in transmission.

The data stream comprising of FS, EoT and CRC code is then scrambled using additive scrambler defined by the polynomial $1+X^{-1}+X^{-15}$of its linear feedback shift registers with initial state 6959_{16}. Data scrambler with initial state is shown in Figure 8(a).One byte consisting of all '0's is then added to the scrambled bits, after which the entire bits are convolution coded. The convolution coding is a forward error correction technique, which improves channel capacity by adding redundant information to the data being transmitted through the channel. The process of adding this redundant information is known as channel coding. The code rate (Ratio of number of bits in to the convolution encoder (k) to the number of channel symbols output by convolution encoder (n) in encoding cycle) of ½ with constraint length (number of k-bit stages that are available to feed the combinatorial logic that produces the output symbols) of 7 is used for channel coding. The octal numbers 133 and 171 represents the code generator polynomials G1 and G2. These are read as $1+X^2+X^3+X^5+X^6$and $1+X^1+X^2+X^3+X^6$ and corresponds to shift register connections to modulo-2 address. The convolution encoder is shown in Figure 8(b). The convolution code is thus obtained by combining output of k – stage shift registers through employment of n Exclusive-OR logic summers. Before convolution coding, message bits are appended with one byte consisting of all '0's to ensure that every message bit proceeds entirely through the shift register and hence involved in complete coding process (Taub and Schilling, 1991).

Preamble comprising of Carrier Recovery (192 symbols-all 0's), Bit Time Recovery (64 symbols-all 1's) and Unique Word of 64 symbols $(07EA\ CDDA\ 4E2F\ 28C2)_{16}$ are prefixed to the convolution coded bits. The resulting 892 bits are then transmitted after differentially coded Non Return to Zero-Linear (NRZ-L) modulation at an uplink frequency of 402.74 MHz and typical transmission output power of 6-7 W with data rate of 4800 bits/sec. The duration of burst transmission is therefore 186 ms (892 bits @ 4800 bits/sec). The complete TDMA data burst format is shown in Figure 8(c).

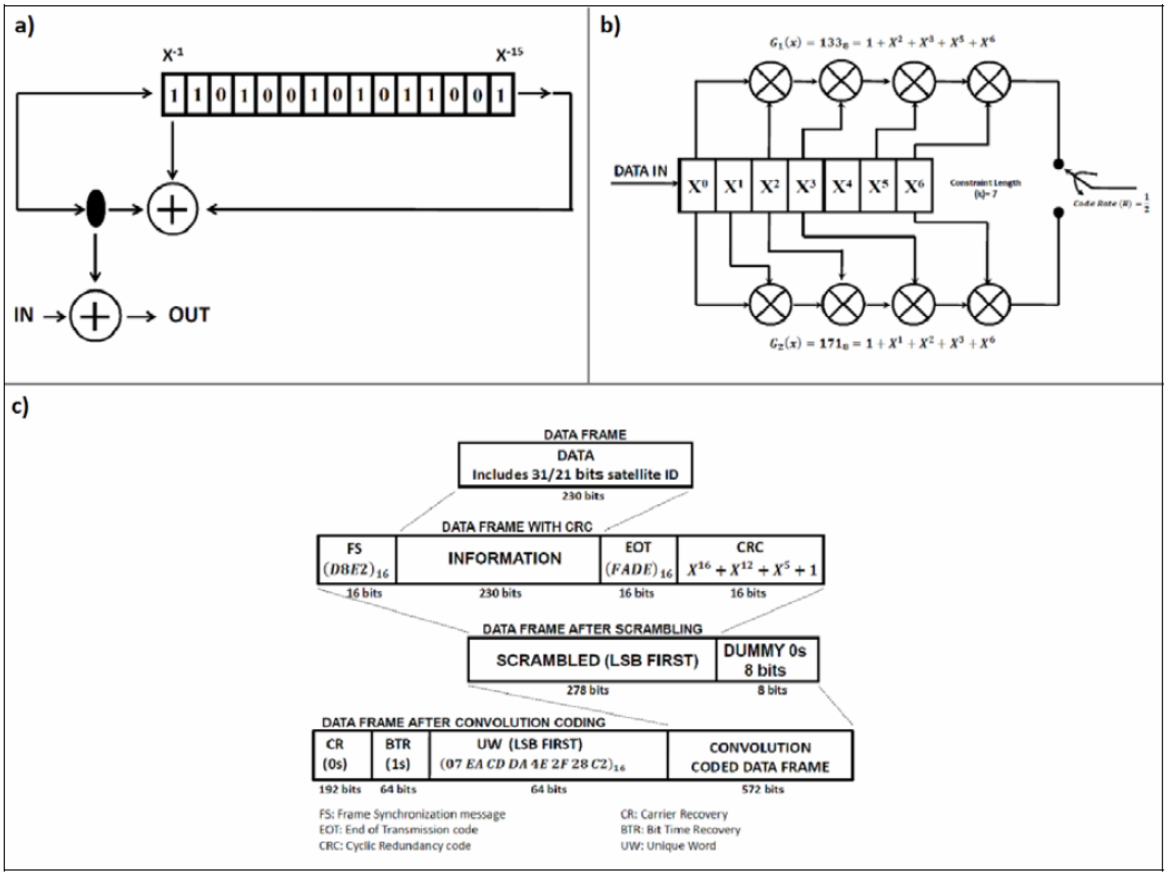

Figure 8(a-c): (a) Additive data scrambler with initial state 696916, (b) Half rate convolution encoder with constraint length 7 and (c) Format of TDMA data burst

11. Data Earth Station

PRBS type :

Every station transmits data to INSAT 3A at an interval of one hour at uplink carrier frequency of 402.75 MHz and transmitted output power in the range of 3 to 10 Watt. The DRT onboard the satellite receives the data burst at an uplink frequency. It then down converts it to 28 MHz, filters and up converts to a down link frequency of 4503.246 MHz.

The signal from the satellite is very weak when it is received at the antenna front end. The power of the signal is of the order of picowatts. Once received, it has to be amplified without adding noise. This function is done by Low Noise Amplifier (LNA). LNA has a minimum gain of 60 dB. LNA Noise Temperature has a major contribution to the system noise. Hence LNAs should have less Noise Temperature in order for the system to have good G/T. The system has redundant LNAs. If one LNA fails second automatically takes over.

The RF signal received through the antenna is amplified by LNA. The signal is splitted at the indoor unit of the Earth Station and fed to the redundant downconverters. The signal in the frequency range 4.5 to 4.8 GHz is received at the input end of the Down converter.Processing of the signal at such higher frequencies requires costly and sophisticated equipments.Hence the signal is down converted to an intermediate frequency of 140 MHz. This value in general depends upon the mixing stages incorporated in the down converter.

The down converted signal of 140 MHz is fed to Digital Satellite Receiver (DSR) which is further down converted to 10 MHz suitable for A/D conversion and then it is digitized and demodulated (4 channels can be simultaneously demodulated). Raw data is then extracted and sent on demand to the central processing computer.

The processing software decodes the raw data to engineering values of meteorological parameters and archives the data in the database. Various data and diagnostic reports and graphical representation of data can be generated and scheduled. Finally the hourly data are encoded into the WMO code format and are disseminated through GTS for operational utilization. The complete telemetry link is shown in Figure9 and the block of diagram of Earth Station is shown in Figure10.

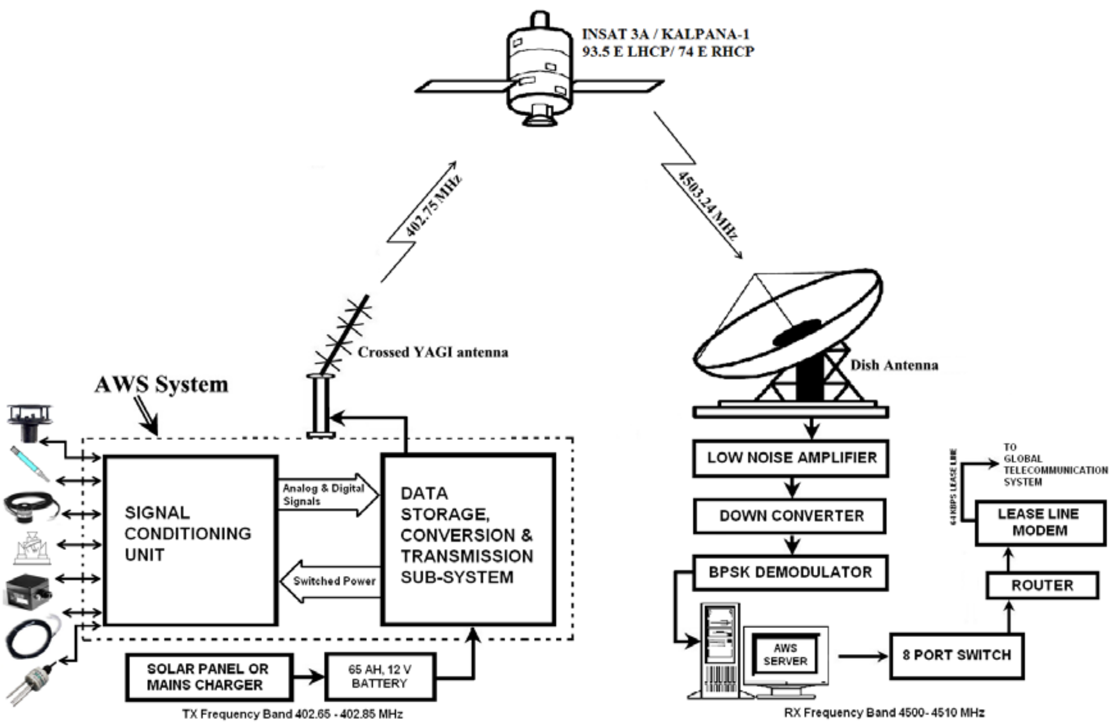

Figure 9: Telemetry link of PRBS type Earth Station.

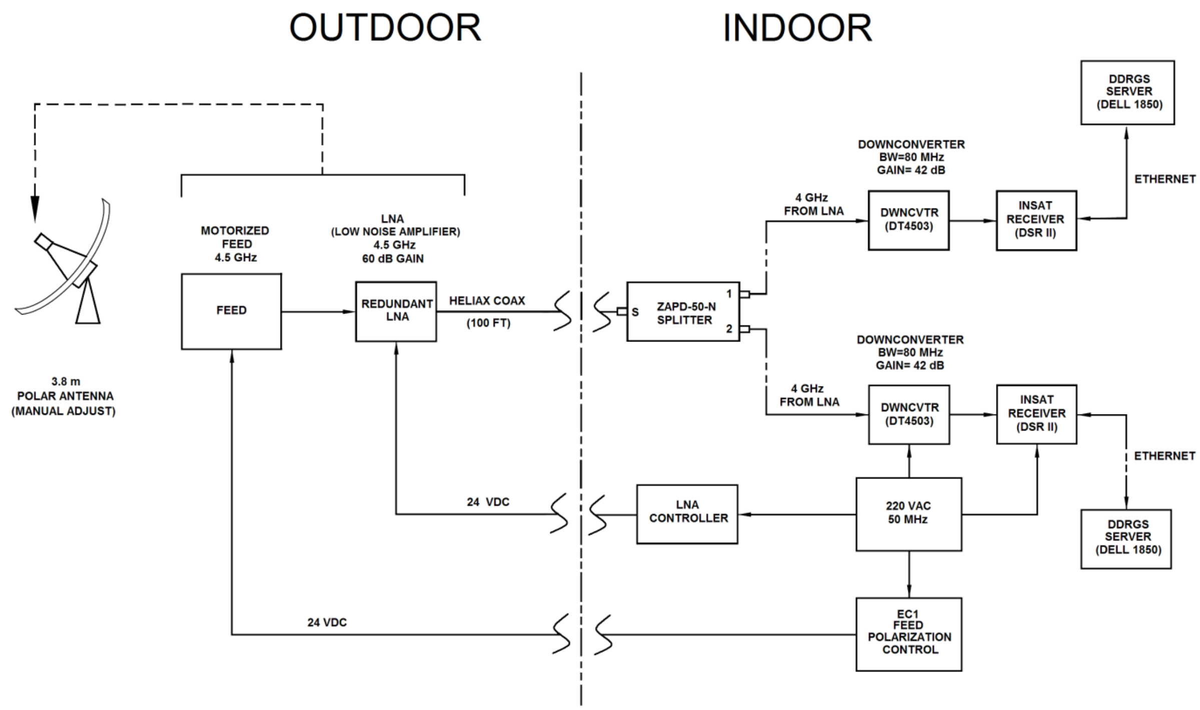

Figure 10: Block diagram of PRBS type receiving Earth Station.

<u>TDMA type</u>:

Data transmitted from each AWS are received centrally in near real time at the data receiving Earth Station facility established at IMD Pune in the year 2009. Data bursts transmitted from AWSat assigned time stamps are received by the DRT aboard INSAT 3A at an uplink frequency. The signal is then downconverted to 28 MHz, filtered and upconverted to a downlink frequency of 4504.19 MHz. The Earth Station is capable of receiving downlink transmissions in the entire 300 MHz band of 4500-4800 MHz. The data receiving Earth Station consists of 3.8 m diameter antenna, Low Noise Amplifier (LNA) in redundant mode, extended C-band frequency downconverter in redundant mode, burst demodulator in redundant mode and data processing workstation with software.

The Astra make antenna model AT512V31-SP of 3.8 m reflector diameter compatible to achieve telemetry link budget has been installed at the Earth Station. The mounting of antenna is suitable for reception of data from any INSAT satellite based DRTs located anywhere in the geostationary arc from 45˚E to 115˚E longitude. The antenna is used only for reception of data and can be aligned manually. Lightning and surge protection is provided to all equipments connected to antenna. The reflectors are made of solid fibreglass material. The feed mount is offset type and feed type is linear. The input frequency for feed is 4.5 to 4.8 GHz. The antenna has gain of 43 dB or more and polarization is linear.

ComTech make C band LNA (model No. CLNA)with redundant switch (model RED-CLNA 1:1) is used in the Earth Station. In the event of primary LNA failure, fast automatic switch-over to the backup LNA is accomplished. The amplifiers incorporate both High Electron Mobility Transistor (HEMT) devices for low noise temperature performance and GaAs Field Effect Transistor (FET) devices for low inter-modulation. At ambient temperature of 25°C the noise temperature is typically 45°K. The bandwidth of LNA is 300 MHz and minimum gain is 60 dB.

The amplified RF signal is split at the indoor unit of the Earth Station and is fed to redundant downconverters. ComTech make model DT-4503/X downconverters are used in the Earth Station system. It has +20 dBm minimum output level at the 1 dB compression point and standard gain of 45 dB. The signal is down converted to intermediate frequency of 70 MHz.The down converted signal is fed to BPSK burst demodulator. An array of 8 demodulators is installed at the Earth Station and with redundancy 4 independent channels can be simultaneously received. The Earth Station is thus capable of receiving data from 7200 stations (1800 stations per channel). The demodulators are interfaced to serversforround the clock reception of raw data at the Earth Station.

The received raw data are decoded in real time and engineering values of meteorological parameters are flushed into relational database. The dew point temperature, mean sea level pressure (for stations with elevation less than 800 m), geopotential height of nearest standard isobaric level in geopotential meter (for stations with elevation greater than or equal to 800 m), daily maximum temperature and daily minimum temperature are derived at the receiving Earth Station. After primary archival at the receiving Earth Station the hourly AWS data are passed through quality control algorithms, coded in WMO alphanumeric and BUFR form and made available to end users via WMO Information System (WIS). The hourly data are also available at www.imd.gov.in. The final archival of data are done at National Data Center of IMD after applying rigorous non real-time quality control checks. The block diagram of receiving Earth Station is shown in Figure 11.

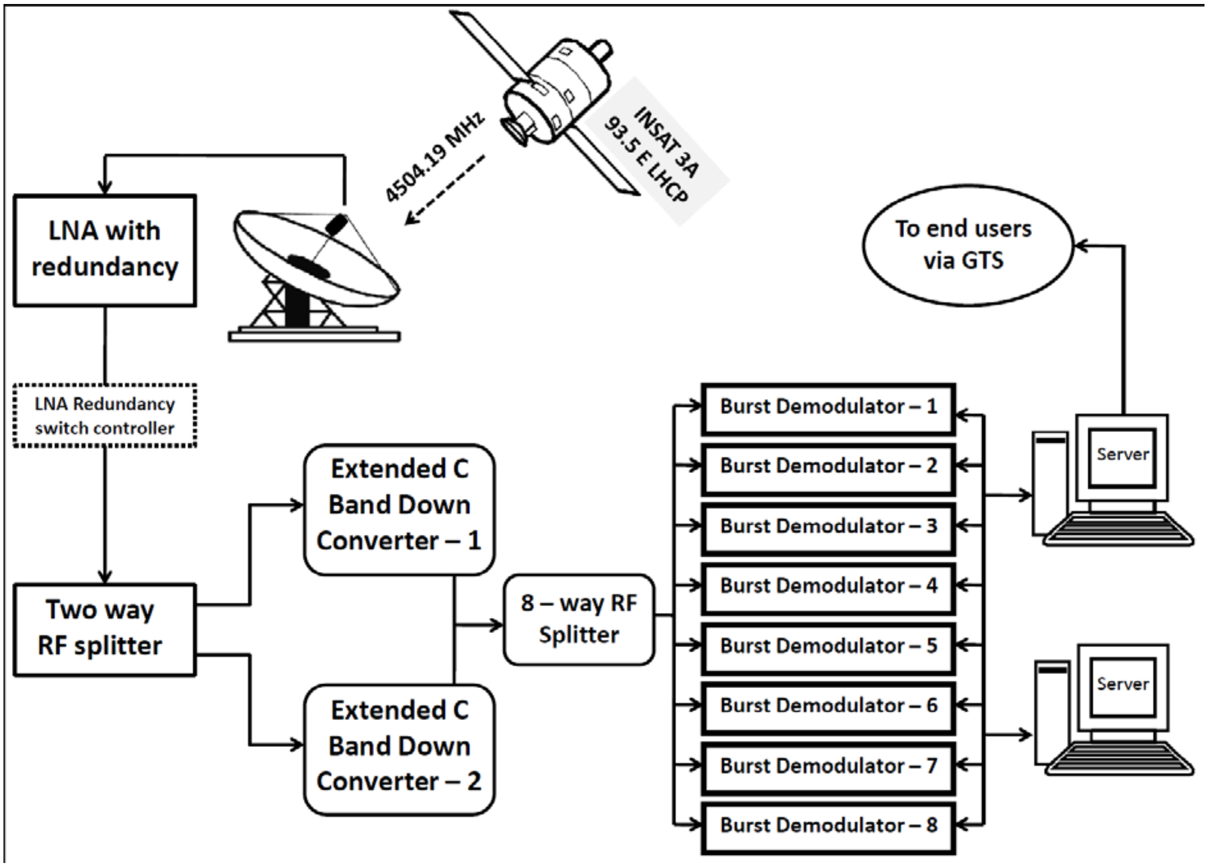

Figure 11: Block diagram of TDMA type Earth Station.

12. Quality objective and link budget

The telemetry link calculations are based on specified quality objectives. At the receiver the modulated carrier is subjected to band pass filter to limit the input noise. For polar NRZ baseband signal and for Binary Phase Shift Keying modulation, the probability of the detector making an error (also known as bit error rate) as a result of noise is given by

$$P_e = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_0}}\right)$$

Where erfc is a complementary error function, E_b is average bit energy in joule, N_0 is noise power spectrum density in joule.

The bit error rate is specified to be 10^{-5}. Once the theoretical value of $\frac{E_b}{N_0}$ is known an implementation margin of 1.0 dB is added to allow for imperfections in the filtering. The effective $\frac{E_b}{N_0}$ is thus 10.6 dB. With the data rate $R_b = 4800\, bitsec^{-1}$ the required $\frac{C}{N_0}$ is therefore given by:

$$\left[\frac{C}{N_0}\right] = \left[\frac{E_b}{N_0}\right] + [R_b] = 10.6 + 10\ log_{10}(4800) = 47.41\ dBHz$$

With these quality objectives the link budget of INSAT 3A is given in Table below.

Uplink		**Downlink**	
Frequency	402.75 MHz	Downlink Frequency	4503.24 MHz
Antenna Gain [G_t]	11 dB	Satellite gain (G_s)	160 dB
Transmitted output power [P_t]	10 Watt	Downlink EIRP = [G_S] + [P_R]	4.36 dBW
$[EIRP]_{uplink}$=[G_t]+[P_t]	21 dBW	Down link free space loss	197.38 dB
Slant Range	38000 km	Down link misc. loss	0.50 dBW
[Free Space Loss]$_{uplink}$	176.14 dB	Antenna gain	43.47 dB
Absorption loss	0.50 dB	System noise temperature	20 dB
Power Flux Density at the I/P of satellite (-105 $dBWm^{-2}$ max.)	-141.588 $dBWm^{-2}$	Hub station $\frac{G}{T}$	19.20 dBK
Carrier power at the I/P of satellite antenna [P_R]	-155.64 dBW	$\frac{C}{N_0}$	54.28 dBHz
Satellite $\frac{G}{T}$	-17 dBK		
$\frac{C}{N_0}$	55.96 dBHz		
Effective $\frac{C}{N_0}$ = 52.03 dBHz			
Required $\frac{C}{N_0}$ = 47.41 dBHz			
Link margin (clear LOS)= 4.62 dBHz			

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