DESIGN OF THE GROUNDSTATION, POLARIZATION MEASUREMENT SETUP AND THE SOCIAL GOAL OF PRATHAM, INDIAN INSTITUTE OF TECHNOLOGY BOMBAY'S FIRST STUDENT SATELLITE

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ABSTRACT

Students from the Indian Institute of Technology Bombay (IITB) are currently in the process of building a fully functional microsatellite named 'Pratham'. The satellite being built is a 260 mm cube and weighs nearly 10kg. This landmark project has completed the phases of Requirements Capture, Conceptual Design, and Preliminary Design and is currently in the Detailed Design Phase. Detailed documentation and thorough reviews were conducted by ISRO scientists and IITB faculty before the conclusion of each of the above Design phases.

The goal of the satellite project is to educate students in the field of Satellite and Space Technology in the process of building a satellite for measuring the Total Electron Count (TEC) of the Ionosphere. This paper will discuss the measurement setup and the unique Groundstation design being used by Pratham for measurement of TEC with 99.9% accuracy using the principle of Faraday rotation. This method has helped in reducing the cost of the ground station as well as the onboard complexity. The satellite will enable the generation of TEC maps of India and France with the help of a network of ground stations set up at eleven Indian universities and the Institut de Physique du Globe de Paris (IPGP), France.

This paper will also discuss the Social Goal of the Project. Pratham will be transmitting onboard data when it passes over India. With a low-cost ground station, students from other universities will also be able to detect the beacon signal and measure TEC. Workshops on making low-cost ground stations have been held at IITB for students from other universities. The Groundstation design has been done in a way to enable other universities to emulate the setup and design their own Groundstation. Real time tracking of satellite and storage of the telemetry data is planned at the groundstation along with an online interface for allowing other universities who are part of Pratham's Groundstation network to upload their Total Electron Count data. The entire documentation of Pratham along with the TEC data will be freely available at www.aero.iitb.ac.in/pratham. We have set up online virtual laboratories for satellite simulation and modeling under the "National Initiative on ICT in Education of Ministry and Human Resource & Education", wherein students can perform experiments with the same tools that helped Pratham team to learn about Satellites and helped us to design Pratham. We hope these will serve as stepping stones for future missions.

Key Words: **TEC, polarization, tomography, ground station, social goal**

FULLTEXT

I. INTRODUCTION

Pratham (which means "the first" in Sanskrit) is a student satellite project that was undertaken by a group of undergraduate students of the Indian Institute of Technology Bombay. The satellite being built is a 260 mm cube and weighs nearly 10kg. Over the last three years the project has completed different stages of the design cycle and is currently in the detailed design and Integration phase. The project was initiated with a fourfold mission in mind with the main objective being learning and involving other students in the project. The mission statement is as follows

1) Enabling students to gain knowledge and experience in the field of Satellite and Space technology.
2) Empowering the Satellite Team with the skills to develop the Satellite through various phases of Design, Analysis, Fabrication and Testing until the Flight Model is made.
3) Launching the satellite into orbit and measuring Total Electron Count (TEC) of the Ionosphere.
4) Involving students from other universities in our Satellite mission by building ground stations in their universities.

In this paper, we present the polarization measurement setup that is being used at the IIT Bombay groundstation for the purpose of Total electron count (TEC) measurement. The paper also describes the design of the groundstation for achieving 99.9 % TEC accuracy which is necessary for scientific usage of the data. In section II, we give a brief introduction to TEC, its significance and the measurement setup used to measure it at the groundstation. In section III, we describe the Groundstation design for TEC measurement. In section IV we shall elaborate on the social goal of the project by which we have been able to connect with students from across the country and beyond.

II. TEC MEASUREMENT SETUP

A. Introduction to TEC

Total Electron Count or TEC is defined as the number of electrons in a column of unit cross sectional area, extending from ground all the way up to the end of the ionosphere. Units of TEC are electrons/m^2. There are two kinds of TEC measurements possible depending on the angle that the column of electrons makes with respect to the groundstation. If this column is vertical, then the TEC is referred to as Vertical TEC (VTEC) and otherwise it is referred to as Slant TEC (STEC). When referring to the TEC at a location, we usually mean the VTEC, unless otherwise stated.

TEC values are of great importance to the scientific community. The Indian subcontinent being close to the magnetic equator is rich in phenomena such as the Equatorial Ionization Anomaly (also known as the Appleton anomaly), the Equatorial Spread F (ESF) and the Equatorial Electro Jet (EEJ). TEC is significant in determining the scintillation and group delay of a radio wave through a medium.

Pratham shall be measuring TEC over India and France, using the principle of Faraday Rotation. When the satellite is launched, the TEC data generated by Pratham will be freely available to the world community. This data will be useful to the scientific community since TEC is a major source of errors in GPS readings and any other global positioning system. Better TEC models will help reduce this error. Moreover, scientists at Institut de Physique du Globe de Paris, France, who are collaborating with Pratham Team, are trying to find if the TEC data can be used for advance warning of Tsunamis and also study interesting effects of the Ionosphere like Electron Ionization Anomaly (EIA), which happens only over the Indian Sub-continent.

There are various techniques for measurement of TEC from LEO satellites:

a) Measurement of Faraday Rotation

b) Measurement of Group Delay of received signals

c) Measurement of Doppler shift of received signals due to ionospheric fluctuations

d) Measurement of amplitude scintillations of received signals.

We decided to opt for the Faraday Rotation technique keeping in mind its simplicity which is of immense importance for a student satellite mission.

When a linearly polarized radio wave passes through an ionized medium with a magnetic field in the direction of propagation, the plane of polarization rotates. This effect is called Faraday rotation.

$$\Delta\phi = 4.87 * 10^{-4} * f^{-2} \int_{h_1}^{h_2} NB\cos\theta \; dl$$

where N – electron density, B - magnetic field of earth, θ - angle between the magnetic field and the direction of propagation of the radio wave, $\Delta\phi$ - is the change in angle of polarization, f – frequency of the wave.

We are using this principle to compute the TEC over a region. We are transmitting linearly polarized signals from the satellite and measuring the change in their polarization angle. Using the average value of the Magnetic field over its path gives us:

$$\phi_f - \phi_i = 4.87 * 10^{-4} * f^{-2} * B_{avg} * TEC$$

where ϕ_f – final angle of polarization, ϕ_i -initial angle of polarization.

B. Measurement Setup for TEC at IITB

We are using two pre deployed linearly polarized monopole antennae onboard for transmitting the radio waves. The linearly polarized waves shall undergo a change in the angle of polarization as it passes through the ionosphere. We plan to measure the change using crossed yagis at the Groundstation. We will be measuring the intensities of the signals at the two feeds of the crossed yagi. The ratio of these intensities will give us the polarization angle. The decision to use a single crossed yagi and not two different perpendicular yagis was taken keeping into mind the symmetry needed in the acquisition chain for TEC.

We shall be using a RF gain and phase detector IC AD8302 at the groundstation for the purpose of measuring ratio of intensities. This IC takes two inputs INPA and INPB and gives a voltage o/p proportional to the level ratio of these signals in dB. In addition, the pin VPHS gives the phase difference between the signal s at the INPA and INPB.

$$v = 0.9 + 0.6\log_{10}(|\tan\,\theta|)$$

The IC is a product of Analog Devices. The measurement of intensities for determining angle leads to an ambiguity in the final value of the angle. We are using the phase information to determine the exact value of the polarization angle in addition to the measurement of ratio of intensities.

Figure 1: Groundstation at IITB

III. GROUNDSTATION DESIGN

The Ground Station setup at IIT Bombay consists of the following elements:

a) Four crossed Yagis (145MHz and 437MHz)

b) Low Noise Amplifiers

c) Two AD 8302 chips

d) Low pass filters of cut off frequency 5KHz

e) A transceiver basestation

The entire setup is divided into 2 separate chains. One chain ends up in a transceiver and TNC thus decoding the telemetry or Beacon data. The other chain is for polarization measurement. The polarization measurement chain contains the LNA's and the AD8302 IC. Due to the stringent requirements on the groundstation to achieve the desired degree of accuracy in TEC measurement an elaborate design cycle was followed for the fabrication of the Groundstation.

A. Design cycle for the Groundstation

The design cycle consisted of planning and implementing the following steps:

a) Generation of a Need statement

b) Identifying the Stakeholders

c) Carrying out the Requirements capture

d) Doing the Function Decomposition

e) Concept Generation

f) Concept Evaluation

g) Planning the Manufacturing or procuring of individual parts

h) Integrating the model

i) Maintenance of the Groundstation

The need statement that was generated as part of the design cycle was to "Design and build a system above Aerospace Department that will use the yagi antennae and rotor to track Pratham with pointing error of less than 10 degrees and enable measurement of TEC with accuracy of 1 TECU"

The stakeholders in the construction of the Groundstation were divided into active and passive stakeholders. The active stakeholders include the Aerospace Department, other universities and organisations who are involved with us for measurement of TEC data around the globe and the Pratham team. The passive stakeholders included external elements like birds, permission granting bodies etc.

The primary requirements of the Groundstation are listed below.

a) Requirements of yagi antenna (other than electrical requirements)

i. The antennae should remain parallel to each other (maximum offset between any two antennae should be less than 10 degree)

ii. The deviation of antennae from their parallel configuration should be measurable after mounting

iii. The elements should not bend in the plane due to mechanical stress or load of wind

iv. The distance between two antennas should be greater than $2D^2/\lambda$ so that there won't be interference. (where λ is the wavelength)

v. The antennae elements should not rotate out of the plane and the rotation angle should be measurable with an accuracy of 1 degree

vi. The antenna should be as far away from any radiating systems as possible (at least 20 meters away)

vii. The antenna assembly should be easy to assemble and disassemble

viii. The clamps should allow for the change in spacing and rotation of the antenna's elements

b) Mount Requirement

i. The antenna mount should be durable and should not act as an antenna director

ii. The antennae should be mounted at 45 degrees to the beam on which it is mounted.

c) Base Requirement

i. The distance between the ground and mounts should be greater than $2D^2/\lambda$.

ii. The antennae must not clash with the ground or the mounting mechanism while rotating

d) System Requirement

i. The field of view of the antenna should be from 30 degree elevation angle throughout 360 of azimuthal rotation.
ii. The LNA and filter should be as close to the antenna as possible (maximum distance between them should not exceed 1m)
iii. There should be no obstructions close to the antennae that might cause scattering. (i.e. No obstruction within 4-5m radius area)
iv. The electrical connections of the LNA and rotor must be waterproof and RF grounded.
v. There should not be any equipment that runs on a clock close to the Antenna system e.g. computer (distance > 4-5 meters)

We decided to have a crossed yagi with a square boom and a mechanical coupler holding the elements to the boom. The major reasons for choosing a square boom over a circular boom were

- Restriction on motion of the coupler
- Ease of mounting on the base

The coupler mechanism was however chosen over other techniques like welding or moulding in one piece because the coupler gave us the flexibility of replacing elements and adjusting the spatial parameters of the yagi even after assembly. The base support for the antenna was to be made of aluminium to make the structure light. the antennae would be mounted on a square rod which will be attached to the rotor. The base of the rotor would be a table top structure for stability reasons.

Thus, the final design of the ground station that was finalised was:

- Antenna having square boom of aluminium and a coupler to hold elements to the boom.
- Elements shall be held in position using screws mainly offering frictional resistance.
- A socket at an angle of 45 degree on the mount to fix antenna to the square boom Socket will be fixed to the mount with the help of screws.
- Two parts of a flange (square shape) and Weber (square shape) will be fastened with the help of L clamps, plates and screws.
- Weber will have slave as an interface between rod and rotor.
- Rotor will sit on the plate that is between midpoints of the opposite sides of top square frame of the table and will be fixed to it with the help of nuts and bolts.
- Square frame at the top and legs will be of I beam. Due to this structure can easily be supported by trusses i.e. connecting trusses will be easy.

- System will be more stabilized by adding square frame at the base of 2m side and connected to central vertical structure.

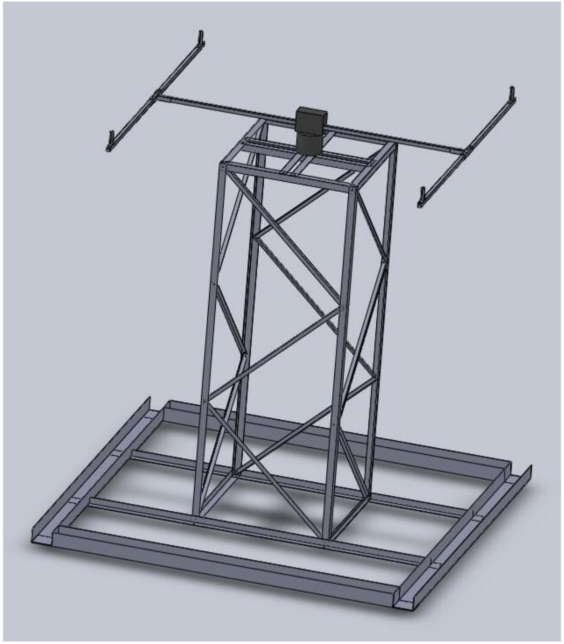

Figure 2: Final Design of the Groundstation structure

We also had to take in mind the wind loading as the super structure will have a considerable height above the ground level. Maximum value of wind in the Mumbai over the year is 20 m/s and maximum area that is exposed to the wind is $1m^2$.Hence there will not be appreciable force to take in to account.

The integration sequence that was followed for the groundstation is as follows

- Assemble the antenna and characterise it for 50 ohms impedance.
- Connect base to vertical legs.
- Connect top square frame.
- Connect L shape beam and plate between midpoints of the sides having holes to fix rotor.
- Connect trusses.
- Fix the rotor by using a stand.
- Connect sockets to half parts of the flange
- Put the Weber beam in to the rotor and place it in the middle with the help of slave.
- Connect half parts of the flange of the weber.
- Connect the antennae in to the socket and filter, LNA on the weber.
- Connect the wires

- Use a theodolite to measure the offset in the angles of the antenna.

The possible errors that might occur during the design and fabrication of the Groundstation include

- All antennae may not be parallel
- Elements may not be in plane or may not be parallel
- The ground level might be uneven
- Rotor starts vibrating or tumbling

We have taken care that such errors are spotted as soon as possible and necessary actions taken to correct them.

III. SOCIAL GOAL

The Social goal of Pratham is an initiative taken by Pratham team to increase awareness about the field of satellite technology in the country and beyond. The ideology behind the social goal is that the knowledge gained in the process of satellite making is enormous and should be disseminated to as many people as possible and give them a hands on experience of the challenges in the field. It is with this in mind that Pratham decided to involve other universities in the project by inviting them to build a ground station for the satellite and be a part of our mission. Thus, we started a series of Groundstation workshops, each focusing on a different area of Groundstation fabrication and setup. The Social goal took a step further with the setting up of Virtual Labs under a project initiated by the Ministry for Human Resources Development, Government of India. We describe each of the above in detail in the sections below.

A. Groundstation workshops

The Groundstation workshop series was based on the principle of CDIO (Conceive, design, Build and Operate). The participants were given an overview of the status of the Ground station at IIT Bombay and were given a set of tasks at the end of each workshop. The tasks were to be completed before the next workshop and generally involved concepts covered in the workshop session. There was no selection criterion for participating in the workshop and anyone who was interested in satellite communication, from students to professionals, could participate in the workshop.

The first Ground station workshop dealt with the conceptual design of the Central ground station. The concept of a satellite and its various subsystems along with a detailed presentation on the communication aspects were presented to the participants. The participants were given a problem statement related to the design of the Yagi Antenna at the end of the workshop. The participants were asked to decide the location of their Groundstation and study the behaviour of different types of antennae to linear and circular polarisation. The participating universities/individuals were given a rough estimate of the budget for

Groundstation fabrication and setup. The entire cost of setting up a Groundstation was less than 500 USD.

The second Groundstation workshop focused on the simulation and optimisation of the crossed yagi antenna using 4NEC2 software. The participants were taught the usage of the software for basic and advanced simulations of antennae. The second task allotted to the universities was to fabricate the Groundstation antenna and characterise them before the third Groundstation workshop.

The third Groundstation workshop involved presentation by the Universities who had already fabricated their Antennae and a discussion on their characterisation result and the issues they faced while doing the same. The workshop included a demo of satellite tracking and reception of signals and a detailed analysis of data storage and analysis after reception. Following is the picture of the Yagi manufactured by one of the participating universities

Currently, IITB is collaborating with 11 different universities, including one in France where ground stations are being setup for TEC measurements. The satellite has an onboard GPS which will enable it to transmit the linearly polarized radio waves over the regions of interest where our ground stations are setup.

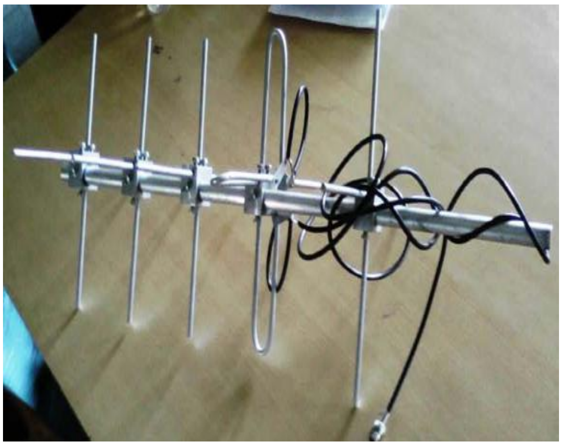

Figure 3: Crossed yagi at 437MHz made by BVCOE Mumbai, India

B. Virtual Labs

The virtual laboratory in Satellite Modeling and Simulation is one of the virtual laboratory of the project "National Initiative on ICT in Education of Ministry and Human Resource & Education" through the Centre of Distance Engineering Education Programme of IIT Bombay. The objective of these virtual laboratories are to provide remote access to labs in order provide learning opportunities to students to conduct these experiments remotely. It is a collection of three experiments (simulations) related to satellites and held understand three major subsystems of the satellite; namely, Thermals, Controls and Measurement of the Total Electron Count in the Ionosphere. These simulations are based on realistic science based models. Each experiment is preceded by a brief tutorial that will help the students brush up necessary background material.

Pratham has provided valuable learning opportunities to a large number of students with IIT Bombay and these virtual laboratories have been set up as a part of fulfilling its social goal of making this knowledge available freely to a broader segment of student community outside IIT Bombay. In this laboratory, students can perform experiments with the same tools that helped Pratham team to learn about Satellites; these are the same tools that helped the team to design Pratham. Experiments are in some ways specific to Pratham, but they offer good amount of learning opportunities about satellites in general.

There are three kinds of target audiences and they are listed below with the benefits they can derive from these virtual experiments.

1. Senior students of engineering who have special interest in Satellite related learning, because they are involved in student satellite project of their college or group of colleges. ISRO has encouraged many institutions to initiate student satellite projects and this activity is expected to peak up in another couple of years. There is a large body of students who are keenly interested in this learning and that size will increase in next couple of years. These virtual experiments will help them move forward in their projects. They can use virtual lab to get results for their own proposed designs. These results (actual numbers) will help them take design decisions.

2. Freshmen and sophomore students of engineering who are keen learners and want answers to their curiosities in satellite and the harsh conditions they face in orbits. They are not interested in actual numbers, but ball-park figures and trends that help them appreciate things. eg. How much solar energy will fall on the satellite during its orbit? When does a satellite designer start worrying about the need to heat a battery? If a mission and choice of camera requires a pointing accuracy of ±1 degree what will happen if we do not have a controller? These and many other questions can be posed here to find answers.

3. Students of science who have a keen interest in space and satellite and do search out reading material. This is small fraction of students but benefits of addressing them are immense, as they are talented and highly motivated. Their curiosity will be at the same level as those in group two.

These simulation interfaces can be accessed at *www.aero.iitb.ac.in/pratham*

IV. CONCLUSION

In this paper, we have described the details of carrying out TEC measurements using the simple Faraday Rotation technique. The algorithm for generating tomograms from the TEC data was also presented. We finally, described the social goal of Pratham and how we have gone about incorporating several other universities into our mission. We hope our efforts serve as stepping stones for larger successes in the future.

V. ACKNOWLEDGEMENTS

We would like to thank Prof. K. Sudhakar, Prof. P. Mujumdar, Prof. H. Arya and other professors at IIT Bombay for their constant support and guidance. We would also like to thank Prof. K. P. Ray from SAMEER for their guidance. We would also like to thank the scientists at the Indian Space Research Organization, lead by D.V.A. Raghav Murthy, for regularly reviewing our work. We are grateful to the Ministry for Human Resource Development (MHRD), Space and Technology Cell - ISRO, Aerospace Engineering Association and Industrial Research and Consultancy Center for their support.

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