Affordable Small Radio Telescope (ASRT) for Solar Observation

Swati Shilaskar
Dept. of Electronics and Telecommunication Engineering,
Vishwakarma Institute of Technology,
Pune-37, India
swati.shilaskar@vit.edu

Sahil Sawant
Dept. of Electronics and Telecommunication Engineering,
Vishwakarma Institute of Technology,
Pune-37, India
sahil.sawant211@vit.edu

Samiksha Gurakhe
Dept. of Electronics and Telecommunication Engineering,
Vishwakarma Institute of Technology,
Pune-37, India
samiksha.gurakhe21@vit.edu

***Abstract*—The goal of the project is to construct an Affordable Small Radio Telescope (ASRT) that will allow students to participate in radio astronomy. With components from Direct-to-Home (DTH) satellite systems operating in the radio frequency (RF) framework, the ASRT offers a user-friendly platform for astronomical observations, with a special emphasis on solar studies. With the help of low-noise block converters (LNBs) and parabolic dish antennas, the ASRT provides students with an inexpensive way to investigate radio astronomy methods. The project places a strong emphasis on experiential learning by letting students assemble and use the telescope under supervision. Students' comprehension of signal capture and processing is improved by the ASRT by utilising the concepts of RF engineering and analogue communication. Through the use of the ASRT, students can conduct solar observations that provide insights into solar variability and phenomena.Overall, the ASRT project contributes to advancing education in both radio astronomy and engineering, fostering interest in scientific exploration and providing a valuable learning experience for students.**

Keywords—Radio Astronomy, Affordable Small Radio Telescope, Direct to Home Satellite System, Radio Frequency Framework, Solar Observations

I. Introduction

The study of celestial objects through their radio wave emissions is known as radio astronomy. Historically, this area has only been accessible to research organizations with substantial funding due to its reliance on huge, expensive equipment. But more recently, developments have produced compact and more reasonably priced radio telescope options, opening up this exciting field of astronomy to a wider audience. The current effort is focused on building an Affordable Small Radio Telescope (ASRT), primarily for solar observations. The purpose of this Introduction is to provide an overview of the project's goals, reasoning, and importance in relation to science and engineering.

The necessity for affordable and easily obtainable resources to investigate the Sun, our closest star, and its diverse occurrences is the main driving force behind the creation of an ASRT. Solar activity, which is typified by phenomena like Sunspots and Coronal Mass Ejections (CMEs), has practical consequences for Earth's technological infrastructure in addition to providing insightful information about stellar dynamics. Researchers can improve their understanding of space weather phenomena and lessen the possibility of interference with GPS navigation, network systems, satellite communication, and electrical grids by keeping an eye on and evaluating solar activity.

The research offers an interesting chance for me as an RF engineer to apply ideas and concepts from communication engineering to radio astronomy. The ASRT makes use of parts that are frequently used in Direct-to-Home (DTH) satellite systems, such as coaxial cables, satellite dishes, and Low-Noise Block (LNB) converters. The project showcases the integration of RF engineering and astronomy by recycling these components and incorporating them into a working radio telescope. This provides an interactive method of learning about both fields.

The process used to build the ASRT centers on putting these parts together and integrating them to create a functional system that can identify radio signals from celestial bodies, especially the Sun. The project makes use of the RF framework and analogue communication concepts in the telescope's construction and calibration to ensure that radio signals are captured and processed as efficiently as possible. Students and hobbyists bridge the gap between theoretical knowledge and actual applications by gaining practical expertise in hardware assembly, signal acquisition, and data analysis through this procedure.

The ASRT-facilitated observations yield important data for researching solar phenomena and how space weather forecasting is affected by them. Through monitoring the frequency and trajectory of CMEs, Sunspots, and other solar phenomena, scientists can improve predictive models and algorithms, improving our capacity to foresee and lessen possible effects on Earth's technological infrastructure. In addition, the ASRT's accessibility and affordability make it a perfect teaching tool, encouraging upcoming generations of engineers and scientists to discover the mysteries of radio astronomy.

In the final analysis, a major advancement in STEM education and scientific research has been made with the creation of an affordable small radio telescope for solar studies. The ASRT provides a singular opportunity to include enthusiasts and students in experiential learning while deepening our understanding of the Sun and its influence on space weather by fusing ideas from RF engineering and astronomy. As the project develops, it has the potential to make significant contributions to the domains of space research, radio astronomy, and communication engineering, opening the door for further advancements and discoveries.

II. Background

Our view of the world has been completely transformed by the use of radio waves to explore the cosmos. These waves have provided us with unique insights into celestial events that are undetectable to optical observatories. With the groundbreaking work of astronomer like Grote Reber and engineers like Karl Jansky, who discovered radio waves coming from the Milky Way, radio astronomy as a field of study came into being in the middle of the 20th century. From then on, developments in technology and instrumentation have elevated radio astronomy to a leading position in astrophysics research, allowing researchers to examine a broad spectrum of cosmic phenomena at various wavelengths.

Developing sensitive and cost-effective radio telescopes that can identify faint signals from far-off celestial objects has been one of the main difficulties in radio astronomy. Major research organisations and observatories have not always been able to use traditional radio telescopes due to their unreasonably high cost and resource requirements. These telescopes are typified by their huge parabolic dishes and intricate receiver systems. But new technological developments and the growing availability of commercial off-the-shelf components have made it possible to create smaller and more affordable radio telescopes.

This project marks an important turning point in the effort to make radio astronomy more accessible to the general public. Through the use of Low-Noise Block (LNB) converters and satellite dishes, which are frequently used in Direct-to-Home (DTH) satellite systems, the project seeks to develop an Affordable Small Radio Telescope (ASRT) appropriate for amateur and educational purposes. This method lowers the cost of construction while also making the telescope easier to assemble and use, opening up access to a larger group of people, including students, teachers, and amateur astronomers.

The project offers an interesting chance for radio frequency (RF) engineers to apply communication engineering principles to the realm of radio astronomy. A thorough understanding of RF hardware and software, as well as competence in antenna design and calibration, are necessary for the design and optimisation of the ASRT's antenna system, signal processing algorithms, and data gathering techniques. The project offers a practical method of using radio waves to investigate the secrets of the universe by bridging the gap between RF engineering and astrophysics by incorporating these ideas into the construction of the ASRT.

III. Literature Review

Deep Learning in Radio Astronomy

These papers collectively demonstrate the effectiveness of deep learning techniques in radio astronomy applications. They address various challenges such as solar radio burst detection, segmentation of extended radio galaxies, and automated detection using multimodal datasets. The methodologies presented in these papers underscore the potential of deep learning to enhance our understanding of celestial phenomena captured through radio telescopes. [1] [4] [8]

Quantum Computing and Its Applications

The Research Paper here explores the field of quantum computing and provides an in-depth analysis of its fundamental ideas, underlying difficulties, and emerging applications in various fields. The paper explores the frontier of quantum cryptography and computational algorithms, highlighting their implications for data security and computational efficiency, by clarifying the transformative potential of quantum systems. It also illuminates the continued efforts to overcome realistic obstacles that prevent the broader implementation of quantum computing technologies, opening the door to a future enabled by quantum. [2]

Machine Learning Techniques in Astronomy

These papers focus on leveraging machine learning techniques for anomaly detection in spectrographic data and Radio Frequency Interference (RFI) detection in radio astronomy. They introduce innovative approaches such as Self-Supervised Learning and Spiking Neural Networks to enhance anomaly detection accuracy and address challenges associated with RFI mitigation. [3] [6]

Computational Methods in Astronomy

This Group however, focuses on the complex interactions that exist between astronomical data analysis and computational methodologies. The paper examines different software platforms and computational techniques used to process astronomical datasets, with a focus on dedispersion techniques used in radio astronomy. In order to facilitate deeper insights into the cosmic phenomena being studied, the paper aims to improve the effectiveness and efficiency of data processing techniques through careful evaluation and optimisation strategies. Group 4 emphasises the critical role that computational techniques play in expanding our understanding of the universe by bridging the fields of computational science and astronomy. [5] [7]

Radio Astronomy Instrumentation and Techniques

This group examines the complex field of radio astronomy equipment and methods, including the various aspects of technological developments and observational approaches. The studies highlight the critical role that spectrum management and accurate satellite tracking play in maintaining the integrity of radio astronomy observations by closely examining the subtleties of satellite tracking techniques and radio frequency interference (RFI) mitigation strategies. The papers enhance our comprehension of celestial phenomena by shedding light on the crucial role that state-of-the-art techniques and sophisticated instrumentation play in solving the universe's mysteries. This is achieved through rigorous examination. [9] [10] [12] [14] [15] [18]

Low-Frequency Radio Astronomy and Space Studies

Collectively, this group, on the other hand, explores the field of low-frequency radio astronomy and space studies, illuminating the special powers of low-frequency radio telescopes for examining space. The papers emphasise the importance of low-frequency radio telescopes in studying various astrophysical phenomena and space studies by highlighting technological advancements in antenna systems and international collaborations. These papers demonstrate the transformative potential of low-frequency radio astronomy in clarifying the fundamental laws governing the universe, opening the door to ground-breaking discoveries and previously unattainable insights into the cosmic tapestry through cooperative efforts and technological innovations. [17] [19] [20]

Additional Papers:

On the other hand, other papers address various aspects of radio astronomy research, such as space weather forecasting, scintillation research, phased subarray deployment, and the establishment of radio astronomy facilities across the globe. Together, these papers contribute to a deeper understanding of the complex role that radio astronomy plays in explaining celestial phenomena and expanding our understanding of science. This Group now expands the scope of radio astronomy research by delving into a diverse range of topics, from space weather dynamics to the technical complexities of radio telescope design. This fosters interdisciplinary collaboration and innovation in the pursuit of astronomical inquiry. [11] [13] [16] [17] [19]

IV. Methodology

Components Used:

DTH Reflector Dish: The Affordable Small Radio Telescope (ASRT) project's main antenna is a Direct-to-Home (DTH) satellite dish (figure1). The DTH dish, which is usually recycled from commercial satellite television systems, is essential for gathering radio waves from astronomical sources. The parabolic form of the DTH dish allows for minimal distortion while focusing incoming radio waves onto the feed horn or LNB (Low-Noise Block). Its off-axis parabolic shape makes it ideal for radio astronomy applications by ensuring effective signal acquisition over a broad field of view.Larger parabolic dishes offer more resolution for observing tiny features in radio sources. The resolution of the ASRT is dependent on the size of the dish.

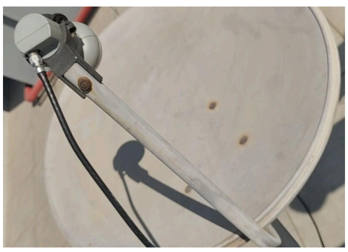

Figure 1.: Offset Parabolic Dish

The ideal parabola size for efficient signal gathering is also determined by the wavelength selection. Although the DTH dish was originally designed for consumer satellite television systems, it has shown adaptability in radio astronomy applications, providing an accessible and reasonably priced means for both amateurs and students to investigate the universe through radio observations.

LNB and Coaxial Cable: Coaxial cable and the Low-Noise Block (LNB) are essential components of the ASRT that enable radio signals picked up by the DTH dish to be transmitted and received. In addition to acting as the interface between the receiver and the dish antenna, the LNB(figure2) is essential for signal conversion and amplification.

Figure 2.: Low Noise Block (LNB)

The LNB converts received radio signals from the Ku band to intermediate frequencies (IF) that can be processed using the superheterodyne reception method. It is made up of parts like a mixer, feed horn, low-noise amplifier (LNA), and local oscillator. Radio waves reflected by the dish are gathered by the feed horn and directed towards the mixer, where they are combined with the output of the local oscillator to create IF signals. The LNA amplifies these signals while minimizing noise, ensuring the preservation of weak radio emissions from celestial sources. The amplified IF signals are sent from the LNB to the receiver or satellite finder via coaxial lines. These cables are distinguished by their design, which consists of a metallic shield and an insulating layer encircling the centre conductor. Excellent electromagnetic interference shielding is provided by this design, preserving signal integrity over extended distances. Coaxial cables also provide low signal attenuation, which enables effective signal transmission with little loss.

Figure3.: Co-axial cable F male connector

The ASRT is able to record, amplify, and transmit radio signals for additional analysis and interpretation because of the reliable transmission system that the LNB and coaxial cable(figure3) create together. Their effective functioning guarantees the radio telescope's dependable performance, enabling the precise and accurate observation of astronomical events.

Equitorial Mount: An essential part of the ASRT setup, the equatorial mount allows for accurate monitoring and movement of astronomical objects across the sky. The equatorial mount moves in accordance with the Earth's rotational axis, in contrast to conventional alt-azimuth mounts, which move in horizontal (azimuth) and vertical (altitude) axes. By allowing the mount to adjust for Earth's rotation, this alignment makes it possible to monitor celestial targets as they appear to move across the sky with accuracy and ease. The equatorial mount, which uses celestial coordinates like right ascension and declination, makes sky mapping easier. It has adjustable axes that are oriented with respect to the celestial equator and the observer's meridian. Users can discover and monitor individual celestial objects with ease by aligning the mount's polar axis with the celestial pole. This feature is especially helpful for observations in radio astronomy, where precise tracking and location are necessary to record radio emissions from far-off celestial sources. All things considered, the equatorial mount improves the capabilities of the ASRT, making it possible to map the sky and observe celestial events more effectively.

Satellite Finder, Voltmeter and Data Acquisition: In order to measure and record the radio signals that the antenna receives, the data acquisition system, voltmeter, and satellite finder (figure4) are essential components of the ASRT setup. By identifying and maximizing signal strength, the satellite finder helps to accurately align the antenna with astronomical objectives like the Sun or certain satellites.

Figure4.: Satellite Finder attached to Power source and LNB

It allows users to maximise the sensitivity of the ASRT system by adjusting the antenna position for best signal reception. The voltmeter is used to measure the voltage output that corresponds to the received radio signals in conjunction with the satellite finder.

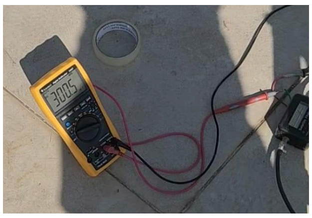

Figure5.: Voltmeter attached to SatFinder

During observations, a defined amount of time is used to record this voltage output (figure5), which is a measure of signal strength. The collected voltage data is then gathered and arranged using the data gathering system, usually in a tabular format. Radio astronomy study and exploration are made easier by this methodical methodology, which enables the analysis and interpretation of radio signals recorded by the ASRT.

Techniques used:

Radio Frequency Spectrum and Ku Band: For its observations, the ASRT makes use of the radio frequency spectrum, with a particular emphasis on the Ku band (12–18 GHz). A vast variety of electromagnetic frequencies utilized for many forms of communication and scientific research are included in the radio frequency spectrum. Due to its beneficial features, the Ku band is especially relevant for satellite communication and broadcasting within this spectrum. The Ku band is appropriate for applications like broadband internet and satellite television because it provides high frequencies that facilitate effective data transmission and reception. Furthermore, signals may travel through Earth's atmosphere with little interference thanks to the Ku band's reasonably good atmospheric penetration. This property makes it useful for observations in radio astronomy, especially for identifying celestial sources of radio emissions such as the Sun and certain satellites. The ASRT can efficiently record and analyse radio signals from astronomical objects and occurrences by utilising the Ku band in the radio frequency spectrum. This helps to further the study of radio astronomy and facilitates scientific exploration of space.

Working of LNB (SuperHeterodyne Reciever): An essential part of the ASRT configuration, the Low-Noise Block (LNB) is in charge of boosting and downconverting radio frequency (RF) signals that the antenna receives (figure6). The LNB functions by downconverting incoming radio frequency signals from the microwave frequency range (Ku band) to a lower intermediate frequency (IF) range, usually in the megahertz (MHz) or kilohertz (kHz) range, using the superheterodyne reception concept. The RF signals are first amplified inside the LNB to make up for any signal losses that may have occurred during transmission. To provide the required intermediate frequency output, these amplified signals are then combined with a local oscillator signal. Downconversion facilitates downstream signal processing and demodulation.

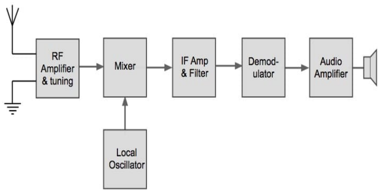

Figure 6.: Super Hetrodyne Receiver Flowchart

In order to reduce extra noise created during signal amplification and maintain a good signal-to-noise ratio (SNR), the LNB also includes a low-noise amplifier (LNA). This is essential for minimising interference from noise sources and detecting faint radio signals from astronomical sources. All things considered, the ASRT system's sensitivity and performance for radio astronomy observations are improved by the LNB's effective functioning.

A. Flow of Radio Telescope:

Radio signals from astronomical sources can be detected and analysed thanks to a number of essential parts and phases in the radio telescope system's operation (figure7). The antenna picks up incoming radio waves from space, and after that, the signal is processed through a number of steps to retrieve relevant data.

Figure7.: Flow of Information

First, a Low-Noise Amplifier (LNA) receives the signal from the antenna. The LNA increases the signal-to-noise ratio (SNR) and boosts the system's sensitivity by amplifying the weak incoming signal while producing the least amount of noise. The mixer receives this signal after it has been boosted.

An intermediate frequency (IF) signal is created at the mixer stage by combining an incoming radio frequency (RF) signal with a local oscillator (LO) signal. This procedure, called heterodyning, lowers the frequency of the incoming signal to a region where it can be processed more easily.

After then, the original information stored in the radio waves is extracted by demodulating the IF signal in a superheterodyne detector. In order to further increase the signal-to-noise ratio of this demodulated signal, time averaging is applied, which entails integrating the signal over a predetermined amount of time.

The processed signal is then recorded for further examination and understanding. During this recording, the signal may be shown in real time for instant inspection or stored digitally for later study. After the data has been acquired, it can be examined using a variety of methods, such as spectral analysis, to learn important details about the astronomical sources that sent the radio waves.

In order to increase sensitivity, lower noise, and extract useful information from the incoming radio signals, a series of precisely planned phases are involved in the radio telescope system's flow from the antenna to the recording stage. To ensure the success of radio astronomy observations and to further our understanding of the universe, each step is essential.

V. OBSERVATIONS

Constant Solar Observation using Continuous Tracing: In Constant Solar Observation utilising Continuous Tracing, temperature fluctuations and accompanying voltage readings are recorded while the Sun's journey is continually tracked across the sky. Voltage is used in this method as a proxy for solar radio intensity. Through the persistent observation of voltage and temperature, scientists can identify fluctuations in solar activity, including coronal magnetic emissions, solar flares, sunspots, and other phenomena. It is possible to create intricate temporal profiles of solar activity by continuously tracking the Sun's motion. These profiles shed light on solar atmospheric dynamics and aid in comprehending the fundamental mechanisms behind solar phenomena. Researchers can examine how solar activity affects Earth's atmosphere and ionosphere by comparing changes in voltage readings with variations in temperature. Continuous Solar Observation using Continuous Tracing is crucial for space weather forecasting and understanding the impact of solar activity on communication systems, satellite operations, and power grids. It also contributes to our broader understanding of the Sun's behavior and its influence on the Earth's environment.

Figure 8.: Setup of ASRT for Tracking

Constant Solar Intensity Observation using Stationary Telescope: The radio telescope is kept stationary during the Constant Solar Intensity Observation to allow for continuous monitoring of solar radio intensity. With this fixed configuration, fluctuations in solar radio emissions over time can be precisely measured independent of telescope movement. Simultaneously, during the observation period, the temperature of Pune or any other pertinent site is recorded. This additional information aids in the comprehension of the relationship between solar activity and regional atmospheric conditions. The observation precisely records variations in solar radio intensity by staying in one place. Changes in solar flares, coronal mass ejections, and other solar events can be better understood in light of these fluctuations. Long-term patterns in solar activity can also be examined, which helps forecast space weather phenomena and their possible effects on Earth's atmosphere. The information gathered from this observation advances our knowledge of solar dynamics and how they affect the atmosphere of Earth. Additionally, it makes it easier to do research on the relationship between solar radiation and atmospheric processes, which is crucial for a number of scientific fields, such as radio astronomy, climatology, and space weather forecasting. All things considered, continuous solar intensity monitoring is an essential resource for researching solar activity and its effects on Earth.

Satellite Tracing (Geo Stationary): Accurately mapping the locations of two geostationary satellites in the sky is the main goal of satellite tracing, or geostationary observations(figure9). Geostationary satellites maintain a stable position with respect to a ground observer because they circle the Earth at the same speed as the planet's rotation. By using a radio telescope, one can identify differences in frequency emissions between the background radiation in the sky and the geostationary satellites . These differences act as differentiators, allowing the telescope to locate and follow the satellites against the background of stars.

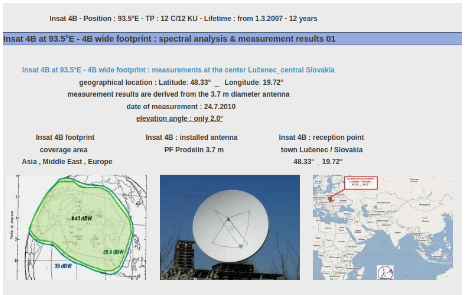

Figure 9.: Insat 3A,4B information and coverage area

The telescope plots the exact locations of the geostationary satellites on a 2D map of the sky using Altitude-Azimuth data. The strength, frequency, and potential interference of satellite communication signals with background radiation may all be studied more easily thanks to this mapping. Researchers can examine satellite communication patterns, keep an eye on signal stability, and look into possible sources of interference with the help of accurate satellite location determination. Furthermore, by shedding light on the mechanics of satellite orbits and how they interact with Earth's atmosphere, this observation advances space research and satellite communication technologies.

Solar Tracing: Solar tracing is the methodical mapping of the sky to follow the Sun's position with respect to coordinates of altitude and azimuth. This observation allows the radio telescope to continuously observe variations in solar radio intensity across multiple azimuth and altitude angles, using methods similar to satellite tracing. (figure10) The telescope captures variations in solar radiation strength as it rotates and surveys the sky, giving important information about solar activity. Researchers can examine variations in solar dynamics, such as sunspot activity, solar flares, and coronal mass ejections, by producing an intricate 2D map of the solar location.

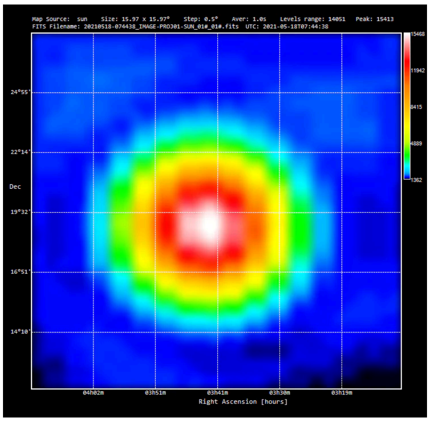

Figure 10.: Sample Solar Trace Map by SPIDR Radio Telescope

Understanding the Sun's behaviour and how it affects space weather phenomena requires knowledge of this information. Through the provision of real-time data on solar radiation patterns, solar tracing makes a substantial contribution to both space weather forecasting and solar research. Furthermore, scientists can learn more about the underlying mechanisms governing solar events by establishing correlations between variations in solar radio strength and other variables like temperature and atmospheric conditions. This observational method helps forecast space weather events that may impact satellite communication, navigation systems, and terrestrial infrastructure in addition to improving our understanding of the Sun's behaviour. As a result, solar tracing is essential to expanding our understanding of solar physics and guaranteeing the dependability of Earthly and space-based technological systems.

VI. Results and Discussion

Solar Flare Detection.: Our observation on March 12, 2024, revealed a notable solar flare between 12:28 PM and 03:56 PM. Graphing the time against solar radio intensity showcased a distinct spike during this period, indicating heightened solar activity. This finding (figure11) highlights the capability of our radio telescope to detect and track solar flares, crucial for space weather forecasting and understanding solar dynamics.

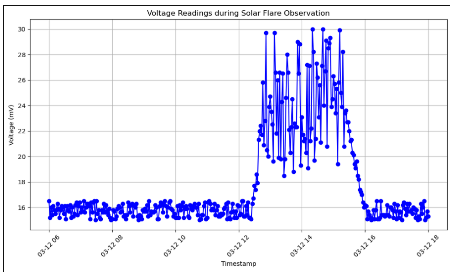

Figure 11.: Solar Storm on 12th March

Solar Intensity vs City Temperature.: Analyzing the relationship between solar intensity and city temperature throughout the day revealed intriguing patterns. We observed a gradual increase in solar intensity until 3:00 PM, followed by a gradual decrease. This correlation sheds light on the influence of solar radiation on local temperature dynamics, contributing to our understanding of Earth's energy balance and atmospheric processes.

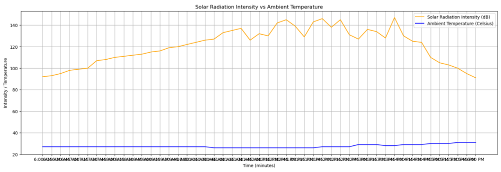

Figure 12.: Solar Intensity of Radio Waves and City Atmospheric temperature

Satellite Observation and Tracing.: By mapping the positions of geostationary satellites visible from Pune, including Intelsat-12 (figure13) and Insat 3A, 4B, (figure14) we gained insights into their spatial distribution and movement patterns. This data is valuable for satellite communication and navigation systems, ensuring accurate tracking and positioning of satellites for various applications such as telecommunications, broadcasting, and weather monitoring.

Figure 13.: Intelsat-12

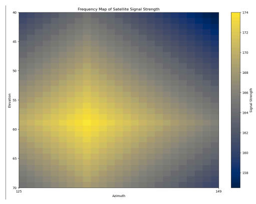

Figure 14.: Insat 3A,4B

Sun Tracking in 2D map of Sky.: Continuous monitoring of the Sun's position revealed dynamic shifts, resulting in minute fluctuations visible as impulses in the 2D sky map (figure15). This observation underscores the dynamic nature of solar activity and the importance of precise solar tracking for solar research and space weather forecasting. By capturing these fluctuations, our radio telescope enhances our understanding of solar dynamics and contributes to ongoing research in the field of radio astronomy.

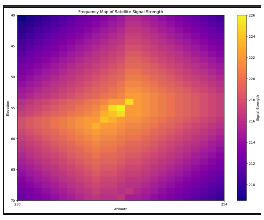

Figure 15.: 2D map of Stellar Coordinates to map Radio-SUN

VII. Novelty

The unique aspect of our work is its capacity to identify radio emissions from RLC circuits, blackbody radiations, and satellites (figure16). Through the integration of physics insights and electronics and telecom engineering concepts, we have developed a prototype model that spans multiple interdisciplinary fields. This convergence of knowledge has opened up new directions for creative study and useful applications by allowing us to investigate a variety of phenomena in radio astronomy.

The project's importance was acknowledged during IUCAA's National Science Day, where it was on display and highlighted how it has advanced scientific understanding and encouraged interdisciplinary cooperation in the fields of engineering and astronomy.

References

[1]. Arrubarrena, Paola, Maud Lemercier, Bojan Nikolic, Terry Lyons, and Thomas Cass. "Novelty Detection on Radio Astronomy Data using Signatures." arXiv preprint arXiv:2402.14892 (2024).

[2]. Ozturk, Cuneyd, Randall A. Berry, Dongning Guo, Michael L. Honig, and Frank D. Lind. "Reducing Satellite Interference to Radio Telescopes Using Beacons." arXiv preprint arXiv:2312.12692 (2023).

[3]. Gupta, Nikhel, Zeeshan Hayder, Ray P. Norris, Minh Hyunh, and Lars Petersson. "A Multimodal Dataset and Benchmark for Radio Galaxy and Infrared Host Detection." arXiv preprint arXiv:2312.06728 (2023).

[4]. Gupta, Nikhel, Zeeshan Hayder, Ray P. Norris, Minh Huynh, and Lars Petersson. "RadioGalaxyNET: Dataset and novel computer vision algorithms for the detection of extended radio galaxies and infrared hosts." Publications of the Astronomical Society of Australia 41 (2024): e001.

[5]. Pritchard, Nicholas J., Andreas Wicenec, Mohammed Bennamoun, and Richard Dodson. "RFI Detection with Spiking Neural Networks." arXiv preprint arXiv:2311.14303 (2023).

[6]. Novotný, Jan, Karel Adámek, M. A. Clark, Mike Giles, and Wes Armour. "Accelerating Dedispersion Using Many-core Architectures." The Astrophysical Journal Supplement Series 269, no. 1 (2023): 29.

[7].Gupta, Nikhel, Zeeshan Hayder, Ray P. Norris, Minh Huynh, Lars Petersson, X. Rosalind Wang, Heinz Andernach, Bärbel S. Koribalski, Miranda Yew, and Evan J. Crawford. "Deep learning for morphological identification of extended radio galaxies using weak labels." Publications of the Astronomical Society of Australia 40 (2023): e044.

[8]. Mesarcik, Michael, Albert-Jan Boonstra, Marco Iacobelli, Elena Ranguelova, C. T. A. M. de Laat, and R. V. van Nieuwpoort. "The ROAD to discovery: Machine-learning-driven anomaly detection in radio astronomy spectrograms." Astronomy & Astrophysics 680 (2023): A74.

[9]. Mesarcik, Michael, Albert-Jan Boonstra, Marco Iacobelli, Elena Ranguelova, C. T. A. M. de Laat, and R. V. van Nieuwpoort. "The ROAD to discovery: Machine-learning-driven anomaly detection in radio astronomy spectrograms." Astronomy & Astrophysics 680 (2023): A74.

[10]. Scully, Jeremiah, Ronan Flynn, Peter Gallagher, Eoin Carley, and Mark Daly. "Improved Type III solar radio burst detection using congruent deep learning models." arXiv preprint arXiv:2305.09327 (2023).

[11]. A. Volvach, G. Kurbasova and L. Volvach, "Radio Antennas for a Forecast of Solar Activity," 2019 IEEE International Scientific-Practical Conference Problems of Infocommunications, Science and Technology (PIC S&T), Kyiv, Ukraine, 2019, pp. 809-812, doi: 10.1109/PICST47496.2019.9061232.

[12]. M. J. Bentum, J. van der Marel, C. J. M. Verhoeven and J. Leijtens, "Measuring the Delfi-C3 satellite using the Westerbork Synthesis Radio Telescope," 2012 6th European Conference on Antennas and Propagation (EUCAP), Prague, Czech Republic, 2012, pp. 1095-1098, doi: 10.1109/EuCAP.2012.6206469.

[13]. T. Hidayat, "Developing radio astronomy at Bosscha Observatory," 2013 3rd International Conference on Instrumentation, Communications, Information Technology and Biomedical Engineering (ICICI-BME), Bandung, Indonesia, 2013, pp. 10-15, doi: 10.1109/ICICI-BME.2013.6698456.

[16]. N. Kalinichenko, N. Kuhai, A. Konovalenko, I. Bubnov, S. Yerin and A. Romanchuk, "Observations of Interplanetary and Ionospheric Scintillations with GURT Decameter-Meter Radio Telescope," 2020 IEEE Ukrainian Microwave Week (UkrMW), Kharkiv, Ukraine, 2020, pp. 765-767, doi: 10.1109/UkrMW49653.2020.9252677.

[17]. S. Yerin et al., "Phased Subarray of the Low-Frequency Radio Telescope GURT as a Standalone Instrument for Radio Astronomy Studies," 2020 IEEE Ukrainian Microwave Week (UkrMW), Kharkiv, Ukraine, 2020, pp. 1-5, doi: 10.1109/UkrMW49653.2020.9252788.

[18]. C. Beaudet, J. Ford, T. Minter, M. McCarty, K. O'Neil and R. Prestage, "Radio frequency interference management efforts at the National Radio Astronomy Observatory Green Bank site," 2013 US National Committee of URSI National Radio Science Meeting (USNC-URSI NRSM), Boulder, CO, USA, 2013, pp. 1-1, doi: 10.1109/USNC-URSI-NRSM.2013.6524992.

[19]. A. Konovalenko et al., "State-of-the-art of low frequency radio astronomy, relevant antenna systems and international cooperation in Ukraine," 2015 International Conference on Antenna Theory and Techniques (ICATT), Kharkiv, Ukraine, 2015, pp. 1-5, doi: 10.1109/ICATT.2015.7136772.

[20]. O. O. Konovalenko and V. V. Zakharenko, "Study of the space by low-frequency radio telescopes," 2014 20th International Conference on Microwaves, Radar and Wireless Communications (MIKON), Gdansk, Poland, 2014, pp. 1-3, doi: 10.1109/MIKON.2014.6899827.