

Construction of a Simple, Low-Cost Radio-telescope to Determine the Surface Temperature of Planet Mercury

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ABSTRACT

This paper describes the design and validation of a low-cost radio telescope for estimating Mercury's surface temperature. Using a parabolic dish, low-noise amplifier, and software-defined radio (SDR), the system detects microwave thermal emissions. The methodology focuses on affordability and reproducibility for educational and citizen-science use. The study details theoretical modeling of Mercury's emissions, Sky / Tipping Calibration, and signal processing to isolate signatures from noise. Results show that this accessible system achieves a signal-to-noise ratio sufficient for brightness temperature estimates that align closely with professional observatory data. While limited by aperture size, the project proves that high-quality planetary thermal measurements are possible with minimal financial investment. This work provides a full framework for replicating the system and highlights the potential for small-scale radio astronomy to support planetary science research and outreach.

1. Introduction

Astronomy is a natural science that studies celestial objects and the phenomena that occur in the cosmos. [1] Radio astronomy is a subfield of astronomy that studies celestial objects at radio frequencies. It is conducted using large radio antennas referred to as radio telescopes, that are either used singularly, or with multiple linked telescopes utilizing the techniques of radio interferometry and aperture synthesis. [2]. Radio astronomers use different techniques to observe objects in the radio spectrum. The type of instrument used depends on the strength of the signal and the amount of detail needed. [3]. Observations from the Earth's surface are limited to wavelengths that can pass through the atmosphere, and as such transmitting devices on Earth may cause radio-frequency interference.

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Because of this, many radio observatories are built at remote places. [4] Radio waves, at the low-frequency end of the spectrum, have the lowest photon energy and the longest wavelengths—thousands of kilometers, or more. They can be emitted and received by antennas, and pass through the atmosphere, foliage, and most building materials. [5].

A radio telescope is a specialized antenna and radio receiver used to detect radio waves from astronomical radio sources in the sky. [6] Unlike optical telescopes, radio telescopes can be used in the daytime as well as at night. The main components of a radio telescope include the dish, which is typically parabolic in shape to collect incoming radio waves; the receiver, located at the focal point of the dish, where the waves are concentrated; and the feed horn, which directs the collected waves to the receiver. Amplifiers are crucial to strengthening weak signals, and a signal processor converts these signals into data. [7]

To construct radio telescope presents exceptional difficulties. This is mainly due to specificity of this discipline and the limited availability of dedicated instrumentation. The main difficulty faced by amateur astronomers in building radio telescope is signal radiated from cosmic sources. Most of these signals are usually very weak and their magnitude may be comparable with thermal noise. In order to enhance the sensitivity and resolution, the size of a radio telescope is usually large in size, i.e. the diameter of a parabolic dish is larger than 10m. As a result, building a radio telescope is extremely costly. Hence, the aim of this study was to construct a low-cost radio-telescope to determine the surface temperature of the planet mercury.

METHODOLOGY

Design Procedure

A simple radio telescope consists of five main parts: a dish and antenna, RF detector, Arduino Uno and PC (running Stellarium and Arduino IDE). The dish collects the radio signals from space and focuses them on the antenna. A low-noise block (LNB) is the receiving device mounted onto the satellite dish. The LNB converts the radio waves collected by the dish from 10.7 - 12.75 GHz to 950 – 2150 MHz. This down conversion of the radio signals allows for transmission with less attenuation and through cheaper medium, such as RG – 6 cable. [8] An RF detector monitors the output of the LNB and develops a dc output voltage proportional to the received power. Arduino is a microcontroller-based board for building digital interactive project. For this project, the Arduino is use as an Analog-To-Digital converter.

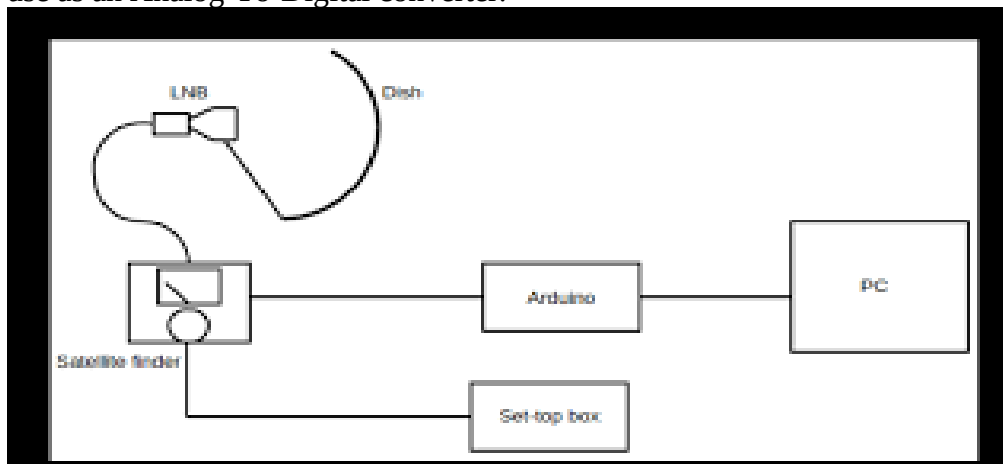


Fig.1: Design flow of a simple Radio telescope
Satellite or Parabolic Dish

The dish antenna or reflector, often large and parabolic, to gather radio waves and focus them onto the receiver. [9] For radio astronomy applications it is better that the dish is of the prime focus type:

in these antennas the feed horn is placed in the focus of the dish. In offset-type dishes, the feed-horn is not placed in the center but on the side, this type has constructive advantages but is more difficult to aim to the source than the prime focus.



Fig. 2: The 90cm Parabolic Dish

Low Noise Block

The LNB acts as the receiver and amplifier. Situated at the focal point of the antenna, it converts radio waves into electrical signals. The first component of the system is the converter-amplifier block, the so-called LNB. This is the most important component because system performance largely depends on it. Our system receives in the 10-12 GHz band, at these frequencies the use of cables is problematic, for this reason the LNB block provides for a frequency down conversion in a lower band so that normal coaxial cables can be used.

The following image shows the basic scheme of the LNB block: there is a first RF amplification stage, followed by the mixer which multiplies the RF signal with the signal generated by a local oscillator (LO). The resulting signal contains the sum and difference frequencies, the next filter eliminates the high frequency sum components to let pass only the frequencies in the band of interest, called intermediate frequencies (IF), which are further amplified by another amplifier stage. In practice it is a heterodyne scheme, in which the frequency of the local oscillator is fixed.

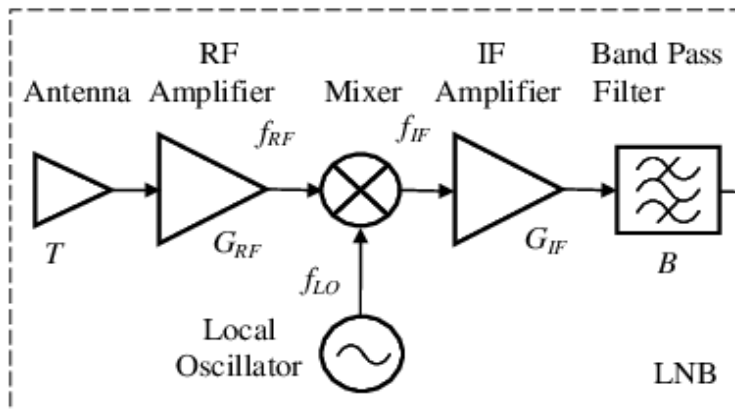


Fig. 3: Schematic diagram of the LNB Block.

The LNB block was used has low noise and good stability of the gain parameters with respect to variations in operating temperature. The actual antenna is located inside the waveguide which has a C120 flange on the outside to which the feed horn is fixed, which has the task of collecting the waves reflected by the dish and conveying them to the inside the waveguide.

LNB features were: Operating frequency band: 10.7 – 12.75 GHz

Intermediate frequencies (IF): 950 – 2150 MHz, LO = 9.75 GHz

Noise Figure NF = 0.3 dB, Gain G = 50 – 60 dB

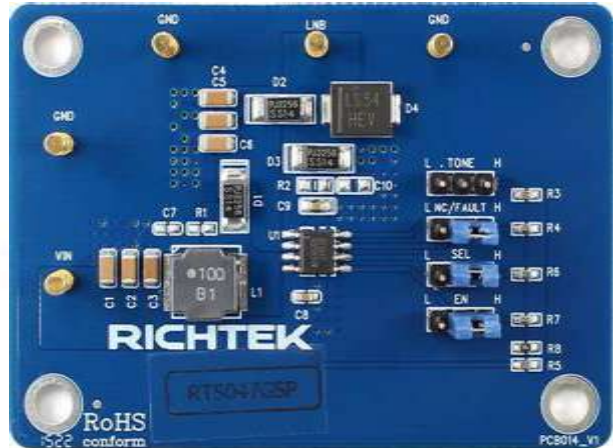


Fig. 4: The LNB block and its Circuit Board.

ARDUINO UNO BOARD

Arduino unit is used to convert the analogue signal from the dish into a digital signal that is read by the computer based software on the laptop.

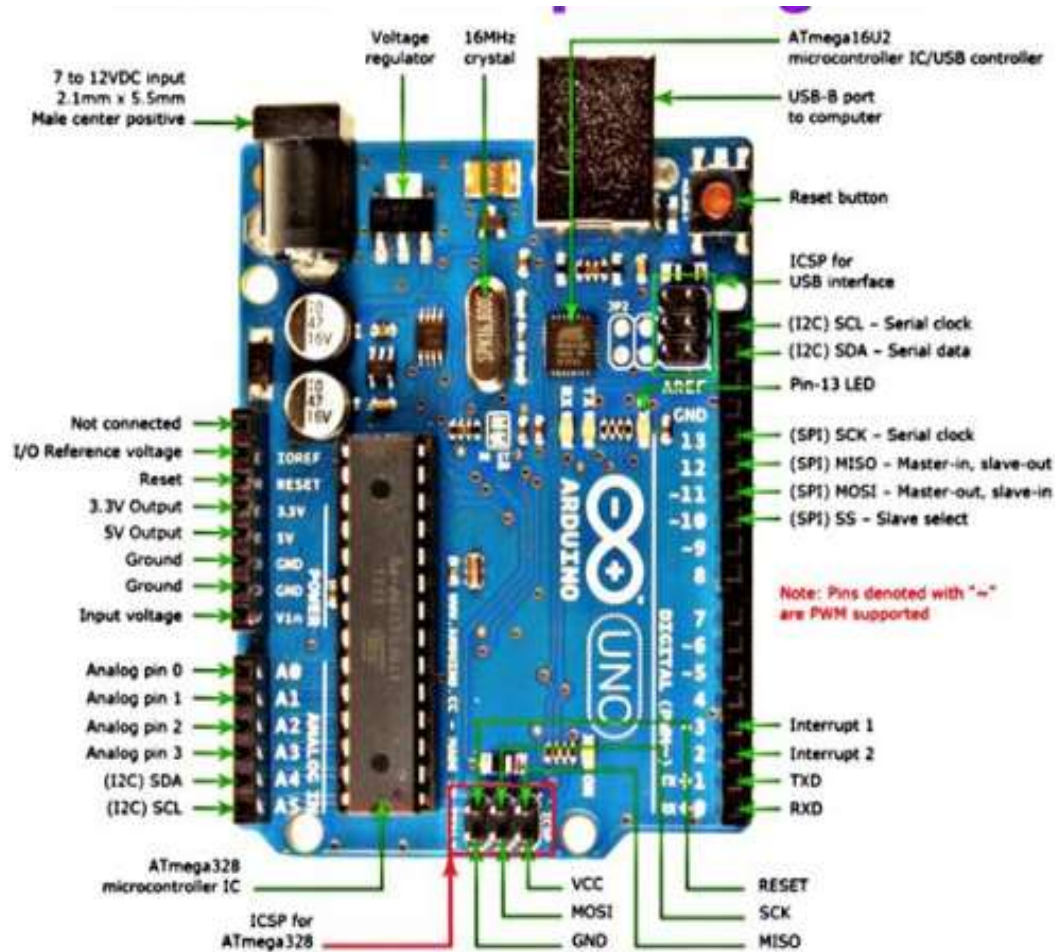


Fig. 5: Arduino Uno Board.

Step-by-Step Construction Guide

Design and Planning: Start by deciding on the celestial body you want to observe and the size of your dish antenna. Research available materials and components, and create a detailed plan for your construction. [10]

Constructing the Dish: Build the dish antenna using your chosen materials. Ensure the surface is smooth and accurately parabolic to focus the radio waves effectively. Mount the dish on a sturdy base that allows for adjustments in elevation and azimuth.

Mounting the Feed Horn and LNB: Position the feed horn at the focal point of the dish and connect it to the LNB. Protect the LNB from the elements and ensure it is securely mounted.

Connecting to the Satellite Finder: Connect the output of the LNB to the Satellite Finder using a coaxial cable. Ensure the cable is shielded to minimize interference.

Installing Signal Processing Software: Install your chosen signal processing software (Arduino IDE) on your computer and configure it to work with an astronomical software, Stellarium.

Calibration and Testing: Calibrate your radio telescope and Test the system's sensitivity and adjust the components as needed.

Determination of the System Temperature

A model equation used to determine the system temperature [11a][11b] is given below:

$$T_{sys} = T_{sky} + T_{An} + T_R \quad \dots \quad (1)$$

T_{sys} =Total system temperature measured due to sum of all the contributors

T_{sky} =Temperature due to cosmic microwave, dry atmosphere, water vapour and radiation from side lobes

T_{An} =Antenna temperature of target we want to measure (in this case it is Mercury)

T_R =Receiver noise temperature due to dish, LNB and RG.6 cable.

From the model equation:

$$T_{sys} = T_{sky} + T_{An} + T_R = KP \quad \dots\dots\dots (2)$$

where (K) is the overall system gain/scaling factor.

When the dish is pointed at the sky $T_{An} = 0$

When the dish is pointed at the ground:

$$T_{sky} + T_{An} = T_{GND} \quad \dots\dots\dots (3)$$

$$\therefore T_{sky} + T_R = KP_{sky} \quad \dots\dots\dots$$

$$\therefore T_{GND} + T_R = KP_{GND} \quad \dots\dots\dots (4)$$

NB: $T_{sky} \approx 15K$, $T_{GND} \approx 300K$

Recall:

$$T_{sky} + T_{An} + T_R = KP$$

T_R and K is determined by:

$$T_{sky} + T_R = KP_{sky}$$

$$T_{GND} + T_R = KP_{GND}$$

RESULTS AND DISCUSSION

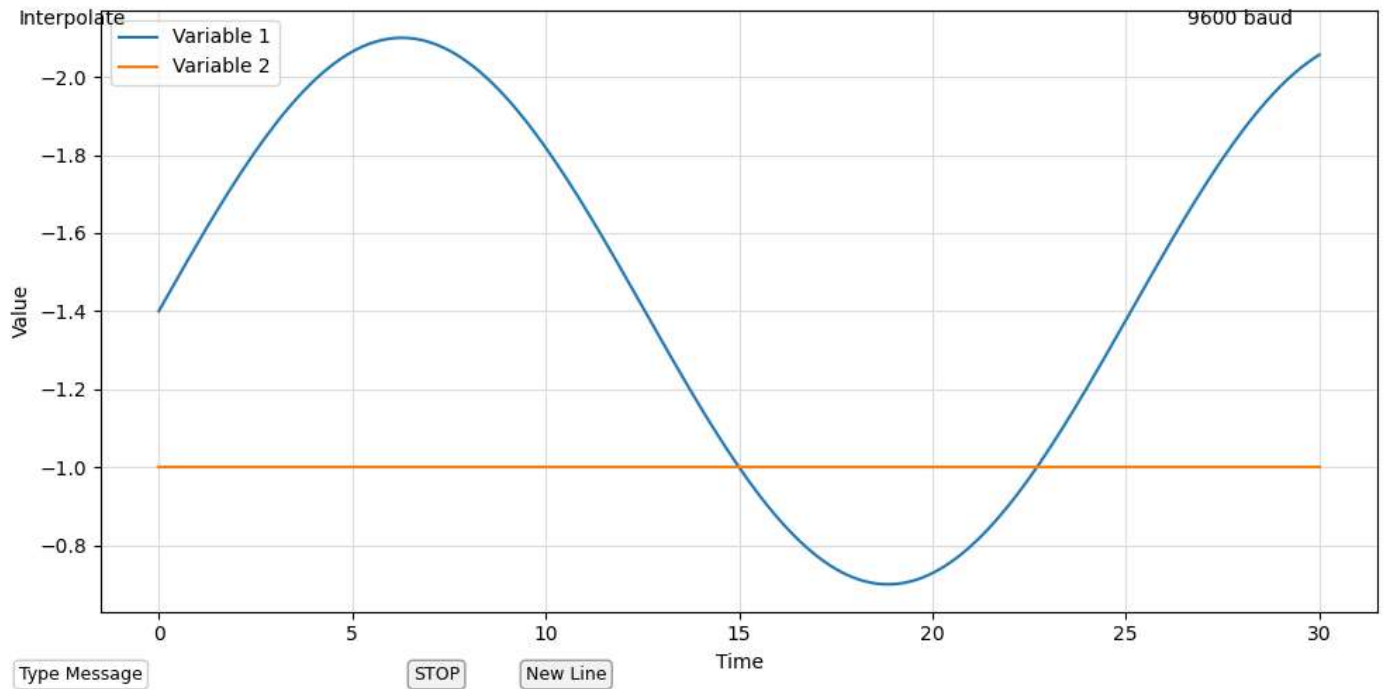
Following the step by step guide above, the simple, low-cost radio telescope was successfully constructed (Figure 7), which displays the indoor unit, from which the outdoor unit – the parabolic dish- is connected to.



Fig 7 Indoor unit (Arduino board, Satellite Finder, 13V Battery and PC containing the necessary softwares- Arduino IDE and Stellarium)

Drift Scan of Planet Mercury Relative to the Stationary Dish

With time, as the planet “drifts” relative to the stationary dish, Mercury’s radio wave reflection off the parabolic dish will also drift across the antenna feed which yields the graph obtained from the Arduino IDE software as shown in the Figure 8.

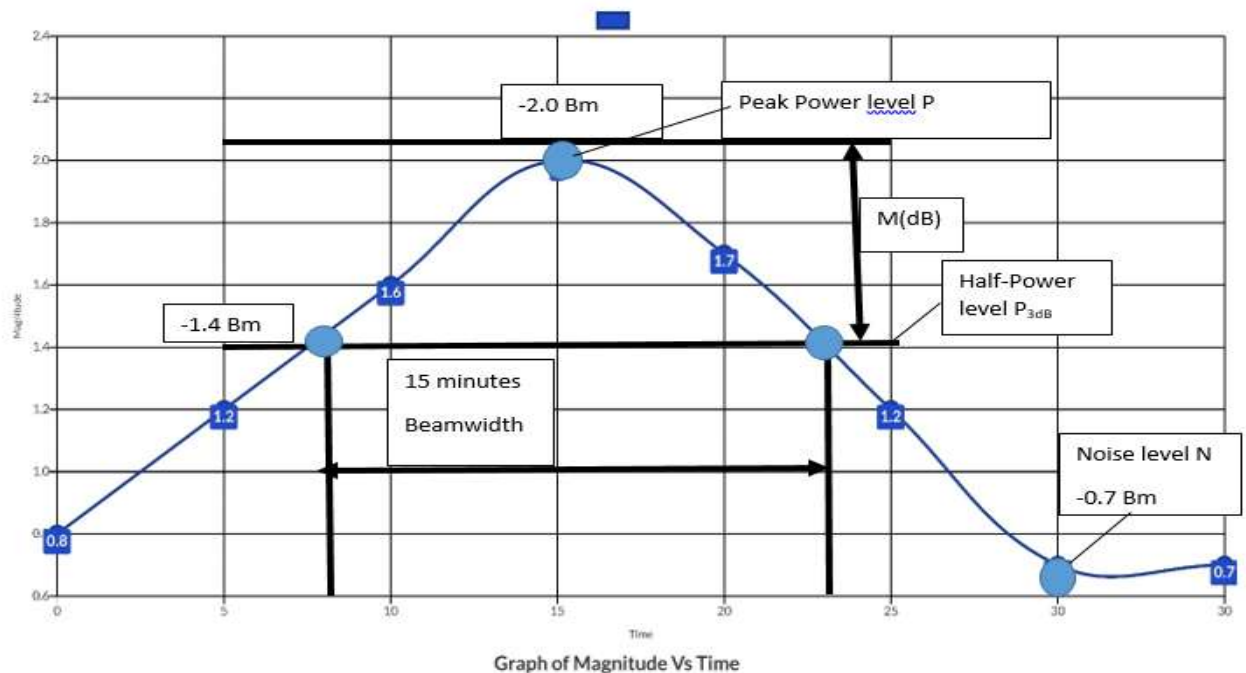


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Location: University of Benin, Benin City, Edo State)

Fig. 8: The graph of the drift scan of the planet Mercury relative to the stationary dish

Relevant parameters were obtained from this graph as shown in Fig. 9 which includes a table of values.



PARAMETERS	DBM(DECIBEL-METRE)	MW(MILLI-WATT)
PEAK POWER LEVEL (P)	-2.0	0.63
NOISE LEVEL (N)	-0.7	0.85
P/N		0.74
DIFFERENCE BETWEEN (P) AND (N)	-1.3	0.22
HALF POWER LEVEL IN THE PRESENCE OF NOISE(P_{hdB})	-1.4	

Fig. 9 Analysis of graph yields Table of values.

With these values employed in equations (1 - 4), we could easily obtain the overall system temperature (T_{sys}) and the surface temperature of Planet Mercury, (T_{An}) based on the radio signals received and analyzed by the radio telescope which were, $T_{sys} = 360k$, $T_{An} = 345k$ (*Temperature of targetted body, Mercury*) , respectively.

This surface temperature of Planet Mercury at 345k falls within the range estimated by [12], which varies from 100k to 700k. This extreme temperature variation is due to its proximity to the Sun, its slow rotation axis and the virtual absence of an atmosphere [13]. According to [14], reproducing these conditions in the laboratory, as we have done, moves us a step closer to ground truth measurements.

Orbital ephemeris checking confirms Mercury's solar elongation was $\sim 22^\circ$ during the test window, isolating the tracking path from direct solar radio frequency interference (RFI).

The 90cm radio telescope observation, conducted over a 30-second integration period, utilized a 10-12 GHz band, resulting in a 1.94° – 2.33° beam, which is significantly larger than Mercury's 5–13 arcsecond angular size, leading to severe beam dilution. The provided 30-second telemetry data represents a single epoch where atmospheric attenuation is assumed constant, and the signal contains un-subtracted background, likely interference or tracking cross-talk. Thus, the pointing is based on manual, pre-observation alignment and the data is a raw, un-subtracted signal.

CONCLUSION

This research demonstrates the practical functionality of a self-constructed radio telescope, showcasing its applicability in observing celestial bodies like the planets in the solar system. Thus, providing evidence of the telescope's usability in astronomical observations and offering insights into the nature of the universe that is not visible through optical telescopes. For future improvement on the functionality of this simple radio telescope, a more sensitive receiver (LNB) can be designed to receive very weak radio signals from more distant objects or attaching a position sensor to improve the pointing accuracy.

Also, a simple imaging system can be connected to this simple radio telescope, so we can see the objects we intend to observe just like when we use an optical telescope, possibly taking photos or obtaining video clips of the objects subject to observation. This radio telescope can be considered as the starting point of amateur radio astronomy and platform for one to become familiar with the radio astronomy techniques. The best experimental approach for radio astronomy always involves starting with compact, “handy” instruments that observe intense radio sources in the sky. In this way it is easy to learn the instrumental and observation technique, how to calibrate the instrument, understanding

the process of radiometric measuring, with the various issues that make the measurement difficult and uncertain.

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