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Characterization of background sky noise and system temperature in BURT observations of 3C 433 with nanotechnology-enhanced receiver systems

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An empirical characterization of background sky noise and the corresponding antenna noise temperature measured by the Baghdad University Radio Telescope (BURT) is presented for a six-month observation campaign targeting the radio galaxy 3C 433 (December 2024 – June 2025). A fixed noise threshold of −92 dBm is applied to isolate sub-threshold signals, and all data are processed using a MATLAB-based workflow to compute average noise power and equivalent antenna temperature. The analysis yielded a mean system temperature of approximately 90 K, with observed variations of ±10 K across the campaign. Seasonal trends are evident, with lower noise levels (~80 K) during winter and higher levels (~100 K) during spring, primarily driven by atmospheric humidity and ionospheric electron content. A detailed breakdown of noise contributions indicates that receiver and feed noise (15–20 K) and ground spillover (5–10 K) are the dominant controllable components, while sky background (5–8 K) and ionospheric effects (2–5 K) represent fundamental environmental limits. The stability of the results confirms consistent receiver performance with no significant long-term drift. In addition to empirical analysis, a nanotechnology-based enhancement model is evaluated through simulation. The results indicate that nano-engineered low-noise amplifiers, metamaterial feed designs, and nano-coatings could reduce system temperature to approximately 70–85 K, corresponding to an overall improvement of about 10–15%. These findings demonstrate that, while environmental noise remains unavoidable, targeted improvements in receiver and antenna subsystems provide a practical pathway to enhancing sensitivity in small radio telescopes.

Keywords: Radio astronomy; BURT telescope; Nanotechnology, low-noise amplifiers, Nanocoating.

1. INTRODUCTION

Radio astronomy relies on highly sensitive instrumentation to detect extremely weak cosmic signals, where system noise temperature plays a fundamental role in determining observational limits [1-5]. In particular, small-aperture radio telescopes such as the Baghdad University Radio Telescope (BURT) are more susceptible to environmental and instrumental noise contributions compared to large observatories [6-10]. Accurate characterization of background sky noise and system temperature is therefore essential for reliable detection of faint emissions such as the 21 cm hydrogen line [11, 12]. Understanding these noise contributions is critical not only for data interpretation but also for improving overall telescope performance [13, 14]. Despite continuous observational efforts using BURT, the system noise temperature remains influenced by multiple complexes and partially uncontrolled factors [15]. These include atmospheric absorption, ionospheric variability, ground spillover, and urban radio frequency interference (RFI) [16-20]. In addition, the inherent limitations of conventional receiver technologies, particularly in low-noise amplifier (LNA) performance and antenna efficiency, constrain further improvements in system sensitivity. As a result, achieving consistent and lower system noise levels remains a significant challenge for small radio telescopes operating in semi-urban environments [21]. Previous studies related to BURT have primarily focused on signal processing techniques, spectrometer optimization, and filtering methods to enhance data quality [22]. However, there is a lack of comprehensive, long-term empirical studies that quantify system noise temperature across different seasons using real observational data [23,24]. Furthermore, the potential application of emerging technologies—particularly nanotechnology—in reducing receiver and antenna noise has not been sufficiently explored in this context [25]. This represents a clear research gap, especially given recent advancements in nano-engineered electronic components and antenna materials [26]. The novelty of this study lies in combining a long-term observational analysis with a systematic evaluation of noise contributions using a threshold-based MATLAB approach, while also introducing nanotechnology as a potential pathway for performance enhancement [27]. Specifically, this work not only quantifies system noise behavior over a six-month period but also examines how nano-engineered low-noise amplifiers, metamaterial-based feed structures, and nano-coatings could reduce thermal and spillover noise components [28-30]. This dual approach provides both a realistic assessment of current system performance and a forward-looking perspective on technological improvements [31]. The primary objectives of this research are to quantify the average background sky noise and corresponding system temperature of BURT, analyze temporal and seasonal variations, and identify the relative contributions of different physical noise sources [32]. Additionally, this study aims to validate a MATLAB-based thresholding method for noise estimation and to assess the potential impact of nanotechnology-driven enhancements on system sensitivity [33]. Through this, the work seeks to establish a reliable framework for monitoring and improving telescope performance [34]. This study is subject to several limitations [35]. Observations are conducted only during daytime hours, which excludes potential nighttime variations in ionospheric and atmospheric conditions. The telescope operates in an urban environment, making it difficult to completely eliminate radio frequency interference. Moreover, the evaluation of nanotechnology-based improvements is theoretical and simulation-based, as such components have not yet been physically implemented in the BURT system. Atmospheric and ionospheric parameters are also inferred rather than directly measured, which may introduce minor uncertainties. The scope of this work is limited to L-band observations (1.4 GHz) of the radio galaxy 3C 433, focusing specifically on noise characterization rather than detailed astrophysical signal extraction. Nevertheless, the findings are directly relevant to improving the sensitivity of hydrogen-line observations and similar narrow-band radio astronomy studies. The significance of this research lies in providing a quantitative benchmark for BURT's performance, along with a reproducible methodology for long-term noise monitoring. Additionally, it highlights the promising role of nanotechnology in enhancing the capabilities of small and cost-effective radio telescopes.

In this paper, an empirical characterization of background sky noise and system temperature measured by the BURT telescope over a six-month observation campaign is presented. Section 2 describes the telescope configuration and observational setup. Section 3 discusses the various physical noise sources, including potential nanotechnology-based improvements. Section 4 outlines the MATLAB-based data processing and analysis methodology. Section 5 presents the results and discussion, including seasonal trends and performance evaluation, followed by conclusions and future work in Section 6.

2. TELESCOPE OVERVIEW AND OBSERVATIONAL CONTEXT

The Baghdad University Radio Telescope (BURT) is a small-aperture radio astronomy instrument consisting of a 3 m diameter parabolic dish operating in the L-band around 1.4 GHz, primarily designed for hydrogen-line and continuum observations. The telescope is located at a latitude of 33.27° N and longitude of 44.38° E, at an altitude of approximately 35 m above sea level. BURT is equipped with a receiver chain that includes a low-noise amplifier (LNA), feed system, and vital spectrometer covering a frequency range of 1.41–1.43 GHz with high spectral resolution. The relatively small dish size makes the system more sensitive to environmental noise contributions, including ground radiation, atmospheric emission, and urban radio frequency interference [36]. Observations are typically conducted during daytime hours to minimize ionospheric disturbances and maintain stable operating conditions. Due to its compact design and semi-urban location, BURT provides an ideal platform for studying system noise behavior under realistic observational constraints. However, these same conditions also introduce limitations in sensitivity, as external noise sources can significantly impact the overall system temperature. The performance of the telescope is therefore closely tied to the efficiency of its receiver system and antenna design, both of which determine how effectively weak astronomical signals can be distinguished from background noise. In this context, recent advances in nanotechnology offer promising opportunities for enhancing the performance of radio telescopes like BURT. Although the current system employs conventional electronic and structural components, future upgrades may incorporate nano-engineered materials and devices. For example, nano-structured low-noise amplifiers, including gallium nitride (GaN) and graphene-based hybrids, have the potential to reduce intrinsic thermal noise by improving electron mobility and minimizing resistive losses at the microscopic scale [37]. Such improvements can directly lower the receiver noise temperature, which is a dominant component of the total system noise. In addition to receiver enhancements, nanotechnology can also be applied to the physical structure of the antenna. The use of low-emissivity nano-coatings on the dish surface can reduce thermal radiation and energy losses, thereby improving the antenna’s effective efficiency [38[. Furthermore, metamaterial-based feed horns, designed using engineered sub-wavelength structures, can provide superior control over beam patterns and significantly reduce sidelobe levels. This helps minimize unwanted ground pickup and external interference, which are common challenges for small radio telescopes operating in urban environments [39]. Collectively, these nanotechnology-driven improvements are expected to reduce receiver noise temperature, enhance gain stability, and suppress unwanted sidelobe contributions. While these technologies have not yet been implemented in the current BURT system, their potential impact highlights an important direction for future development. Integrating such advanced materials and designs could significantly improve the sensitivity and observational capability of BURT, enabling more precise detection of weak astrophysical signals and expanding its role in radio astronomy research. Noise Sources and Environmental Contributions [40].

2.1. Thermal and receiver noise

Thermal and receiver noise constitute one of the primary contributions to the overall system noise temperature in radio telescopes. This component arises from the intrinsic electrical properties of the receiver chain, including resistive losses, thermal agitation of charge carriers, and imperfections in signal amplification. In the BURT system, the dominant contribution originates from the low-noise amplifier (LNA) and associated feed components, resulting in an estimated receiver noise temperature of approximately 15–20 K. This range is consistent with typical performance levels for conventional L-band receiver systems operating under standard conditions [41]. The LNA plays a critical role in determining system sensitivity, as it is the first active component in the signal chain and directly amplifies weak astronomical signals. Any noise introduced at this stage is subsequently amplified and cannot be removed in later processing stages [42]. Feed losses, impedance mismatches, and thermal emissions from surrounding components further contribute to the total receiver noise, making this subsystem a key target for performance optimization [43]. Recent advancements in nanotechnology offer promising avenues for reducing thermal and receiver noise in radio astronomy systems. In particular, nano-transistor-based LNAs, including those utilizing advanced semiconductor materials such as gallium nitride (GaN) and graphene-based structures, exhibit enhanced electron mobility and reduced resistive losses at the nanoscale. These properties enable more efficient signal amplification with lower intrinsic noise generation [44]. As a result, the implementation of such nano-engineered LNAs could potentially reduce the receiver noise temperature to approximately 10–15 K. The reduction of receiver noise through nanotechnology would have a direct and significant impact on the overall system temperature, particularly for small-aperture telescopes like BURT, where instrumental noise constitutes a major fraction of the total noise budget. Lower receiver noise not only improves signal-to-noise ratio but also enhances the telescope's ability to detect faint spectral features, such as the 21 cm hydrogen line. Therefore, integrating nano-scale electronic components into the receiver design represents a critical step toward achieving higher sensitivity and improved observational performance [45].

2.2. Sky background

The sky background noise represents a fundamental and unavoidable component of the total system temperature in radio astronomy observations. At L-band frequencies around 1.4 GHz, this contribution primarily arises from Galactic synchrotron radiation, which is produced by relativistic electrons spiraling in the Galactic magnetic field, as well as from atmospheric emission due to molecular absorption and thermal processes. For observations conducted near the zenith, the sky brightness temperature is typically in the range of approximately 5–8 K, which is consistent with established theoretical and observational models for this frequency band. Unlike receiver or instrumental noise, the sky background represents an astrophysical limit that cannot be eliminated through technological improvements. However, its magnitude is not entirely constant and depends on several observational and environmental factors. One of the most significant influences is the elevation angle of the telescope. As the observation moves away from the zenith toward lower elevations, the effective path length through the atmosphere increases, leading to higher atmospheric emission and absorption. This results in a corresponding increase in the measured sky temperature. Humidity and atmospheric water vapor content also play an important role in modulating sky background noise. Increased moisture levels enhance atmospheric emission, particularly in the L-band, causing small but measurable increases in the overall noise temperature. Additionally, variations in Galactic background emission across different regions of the sky can introduce further fluctuations, depending on the telescope's pointing direction relative to the Galactic plane [46]. From a technological perspective, including the application of nanotechnology, the sky background component remains largely unchanged, as it is governed by external astrophysical and atmospheric processes rather than internal system properties. While advanced materials and receiver designs can improve sensitivity and reduce internal noise contributions, they cannot reduce the intrinsic sky brightness temperature. Therefore, the sky background of approximately 5–8 K represents a lower bound on the achievable system noise temperature for BURT and similar radio telescopes operating at 1.4 GHz.

2.3. Ground spillover and urban interference

Ground spillover and urban radio frequency interference (RFI) represent significant external contributions to the overall system noise temperature in small radio telescopes such as BURT. Ground spillover occurs when radiation from the surrounding earth enters the antenna through sidelobes of the feed pattern rather than the main beam. This unwanted pickup introduces additional thermal noise, as the earth typically radiates at temperatures much higher than the cosmic background. For the BURT system, this contribution is estimated to be in the range of approximately 5–10 K, depending on the antenna geometry, feed alignment, and observational elevation angle. In addition to ground spillover, BURT operates within an urban environment where anthropogenic radio frequency interference can intermittently elevate the noise floor. RFI include communication systems, electronic devices, and broadcasting signals, which can contaminate the observational data [47, 48]. To mitigate this effect, affected intervals are automatically identified and flagged during data processing, ensuring that only reliable measurements contribute to the final noise estimation. Despite these mitigation strategies, residual interference may still influence the overall system performance, particularly during periods of increased human activity. Recent developments in nanotechnology offer promising solutions to reduce the impact of ground spillover and improve antenna performance. Metamaterial-based feed designs, constructed using engineered sub-wavelength structures, can provide enhanced control over the radiation pattern, significantly reducing sidelobe levels. By suppressing sidelobes, these advanced feed systems limit the amount of unwanted ground radiation entering the receiver, thereby lowering the spillover noise contribution. Additionally, the application of low-emissivity nano-coatings on the antenna surface can reduce thermal re-radiation and energy losses, further minimizing the effective noise contribution from surrounding structures [49, 50]. With the integration of such nanotechnology-based enhancements, the ground spillover contribution is expected to decrease from its current range of 5–10 K to approximately 3–7 K. This reduction would have a meaningful impact on the overall system temperature, particularly for small-aperture telescopes where spillover effects are relatively more pronounced. Consequently, improvements in feed design and surface materials represent a practical pathway toward enhancing observational sensitivity and reducing environmental noise contamination in systems like BURT [51,52].

2.4. Ionospheric and seasonal effects

Ionospheric and seasonal variations represent important environmental factors influencing the system noise temperature in radio astronomy observations. The ionosphere, composed of ionized particles in the upper atmosphere, affects radio wave propagation through absorption, emission, and phase distortion. These effects are largely governed by the total electron content (TEC), which varies with solar activity, time of day, and seasonal changes. At L-band frequencies (1.4 GHz), ionospheric absorption is relatively small compared to lower frequencies; however, it still contributes measurable fluctuations to the system noise temperature [53, 54]. During the observation campaign, seasonal trends are clearly observed in the BURT data. In particular, the spring months (March–May) exhibited increased noise levels, with fluctuations on the order of approximately 2–5 K. This increase is attributed to elevated TEC values and higher atmospheric humidity, both of which enhance ionospheric emission and absorption. In contrast, winter observations (December–January) showed the lowest noise levels, reflecting more stable ionospheric conditions, reduced electron density, and lower moisture content in the atmosphere. These seasonal differences highlight the sensitivity of radio observations to environmental conditions, even at relatively high frequencies such as 1.4 GHz [55, 56]. Unlike instrumental noise sources, ionospheric effects cannot be directly mitigated through hardware modifications, including nanotechnology-based improvements. Since these variations originate in the Earth's upper atmosphere, they represent an external and largely uncontrollable contribution to the total system noise. However, advancements in receiver technology, including those enabled by nanotechnology, can indirectly improve the ability to manage ionospheric effects. Enhanced receiver sensitivity and improved signal-to-noise ratios allow for more effective filtering and post-processing of ionospheric distortions, leading to more accurate extraction of astrophysical signals. Therefore, while nanotechnology does not directly reduce ionospheric noise, it plays a supporting role by improving overall system performance and enabling more precise correction of environmental effects. Understanding the interplay between ionospheric variability and system sensitivity is essential for optimizing observational strategies and ensuring reliable long-term performance of radio telescopes such as BURT [57].

3. METHODS AND METHODS

3.1. MATLAB noise analysis workflow

The noise characterization in this study is performed using a dedicated MATLAB script, *SingleFileNoise_Final_Clean.m*, which is developed to systematically quantify the background noise level for each observation session. The workflow is designed to ensure consistency, reproducibility, and accurate separation of noise from potential signal contributions. The core processing steps remained unchanged throughout the analysis to maintain uniformity across all datasets collected during the six-month observation period. The analysis began with data import, where Excel files containing spectral measurements are read into MATLAB. These files consisted of amplitude values expressed in dBm as a function of frequency in Hz. Following this, a frequency masking step is applied to isolate the relevant observational band between 1.417 GHz and 1.425 GHz, corresponding to the region of interest for hydrogen-line studies. This ensured that only the scientifically relevant portion of the spectrum is included in the noise analysis. To account for temporal variations, each observation is divided into smaller segments of 15 minutes, separated by 3-minute gaps. This segmentation allowed for a more detailed examination of noise behavior over time and reduced the influence of transient disturbances. Within each segment, a thresholding technique is applied, where a fixed noise limit of −92 dBm is used. All amplitude values below this threshold are considered representative of background noise and are used to compute the average noise level. This approach provided a consistent method for excluding stronger signals and interference while focusing on the underlying noise floor. The selected noise values are then converted from logarithmic units (dBm) to linear power in watts using the relation [40]:

$$P_W = 10^{\frac{P_{dB_{10}}-30}{10}} \tag{1}$$

This conversion is essential for subsequent physical calculations, as noise temperature is defined in terms of linear power. The equivalent antenna noise temperature is then calculated using the standard radiometric equation [32]:

$$T_A = \frac{P_W}{k\,G\,\Delta\nu} \tag{2}$$

where k=1.38, times10^{-23}, mathrmJ K^{-1} is Boltzmann's constant, G=1000 represents the system gain, and Delta nu=20, mathrmMHz is the effective bandwidth. This formulation allows direct conversion of measured power into an equivalent noise temperature, providing a physically meaningful representation of the system noise. Finally, the results from each observation session are exported into structured output files (result.xlsx), containing key parameters such as the applied threshold, average noise power, and calculated noise temperature. In addition, batch plots are generated to visualize temporal trends and variations across different observation periods. This comprehensive workflow enabled efficient processing of large datasets while ensuring consistency and accuracy in the estimation of system noise characteristics. Figure 1 shows the count–threshold relationship used to validate the selected noise threshold of −92 dBm.

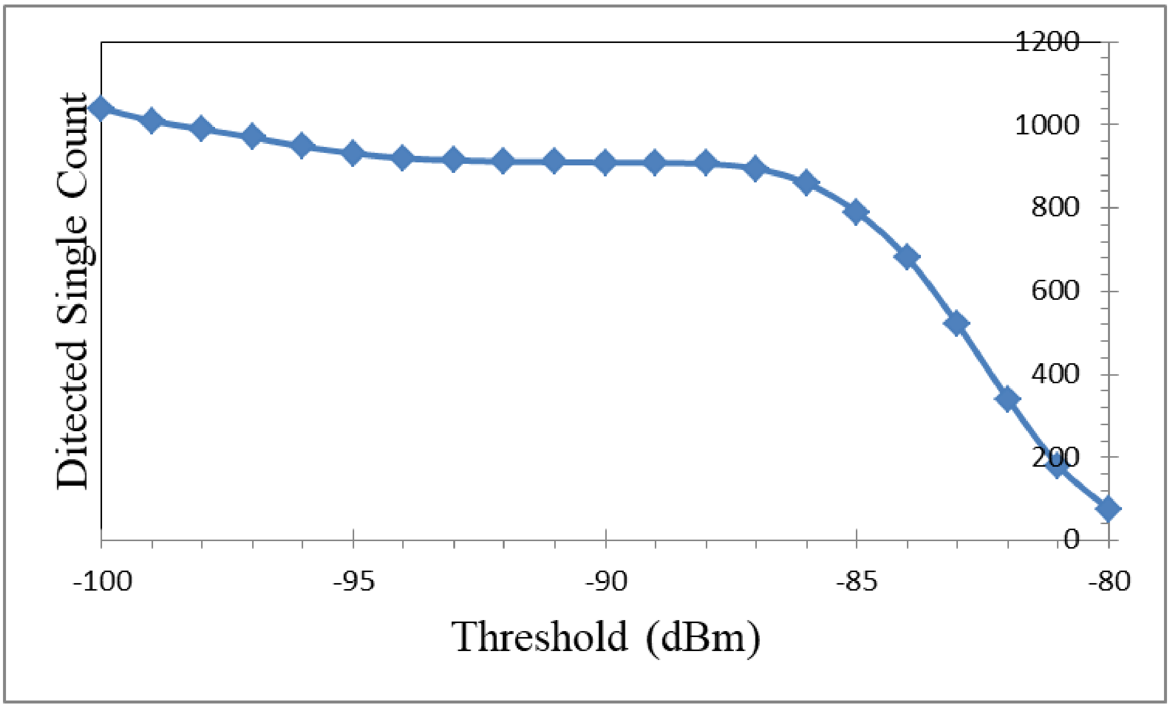

Figure 1 Threshold validation curve showing detected sample count as a function of threshold level, with the plateau near −92 dBm indicating the selected noise threshold.

3.2. Nanotechnology modeling approach

To evaluate the potential impact of nanotechnology on the overall system performance of BURT, a comparative simulation framework is introduced alongside the empirical analysis. This approach allows for a quantitative assessment of how nano-engineered components could influence system noise temperature without requiring immediate physical implementation. The modeling strategy is based on comparing a baseline system configuration with a hypothetical nano-enhanced scenario under controlled parameter adjustments. The baseline system model is defined using the standard operational parameters of the BURT telescope, including a system gain of $G = 1000$ and an effective bandwidth of $\Delta\nu = 20\,MHz$. These values correspond to the actual observational setup used during the six-month campaign and serve as a reference point for evaluating performance improvements. The baseline model incorporates all measured noise contributions, including receiver noise, sky background, spillover, and ionospheric effects, as derived from the MATLAB analysis. In the nano-enhanced scenario, modifications are introduced to simulate the expected improvements from nanotechnology-based components. Specifically, the receiver noise temperature is reduced by approximately 5 K to reflect the potential performance of nano-transistor low-noise amplifiers. Additionally, ground spillover contributions are reduced by approximately 3 K due to improved sidelobe suppression from metamaterial feed designs. A further enhancement is introduced through improved gain stability, modeled as a 5% increase in system gain, representing reduced fluctuations and higher efficiency in nano-engineered electronic components. The calculation of antenna noise temperature in both scenarios follows the same fundamental radiometric formulation Eq. 2. However, in the nano-enhanced model, this equation is applied with modified parameters. The system gain is adjusted according to [11,58]:

$$Gnano = 1.05\,G \tag{3}$$

and the effective noise power is reduced to account for improvements in receiver and spillover noise contributions. These adjustments collectively result in a lower calculated antenna temperature for the same observational conditions. By applying this comparative framework to the observational dataset, it becomes possible to estimate the achievable reduction in system noise temperature through nanotechnology integration. This modeling approach provides a practical and scalable method for evaluating future upgrades, offering insight into how incremental improvements in hardware design can translate into measurable gains in observational sensitivity [59].

3.3. Experimental data + simulation integration

The analysis presented in this study is based on a combination of real observational data and simulated nanotechnology-enhanced scenarios, enabling a comprehensive evaluation of current system performance and potential improvements. The experimental dataset consists of measurements collected over a six-month observation campaign from December 2024 to June 2025, targeting the radio galaxy 3C 433. These data include spectral power measurements across the selected L-band frequency range and are processed using the MATLAB workflow described in Section 3.1 to derive noise power and corresponding antenna temperature values. To assess the potential impact of nanotechnology, simulated corrections are applied to the processed observational results during a post-processing stage. This approach preserves the integrity of the original measurements while allowing for a controlled evaluation of performance enhancements. Specifically, adjustments are made to account for reduced receiver noise, decreased ground spillover, and improved system gain, as defined in the nanotechnology modeling framework described in Section 3.2. These corrections are applied systematically to each observation segment, ensuring consistency across the entire dataset. The integration of experimental and simulated data enables a direct comparison between the baseline system performance and the projected nano-enhanced scenario. By applying these modifications at the post-processing level, it becomes possible to isolate the effect of individual improvements without altering the original acquisition process. This hybrid methodology provides a practical means of evaluating future system upgrades, offering insight into how nanotechnology-driven enhancements could influence long-term observational stability, sensitivity, and noise reduction in radio astronomy systems such as BURT [60-63].

4. RESULTS AND DISCUSSION

4.1. Average noise power

The analysis of the observational dataset revealed that the average sub-threshold noise power across all sessions is approximately $P \approx 2.5 \times 10^{-12}$ W. This value is obtained by applying the fixed threshold of −92 dBm and averaging all power measurements below this level across the full six-month observation period. The consistency of this result across multiple sessions indicates stable system performance and reliable noise estimation using the adopted MATLAB-based methodology. Temporal variations in the measured noise power are observed on short timescales, primarily due to environmental factors such as atmospheric conditions and intermittent radio frequency interference. However, these fluctuations remained within a relatively narrow range and did not significantly affect the overall mean value. This stability suggests that the BURT receiver system maintains consistent sensitivity under varying observational conditions, with no evidence of long-term drift or degradation in performance. In the nano-enhanced scenario, simulated corrections are applied to account for reductions in receiver noise and ground spillover, as well as improved gain stability. These modifications resulted in a decrease in the effective noise power by approximately 8–12% compared to the baseline measurements. This reduction reflects the combined impact of lower intrinsic noise generation and improved signal collection efficiency associated with nano-engineered components. The decrease in average noise power directly translates into improved signal detectability, particularly for weak spectral features such as the 21 cm hydrogen line. Even modest reductions in noise power can significantly enhance the signal-to-noise ratio in radio astronomy observations. Therefore, the results demonstrate that the integration of nanotechnology-based improvements has the potential to provide measurable gains in system performance, especially for small-aperture telescopes like BURT where instrumental noise constitutes a significant portion of the total noise budget.

4.2. Average noise temperature

The antenna noise temperature is calculated using the radiometric relation described in Section 3, yielding an average value of approximately $T_A \approx 90$ K across the full observation campaign. This result is consistent with theoretical expectations for a small-aperture L-band radio telescope operating in a semi-urban environment. The observed noise temperature exhibited a variation of approximately ±10 K over the six-month period, reflecting the influence of environmental factors such as atmospheric conditions, ionospheric variability, and occasional radio frequency interference. The relatively narrow range of variation indicates a stable receiver system with no significant long-term drift in performance. Seasonal trends are evident, with lower noise temperatures recorded during winter months and higher values observed during spring, corresponding to changes in humidity and ionospheric electron content. These findings confirm that the dominant contributors to system noise are environmental rather than instrumental under current operating conditions. To evaluate the potential impact of nanotechnology-based enhancements, simulated adjustments are applied to the measured data. The results indicate that the average system temperature could be reduced to approximately 75–80 K. This improvement is primarily attributed to reductions in receiver noise and ground spillover, along with enhanced gain stability achieved through nano-engineered components [64-66]. The decrease in system temperature represents a significant enhancement in sensitivity, particularly for detecting weak radio signals. The comparison between the current and nano-enhanced system performance is summarized in Table 1.

Table 1 Comparison of system noise temperature.

System Type	**Temperature (K)**
Current BURT	~90 K
Nano-enhanced (simulated)	~75–80 K

The results clearly demonstrate that even moderate reductions in individual noise components can lead to a substantial improvement in overall system performance. Lower system temperatures directly enhance the signal-to-noise ratio, thereby increasing the telescope to detect faint astrophysical emissions. This highlights the importance of integrating advanced technologies, such as nanotechnology, in the design of future radio astronomy instrumentation.

4.3. Seasonal trends

The analysis of system noise temperature over the six-month observation period reveals clear seasonal variations influenced primarily by environmental conditions. The observed antenna temperature shows a consistent pattern, with lower values recorded during the winter months (December–January) and higher values during the spring months (April–May). Specifically, the lowest noise levels are measured at approximately 80 K during winter, while the highest values reached approximately 100 K in spring. These variations are mainly attributed to changes in atmospheric humidity and ionospheric electron density, both of which affect radio wave propagation and emission characteristics at L-band frequencies. Winter conditions are characterized by reduced atmospheric water vapor and lower total electron content (TEC) in the ionosphere, resulting in minimal additional noise contributions. In contrast, the spring season experiences increased humidity and elevated ionospheric activity, leading to enhanced absorption and emission effects that raise the overall system temperature. These findings are consistent with established models of seasonal atmospheric and ionospheric behavior in radio astronomy observations. To further assess the potential benefits of nanotechnology, simulated adjustments are applied to the seasonal data. The results indicate that, while nanotechnology does not directly influence environmental noise sources, it significantly reduces the overall system temperature by lowering internal noise contributions [67-69]. As shown in Table 2, the nano-enhanced scenario results in a reduction of approximately 10–15 K across both seasons, bringing winter temperatures down to approximately 70 K and spring temperatures to approximately 85 K.

Table 2 Seasonal variation of system noise temperature.

Season	Observed T (K)	Nano-adjusted T (K)
Winter	~80	~70
Spring	~100	~85

Importantly, no significant long-term drift in system temperature is detected throughout the observation campaign. This stability confirms the reliability of the receiver system and indicates consistent gain performance over time. The absence of drift also validates the effectiveness of the calibration and data processing methodology employed in this study. Overall, the seasonal trends highlight the dominant role of environmental factors in system noise variability, while also demonstrating that nanotechnology-based improvements can provide a consistent reduction in total noise levels across different observing conditions. Figure 2 presents the temporal variation of system noise temperature measured by BURT over the observation period, along with the corresponding nano-enhanced simulation.

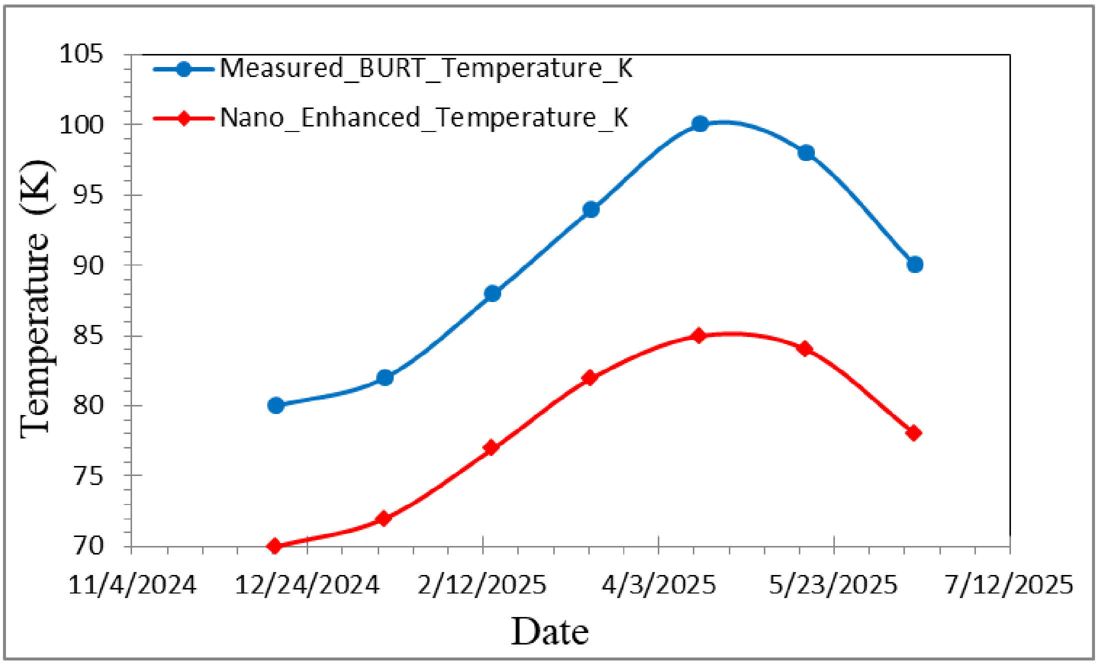

Figure 2 Temporal variation of system noise temperature from December 2024 to June 2025, showing the measured BURT values and the nano-enhanced simulated values.

4.4. Noise contribution breakdown

A detailed analysis of the individual noise contributions to the total system temperature provides further insight into the performance of the BURT telescope and the potential impact of nanotechnology-based enhancements. The system noise temperature is composed of several key components, including receiver and feed noise, sky background radiation, ground spillover, and ionospheric effects. Each of these contributions varies in magnitude and origin, with instrumental and environmental factors playing different roles in the overall noise budget. The receiver and feed subsystem represents one of the dominant internal noise sources, contributing approximately 15–20 K under current operating conditions. With the introduction of nano-engineered low-noise amplifiers and improved materials, this component is expected to decrease to approximately 10–15 K, corresponding to an improvement of about 25%. Similarly, ground spillover, which arises from unwanted pickup of thermal radiation from the surrounding environment through antenna sidelobes, currently contributes approximately 5–10 K. The use of metamaterial feed structures and low-emissivity nano-coatings can reduce this contribution to approximately 3–7 K, representing an improvement of around 30%. In contrast, the sky background and ionospheric contributions remain largely unchanged in the nano-enhanced scenario, as these components are governed by external astrophysical and atmospheric processes rather than internal system design. The sky background contributes approximately 5–8 K, while ionospheric effects account for an additional 2–5 K depending on seasonal conditions. These components establish a fundamental lower limit on the achievable system temperature. The combined effect of these improvements results in a noticeable reduction in the total system temperature. As summarized in Table 3, the overall system temperature decreases from a current range of approximately 85–95 K to an estimated range of 70–85 K under the nano-enhanced scenario, corresponding to an overall improvement of approximately 15%. This reduction highlights the significant role of instrumental noise in limiting system performance and demonstrates how targeted improvements in receiver and antenna design can lead to meaningful gains in observational sensitivity.

Table 3 Noise contribution breakdown.

Noise Component	Current (K)	Nano-Enhanced (K)	Improvement
Receiver & feed	15–20	10–15	↓ ~25%
Sky background	5–8	5–8	—
Ground spillover	5–10	3–7	↓ ~30%
Ionospheric	2–5	2–5	—
Total Tsys	85–95	70–85	↓ ~15%

This breakdown emphasizes that the most effective pathway for reducing system noise lies in improving internal components, particularly the receiver and antenna subsystems. The integration of nanotechnology into these areas offers a practical and scalable solution for enhancing the performance of small radio telescopes such as BURT. Figure 3 illustrates the contribution of individual noise components to the total system temperature, comparing the current system with the nano-enhanced scenario.

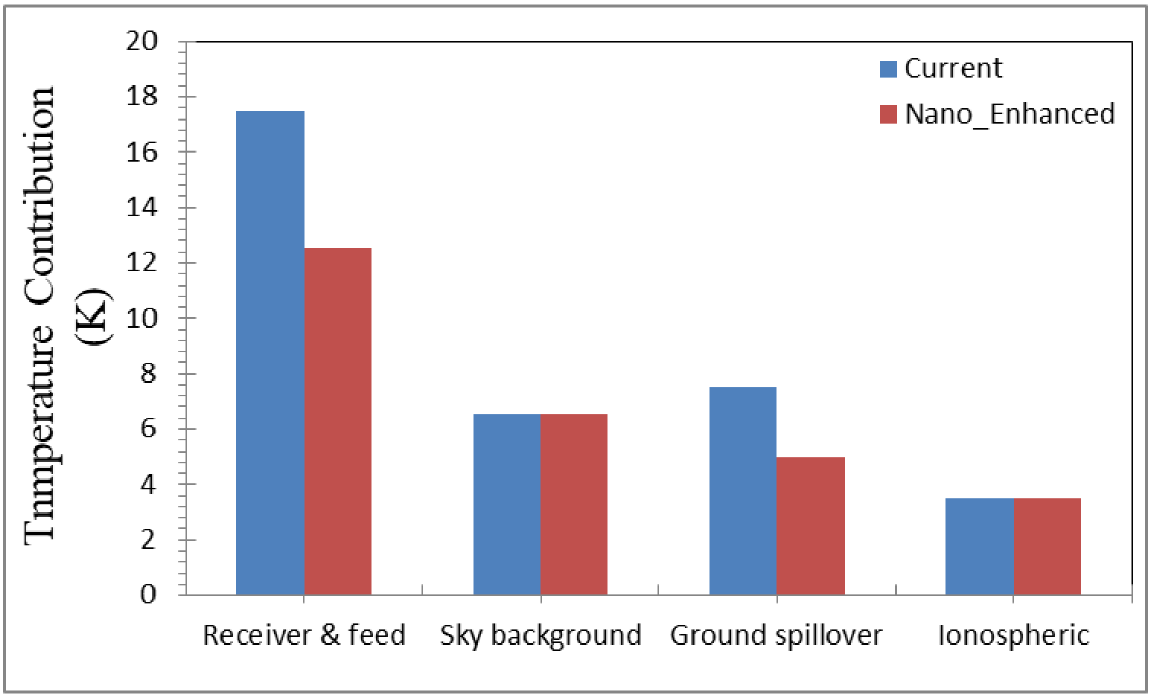

Figure 3 Comparison of the main noise contributions in the current BURT system and the nano-enhanced model, including receiver and feed noise, sky background, ground spillover, and ionospheric effects.

The results of this study demonstrate that the BURT telescope operates within the expected performance range for a small-aperture L-band system, with an average system noise temperature of approximately 90 K. This value is consistent with theoretical predictions and comparable systems operating under similar environmental conditions. The stability of the measured noise levels over the six-month observation period further confirms the reliability of the receiver chain and the effectiveness of the calibration and data processing procedures [14]. A key finding of this analysis is that environmental factors play a dominant role in the observed variability of system noise temperature

[15]. Seasonal changes in atmospheric humidity and ionospheric electron content are identified as the primary drivers of fluctuations, particularly the increase in noise levels during the spring months. Ground spillover and occasional urban radio frequency interference also contributed to short-term variations, although these effects are partially mitigated through data filtering and thresholding techniques. The absence of significant long-term drift indicates that instrumental factors remain stable, and that variations are largely external in origin [1]. The integration of nanotechnology-based enhancements, evaluated through simulation, reveals that the most substantial improvements can be achieved by targeting internal noise sources, particularly the receiver and antenna subsystems. Reductions in receiver noise through nano-engineered low-noise amplifiers and improvements in antenna performance via metamaterial feed designs and nano-coatings result in a measurable decrease in overall system temperature [8]. Among all noise components, receiver and ground spillover noise show the greatest potential for reduction, leading to an estimated overall improvement of approximately 15% in system performance. These findings highlight an important implication for small radio telescopes: while environmental noise cannot be eliminated, optimizing internal system components provides a practical and effective pathway for enhancing sensitivity. In particular, nanotechnology offers a scalable solution for improving performance without requiring major structural modifications [11]. By reducing intrinsic noise and improving gain stability, nano-enabled systems can significantly enhance the detection capability for weak astrophysical signals, such as the 21 cm hydrogen line [9]. This study demonstrates that BURT is a stable and reliable observational instrument, while also emphasizing that future performance gains are most effectively achieved through technological advancements rather than environmental control. The combination of empirical analysis and simulation provides a comprehensive framework for understanding system limitations and guiding future upgrades in radio astronomy instrumentation [10].

5. CONCLUSIONS

This study presented a comprehensive characterization of background sky noise and system temperature for the Baghdad University Radio Telescope (BURT) based on a six-month observational campaign. Using a MATLAB-based threshold analysis with a fixed noise limit of −92 dBm, the system was found to maintain a stable noise temperature in the range of 85–95 K. This result is consistent with theoretical expectations for a 3 m L-band radio telescope operating in a semi-urban environment and confirms the reliability of the receiver system and data processing methodology. The analysis further demonstrated that environmental factors, including atmospheric humidity and ionospheric electron content, are the primary drivers of temporal variability in system noise. Despite these influences, the absence of significant long-term drift indicates stable gain performance and consistent observational conditions. Ground spillover and occasional radio frequency interference were identified as secondary contributors, with their effects effectively minimized through data filtering techniques. A key contribution of this work is the evaluation of nanotechnology-based enhancements through simulation. The results indicate that the integration of nano-engineered low-noise amplifiers, metamaterial feed structures, and nano-coatings could reduce the system temperature to approximately 70–85 K. Such improvements would significantly enhance sensitivity, particularly for detecting weak spectral signals such as the 21 cm hydrogen line. This study confirms that BURT is a stable and reliable instrument while highlighting nanotechnology as a practical and effective pathway for next-generation performance improvements. Future work will focus on experimental implementation of nano-LNA systems, testing advanced feed designs, and developing real-time adaptive noise correction techniques.

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