A Model of Sky Temperature Estimation at 1.42 GHz using University of Baghdad’s Radio Telescope

Ahmed A. Hameed\textsuperscript{1}, Kamal M. Abood\textsuperscript{2}

\textsuperscript{1}Department of Astronomy and Space, College of Science, University of Baghdad, Baghdad, Iraq
\textsuperscript{2}College of Remote Sensing & Geophysics, Al-Karkh University of Science, Baghdad, Iraq

Received: 8/1/2021 Accepted: 11/4/2021

Abstract

The objective of this study is to select a suitable observing region at Baghdad location (44° 22′ 48″, 33° 16′ 30″) with low interference that may affect frequency of 1.42 GHz. Baghdad University Radio Telescope (BURT) is used in this study to determine a convenient region for observation in Baghdad sky. Different azimuths and elevations were chosen at different observations time. The results of this study showed that the best observations regions were located at azimuth (120°-160°) and (210°-260°). These regions included less sky temperature and estimated to be (42.8 to 163) K. The sky temperature model could be represented as a polynomial of third degree that could fit the behavior of the observation points.

Keywords: 21 cm Line Emission, Sky Temperature, Antenna Temperature.

1. Introduction

One of the important radio information is the hydrogen line emission at frequency of 1.42 GHz. A neutral hydrogen (HI) atom has only one proton and one electron. Both particles have quantized total spin (s) of 1/2 and a spin in the z-direction (m) of either 0.5 or -0.5 [1]. When a hydrogen atom makes a transition from the external state into the ground state, a photon is emitted carrying away the energy difference [2]. The emission due to spin-spin coupling with the photon has a wavelength of 21 cm. This line is usually used to study various astronomical
phenomena, and has different applications in radio astrophysics [3]. Although, this line is considered a unique phenomenon in radio astronomy, but it suffered from the noise. The noise sources could be classified into two types, artificial and natural sources. The artificial noise is generated due to telecommunication system, while the natural noise is formed due to astronomical sources. Antenna noise temperature is a parameter that explains how much noise an antenna may show in a specific environment. The antenna noise can be classified into two kinds according to source of noise. First type, due to the loss resistance of the antenna itself, and second is the noise the antenna picks up from the neighboring environment. Since any object whose temperature over the absolute zero emits electromagnetic radiation energy. Consequently, each antenna is surrounded by noise sources [4]. Any observing system consists of a receiver, an antenna and a transmission line. All these system components have their contribution to the system noise. The system temperature is a necessary factor in determining the sensitivity and the signal to noise ratio (SNR) of a receiving system. If the antenna has some losses, then the noise temperature consists of two terms. These are the antenna temperature due to the habitat factors around the antenna \( T_A \), and the temperature due to the tangible temperature of the antenna \( T_{AP} \) [5].

Several studies were concentrated about the radio noise that associated with the observing system. The most important of these studies is Lanre O. Daniyan (2011). In this study, the sky temperature and antenna temperature of Nsukka city, Nigeria \((6^0 50 \, 09'' \, N \, 7^0 23 \, 36'' \, E)\) were estimated [6]. Shkelzen C. and Bexhet K. (2011) study the temperature of antenna noise for low earth orbiting satellite ground stations at L and S band [7]. Rodolfo J. Montez, studied the electronic noise calibrator for MIT Haystck Observatory, and developed a small radio telescope in L-band \((1.42 \, GHz)\) [8]. In this study, we chose different azimuths and elevations at different observations time. The results of this study showed that the best observations regions are located at azimuth \((120^0-160^0)\) and \((210^0-260^0)\).

2. Theoretical Concepts

The concept of the antenna temperature \( T_A \) could be defined as the temperature of antenna radiation resistance, which equals the resistance temperature. \( T_A \) is created due to the relation between the power radiated by the source, which is related to the brightness temperature \( T_B \), and the antenna normalized power pattern \( P(\theta, \Phi) \). Considering a receiving antenna that is pointed to a source brightness distribution \( B(\theta, \Phi) \), the source power radiation is intercepted by the antenna terminals which creates power called antenna power \( P_A \). \( T_A \) is associated with \( P_A \) at antenna radiometer, and \( P_A \) could be given by [9]:

\[
P_A = \frac{1}{2} A e \int B(\theta, \Phi) P(\theta, \Phi) \, d\Omega
\]

(1)

Where \((\theta, \Phi)\) are the azimuth and elevation of the source. \( A_e \) is the effective aperture of the radio telescope antenna, and \( d\Omega \) is the element solid angle. Utilizing Raleigh-Jeans limit. Therefore, the brightness distribution given by Eq. (1) can be changed by an equivalent \( T_B \), and \( T_A \), as given by the following equation [9]:

\[
T_A = \frac{1}{2} A e \int T_B(\theta, \Phi) P(\theta, \Phi) \, d\Omega
\]

(2)

This means that \( T_A \) is equivalent to the convolution between the source brightness temperature and beam power pattern of the radio telescope. Using the Nyquist theorem, \( T_A \) can introduce by [10]:

\[
T_A = \frac{P_A}{k G \Delta v}
\]

(3)

Where \( \Delta v \) is the bandwidth frequency of the telescope radiometer in Hz, \( G \) is antenna gain.

3. Observations and Data Reduction:

The observations in this work are carried out using Baghdad University Radio Telescope (BURT). This telescope has diameter \((D = 3 \, m)\), focal length \((f = 1.18 \, m)\) and \(f/D \) ratio is 0.39.
[11]. Any radio telescope should be calibrated before any process of observation. This telescope has been calibrated using the sun and the moon as a reference source [12]. This telescope can make daily measurements of the radio signals at the frequency of 1.42GHz. The spectrometer software of this telescope divides the received data into 600 channels of the frequency. These channels are used to obtain the amplitude of the measured power in unit (dBm). The values of this power are divided according to the frequency channels and arrangements as rows data. This power has been obtained after setting the optimum values of spectrometer parameters of the radio telescope. These parameters are span, sweep time, center frequency, Resolution Bandwidth (RBW), and Video Bandwidth (VBW) [13]. The observations date, the BURT antenna position (azimuth and elevation) and the best spectrometer parameters as listed in table (1).

| Observation date | Antenna position | Input value of spectrometer parameters |
|------------------|------------------|----------------------------------------|
|                  | Azimuth (degree) | Elevation (degree) | Center Freq.(Hz) | Sweep Time (sec.) | Span (Hz) | RBW (Hz) | VBW (Hz) |
| 31-8-2020 30-9-2020 | 120° | 20°,30°,40°,50°,60°,70°,80°,90° | 1.42 × 10⁶ | 30 | 2 × 10⁷ | 100 | 10 |
| 4-5-2020 8-9-2020 | 130° | 20°,30°,40°,50°,60°,70°,80°,90° |
| 2-9-2020 21-10-2020 | 140° | 20°,30°,40°,50°,60°,70°,80°,90° |
| 10-9-2020 21-10-2020 | 150° | 20°,30°,40°,50°,60°,70°,80°,90° |
| 10-9-2020 21-10-2020 | 160° | 20°,30°,40°,50°,60°,70°,80°,90° |
| 6-9-2020 11-10-2020 | 210° | 20°,30°,40°,50°,60°,70°,80°,90° |
| 31-8-2020 30-9-2020 | 220° | 20°,30°,40°,50°,60°,70°,80°,90° |
| 22-6-2020 21-7-2020 | 230° | 20°,30°,40°,50°,60°,70°,80°,90° |
| 31-8-2020 30-9-2020 | 240° | 20°,30°,40°,50°,60°,70°,80°,90° |
| 4-5-2020 8-9-2020 | 250° | 20°,30°,40°,50°,60°,70°,80°,90° |
| 22-6-2020 2-9-2020 | 260° | 20°,30°,40°,50°,60°,70°,80°,90° |

4. Results and Discussion
Our observations were carried out to estimate the optimum part in the sky that has less sky background noise. This estimation was achieved via pointed BURT to several azimuths’ values at different observations. The scanned region was located between 10-300 degree in azimuth angles. Then each azimuth value was observed with eight elevations values. The change in the elevation value was selected from 20 degrees to the 90 degree, and then the sky background noise temperature was computed according to equation (3) for each elevation. The results were demonstrated in Figures 1-11.
Figure 1- $T_{\text{sky}} (k)$ as a function of elevation angle (degree) for azimuth 120°: (a) on 31-Aug-2020, (b) on 30-Sept-2020.

It should be pointed out here that, $(R^2)$ is the norm residual error. The norm residual is a measure of better of fit, where the value closer to one means is the best result.

Figure 2- $T_{\text{sky}} (k)$ as a function of elevation angle (degree) for azimuth 130°: (a) on 4-May-2020, (b) on 8-Sept-2020.

Figure 3- $T_{\text{sky}} (k)$ as a function of elevation angle (degree) for azimuth 140°: (a) on 2-Sept-2020,(b) on 21-Oct-2020.
Figure 4- $T_{sk}$ (k) as a function of elevation angle (degree) for azimuth 150°: (a) on 10-Sept-2020, (b) on 21-Oct-2020.

Figure 5- $T_{sk}$ (k) as a function of elevation angle (degree) for azimuth 160°: (a) on 10-Sept-2020, (b) on 21-Oct-2020.

Figure 6- $T_{sk}$ (k) as a function of elevation angle (degree) for azimuth 210°: (a) on 6-Sept-2020, (b) on 11-Oct-2020.
Figure 7- $T_{\text{sky}}$ (k) as a function of elevation angle (degree) for azimuth 220°: (a) on 31-Aug-2020, (b) on 30-Sept-2020.

Figure 8- $T_{\text{sky}}$ (k) as a function of elevation angle (degree) for azimuth 230°: (a) on 21-July-2020, (b) on 11-Oct-2020.

Figure 9- $T_{\text{sky}}$ (k) as a function of elevation angle (degree) for azimuth 240°: (a) on 22-Jun-2020, (b) on 21-July-2020.
The average values of $T_{SKY}$ during May to October in 2020 have been computed. Then the result is plotted with the observation date, as shown in Figure 12.

**Figure 10** - $T_{sky}$ (k) as a function of elevation angle (degree) for azimuth 250°: (a) on 4-May-2020, (b) on 8-Sept-2020.

**Figure 11** - $T_{sky}$ (k) as a function of elevation angle (degree) for azimuth 260°: (a) on 22-Jun-2020, (b) on 2-Sept-2020.

**Figure 12** - $T_{sky}$ average (k) as a function of observation date.
From the Figure 12 the average value of $T_{\text{sky}}$ is estimated to be (44.5 to 155.5 K).

5. Conclusions
1- The best observation region in Baghdad University is found at azimuths between (120° to 160°) and (210° to 260°).
2- The sky temperature model could be represented as a polynomial of third degree that could be fitted the behavior of the observation points.
3- The norm residual error ($R^2$) was computed to verify our model. $R$ is estimated to be varied between (0.996 to 0.9308).
4- The sky temperatures of Baghdad City are estimated to be varied between (44.5 to 155.5) K, as shown in Figure 12.

Acknowledgments
The authors would like to express their thanks to Uday Jallod for his valuable technical and language assistance in creating this article. We would also like to thank and appreciate the Head of the Department of Astronomy and Space, Academic Staff, Colleagues and all friends at the College of Science, University of Baghdad for their valuable advices and encouragement.

References
[1] Usoslin I. G. “A History of Solar Activity Over Millennia”, Living rev., Solar Physics, vol. 5, no. 3, pp. 6–19, 2008.
[2] Surajit P, Suklima G, 2004, “Setting up a 21-cm Hydrogen Line Radio Telescope and Receiver /Spectrometer”, Master's Thesis. Department of Physics, University of Pune, pp. 7, 2004.
[3] Diane F. M. “Basic of Radio Astronomy for the Gold Stone –Apple Valley Radio Telescope”, California Institute of Technology, 1998.
[4] Smyth D. “Handbook on radio Astronomy, ITU”, Australia Radio Communication Bureau, Third Ed, 2013.
[5] Balanis C A. “Antenna Theory Analysis and Design”, (John Wiley & Sons. Inc. Canada), Third edition, 106, 2005.
[6] Lanre O. “The Concept of Radio Telescope Receiver Design”, International Journal of Electronics and Communication Engineering. ISSN 0974-2166, vol. 4, no. 4, pp. 461-471, 2011.
[7] “The Third International Conference on Advance in Satellite and Space Communications”.
[8] Rodolfo M, “Electronic Noise Calibrator for Small Radio Telescope”, MIT Haystcks Observatory, 2011.
[9] Ptatap P and McIntosh G. “Measurements of the Radiation from Thermal and Non-Thermal Radio Sources”, American Association of Physics Teachers, vol. 73, no. 5, pp. 399–404, 2004.
[10] Neil, K. O. “Single Dish Calibration Techniques at Radio Wavelength”, Astronomical Society of the Pacific ASP Conference Series, vol. 278, San Francisco, CA, 2001.
[11] Uday E J and Kamal M A. “Characteristics Measurement of Baghdad University Radio Telescope for Hydrogen Emission Line”, AIP Conference Proceedings 2190, 020035; Published Online, 2019.
[12] Kamal M A and Kitas a M. “Background Radio Emissions at 1.42 GHz”, Iraqi Journal of Science, vol. 59, no. 2A, pp. 786–791, 2018.
[13] Uday E J, and Kamal M A, “Solar Measurements for 21 cm Wavelength Using 3 m Radio Telescope”, Electromagnetics Research Letters, vol. 85, pp. 17-24, 2019.