A Local Hot-Cold Antenna Measurement System

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Abstract — This paper presents a hot-cold antenna measurement facility, developed on Stellenbosch University grounds, that can measure the noise temperature of integrated antenna systems. The facility allows outdoor Y-factor measurements to be performed in an RFI rich environment for preliminary characterisation of integrated antenna system prototypes from 1 – 2 GHz.

Keywords — antenna measurement, y-factor, hot-cold, integrated antennas

I. INTRODUCTION

Recent developments in telescopes for radio astronomy aim to achieve high sensitivity, expressed as

\[ \text{Sensitivity} = \frac{A_{\text{eff}}}{T_{\text{sys}}} \]  

where \( A_{\text{eff}} \) is the effective collecting area of the telescope and \( T_{\text{sys}} \) the system noise temperature. In order to achieve higher sensitivity, certain topologies of antennas and antenna arrays have low noise amplifiers (LNAs) closely integrated into the antenna. In these designs, the antenna and the LNA cannot be physically separated, so it is impossible to measure the noise temperature of each component individually. To quantify systems like these, another approach is therefore required.

A solution is to conduct an outdoor Y-factor measurement to measure the system noise temperature \( (T_{\text{sys}}) \) of the integrated system. The technique uses absorber material at ambient temperature as the hot load, and sky as the cold load. Over the years, a number of facilities have been developed to conduct measurements using this technique.

At the Netherlands institute for radio astronomy (ASTRON), the system noise temperature of an active antenna array was measured using a simple outdoor Y-factor measurement [1]. After seeing the influence of external noise sources, the proposal was made to develop a funnel-shaped aluminium box that enables outdoor noise temperature measurements while suppressing noise from external sources. This measurement facility is known as THACO: Temperature Hot And Cold. [2]

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) developed an aperture array noise temperature testing capability at Parkes Observatory, Australia. The absorber material is supported by an open frame and suspended above the antenna under test using a crane. A reference antenna is used to constrain the pointing of the beam towards zenith and the middle of the absorber. Chippendale [3] found that the influence of the metal shield was minimal for larger arrays with directive beams. Hayman successfully characterised the noise temperature of a phased array with the use of the testing capability. [4], [5]

In [6], Hovey describes a Hot/Cold Test Facility (HCTF) similar in design to the facility at ASTRON, but where the measurement process is automated. The authors successfully measured the noise temperature of an L-band receiver. The facility proved to minimize operator error and improve the repeatability of the measurements.

This paper presents an antenna noise temperature measurement system, named SU-THACO (Stellenbosch University - Temperature Hot And Cold), which is deployed on the roof of the Electrical and Electronic Engineering Faculty of Stellenbosch University in South Africa. SU-THACO is used for teaching and research purposes, providing a facility that is easily accessible and enables initial, reliable noise temperature measurements of integrated receiver prototypes, single active antennas and active antenna arrays. It holds the benefit of being user-friendly, cost-effective and small in structure.

Fig. 1. Image of developed measurement system at Stellenbosch University.

II. DESIGN

Given the deployment location and method, a constraint is placed on the maximum panel size of the measurement facility. The panels should not exceed the height or width of a standard door and the overall weight of the individual panels should be minimised. The panels are assembled on the roof to form the measurement facility. In order to provide adequate space to fit...
an integrated antenna system tile, a minimum base size of 1 m$^2$ is defined. A removable roof enables the difference between the hot and cold measurements.

The measurement facility’s system noise temperature contribution requirement is based on the system noise temperature requirements of the Square Kilometre Array (SKA). [7] The measurement facility is required to have a noise temperature contribution of $< 20$ K.

A simulation is done to find the optimum size and shape of the measurement facility to adhere to the design goals. As shown in Fig. 2, a half-wavelength dipole antenna is simulated inside a truncated pyramid shape with the base size, $L$, of the funnel chosen as 1 m $\times$ 1 m. The antenna noise temperature is calculated under the assumption of a specified temperature distribution in the environment outside the funnel as,

$$T_A = \frac{\int_{0=0}^{2\pi} \int_{\phi=0}^{\pi} T_b(\theta, \phi) D(\theta, \phi) \sin \theta d\theta d\phi}{\int_{0=0}^{2\pi} \int_{\phi=0}^{\pi} D(\theta, \phi) \sin \theta d\theta d\phi},$$

(2)

where $T_b(\theta, \phi)$ is the brightness temperature distribution of the surroundings of the antenna and $D(\theta, \phi)$ is the directivity of the antenna. The assumed environment temperature distribution is specified as follows:

$T_b = 0$ K for $0^\circ < \theta < \theta_0$,  
$T_b = 300$ K for $\theta_0 < \theta < 180^\circ$,

where $\theta_0$ is the angle at which the temperature distribution assumption in the environment changes from no obstructions (0 K) to obstructions (300 K) close to the funnel, as represented by a tree in Fig. 2.

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The simulated system temperature plots for $\theta_0$ from $10 – 90^\circ$ are shown in Fig. 3. It is clear that for larger values of $\theta_0$, $T_{sys}$ is smaller at a chosen height and flare when compared to smaller values of $\theta_0$. This makes sense since a larger $\theta_0$ means a wider unobstructed field of view towards the sky.

Inspection of the deployment location of the facility suggests that the $\theta_0 = 60^\circ$ temperature plot be used to decide on the appropriate shape of the funnel. Including considerations for a minimized overall size and a maximum system temperature contribution of 20 K, a height of 1.13 m, flare angle of 20$^\circ$, bottom width of 1 m, and top width of 1.8 m is chosen.

### III. Measured Results

The typical measurement setup of SU-THACO is shown in Fig. 4, with the roof closed and the door opened. A Rohde and Schwarz FSEK30 spectrum analyser is operated through a MATLAB graphical user interface (GUI) for a user-friendly, time effective measurement experience.
A. RFI-suppression

The measurement system should reduce the amount of RFI present in the operating band to be able to adequately differentiate between the hot and cold measurements. The level of RFI suppression achieved by SU-THACO, with and without the roof, is investigated. A log-periodic dipole antenna (LPDA) is used to measure the RFI from 0.5 GHz to 2 GHz outside the enclosure, inside the enclosure with an open roof, and inside the enclosure with a closed roof.

Figure 5 shows the measured RFI spectrum for the three cases. In the frequency band for SU-THACO, 1 GHz to 2 GHz, three peaks between 1.2 GHz and 1.4 GHz, and a larger peak spanning from 1.8 GHz to 1.9 GHz are observed for the outside measurement without any enclosure.

Figure 5 also shows that when the LPDA is placed inside SU-THACO with the roof opened, the three peaks between 1.2 GHz and 1.4 GHz are suppressed. The 1.3 GHz peak is suppressed by 6.4 dB to the noise floor level of the spectrum analyser. The peaks between 1.8 GHz and 1.9 GHz are still present, but was suppressed by 15.19 dB at 1.81 GHz and 15.34 dB at 1.88 GHz.

Lastly, the spectrum obtained with a closed roof is shown in Figure 5. It is observed that the RFI over the band of interest, 1 GHz to 2 GHz, is suppressed to the noise floor level of the spectrum analyser, which is -113 dBm. The largest peak at 1.88 GHz is suppressed by 43.39 dB, which indicates the level of suppression achieved when the roof is closed. The small peaks that are present below 1 GHz, outside the band of interest, are also somewhat suppressed. The peak at 945 MHz is suppressed by 39 dB, but is still approximately 10 dB above the noise floor. The signals below 1 GHz falls below the specified operating frequency of the measurement system.

B. Y-factor measurement of an active antenna

To test whether SU-THACO is functional, a Y-factor measurement is done for an active GNSS receiver available at Stellenbosch University. The measurement is deemed successful if two requirements are met. Firstly, there should be a distinguishable difference between the hot and cold measurement. Secondly, the measured result should be within reasonable agreement with the data sheet specification.

The hot and cold measurements are completed for a bandwidth of 50 MHz, to calculate the system noise temperature of the GNSS receiver within its operating frequency. The measurements are shown in Fig. 6, where distinction between the hot and cold measurement is clearly visible.

The system noise temperature of the active GNSS antenna is calculated with the Y-factor method as,

$$T_{sys} = \frac{T_{hot} - YT_{cold}}{Y - 1}$$

with,

$$Y = \frac{P_{hot}}{P_{cold}}.$$
value to be lower than and equal to unity, which decreases the accuracy of the measurement.

The calculated noise temperature of the active GNNS receiver over the entire measured bandwidth is presented in Fig. 7. To minimize the effect of the RFI, averaging is applied to the raw data, presented in the red curve on Fig. 7. The minimum average value is 131.2 K at 1.565 GHz and the maximum value is 528.7 K at 1.6 GHz.

A zoomed version of the raw data, from 1.562 – 1.574 GHz, is shown in Fig. 8. The expected value derived from the data sheet, 119.64 K, is also shown in Fig. 8. It is clear that the measured values are comparable to the expected data sheet value. A minimum measured value of 85.99 K at 1.567 GHz and a maximum value of 420 K at 1.573 GHz is observed on Fig. 8. The minimum value is within 33.65 K of the expected value and the maximum value is 300.36 K from the expected value. The minimum average value from Fig. 7 is within 11.56 K of the expected data sheet value.

![Fig. 7. Calculated noise temperature of active antenna.](image)

![Fig. 8. Calculated noise temperature of active antenna over a smaller band.](image)

IV. CONCLUSION

The presented measurement results and discussions show the ability of the developed measurement system to execute a Y-factor measurement. The measurement system provides a quick and user-friendly initial characterisation option for prototype designs at the university. Results are not necessarily reliable enough for the full characterisation of a receiver system for industry or commercial use. However, future work will determine how large the difference is between the industry and SU-THACO results. These conclusions are currently based on the 1 GHz to 2 GHz bandwidth of operation for SU-THACO and further tests should be done for other frequencies of interests. SU-THACO will be tested further using different antenna types, repeating measurements, and optimising the performance for improved speed, repeatability, and reliability.

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REFERENCES