Pre-Correction of Water Vapour Emission for Radio Astronomy Observations at Al-Uyayna Observatory

Y. A. Hafez¹, F. H. Albaqami² and A. Z. Almutairi², T. Y. Hafez³

¹National Center for Astronomy, KACST, PO Box 6086, Riyadh 11442, Saudi Arabia
²National Center for Applied Physics, KACST, PO Box 6086, Riyadh 11442, Saudi Arabia
³College of Engineering, Taibah University, Mailbox: 344, Al-Madina 41411, Saudi Arabia

Email: yhafez@kacst.edu.sa

Abstract. Al-Uyayna radio astronomy telescope near Riyadh, Saudi Arabia has been built as a prototype to study the nearby sky objects at ~10 GHz. Good observations were obtained during the operation period of the telescope. The measurements indicated that the contribution of water vapour has a significant contribution to the observations of the weak astronomical signals. This contribution has to be taken into account and flagged to achieve correct and more accurate results depending on the strength of the astronomical signal observed at 10.3 GHz. Our study showed that the astronomical data must be corrected by 0.205 ± 0.003 for the noise from water vapour radio emission. A model was made for this purpose, and more studies will be shown in future work.

1. Introduction

In 2010, King Abdulaziz City for Science and Technology (KACST) has planned to build a prototype for the first specialized-full operated radio telescope in the Arabic world to observe the crescent of the new moon to determine the first day of each Hijri month of the year. This goal extended later on to cover the study of all nearby sky objects. The plan has been successfully achieved and the prototype has been assembled and built in 2012 in collaboration with colleagues from University of Manchester to build and assemble the telescope.

The dry site of Al-Uyayna Solar Village (46° 24′ E, 24° 54′ N) with average annual humidity of 7% was chosen as a good location to build the telescope, considering our future plans to build more radio telescopes and one radio interferometer in the same location to detect the Cosmic Microwave Background Radiation (CMBR); and so, the telescopes have to be built in a dry location good enough to observe the weak signals from the sky at certain frequencies such as 10, 15 and 33 GHz and avoiding any radio interference from the atmosphere at the frequencies we will use[1].

Between February 2012 - March 2013, KACST First radio telescope (KACST-FRT) was in operation, and good observations results were collected and published in the Monthly Notices of Royal Astronomical Society in 2014 (Hafez et al. 2014) [2].
The standard operation form of the reflecting surface of any radio telescope must not be different from the calculated one (theoretically) by more than 0.1 of the wavelength, and so we have focused to meet this as a standard requirement for the telescope design.

Because the telescope was built as a prototype, in April 2013 the operation was partially stopped for some maintenance and to improve the quality of the electronic and mechanical parts of the telescope. The build and assembly of KACST-FRT (Fig. 1) was one of several Radio Astronomy collaborative projects that KACST has initiated with international organizations such as Caltech (USA), University of Oxford (UK), University of Manchester (UK), IAC (Spain), HartRAO (South Africa), Istituto Nazionale di Astrofisica (Italy).

This paper summarizes the talk given in the fourth Algerian Conference on Astronomy and Astrophysics, 2017 (ACAA2017) at Khenchela University, Khenchela in Algeria. The overall specifications of the prototype system is shown in section 2. In this paper, we will also reveal our experience in measuring the water vapour radio effect at 10.3 as a preparation to observe the weak astronomical signals from the sky such as the CMBR at 10.3 GHz where this effect should be flagged (section 3). Finally, the conclusion and summary of the paper is given in section 4.

![Figure 1. The KACST-FRT at Al-Uayyna Solar Village (46° 24′ E, 24° 54′ N)](image)

2. The overall specifications of the system
The first design of KACST-FRT compact reflector of 3.7m is a homologous deformation, this gives the best fit paraboloid of about 0.07 mm in rms. The design was improved later on to have better quality in July 2014. The rear structure is covered with heat insulation panels, and the air inside is circulated to reduce temperature panels.

The receiver is located on the dish primary focus and the operating frequency of the receiver feed and
first LNA is 10.3 GHz (i.e. X/Ku band) with a 1 GHz bandwidth. Given the dish size and the working frequency, the telescope will have a main beam of 36 arcmin in angular size; this value is sufficient to resolve sky objects such as the Sun and the Moon even during the New Moon phase.

As the telescope has half power BW of 36 arcmin, a high pointing accuracy is needed, therefore, several monitors and pointing-angle devices were installed to support the observations. The sufficient pointing accuracy of 20 arcmin for our telescope was measured for winds less than 7m/sec. Summarize of KACST-FRT technical specifications is given in Table 1.

The telescope receiver is a commercial LNB working at room temperature. The LNB contains an LO and a mixer which converts the LNA operating frequency to the line frequency (LF) of 1 GHz as well as band pass filters to remove high harmonics. All analogue components after the LNB operate at the LF. The LNB signal is converted into a DC value by a power detector diode; the DC voltage is amplified using a non-inverting op-amp, filtered by an RC filter with cut-off frequency of 0.150 MHz and again amplified using another non-inverting op-amp. After DC filtering and amplification, the signal is then sampled by an AD converter and sent to the control PC for post processing. The AD sampling rate can be selected up to 0.025 MHz, the dynamic range of the sampler is 16-bits [2].

All components within the detection chain have a broad dynamic range: the receiver has 0.3 dB Noise figure and the AD converter has an 18-bits maximum resolution at 0.025 MHz. The RF/LF chain has relatively high impedance (75 Ohm); high impedance has the advantage of reducing design time and component costs.

In addition to the signal detection and sky mapping facilities, the KACST-FRT has a number of additional features: a webcam is used to visualise the state of the antenna (useful when the antenna is remotely controlled); a weather station measures the wind speed (this is required in order to prevent the antenna from moving when the wind pressure could damage the mechanical components supporting the dish) and the NTP server using the GPS system provides accurate timing for the astronomical observations. The internal components and cabling diagram of KACST-FRT is shown in Figure 2 (cables attached to outdoor components are marked by a small diamond).

### Table 1. KACST Radio Telescope (KRT) specifications [2]

| Parameter          | Value     |
|--------------------|-----------|
| Reflect diameter   | 3.7 m     |
| FWHM beamwidth     | 36 arcmin |
| Azimuth drive speed| ≥30 arcmin s⁻¹ |
| Pointing accuracy  | 20 arcmin |
| Frequency          | 10.8 GHz  |
| Bandwidth          | 1 GHz     |
| $T_{sys}$ at zenith| 100 K     |
3. The water vapour Contribution to Radio Astronomy Observations

3.1. Water vapour emission at 10.3 GHz

Generally, the significant contribution from atmospheric emission to any radio observations depends on (1) the frequency we use and (2) the radio astronomy signals we are trying to observe from the sky. Water vapor is the third largest component in the earth atmosphere after Nitrogen and Oxygen. The water vapour effect will negligible when sky objects, such as the sun and the moon, emit radio signal strong enough comparing to radio signal from water vapour above the observatory. However, as the site will be used to build more radio telescopes to observe weak radio astronomical signals, e.g. CMBR, we must be aware of the atmospheric contribution to sky observations at the site we make observations at 10.3 GHz [3-4], therefore, this contribution must be subtracted from the astronomical observations for correct and accurate measurements.

Unlike the water vapour, emissions from oxygen and Nitrogen molecules are distributed homogenously in the atmosphere, and so they will be easily measured and flagged from any weak astronomical signals we observe [5], this effect will be discussed in a future paper.

The effect of the water vapour could be rising in two forms: (1) an increase in short-term noise as local atmospheric structure moves through the beam geometry [6], and (2) a longer-term drift due to changes in atmospheric conditions.

3.2. Our observations and results

As mentioned above, KACST-FRT has operated at 10.3 GHz, this operation made together with a Moisture Meter simultaneously where the use of the second device will allow us to compare the measurements from both devices, i.e. the KACST-FRT and the Moisture Meter. Any similarity in the measurements from the two devices will result from the atmospheric contribution; this means that the water vapour components of noise and instability can be identified and separated from receiver noise.
In order to achieve this, we have pointed the telescope to blank areas in sky at same Azimuth and different elevations over available range of HA away from any strong sky object signals (such as the sun the moon). This gave a direct measure of the total atmospheric emission and the corresponding elevation range allowed a cosecant estimate to be made of the total emission on good days with a steady atmosphere while using the most stable time of the receiver system. The measurements of the weather in good clear days chosen over 10 months (from February to December 2012) show that the noise due to the radio emission from the water vapour can be corrected by calculating the linear slope of this emission values plotted versus cosecant elevation as shown in Figure 3. The emission values of the water vapour were measured from the direct output voltage readings converted to unitless level numbers relative to the overall average value of the voltage readings over the full period of observations. So, any radio astronomical observation made at Al-Uyayna solar village at 10.3 GHz must be corrected by $0.205 \pm 0.003$ to flag the water vapour radio noise contributes to our astronomical data using Figure 3 as a model good enough to achieve this.

![Figure 3](image-url)

**Figure 3.** Relative voltage output values of the water vapour emission at 10.3 GHz measured by KACST-FRT over 10 months (Feb-Dec 2012) versus cosecant elevation. The obtained correction value for the water vapour emission contribution to the weak astronomical signal is $0.205 \pm 0.003$.

4. Conclusion

We have designed and built the first specialized and fully operated radio telescope in the Arabic world as a prototype to observe the crescent of the new moon to determine the first day of each Hijri month. Our goal extended afterward to cover observations of all nearby sky objects. Good data was collected and results were published in a distinctive journal. Unlike the homogenous distribution of radio emission from the Nitrogen and Oxygen molecules, Water vapour distributes randomly in the atmosphere, and so, its emission must be flagged when weak radio astronomical signals (e.g. CMBRs) are observed at certain frequency such as 10.3 GHz.
As we plan to observe the CMBR from Al-Uyayna Solar village, we had to study the contribution of water vapour radio emission above this location, and so we initiated a model from the measurements we achieved to flag the water vapour noise contribution to our astronomical observations at 10.3 GHz. For correct and accurate results at 10.3 we must correct all our observation by $0.205 \pm 0.003$ for the noise resulted from water vapour radio emission, mainly when we measure weak astronomical signal such as those from the CMBR. More atmospheric studies will be done in a future work.

Acknowledgements

We would like to especially thank HH Prince Dr Turki Bin Saud Bin Mohammad Al-Saud for all his support this project; without his support we could not have completed this work. We would like to thank the staff at the Jodrell Bank Observatory and School of Physics and Astronomy at University of Manchester for their assistance during the construction and commissioning of the telescope.

References

[1] Davies R D, Gutierrez C M, Hopkins J, Melhuish S, Watson R, Hoyland R, Rebolo R, Lasenby A and Hancock S 1996 MNRAS 278 883
[2] Hafez Y, Trojan L, Albaqami F, Almutairi A, Davies R D, Dickinson C and Piccirillo L 2014 MNRAS 439 2271
[3] Danese L, Partridge R B 1989 Astrophysical Journal 342 604
[4] Smoot G F, Levin S M, Kogut A, De Amici G and Witebsky C 1987 Radio Science 22 521
[5] Staggs S T, Jarosik N C, Wilkinson D T, Wollack E J 1996 Astrophysical Journal 458 407
[6] Zhang X Z, Gray A, Su Y, Li J D, Landecker T, Zhang H B, Li C L 2012 Res. Astron. Astrophys. 12 1297