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DOI: https://doi.org/10.64388/IREV9I10-1716843

Overview of Spectrum Characterization / Radio Quietness Profile at CBSS Observatory, Ebirimirin – Agu, Nsukka, Nigeria in June, 2025.

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Abstract - This project seeks to characterize Radio Frequency Interference (RFI) around Centre for Basic Space Science and Astronomy (CBSS) premises where a 3.7m Radio Telescope was newly installed in addition to a range of smaller radio astronomy telescopes, radio antennas and RF devices that operate within the premises. The experiment was carried out over a range of frequency bands spanning VHF (35MHz) through C – Band (up to 6.2GHz) to determine achievable science goals, band utilization, system usefulness and performance requirements of any radio astronomy equipment to be operated within the premises. Measurements were taken at specific bands covering VHF (36MHz – 300MHz), UHF (300MHz – 1GHz), L – Band (1GHz – 2GHz), S – Band (2GHz – 4GHz) and C – Band (4GHz – 6.2GHz). The results present the RFI profile of the premises, giving an indication of its radio quietness profile. Thus, the results serve as important guide on astronomy band utilization, equipment performance requirements and achievable science goals within the premises while highlighting attendant effects of urbanization on astronomy studies.

***Keywords:** Bands, Frequency, RFI, Spectrum, Telescope.*

I. INTRODUCTION

Radio astronomy observatories face a significant challenge in mitigating Radio Frequency Interference (RFI), which originates from man – made sources such as communication devices, satellite systems, radars, machineries among others. Radio Frequency Interference (RFI) has become a significant factor in our ability to observe natural phenomena on Earth, in our solar system, and the nearby and distant universe [1]. Understanding and mitigating RFI are crucial for ensuring the accuracy and reliability of astronomical observations. RFI has always influenced the search for and analysis of interesting astronomical objects [2]. Thus, Radio quietness is a fundamental requirement in Radio Astronomy instrumentation deployment as RF Interference which is considered a form of pollution constitutes a major barrier to radio astronomy observation at given frequency bands.

Sensitivity of observational equipment are impacted in environments where RFI footprints are strong enough to significantly mask intended signals. The influence of RFI on radio astronomy measurements ranges from total disruption by saturation of the receiver to very subtle distortions of the data [3]. The performance of the receiver system is fundamental to the overall performance of a radio telescope [4]. Certain frequency bands designated for radio astronomy as a result of their correspondence with cosmic emissions have gradually become invaded by terrestrial interferences. Also, data integrity is jeopardized by RFI thereby resulting in inaccurate interpretations of astronomy phenomena. Radio Frequency Interference (RFI) corrupts astronomical measurements, thus affecting the performance of radio telescopes [5]. Urbanization also plays major role in aggravating these challenges as human activities continue to increase and expand to places hitherto considered radio – quiet zones.

These aforementioned challenges underscore the need for continued RF spectrum characterization with a view to understand and mitigate these challenges. The spatial and temporal variability of RFI requires constant monitoring for new or stronger sources [6]. The need to achieve greater sensitivity and observing efficiency in receiver systems calls for efforts to have tighter control of systematic errors in astronomy instruments and effectively correct them [7]. RFI studies would help to preserve equipment sensitivity and also help to identify frequency bands that are most affected by interferences. This could help in the evolution of policy documents by regulatory bodies geared towards the protection of such bands. In addition, information from spectrum characterization could engender better techniques to filter out unwanted signals thereby improving detection technologies, quality and reliability of data. Moreover, spectrum characterization fosters collaboration between astronomers, engineers, regulators and industry stakeholders thereby driving advancements in radio frequency technologies, protection of radio astronomy bands and policies that minimize interferences. This RFI studies has become imperative in view of a good number of radio astronomy equipment deployed at the Centre for Basic Space Science, Ebirimirin, Nsukka.

II. ITU ASTRONOMY BAND ALLOCATION

Table 1 below shows preferred frequency bands for radio astronomical measurements.

Table 1: Table showing preferred frequency bands for radio astronomical measurements below 275GHz [8]

S/N	Substance	Rest frequency	Suggested minimum band
1	Deuterium (Dl)	327.384MHz	327.0 – 327.7 MHz
2	Hydrogen (Hl)	1420.406 MHz	1370.0 – 1427.0 MHz
3	Hydroxyl radical (OH)	1612.231MHz	1606.8 – 1613.8MHz
4	Hydroxyl radical (OH)	1665.402 MHz	1659.8 – 1667.1 MHz
5	Hydroxyl radical (OH)	1667.359 MHz	1661.8 – 1669.0 MHz
6	Hydroxyl radical (OH)	1720.530 MHz	1714.8 – 1722.2 MHz
7	Methyladyne (CH)	3263.794MHz	3252.9 – 3267.1 MHz
8	Methyladyne (CH)	3335.481 MHz	3324.4 – 3338.8 MHz
9	Methyladyne (CH)	3349.193 MHz	3338.0 – 3352.5 MHz
10	Formaldehyde (H_2CO)	4829.660 MHz	4813.6 – 4834.5 MHz
11	Methanol (CH_3OH)	6668.518MHz	6661.8 – 6675.2MHz
12	Helium ($^3He^+$)	8665.650 MHz	8657.0 – 8674.3 MHz
13	Methanol (CH_3OH)	12.178GHz	12.17 – 12.19 GHz
14	Formaldehyde (H_2CO)	14.448 GHz	14.44 – 14.50 GHz
15	Cyclopropenylidene (C_3H_2)	18.343 GHz	18.28 – 18.36 GHz
16	Water vapour (H_2O)	22.235 GHz	22.16 – 22.26 GHz
17	Ammonia (NH_3)	23.694 GHz	23.61 – 23.71 GHz
18	Ammonia (NH_3)	23.723 GHz	23.64 – 23.74 GHz
19	Ammonia (NH_3)	23.870 GHz	23.79 – 23.89 GHz
20	Sulphur Monoxide (SO)	30.002 GHz	29.97 – 30.03 GHz
21	Methanol (CH_3OH)	36.169 GHz	36.13 – 36.21GHz
22	Silicon monoxide (SiO)	42.821 GHz	42.77 – 42.86GHz
23	Silicon monoxide (SiO)	43.122 GHz	43.07 – 43.17GHz
24	Dicarbon monosilphide (CCS)	45.379 GHz	45.33 – 45.44GHz
25	Carbon monosulphide (CS)	48.991 GHz	48.94 – 49.04GHz

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DOI: https://doi.org/10.64388/IREV9I10-1716843

26	Oxygen (O_2)	61.1 GHz	56.31 – 63.06GHz
27	Deuterated water (HDO)	80.578 GHz	80.50 – 80.66GHz
28	Cyclopropenylidene (C_3H_2)	83.339 GHz	83.05 – 82.42GHz
29	Silicon monoxide (SiO)	86.243 GHz	86.16 – 86.33 GHz
30	Formylium ($H^{13}CO^+$)	86.754 GHz	86.66 – 86.84GHz
31	Silicon monoxide (SiO)	86.847 GHz	86.76 – 86.93GHz
32	Ethynyl radical (C_2H)	87.3 GHz	87.21 – 87.39GHz
33	Hydrogen Cyanide (HCN)	88.632 GHz	88.34 – 88.72GHz
34	Formylium (HCO^+)	89.189 GHz	88.89 – 89.28GHz
35	Hydrogen isocyanide (HNC)	90.664GHz	90.57 – 90.76GHz

From Table 1 above, and with respect to the bandwidth of the instrument used in this experiment which spans from 35MHz through 6200MHz, interferences with only the first ten sources / substances could be investigated in this study.

III. SPECTRUM OF INTEREST

Spectrum of interest in the course of this project include VHF (30MHz – 300MHz), UHF (300MHz – 1GHz), L – Band (1GHz – 2GHz), S – Band (2GHz – 4GHz) and C – Band (4GHz – 8GHz) which are largely used for radio astronomy observations [9].

IV. METHODOLOGY

The RFI characterization exercises were carried out at the Centre for Basic Space Science (CBSS), Nsukka Observatory premises. GPS Coordinate for this location / study area is Lat: 6.8; Long:7.4 and with an attitude of 432m above sea level. This premises co – located the Spectrum Analyzer instrument with the arrays of Radio Telescope facilities at the Centre for Basic Space Science (CBSS).

Arinst Spectrum Analyzer SSA – TG R2 instrument shown in Figure 1 below was employed for the RF characterization. The bandwidth capacity of the Spectrum Analyzer spans from 35MHz through 6.2GHz.

Figure 1: Arinst SA – TG R2 Spectrum Analyzer [10]

This implies that measurement could be carried out within VHF band (36MHz – 300MHz) through C band (4GHz – 6.2GHz). The instrument was set up and interfaced with Aaronia antenna. A computer was connected with the Spectrum Analyzer for the purpose of configuration, monitoring and data acquisition. With the aid of ArinstSSA DAQ software application, communication was established with the instrument as well control; and data storage and retrieval.

Figure 2: RFI Investigation Site

As shown in Figure 2 above, the instrument was set up by connecting the antenna via a BNC connector interface onto the Spectrum analyzer, which in turn was connected to a computer server via ArinstSSA DAQ software application on the computer, from

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DOI: https://doi.org/10.64388/IREV9I10-1716843

where spectrum monitoring, data charting, data archiving and retrieval were handled. Measurements were taken for 3 days at specific bandwidths of VHF Band, UHF Band, L – Band, S – Band and C – Band, up to the 6.2GHz upper bandwidth limit of the instrument. Prominent results were thereafter stored for analysis.

V. RESULTS AND DISCUSSION

The following figures shows prominent results obtained from the RFI characterization experiment.

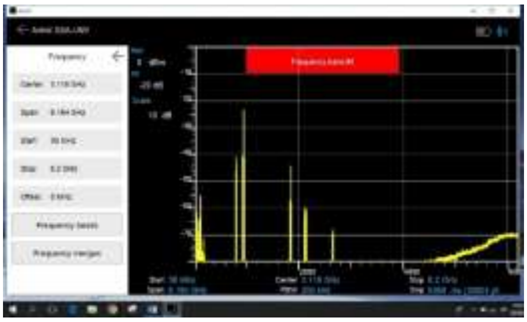

Fig3: Broad Spectrum Characterization

Figure 3 above shows result from a broad spectrum RFI characterization. It underscores the fact that the radio quietness of the observatory is not absolute. A range of RF presence across different bands was observed. RFI power spectra were seen, and in few cases as strong as -23dB in amplitude. This necessitated the need to look through each band in more details with a view to understand specific spectrum section that are safe for various radio astronomy observations.

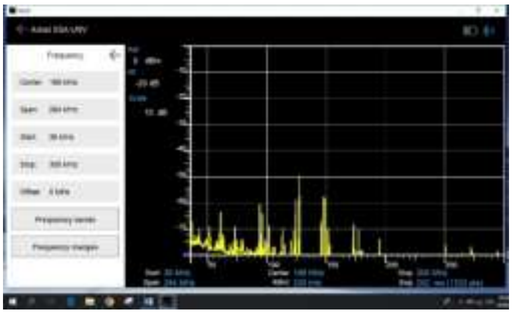

Fig4: VHF Characterization

At VHF (36MHz – 300MHz), as shown in figure 4 above, RFI was seen notably, particularly from 36MHz through 200MHz. This band is usually used by radio stations and broadcast channels. A good number of Frequency Modulation (FM) radio stations nearby using spectrum 88MHz through 108MHz which also falls within this band were seen very active with significant spectra power up to -49.5dB in some cases. Relative radio quietness was observed in the spectrum range of 200MHz through 300MHz. Intended radio astronomy observations in the range of 36MHz through 200MHz would largely experience significant levels of noise and RFI and thus would require very expensive receivers to handle such RF pollution or the spectrum should be avoided outrightly while engaging 200MHz to 300MHz for astronomy observations with the CBSS observatory premises.

Fig5: UHF Spectrum Characterization

At UHF (300MHz – 1GHz), as shown in figure 5 above, there is a remarkable clean spectrum for radio astronomy observation from 300MHz through 790MHz. However, spectrum spanning 790MHz through 810MHz was seen to be significantly noisy with power reaching -45dB. This RFI was also seen much more significant in the range of about 930MHz through 960MHz with power spectra reaching about -22dB. This is not unexpected as GSM communications uses spectrum around 800MHz through 950MHz. Also, the high amplitude of the RFI was traceable to a GSM BTS mast in close proximity, about 60 meters from the CBSS observatory premises.

Fig6: L - Band Spectrum Characterization

L – Band (1GHz – 2GHz) is a popular band in radio astronomy due to an array of cosmic phenomena that are detectable within the band, it is a band of significant astronomy interest. As shown in figure 6 above, A significant radio quietness was observed from the lower band limit of 1GHz through 1.83GHz. This quietness was interrupted briefly, though significantly within the bandwidth of 1.83GHz through 1.862GHz with RFI reaching about -49dB. This RFI within the L – band could be attributed to GSM communications services around the premises. Nonetheless, the L – Band was identified as the most radio – quiet spectrum within the bands under investigation.

Fig7: S - Band Spectrum Characterization

The S – Band was significantly quiet across from around 2.7GHz through 4GHz upper band limit as shown in Figure 7 above. The few observed RFI were narrow bound around 2.1GHz - 2.15GHz and also around 2.65GHz. These observed RFI were attributed to a range of wireless devices and Bluetooth systems operational in close proximity to the site where the investigation was carried out. This RFI posed no threat to the use of the band spectrum as it was generated by team members and could easily be controlled. This result also makes this band very useful for astronomy observation within minimal RFI.

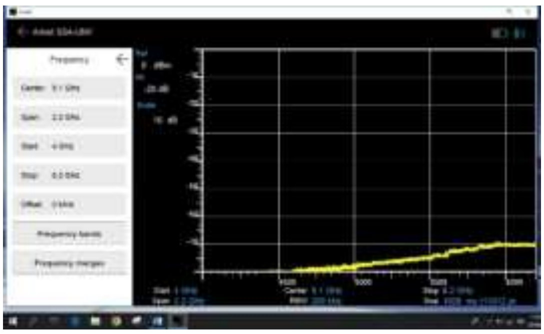

Fig8: C - Band Spectrum Characterization

At C – Band, spectrum section investigated spanned from 4GHz through 6.2GHz. Quiet section of the spectrum range was observed to span from 4GHz through 4.6GHz. RFI dB level around the quiet range was seen to be around -80dB. However, a progressive increase in RFI was observed from a range of 4.6GHz through 6.2GHz with an almost constant dB level of about -70dB from 5.9GHz through 6.2GHz as shown in figure 8 above. This observed RFI power spectra could be attributed to fixed satellite services. Consequently, radio astronomy science within the C – Band could be safely pursued around the 4GHz - 4.6GHz if around the CBSS premises.

VI. ASTRO-SCIENCE IMPLICATIONS

With respect to the results discussed above, the target environment and the frequencies for radio astronomy measurements as shown in Table 1 above, recommended science within the target site include Deuterium (D) [11] with a minimum band requirement of 327.0MHz – 327.7MHz and a rest frequency of 327.384MHz; Hydrogen (H) with a minimum band requirement of 1370.0 MHz - 1 427.0 MHz and a rest frequency of 1420.405MHz [12]; all the Hydroxyl radicals (OH) lines with a minimum band requirements of 1606.8MHz - 1613.8MHz, 1659.8MHz - 1667.1MHz, 1661.8MHz - 1669.0 MHz, 1714.8MHz - 1722.2MHz and rest frequencies of 1612.231MHz, 1665.402MHz, 1667.359MHz and 1720.530MHz respectively. With observable significant radio quietness from around 2.7GHz through 4GHz upper band limit of the S – Band observation of Methyladyne (CH) across its spectrum with minimum band requirements of 3252.9MHz - 3267.1MHz, 3324.4MHz - 3338.8MHz, 3338.0MHz - 3352.5MHz and rest frequencies of 3263.794MHz, 3335.481MHz and 3349.193MHz respectively could be handled without difficulty [13].

For Formaldehyde (H2CO) observation with a minimum band requirement 4813.6MHz - 4834.5MHz and a rest frequency of 4829.660MHz [14]; noise levels around the indicated spectrum was observed to be around -77dB which could be handled by receivers with acceptable Signal / Noise ratio.

VII. CONCLUSION

Observations collected with radio astronomy and earth remote sensing instruments can easily be rendered unusable due to Radio Frequency

Interference (RFI) whether it is from Out – Of – Band (OOBE) or spurious emissions in the bands used by sensors [15]. Urbanization and RFI are major problems facing astronomy observatories globally. Continuous RFI characterization is essential to understand the impacts on both environment and also on science. The knowledge would also provide insights into spectrum conservation and instrumentation requirements in RFI prevalent areas.

Radio astronomy infrastructures are operational at the NASRDA Centre for Basic Space Science and in this work; RF measurements were carried out within the stated bandwidth of 35MHz through 6200MHz with a view of profiling the RFI at the target site, and also to investigate its impact on spectrum used in astronomy for cosmic radio observations.

Results were obtained at VHF, UHF, L – Band, S – Band and C – Band showing the RFI profiles at each of the stated bands. Also, the impacts of the RFI on spectrum usage in radio astronomy observations were indicated. Within the boundary of the investigated spectrum at the site of investigation, radio sources recommended for observation without difficulty include Deuterium (DI), Hydroden (HI), Hydroxyl radicals (OH) and Methyladyne (CH).

LIST OF ABBREVIATIONS

RFI – Radio Frequency Interference
CBSS – Centre for Basic Space Science
RF – Radio Frequency
VHF – Very High Frequency
UHF – Ultra High Frequency
FM – Frequency Modulation
GSM – Global System for Mobile Communications
BTS – Base Transceiver Station

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