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Investigation of Potential RFI Threats to Ghana Radio Telescope Observatory-Nkutunse

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Abstract- **This research seeks to investigate potential Radio Frequency Interference that could threaten the operation of the yet to be deployed telescope observatory at Nkutunse, Ghana. The observatory receiver system of which would be operating at 5GHz and 6.7GHz radio astronomy frequency band, is to be realized from the conversion of the decommission 32-m diameter earth satellite station at Nkutunse. A survey was conducted to determine the power level of those interferers with two different methods of RFI detection setups. Signals that are of potential threat were found at 4.92 GHz, 5.02 GHz, and 6.59 GHz, 6.62 GHz that are of concern due to the broadband nature of the observation techniques. These detections could have a significant effect on the telescope operations considering potential image frequencies and spurious responses that may arise from these interferers. A convolution technique was employed to mitigate RFI in the operating frequency window and fits a function to predict the outcome using a Savitsky Galoy filter.**

Keywords- Interference; Spectrum; Telescope; Convolution; Filter and Polarization.

I. INTRODUCTION

Radio astronomy is the observation of astronomical objects such as stars, galaxies, quasar, etc. using radio telescopes. Astronomers use telescopes with highly sensitive receivers to be able to detect weak celestial emissions. These emissions give valuable information of the physical nature of the universe [1]. There is an opportunity to establish an African Network of Very Long Baseline Interferometry (VLBI) - capable telescope by converting redundant large satellite telecommunications antennas in certain parts of Africa into VLBI-capable radio telescopes.

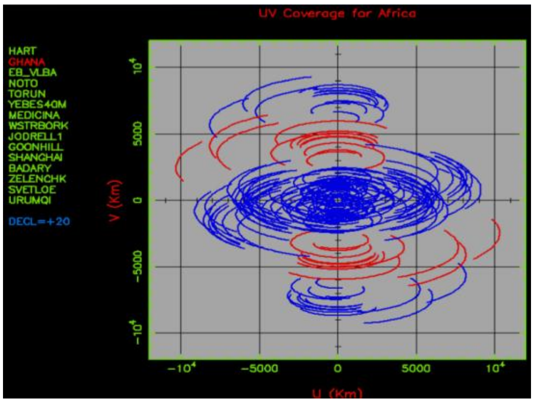

Fig 1: Ghana’s Contribution in Red of the UV Plot

Adding stations across Africa increases the range of baselines available globally and significantly improving the UV coverage by filling the ‘gap’ as seen in Fig 1. The list of proposed conversion of decommission earth station into radio telescope for Africa, is indicated with dots on the globe in Fig 2. [2].

Currently, participating countries are Botswana, Ghana, Kenya, Madagascar, Mauritius, Mozambique, Namibia, and Zambia.

Fig 2: Africa Network of Telescopes

The yellow dot indicates the working one in South Africa and the yet to be deployed Ghana Radio Telescope Observatory. The Ghana satellite earth station is located (5°45'02.1"N 0°18'18.7"W)[3] at Nkutunse of the Accra Nsawam road. The satellite earth station consists of a 9 m, 16 m, and 32 m to serve as Ghana’s gateway for international telecommunication traffic until it was decommissioned in 2003. The 32m antenna shown in Fig 3.

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Fig 3: Ghana Radio Telescope Observatory yet to be deployed

Radio astronomy is a passive activity focused on receiving very weak astronomical signals. Radio astronomy receives *broadband signals of interest*, meaning that *wider-band* receivers produce *better signal-to-noise* measurements. This is often extremely confusing to people from a telecommunications background, where *narrow-band signals of interest* mean that the *better signal-to-noise* is achieved by *narrower* receiver bandwidth. The result is that the quality of radio astronomy data can easily be affected by nearby interfering signals, which limits the possible bandwidth of the receiver. With the ever-increasing demand for radio-based services, the observatory needs to constantly monitor the ambient radio environment and take appropriate preventive and corrective measure to ensure the continued quality of the astronomical data collected [4]. The initial receiver system would operate in the frequency of 5 GHz band (Continuum), and 6.7GHz band (Methanol Maser) ±200 MHz But this will be an interim solution to provide an initial operating capability [5]. The environment of the 32 m- Cassegrain antenna at Nkutunse has challenges such as cell towers and settlements encroachments. This research is aimed at characterizing the radio space of the telescope site by identifying possible RFI in the surrounding that would likely interfere with the proposed operating frequency band. The success of this conversion will improve UV coverage by bridging the “gap” between European VLBI Network (EVN) and Hartebeesthoek telescope in South Africa

II. RADIO ASTRONOMY & RFI MITIGATION

Observatories are mandated to monitor the ambient radio environment constantly due to surrounding interfering radio emissions. These directives are to ensure the reliability of the astronomical measurements [6]. Limitation of the frequency spectrum is due to the attenuation of the earth’s atmosphere and man-made RFI for the most ground-based radio telescope. Within 30 MHz – 300 GHz of the radio window, the electromagnetic radiation is evident to the earth’s atmosphere of which man-made RFI is the biggest spectrum limiting factor in radio astronomy studies [7] as the receiver may be driven to non-linearity by such potential RFI signals [8]. Spectrum monitoring aids in the design of receivers that have the capability of filtering certain RFI so that the main goal of radio astronomy, desirable observation is achieved Square Kilometre Array (SKA) seeks to achieve the scientific goal of astronomy by improving RFI mitigation techniques [9].

Radio frequency interference (RFI) mitigation has become an important aspect of radio astronomy since terrestrial and space-based radio transmitters have become more powerful and wide spread [10]. RFI is one of the major problems in radio telescopes observation since it has a direct impact on the latter’s operational performance. Achievement of C-Band All Sky Survey (C-BASS) and Precision Array for Probing the Epoch of Reionization (PAPER) from the international community and SKA in South Africa was possible due to the location of a radio-quiet environment [11]. The location of the dish was a radio quiet-zone until recently due to urbanization, which has necessitated the effective mitigation of man-made RFI at the proposed telescope site.

III. SURVEY REQUIREMENT

The investigation was to detect strong interference signals as well as weak signals at the observatory. The most common sources of interference are likely to be coming from the communication towers, which are physically visible in every direction. These signals could compromise the Radio Telescope receiver due to its sensitivity, which is highly receptive when pointing in the direction of the signals. This is a likely scenario considering the distribution of communication towers around the Nkutunse site.
The operating wavelengths of the frequency are;

- 6cm Wavelength at 5GHz
- 4.5cm Wavelength at 6.7GHz

During the investigation, signals that are detected within this window of frequency band are as considered interference.

A. Polarization

Polarization describes the shape and orientation of the electric and magnetic field vector as a variation with time. This work concentrates on the linear polarization, which gives rise to the vertical and horizontal plane; of which the receiving antenna polarization must match with the incident wave been observed in Fig 4.

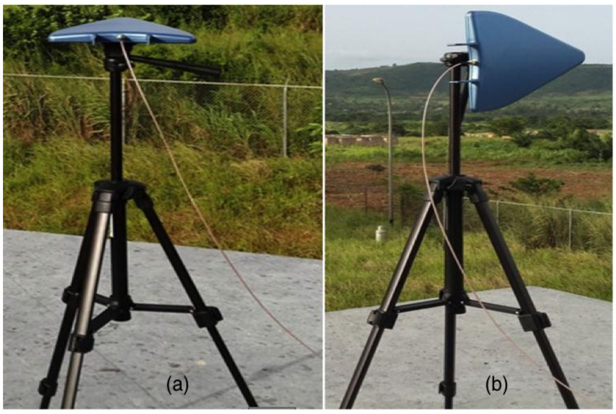

Fig 4: (a) Horizontal and (b) Vertical Polarization

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B. Measurement Coordinates

In any of the direction of measurement, a unique cardinal identifier was assigned as a reference to cataloging all data. These are positions where the measurements were performed and are indicated in Fig 5.

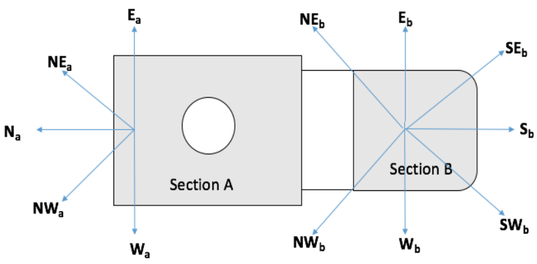

Fig 5: Measurement Directions and Platform

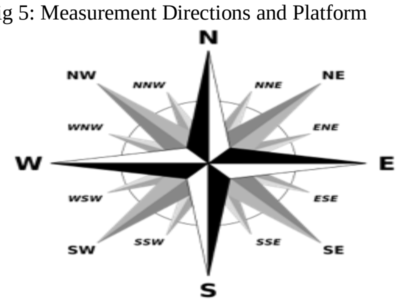

Fig 6: Reference Compass

The Aaronia antenna beam pattern for both polarizations influence the survey points/angle position chosen for this measurement [12].

C. Measuring Setup

The methods used here involve two setups; the first setup was without any external active or passive device in Fig 7 and the second setup made use of a High Pass filter (HPF) and a Low Noise Amplifier (LNA) in order to detect very low signals, and the filter to pass frequencies of 3.7Ghz and cuts-off frequencies below it pass-band in Figure 8. The introduction of the LNA was to amplify the radiated power being measured and to reduce the noise level since the antenna only captures just a fraction of the radiated signal observed. Setup equipment listed in Table 1.

Table 1: Measuring Equipment List

Quantity	Description	Model/Part Number
1	Log-periodic antenna	Hyper log 60100
1	Tripod Stand	105cm Tripod
1	Spectrum Analyzer	FSH8 (9Khz-22Ghz)
1	Low Noise Amplifier	UBBV2 (30-40dB)
1	High-Pass Filter	4Ghz with >85dB(DC-3Ghz)
1	1m RF Cable Male-to-Male SMA	8Ghz Capable
1	SMA Adaptor Male-to-Male	8Ghz Capable
1	SMA Adaptor Female-to-Female	8Ghz Capable

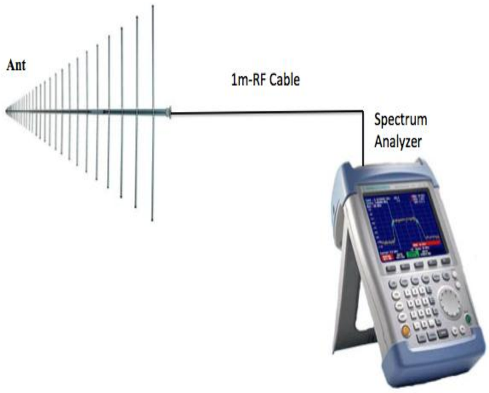

Fig 7: First Setup

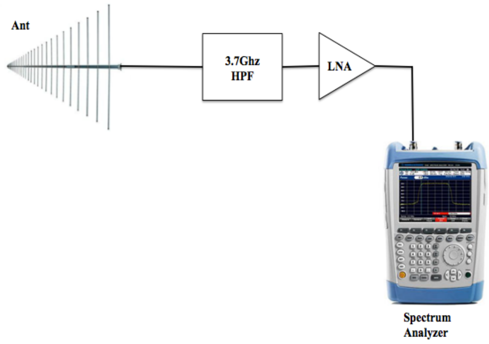

Fig 8: Second Setup

D. Instrument Parameter Setting

An analyzer basically resolves the received signal by measuring the frequency of the signal and the power associated with each unit frequency. The following configuration parameters are chosen for a full sweep by the Spectrum Analyzer. This would give a clear picture of the spectrum usage at the site.

Table 2: Analyzer Parameter Settings

Parameter Setting	Value
Start Frequency	1Mhz
Stop Frequency	8Ghz
Resolution Bandwidth	100Khz, 300Khz , 3Mhz
Video Bandwidth	3Mhz
Sweep Points	Maximum Possible
Measurement Mode	Auto Low Noise
Preamplifier	ON
Attenuator	0dB
Trace Detector Type	Peak
Max Hold	On
Sweep Time	Auto
Amplitude	dBm
Reference Amplitude	0dBm
Range/Scale	100dB
Trigger Mode	Free Running

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IV. DATA COLLECTION & ANALYSIS

The power levels of the signals are recorded for both antenna orientations in the H-plane and E-plane with respect to the cardinal points. The data was saved in .CSV and .SWP format and exported to excel for analysis. The data was collected at various directions of the measurement plan representing the power levels of the signal in (dBm) present at the observatory.

Since the power levels of the signals are in the unit of (dBm), it is important to convert them into a plane-wave equivalent voltage (dBμV) for this work. This is done by adding a factor of 107dB, which is only applicable in a 50Ω system, and computing this power level into an equivalent voltage for receiver sensitivity (S_R) would yield,

$$S_R = P(dBm) + 107dB = dB\mu V \qquad (1)$$

After obtaining equivalent voltage the field strength (dBμV/m) and the system sensitivity (S_e) was computed by adding the antenna factor (AF) dB/m and thus

$$S_e = S_R(dB\mu V) + AF(dB/m) = dB\mu V/m \qquad (2)$$

Applying the above formulae for the data collected, the equivalent field strength is obtained in (dBμV/m). Finally accounting for the cable loss,

$$S_e = S_R(dB\mu V) + AF(dB/m) + C_{loss} = dB\mu V/m \qquad (3)$$

V. RESULT AND DISCUSSION

The result gives a true representation of the radio space of the telescope site. The following graphs represent the Power levels in E-field strength of the measured radiated power at a point in space, for various frequency ranges in H-plane (Horizontal) and E-plane (Vertical). The spectrum indicates many activities in the L-band and this is as a result of the GSM signals from the cell tower around and a few interferences in the S-Band at 2.4 GHz for microwave oven, but the interest is interference from 4 – 8 GHz, the plots are shown in Fig 9 and Fig 10. For the frequency range at which interference is of much concern for the telescope operation.

With the introduction of the High-Pass Filter without the external LNA of the Spectrum Analyzer, detection of intermodulation product is not possible as the input power is sufficiently low.

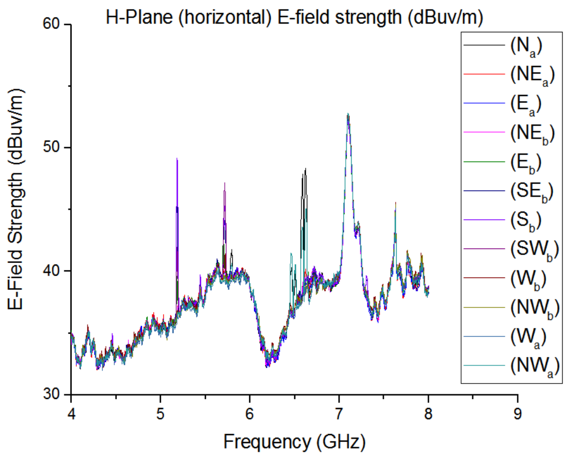

Fig 9: H-plane E-field strength at 4 – 8 GHz

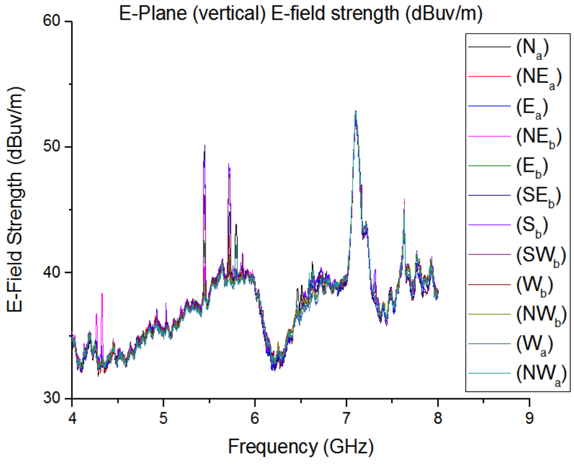

Fig 10: E-plane E-field strength at 4 – 8 GHz

It is likely the spectrum analyzer may not detect possible interference due to insufficient input power. However, with the introduction of a low noise amplifier, some of the possible interferers are detected.

At the north of the cardinal direction, the following signals were detected at 6.59 GHz and 6.62 GHz all due to the amplification of the signals with the introduction of external LNA, with the antenna pointed in the H-plane direction. As can be seen, there are several interfering sources around 6 GHz ranging from 6.45 to 6.50 GHz but that is not of interest for this work because this is outside the filters pass-band, the concern is the immediate interferers available on the bandwidth window which is ±200 MHz of the operating frequencies. The signal is more evident in the E-plane of the antenna orientation. Which is of concern even though they seem weak, but could bring about intermodulation issues.

Referencing the Frequency Allocation Table (FAT) of the National Communication Authority (NCA) of Ghana [13]. Suggest that the 5 GHz band is a standard frequency time signal unallocated but it adjacent band are for fixed mobile broadcasting and the 6.7 GHz thou unallocated is for aeronautical mobile with its adjacent band far from the bandwidth window of interest.

VI. INTERFERENCE MITIGATION

One of the key challenges for very sensitive radio antennas such as the Nkutunse antenna is the effect of RFI during observation. This effect mostly decreases the antenna sensitivity, particularly, producing artifacts in the measured data [14]. Several techniques such as: (1) Probability method; (2) Adaptive noise cancelling (ANC); (3) Spatial filtering; (4) and (5) AOflagger have been produced and used in RFI mitigation [15]. This paper proposes a convolution technique to mitigate the RFI observed in Nkutunse data and then tries to fit a function to predict the filtered data.

A. Convolution Technique

This technique simply interpolates two functions χ_1 and χ_2 to give a third function ζ that is viewed as a modification of one of the original functions. Let consider C_v (ϖ) to be the convolution of F_1 (ϖ) with F_2 (ϖ) , then its Fourier pair ζ , is the product of χ_1 (ν) and χ_2 (ν) which are the Fourier pairs of F_1 (ϖ) and F_2 (ϖ) respectively. Thus,

$$F_1(\varpi)\otimes F_2 \rightleftharpoons \chi_1(v).\chi_2(v) \quad (4)$$

where the symbol $\otimes$ denotes the convolution operator. By definition,

$$C_v(\varpi)=F_1(\varpi)\otimes F_2(\varpi) \quad (5a)$$

$$C_v(\varpi)=\int_{-\infty}^{\infty} F_1(\varpi').F_2(\varpi-\varpi')d\varpi \quad (5b)$$

taking the Fourier transform of both sides in equation (5b), we get;

$$\zeta(v)=\int_{-\infty}^{\infty} C_v(\varpi)e^{-2\pi jv\varpi}d\varpi \quad (6a)$$

$$\zeta(v)=\chi_1(v).\chi_2(v) \quad (6b)$$

Expressing the general definition in equation (6b) into 1D discrete form, we have;

$$\zeta(v)=\sum_{k=0}^{N} F_1(v).F_2(k-v) \quad (7)$$

In this paper, $\zeta(\nu)$ is a discrete function denoting the filter signal, $F_1(\nu)$ is the observed signal with RFI and the kernel function F_2 (k-ν), in this case a Gaussian function with mean 0 and standard deviation 1is assumed.

In Fig 11 and Fig 12, note how the convolution technique clearly reduced the RFI at frequencies between (i.e. < 4 – 8 GHz) of interest, using Savitzky Golay Filter [16], we are able to reconstruct the filtered signal.

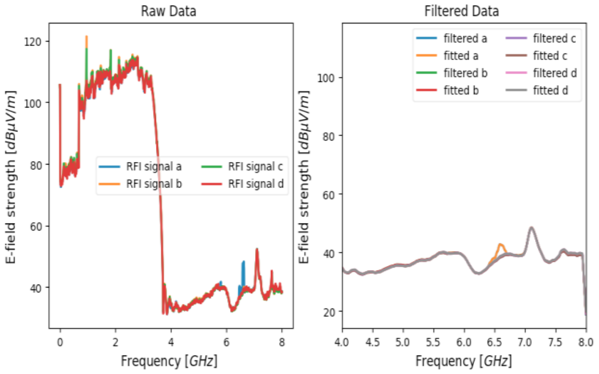

Fig 11: True North Direction, Left- hand side: High RFI in the observed signal. Right-hand side: Filtered RFI signal using gaussian filter to convolve the RFI signal and reconstructing the filtered with Savitzky Golay scheme.

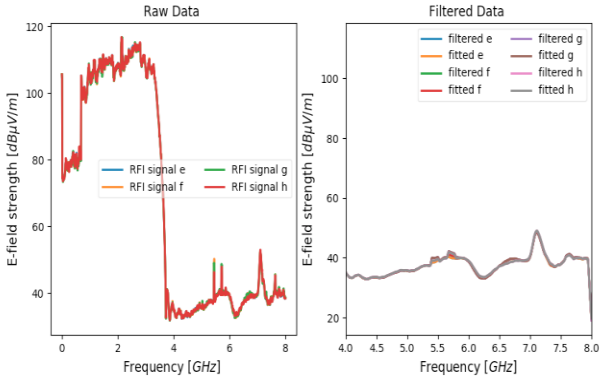

Fig 12: Southern Direction, Left- hand side: High RFI in the observed signal. Right-hand side: Filtered RFI signal using gaussian filter to convolve the RFI signal and reconstructing the filtered with Savitzky Golay scheme.

VII. CONCLUSION

Since the frequency requirement proposed for the conversion is 5 GHz (Continuum) and 6.7 GHz (Methanol Maser), it is ideal to have $\pm$200 MHz wide transition band for the respective frequencies so that spectrum could be cleared for astronomical science.

The NCA frequency allocation table suggests that those interfering frequencies are a significant part of the communication band for some Telecom operators and can be mitigated with a dialogue between them to move to other frequency bands possible by clearly defining the importance of the telescope in relation to socio-economic development.

It is prudent to continually monitor the radio space for RFI, which is the aim of this research and will result in a proposed design of an automated monitoring system to determine the kind of filter bank that can be deployed in the receiver system using the convolution technique. However, it is recommended that the regulatory body negotiate and control the spectrum usage of the observatory.

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