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Design and Implementation of Remote RFI Monitoring System for Ghana Radio Telescope Observatory-Nkutunse

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Abstract Radio telescope receivers are sensitive instruments designed to detect very weak signals radiating from astronomical sources. These signals travel several light years and are sometimes drain by the interference of man-made and terrestrials RFI's. This work aims at the design of a cost-effective Radio Frequency Interference Monitoring System (RFIMS) for the Ghana Radio Astronomy Observatory at Nkutunse. The design of automated RFIMS was constructed with a log-periodic antenna for receiving the electric field being radiated, Low Noise Amplifier (LNA) to amplify the weak signals for detectability, an attenuator to control the high power interfering signals, a filter to pass frequency of interest and a spectrum analyzer as backend. Ideally, telescopes are supposed to be sited at a radio quiet environment. The implementation is to continually monitor the radio space for potential interference at the telescope site for remedial actions since it has become a global candidate site by location and necessitation.

Keywords: *sensitivity, automation, interference, observatory, monitoring*

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1. Introduction

The conversion of a 32m dish into a radio telescope in Ghana is yet to be deployed, as the second telescope in Africa and part of a network of telescopes in the globe in Figure 1. An investigation was conducted to determine potential radio frequency interference threats to the yet to be deployed telescope which is to operate at 5 GHz (Continuum) and 6.7 GHz (Methanol maser) frequencies.

Figure 1. Ghana Radio Telescope Observatory

The results of the investigation did yield some interfering signals at 4.92 GHz and 5.02 GHz of the 5 GHz frequency band at the southern direction of the telescope location without much concern, of the sources from the 6.7 GHz frequency band which are 6.59 GHz and 6.62 GHz outside the ±200 MHz spectrum window [1]. This paper proposes an implementation of remote automated RFI monitoring system for continues spectrum survey for interferers. The Front-end consist of a log-periodic antenna for capturing the radiated emission as compared to most RFIMS reviewed in this work. The design is simple and effective, utilizing a single antenna been controlled by two stepper motors, one motor for antenna polarization in E/H plane and the second motor to rotate the upper motor subassembly in azimuth. The received emission goes through a signal conditioner of Filters for desired frequency, amplification by LNA and Attenuator to protect any high power from damaging the analyzer.

The Back-end has the spectrum analyzer to resolve the emission into power (dBm) for analysis, it also consists of a Computer interfaced with the analyzer for remote parameter configuration and control of electromechanical parts of the antenna steering unit. A graphical user interface (GUI) is developed for the antenna steering control for precise plane and direction pointing, with a customized spreadsheet for data analysis with the computer. This computer has an internet access with public IP from an ISP to enable remote use of the RFIMS, importantly for accurate pointing and calibration of the instrument a noise diode to establish noise floor baseline. Portability of the RFIMS was also factored for easy assembly on a tripod and transporting of the system to find other future candidate sites.

Continues monitoring of radio frequency interference (RFI) situation at the site, would help establish a minimum allowable RFI signal level so not to damage the receiver or data with high interfering signals. Besides the weak signal nature of the observed object, the receiver sensitivity is so high and with interferometry of dishes, the collecting surface is large enough to detect signals that are not of interest, with anticipation of future usage of the spectrum [2]. Traditionally astronomy was assigned higher bands of frequency at the end of the frequency spectrum. lower band for commercial purpose but due to accelerated growth in communication, the radio spectrum is a limited commodity for the communication industry [3]. A proposed RFI monitoring protocol for characterizing sites is to help detect RFI originating not from satellite and astrophysical objects but terrestrials or airborne sources [4]. This research seeks to design and implement an RFI monitoring system for this Ghana telescope candidate site for continual monitoring of the radio space.

2. Radio Frequency Interference Monitoring System (RFIMS)

Implementation of Remote RFI monitoring system is to aid in monitoring the radio space for spectrum usage around observatories. Noise floor is a determining parameter in astronomy and space exploration due to the sensitivity of the receivers. To achieve an effective radio communication a country must adhere to effective spectrum management system by International Telecommunication Union (ITU) [5]. The design of such manual system in locating a radio quiet zone for SKA site in Argentina was developed. The team used two feed horns for both polarizations, with LNA for each antenna, a power combiner, spectrum analyzer and a custom data logging software.

The advantage of manual RFIMS is the signal combiner and custom data logging for analysis of both polarizations, but much cost is incurred in the design of such manual system. The deployment of two antennas and LNA's makes it expensive to the proposed design this work, using one of each of the component mentioned [6]. The cost in receiver design necessitated the SKA to put-up a team to develop an automated RFIMS on wheels for candidate sites. The design includes two antennas of different operating frequencies with an RF switch-1 to select an antenna of interest, there are two LNA's for the individual antenna to a switch-2 and another signal chain LNA, filter, mixer, local oscillator, the output of switch-2 is connected to an LNA to the spectrum analyzer. This system is automated, mobile with good signal conditioner unit but still employs two antennas. Two antennas mean cost of separate signal channel to switch between measurements-it is an ideal system for well-established organizations [7].

On Giant Meter wave Radio Telescope designed an RFIMS unit with four log- periodic antennas each pointing at North, East, South and West coordinates in the E-plane. These antennas are connected to a switch with LNA, spectrum analyzer to a computer, this manual unit operates by selecting a particular antenna at a time. what is proposed here is an automated RFIMS with one antenna pointing anywhere in-between the cardinal direction for both E/H plane [8]. An experimental RFI monitoring system was setup to aid in the mitigation of RFI at mm-wave band for the 10.4 m Sardinia telescopes but later encountered some challenges when during an upgrade of the receiver to operate at 1.4GHz; at such low frequencies signals are likely to be contaminated with spurious and intermodulation products, which is avoidable by the introduction of cavity filter. An objective of this work is to collect data on the spectrum usage at the telescope site for an informed future upgrade to operate in other frequencies [9].

A sophisticated RFIMS was designed by the institute of telecommunication science for the Federal Aviation Administration (FAA). and the objective was to monitor the spectrum usage for Radar, HF communication, commercial broad- cast system and navigational aids. This unit uses a Loop, Omni, Horn and Log-periodic antenna of different frequency range. This is basically a spectrum monitoring Van for regulatory authority. The unit mentioned here was built for safety to human and equipment, to detect interference against various communication channels at the airport. These various antenna types are purposed for all kinds of emissions but not appropriate for this work and costly as well [10].

Another design of a Van RFIMS was constructed and developed for FAA due to the concerns of Federal Communication Commission (FCC). over spectrum monitoring. The purpose of the new RFIMS was for characterizing the RF signal radiated from transmitters [11]. The unit described includes a basic RFI monitor and a digital spectrometer for comparison in real time with a computer for the Sardinia radio telescope. The advantage of this assembly is the addition of RF spectrometer for comparison of the RF signal with a spectrum analyzer.

The RFIMS design is adequate for detecting interference within the window of observation but over budget for this work [12]. A similar design of RFIMS propose in this research is described here, except there are some additions to the proposed one. These uses a log-periodic antenna, LNA, Noise Diode, RF Switch, RF Cable and the spectrum analyzer. the additions made for the of requirement is the implementation of a Filter to pass desired frequency and an attenuator to protect from damage from high power signals [13]. From the literatures reviewed, most of the RFIMS employed were a maximum of four antennas pointing at the four main cardinal directions, North, South, East and West. This kind of system did impose cost base on the number of antenna and the switch to toggle between antennas for a particular direction of survey.

3. Nkutunse Radio Frequency Interference Monitoring System

The environmental surrounding of the yet to be deployed telescope requires that a continues monitoring of the radio space is carried out weekly/monthly.

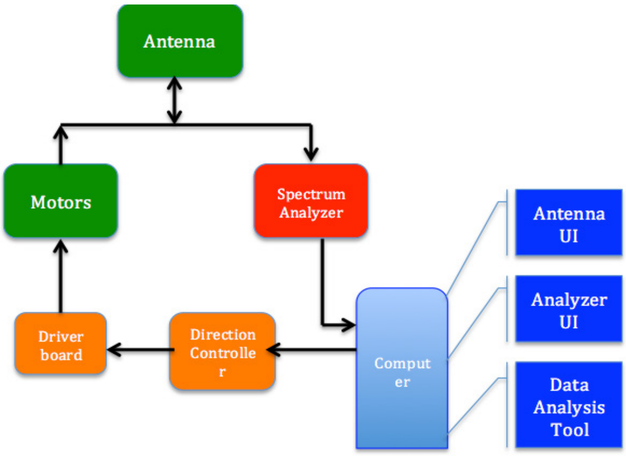

Figure 2. RFIMS Setup

This is because it not a new candidate site but the conversion of a decommission satellite antenna. The proposed design setup of the Nkutunse RFIMS is shown in Figure 2. The initial design of this unit would comprise of a Rohde and Schwarz FSH4/8 spectrum analyzer (9 KHz-22 GHz), a log-periodic antenna 680 MHz – 18 GHz with 3.7 GHz cutoff filter since the telescope would be operating in the C-band. LNA of 40dB for a signal that is weak in nature and a 20dB attenuator to prevent damage to the receiver in the case of high interfering signals. RF cable and a switch between the antenna and LNA to calibrate the instrument with a noise diode of 6dB before an actual measurement is conducted as shown in Figure 3.

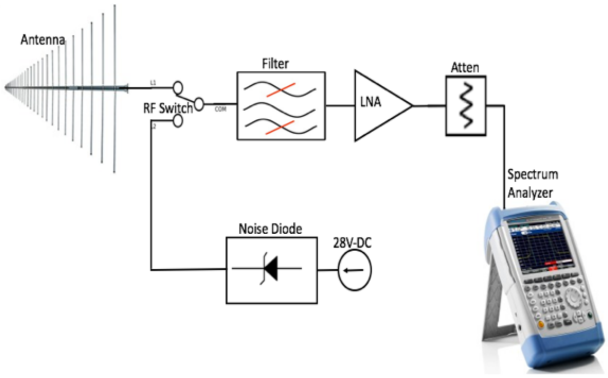

Figure 3. RF Signal Chain Setup

This will be the interim RFI monitoring system for the site due to the current operating frequencies and lack of financial resource. It is subject to upgrade as the demand for other frequency is required in future.

4. Mechanical Design of RFIMS

The mechanical components of the RFIMS constitute the stand, electronic enclosure, polarization, and azimuth subsystems. The stand is a tripod that supports the RFIMS at a height that can be manually adjusted. The electronic enclosure houses the RFIMS circuit boards which provide controls to the polarization and azimuth subsystem's stepper motors. The entire mechanical hardware components are designed with a good material selection to resist the harsh weather conditions such as heavy rain, strong wind and high temperature. This also requires the system to be waterproofed and to withstand wear and tear over the next 15 years.

4.1. Polarization Subsystem

This subsystem determines the antenna polarization in the E/H (Vertical and Horizontal) plane of the radiating source's field position. The unit consists of a stepper motor with shaft extension, supported by three bearing and housed in a tube as shown in Figure 4. The extended motor shaft is coupled to the log-periodic antenna by means of a connector to provide the log-periodic antenna's rotation. The rotating assembly is supported on a polarization-bracket that interfaces with the azimuth subsystem and balanced by a counterweight.

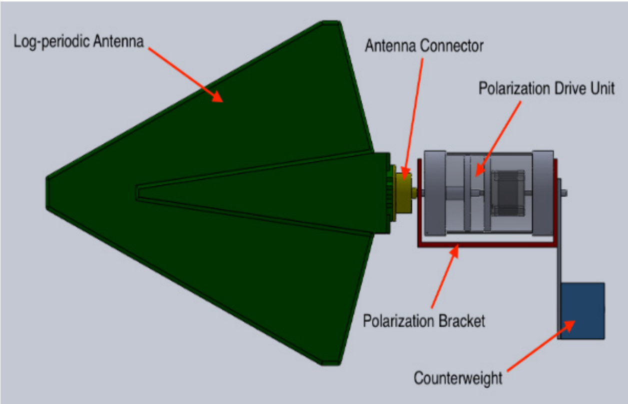

Figure 4. Polarization Subsystem

4.2. Azimuth Subsystem

The mechanics of this unit is similar to the polarization subsystem except that it does not have the log-periodic antenna, bracket and counterweight. The rotating shaft of the azimuth subsystem is coupled to the polarization-bracket by a connector that allows the entire rotation of the polarization subsystem about its vertical axis. Once that is achieved vertical and horizontal polarization is realizable.

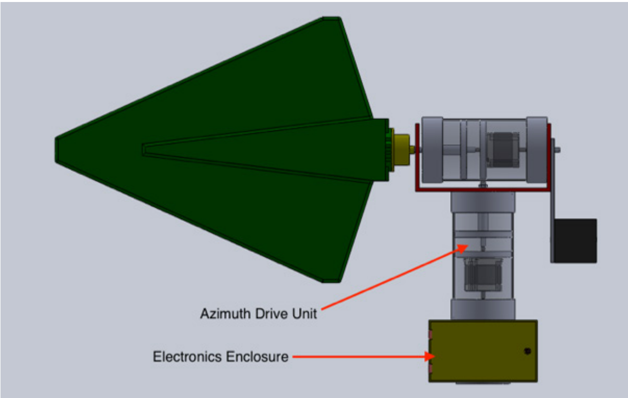

Figure 5. The Azimuth Subsystem and Electronics Enclosure

Figure 6. The Complete RFIMS

5. RFIMS User Interface

The remote usage of this automated system is aided by a user interface designed with Qt-creator [14]. For pointing at a pre-defined position and plane of the radiating emission.

A simple interface design to control the electromechanical part of the antenna steering unit. As seen in Figure 7. it comprises of two basic control button for controlling the polarization (Horizontal and Vertical) plane and the azimuth angles of 45° per step.

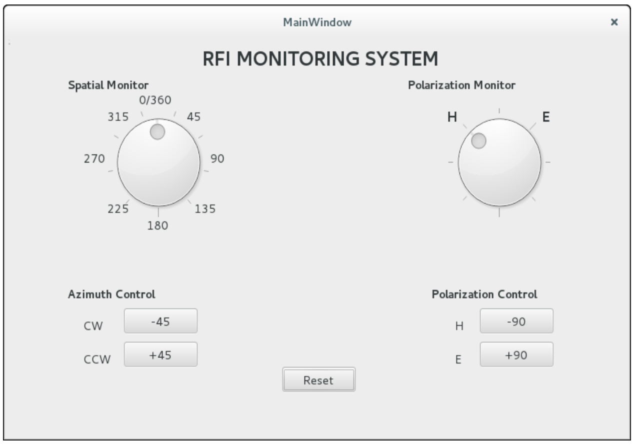

Figure 7. The Automated RFIMS User Interface

6. Control Circuitry

The RFIMS unit is operable by being able to control the azimuth and polarization subsystem. The design of the control circuitry consists of an Arduino board, DRV8825 driver board, power supply and stepper motors for both subsystems. The current setting of the Driver board is dependent on the current consumption of the motors. A simple breadboard connection diagram is shown in Figure 8. using Fritzing software [15].

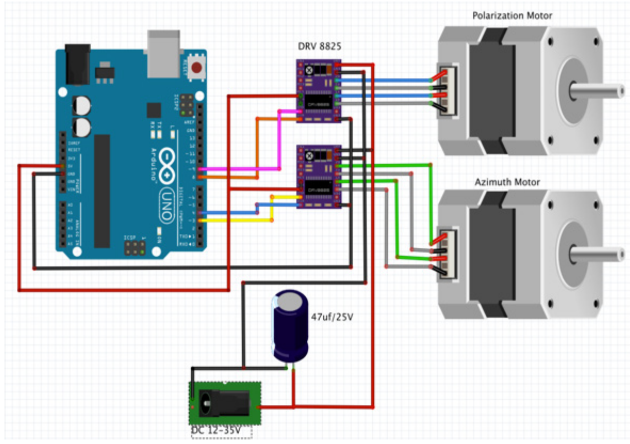

Figure 8. Control Unit Wiring Diagram

The Arduino board ground terminal and the 5 V terminal are respectively connected to the driver board ground terminals and the VDD terminal. Short circuiting the Reset and Sleep pin of the driver boards together minimizes power consumption and predefines the motor home state when idle. Connect any of the digital write pins of the Arduino to the Dir-terminal of the driver board and any of the pulse width modulation pin from the Arduino to the Step pins on the driver board. Pin 2A, 2B of the driver board be connected to Red and Blue cables of motor –A and 1B, 1B to Green and Black cables to motor -B. Finally, connect an external power source of 18V to 30V DC to terminals VMOT and GND through an electrolytic capacitor for the motors.

6.1. Precision Stepping of RFIMS

Accuracy can be defined as the difference between a theoretical and actual rotor position as a percentage of the step angle. National electronics and manufacturing association (NEMA) stepper motors has a standard accuracy of $\pm 5\%$ and a step angle of 1.8 degree for a step motor, which are operated with a series of input pulses, since each pulse propels the rotor to advance one step [16].

The design objectives are not to drive the device to it resonant frequency when it would cease to turn and this is carefully considered in the choice of driver method. Precision position/ speed control is achieved with computer control stepping and this makes the best choice for precision motion control application.

6.2. Motor Operation Mode

The NEMA-23s is a 57BYGH420 model with 6Lead unipolar stepper motor, but for the purpose of this work it is configured to operate as a 4Lead bipolar stepper motor. A 4Lead bipolar configuration is achieved by not connecting the center tape of coil, once the color code of the coil terminal is known. With the 6Lead wires table shown in Figure 9. the color White and Yellow are the common terminals to Red, Blue, Green and Black respectively. If the common terminals are open-circuited, a 4Lead bipolar stepper is obtain looking at the color code table for a 4Lead wire.

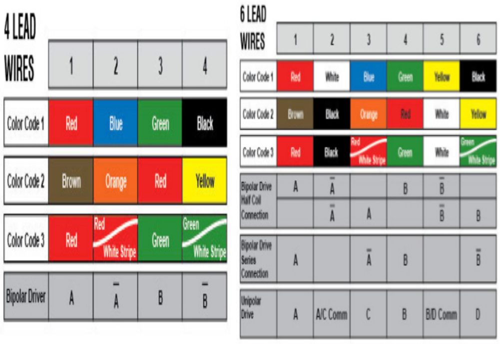

Figure 9. Wiring Configuration [17]

As shown in the Figure 10. above the 4Lead wire configuration is obtained from the 6Lead wire by ignoring the connection of the common coil terminals.

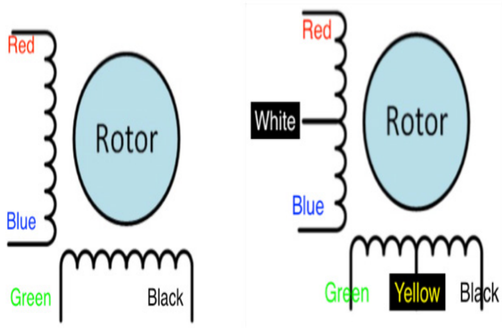

Figure 10. A 4 Lead wire from a 6 Lead

The Step-terminal pulse of the driver excites the coils and the Dir-terminal pulse regulates its direction been clockwise or counter-clockwise.

6.3. State Machine Function

A state machine describes a motor flow chart. when an application is initiated or when it is in its idle state, the state machine is in the state “Stop”. When the system is initializing a new state is set and a timer interrupt is enable, by moving one step the state machine goes to ACCEL, when the desired speed is achieved the state change to DECEL.

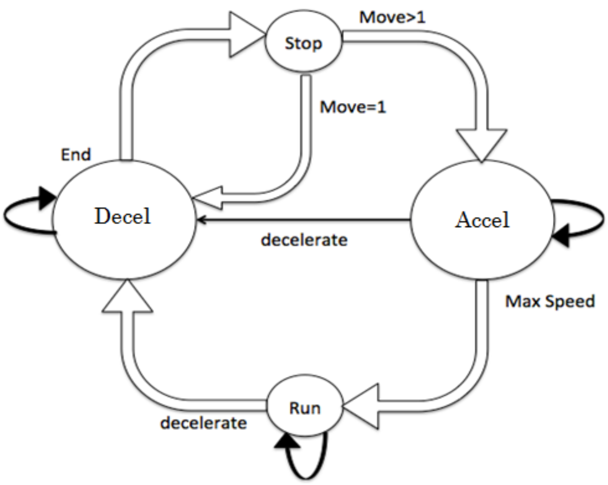

Figure 11. State Machine [18]

The motor is said to be at constant speed when the state is set to RUN, until the state is set DECEL and the speed reaches zero, state changes to Stop [18].

6.4. Step per Revolution

The stepper motor plays a major role in this method; the type of motor is useful in determining the number of steps required by the motor to complete a cycle, with a motor of 1.8-degree step size, the following equation is used to determine the number of step per revolution.

$$step_{rev} = \frac{1Rev}{step_z} = \frac{360}{1.8} = 200step/rev. \quad (1)$$

For antenna polarization in E/H plane its step angle is obtained by multiplying the $step_{rev}$ to the number of micro stepping per revolution. And so in achieving 90^o angle for a full revolution would be, where (*P-Angle*) is Polarization angle:

$$P\_Angle = \frac{Step_{rev}}{microsteping} = \frac{200}{1/4} = 50step/rev. \quad (2)$$

Considering the antenna pattern it is recommended that monitoring be done at an angle of 45^o for a full revolution of 360^o, with (*A_angle*) as azimuth angle of rotation.

$$A\_Angle = \frac{Step_{rev}}{microsteping} = \frac{200}{1/8} = 25step/rev. \quad (3)$$

There are several other equations in achieving proper setup of a machine but this is appropriate for this work since it does not involve gear ratio and lead crew [19]. The selection for step size per revolution was as a result of the orientation of the antenna and it beam pattern. This is so because the suspected interfering sources are coming from the Telecom mast around, with a distance of 6 km from the monitoring point and the interfering sources. This makes the device sensitive since the beam is widened toward the direction of interfering signal sources.

7. Cost Analysis of Designed RFIMS

The objective of every design is aimed toward cost and performance, since the conversion of the 32m dish into radio telescope has no budget allocated for the design of an RFIMS. The cost of log-periodic antenna HL033 of 80MHz - 2GHz is €5,000 and a spectrum analyzer of 9KHz – 20GHz also is €18,000. The cost of design and implementing this system is $500.00 been mechanical, electronics and enclosure point of view, excluding the two borrowed items (e.g. log-periodic antenna and a spectrum analyzer) from the SKA-AVN group.

The cost of state of the Art Mobile Van RFIMS is $1.2M, for which some function might not be needed for the work at hand [20]. Summing the borrowed items cost and cost of designed system comparatively, the proposed design is less cost effective for the task.

8. Results and Discussion

The plots in Figure 12 and Figure 13 are obtained using the automated RFIMS pointing at both polarization of the frequency range of interest. With the 20MHz window of the frequencies, Figure 12. Shows no activating of interference but Figure 13. has interference sources at 4.92GHz and 5.02GHz of the operating band window. These sources would be mitigated in the final receiver design but those other detected interferers are beyond the operating range.

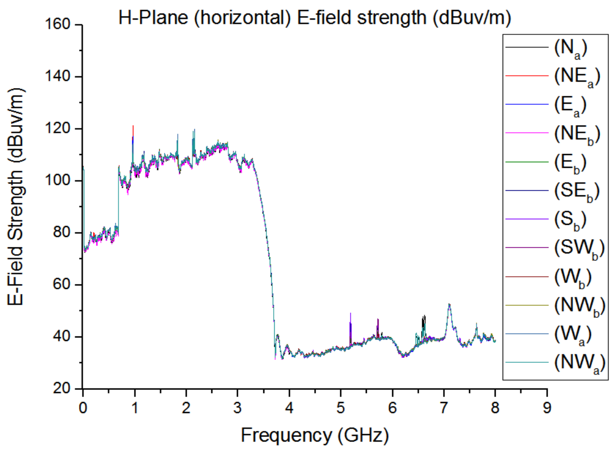

Figure 12. Interference Detection in H-plane

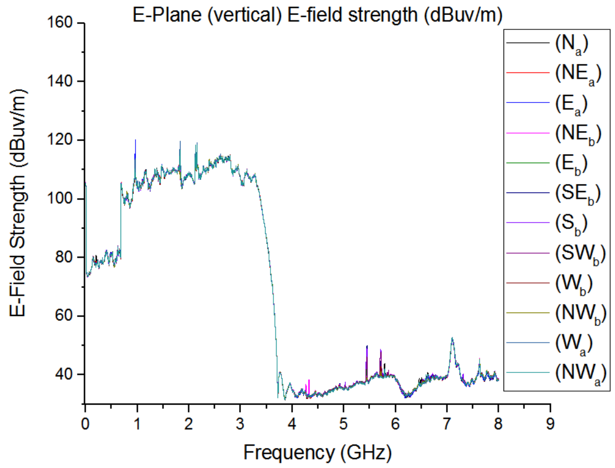

Figure 13. Interference Detection in E-plane

There are lots of interferences on the monitored frequency spectrum, with which the direction of an interfering frequency is identifiable with the automated RFIMS aided with the cardinal direction of a compass. The angle of pointing is dependent to the measurement site for which the automated system program control codes is modifiable to suit the measurement plan of the candidate site.

9. Conclusion

The exact direction of an interfering signal is based on its measured power level of the detected interferer and the quadrant of which the signal is measured in relation to the cardinal compass. Results obtained from the measurement were consolidate, manual and automate survey RFI report. The RFIMS repeatability would yield reliable results, making core sites feasibility test comprehensive. This RFIMS design is implementable for continues monitoring of interference and can be used for interference shielding test purposes.

References

[1] Joseph A. K. Nsor, Abdul-Rahman Ahmed, Joyce Koranteng-Acquah, Sani Ellis Mubarak "Investigation of Potential RFI Threats to Ghana Radio Telescope Observatory-Nkutunse" International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181

[2] Ellingson, S.W., RFI mitigation and the SKA. In *The Square Kilometre Array: An Engineering Perspective* (pp. 261-267). Springer Netherlands, 2005.

[3] Dunn, S.B., A study of the SA SKA RFI measurement systems (Doctoral dissertation, University of Cape Town), 2008.

[4] Ambrosini, R., Beresford, R., Boonstra, A.J., Ellingson, S., Tapping, K. and Terzian, Y., RFI measurement protocol for candidate ska sites. *SKA Memo Series*, 2003.

[5] Banks, Paul Russell. *Characterisation of the radio noise environment in New Zealand*. Diss. Auckland University of Technology, 2009.

[6] Hase, H., Gancio, G., Perilli, D., Larrarte, J.J., Guarrera, L., Garcia L., Kronschnabl, G. and Plotz, C., 'Radio Frequency Interference Observations at IAR La Plata'2012.

[7] Petrick, G., 'Radio frequency interference measurements', Engineer IT Magazine, (8), 2006, pp.32-36.

[8] Joardar, S., 'RFI monitoring system of GMRT and radio interference analysis on various radio astronomy bands', Proceedings of the XXVIIIth General Assembly of International Union of Radio Science, 2005.

[9] K. Jeeva Priya, Danish Roshi 'An experimental to develop RFI mitigation techniques for radio astronomy', Reman Research Institute, Bangalore 560080.

[10] Raush, P., Kub, J., Bedford, B., Sparkman, T., Davidson, S. and Gray, E., 1998, August. 'The radio frequency interference monitoring system (RFIMS)', In Electromagnetic Compatibility, 1998. 1998 IEEE International Symposium on (Vol. 2, pp. 679-684). IEEE.

[11] Raush, P., J. Kub, and E. Gray. "Automatic radio frequency monitoring measurements." *1999 IEEE International Symposium on Electromagnetic Compatability. Symposium Record (Cat. No. 99CH36261)*. Vol. 2. IEEE, 1999.

[12] Melis, A., Gaudiomonte, F., Barbaro, M., Concu, R., Migoni, C., Trois, A. and Valente, G., 2014, July. 'An RFI monitoring system based on a hybrid configuration for radio astronomy', In SPIE Astronomical Telescopes+ Instrumentation (pp. 915338-915338). International Society for Optics and Photonics.

[13] Millenaar, R.P. and Schilizzi, R.T., 'SKA site spectrum monitoring, measurement program and data processing' 2011.

[14] The Qt Company Bartel Jungin Aukio D3A02600 Espoo, Finland. www.qt.io.

[15] Fritzing UG, Paul-Lincke-Ufer 39/40 10999; Berlin, Germany. www.f ritzing.org.

[16] Shinano Kenshi Corporation, 6065 Bristol Parkway, Culver City, CA. www.shinano.com.

[17] LIN ENGINEERING, LLC 16245, Vineyard Blvd, Morgan Hill, CA, 95037. www.linengineering.com.

[18] MIT Open Course Ware. 'State machine', 145 Broadway Cambridge, MA02142, Spring 2011-April, 25 2011. www.ocw.mit.edu.

[19] A Quick CNC 'Stepper Motor Calculation', Denver Colorado. www.aquickcnc.com.

[20] EMI Technologies "Frequency Surveillance System" www.emitechnologies.com.