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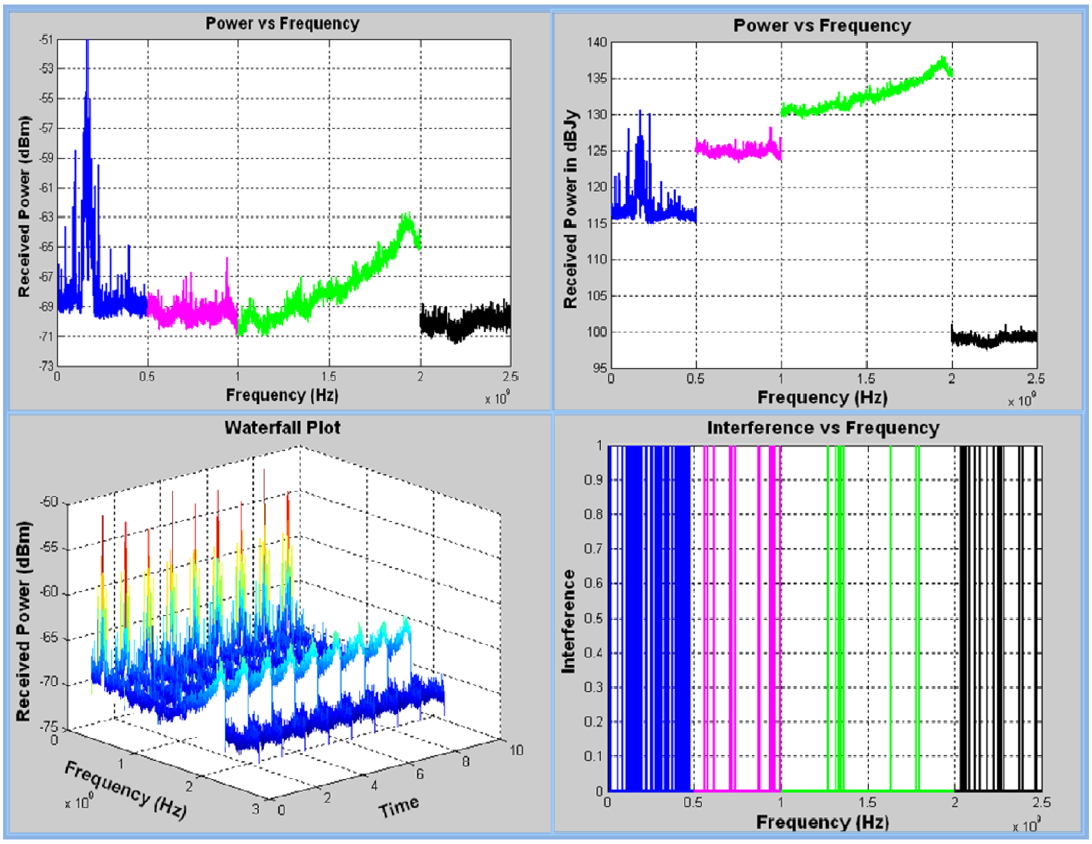

RF Interference Monitoring for the Onsala Space Observatory

Master of Science Thesis (Communication Engineering)

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Göteborg, Sweden, 2010.

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ABSTRACT

With the continuous and rapid developments in wireless services and allocation of radio frequency spectrum to these services, huge interferences have been observed in the field of radio astronomy. According to the international regulations, parts of the spectra are reserved for radio-astronomical observations. Man-made signals entering the receiver chain of a radio telescope have much higher power compared to natural or passive signals received at the radio telescopes. Passive signals received at radio telescopes are normally 60 dB below the receiver noise level. Active signals generated by man-made wireless services pollute the natural emissions by completely masking them due to high signal strength. The cosmic radiation is determined by the fundamental laws of physics, thus the frequencies are fixed and cannot be changed. So interferences created by active services lead to wrong interpretations of the astronomical data.

The present thesis deals with RF interference monitoring system for the Onsala Space Observatory. As part of the thesis, a software application has been developed, which communicates with different type of digital receivers (spectrum analyzers) attached with antenna controlling hardware to control omnidirectional and steerable antennas. A steerable antenna is used to find the direction of interference source by moving the antenna in azimuth and elevation direction. The detection of interference signals is done using the recently proposed GSK estimator which is state-of-the-art methodology for detecting interferences at observatories. The interference finding criteria is based on the decision thresholds of the variance of the received power levels. If the variance exceeds a threshold value on a particular frequency, interference is marked on that frequency.

The RFI monitoring system developed in this thesis work reads the spectra of a number of different desired frequency spans associated with particular antennas. This application supports four channels and each channel can be associated with any of the three omnidirectional antennas and a steerable antenna. When the measurements are completed, a file containing frequency points, power levels and the indication of any interference is saved and plots are generated. These plots include received power levels (in dBm and Jansky units) and the interferences at particular frequency. These plots are also replicated to a web server and can be viewed on HTML page for remote monitoring. The RFI monitoring system can also be used to analyze the offline data by generating different plots for a particular antenna associated with a particular channel.

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LIST OF ABBREVIATIONS

A	Ampere Current
CPP	C++
CRT	Cathode Ray Tube
DBA	Database Administrator
FFTS	Fast Fourier Transform Spectrometer
FPGA	Field Programmable Gate Array
GPIB	General Purpose Interface Board
GSK	Generalized Spectral Kurtosis
GSM	Global System for Mobile Communication
GUI	Graphical User Interface
HTML	Hyper Text Markup Language
IBOB	Interconnect Break-out Board
IF	Intermediate Frequency
LNA	Low Noise Amplifier
LO	Local Oscillator
LOFAR	Low Frequency Array
MHz	Mega Hertz
OSO	Onsala Space Observatory
RFI	Radio Frequency Interference
SK	Spectral Kurtosis
SKA	Square Kilometre Array
SQL	Structured Query Language
V	Volts
VCO	Voltage Control Oscillator
VHF	Very High Frequency
Wi-Fi	Wireless Fidelity

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

CHAPTER 1

RADIO ASTRONOMY & RF INTERFERENCE MONITORING

1.1 THESIS BACKGROUND

Astronomers observe various astronomical objects, e.g. galaxies, stars and quasars, to improve the understanding of the universe and its evolution. These objects emit radiations over a wide range of wavelengths, from the radio to the optical regime and beyond. The emitted radiations from these sources travel on predefined spectral lines that cannot be changed. Therefore, there are always chances of interference of signals at the same frequency from two different sources both from astronomical objects and from normal man-made wireless services. Due to the technological advancements in wireless regime, the use of the electromagnetic spectrum is increasing day by day. Different services like mobile communication and broadcasting use different frequency bands.

In normal wireless communication, we can transmit and receive signals. We have complete control over the signals. We can increase the transmit power of the signals. Therefore, services associated with such communications are referred to as active services. But we have no control over the signals emitted through cosmic or celestial objects. Their strength gradually decreases after travelling long distances and when they reach a telescope, the signal strength is reduced to 30 to 60 dB below the noise floor of a radio-astronomical receiver [1]. These signals are therefore termed as passive signals and need low noise amplification before any further processing. The noise floor varies from receiver to receiver due to different noise figure. For instance, if the noise floor of a receiver e.g. Agilent, is -90 dB then signals received from cosmic sources have strength even below this noise floor.

The signal strength of active services is normally 20 dB above the noise floor [1]. A GSM signal has signal strength of -65dB which is above the noise floor (-90 dB). Active services operate in frequency bands which are also occupied by passive services. For instance, low frequencies (50 to 600 MHz) are important for pulsar observations. At these frequencies, fixed/mobile or FM services populate significant part of the spectra. When these signals interfere with the signals received from cosmic sources, because of high signal strength, they contaminate the data or completely mask the astronomical signals and result in misinterpretation of the radio-astronomical data.

For passive services, highly directed antennas are used to receive the signal while broadcasting omnidirectional antennas are used for active services to transmit and receive signals. Similarly, in optical astronomy, it is hard to do optical observations in densely populated regions due to man-made light pollution. Therefore, there is a great need of developing RFI monitoring systems which can detect and record the interferences and astronomers could have knowledge of these interferences before the interpretation of astronomical data.

1.2 RADIO ASTRONOMY

In radio astronomy, we study celestial objects at different radio frequencies. The first ever detection of radio waves from an astronomical object was made in 1932 by Karl Jansky during observing noise levels in long distance communication links. He found cosmic radio noise coming from the Milky Way.

Later on different sources of radio emission were identified which include stars and galaxies, as well as entirely new classes of objects, such as radio galaxies, quasars, and pulsars.

1.2.1 Frequencies of Interest

Low frequency bands are of higher interest for radio astronomers today for the study of low frequency radiations from different astronomical sources like pulsar, weather prediction etc. Different projects like LOFAR and SKA are in a development phase to study the universe in these low frequency bands. The LOFAR project [21] aims at measurements of signals below 250 MHz with high sensitivity and will use large arrays of parabolic and omnidirectional dipoles all over Europe. The SKA project [22] is in a development phase and aims at 50 times more sensitivity than any other telescope. It will observe the sky ten thousand times faster than before and will provide coverage from 70 MHz to 10 GHz.

1.2.2 Instruments Used to Receive Astronomical Data

To receive astronomical signals, large telescopes with very sensitive and highly directed antennas are used. These antennas have very high gain to compensate the low received signal power. The signals are usually amplified by LNAs and then the signals are passed to different receivers. In radio astronomy direct or heterodyne detection (spectrometer) mechanisms are used to receive signals. The main components of a radio astronomy receiver are shown in Figure 1.1.

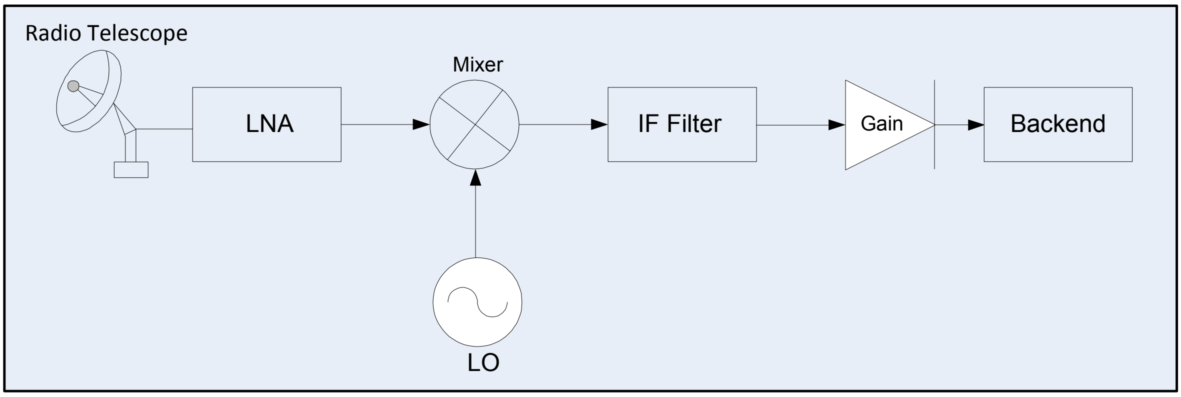


Figure 1.1: Block Diagram of a Typical Radio Astronomy Receiver.

1.2.3 Impact of Interference Signals

Normally, in HF, VHF, L (1-2 GHz) and S (2-4 GHz) bands, different FM radio, mobile and other wireless services like Wi-Fi (Wireless Ethernet) operate. The HF band is popular for direct, long distance shortwave radio broadcasting. The VHF band is ideal for short distance terrestrial communication and is less affected by atmospheric noise and interference as compared to HF band. The UHF band is used for two-way radio communication like mobile and other wireless networks.

Since the low frequency bands carry many useful astronomical signals, these man-made signals create a huge interference with these signals. If the signals from both sources have the same frequency, a frequency overlap occurs. Even if both have different frequencies, inter-modulation in LNA results in masking of the astronomical signal.

1.3 SOLUTIONS FOR RF INTERFERENCE MONITORING

RFI present in astronomical measurements leads to erroneous interpretation of data. Sources of RFI include spurious signals, spread-spectrum signals overlapping the used bands or out-of-band emissions not properly rejected by the pre-detection filters due to their finite rejection capabilities. In recent years, different techniques to detect the presence of RFI in astronomical data have been proposed. They include time or frequency domain statistical analyses of the received signal which in the absence of RFI must be a zero-mean Gaussian process. Statistical analyses performed to date include the calculation of the kurtosis and the normality tests of the received signal [2]. Recently, a novel approach called GSK estimator has been developed for excision or monitoring of RFI from a received signal. Many implementations and variants of this algorithm have been published online [4]. Different hardware solutions like FPGA-based FFTS solutions have been implemented. One such solution is the implementation of a GSK estimator with the IBOB [3], [12]. There are some spectrum analyzers from different vendors also available for monitoring RFI in received data at radio telescopes. For this thesis work, I have used Anritsu MS2602A and HP Agilent E4407B spectrum analyzers for monitoring RFI at OSO. They will be discussed in detail in Chapter 2. This thesis combines the functionalities of GSK estimator and spectrum analyzers to identify new signals at OSO.

1.4 THESIS MOTIVATION

The main factors which motivated me for this thesis are to:

- Get knowledge about RFI at OSO.
- Create a database so that it could be used for checking any interference later.
- Provide online and offline monitoring of data.

With implementation of this thesis, astronomers at OSO will be able to monitor the system remotely through web or in LAN environment. There will be minor physical interaction with the hardware. Results will be available in terms of different plots. The offline analysis application will also generate plots of the saved data in the database.

1.5 THESIS ORGANIZATION

This thesis work consists of three major parts.

The first part is to manage different antennas and get the data from the activated antenna. There are three omnidirectional antennas to monitor the presence of RFI. If RFI is detected, a steerable antenna will be used to find the direction of interference source by moving the antenna in azimuth or elevation direction. The RFI monitoring system switches between the antennas depending on the channel they use. This part is purely implemented in C++ and only it is called from Matlab using MEX function routines to bridge the gap between Matlab and C++. This application also sets parameters for the spectrum analyzer and the application runs on a stand-alone computer connected in LAN environment with the analyzer. All communication with receivers is implemented in Matlab R2010a. After a certain time, data received from the spectrum analyzer is plotted for analysis.

In the second part, the generated data are saved in a proper sequence and proper file format. Files are saved in different folders created date-wise and the generated plots are replicated to a web server for online monitoring through an HTML page. The web page refreshes automatically after sometime to show the most recent plots.

In the third part, this application helps to analyze the offline stored data. Different plots of the offline data are available to view using this application.

The rest of the report is organized such that all the details of this thesis are well demonstrated. Chapter 2 briefly discusses the available RFI receivers. Chapter 3 covers the RFI monitoring system design and its working. Chapter 4 discusses how the antennas are being managed by the application and which hardware is involved for managing the antennas. Chapter 5 interprets the results in the form of different type of plots. Chapter 6 deals with analysis of offline data. Chapter 6 also covers the representation of results online on HTML page and in Chapter 7 the thesis is concluded with some recommendations for future improvements.

CHAPTER 2

RF INTERFERENCE MONITORING RECEIVERS

2.1 INSTRUMENTS FOR THE ANALYSIS OF RF INTERFERENCE

Receivers from different vendors are available with different features and frequency spans. All the receivers take the RF signal as an input and show it on a display after processing. The processing of signals involves some necessary components inside the spectrum analyzer as shown in the diagram below.

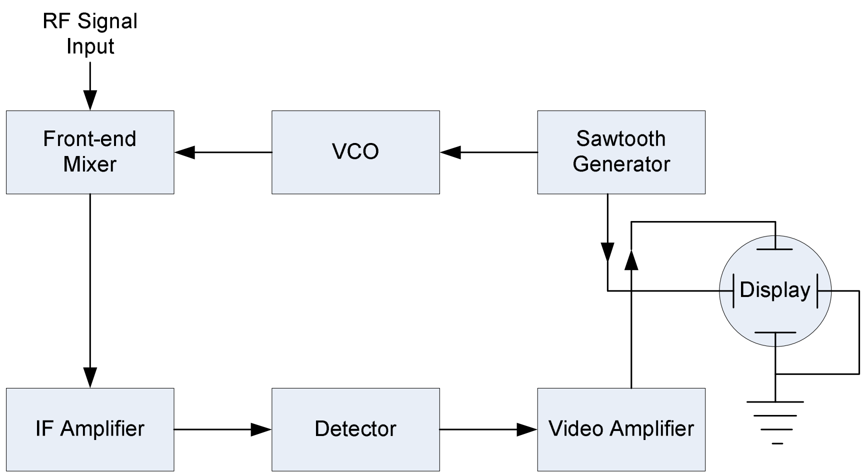


Figure 2.1: Block Diagram of Heterodyne Spectrum Analyzer.

The front-end mixer use Voltage Controlled Oscillator (VCO) to down convert the RF input signal. Band pass filters are also used to accept or reject the particular bands of frequency [23]. Some of the receivers used for RFI detection are discussed in the following sub-sections.

2.1.1 Anritsu MS2602A

The Anritsu MS2602A spectrum analyzer is a wideband, very sensitive receiver. It works on the principle of super-heterodyne receiver. It has been designed to meet the future needs of expanded use of frequencies in the RF bands. The instrument covers frequencies between 100 Hz and 8.5 GHz and it can analyze frequencies up to three to five times the higher harmonics range of cordless telephones (1.9 GHz), digital car phones, portable phones (1.5 GHz) and private mobile telephones (1.5 GHz). It has built-in GPIB ports available for communication with other devices. Port one can be used for communication with a computer through a GPIB box or GPIB card, and the GPIB box supports Ethernet interface for connectivity with computer. The second port can be used to communicate with other devices like printers etc.

This analyzer has a high signal purity and low distortion. Time domain and burst measurement functions allow analysis of various burst signals including TDM based radio communication systems.

More information about the functionalities of this analyzer can be found in [9]. Figure 2.2 shows the front-end display of the analyzer.

Figure 2.2: Anritsu MS2602A Spectrum Analyzer [9].

2.1.2 HP Agilent E4407B

The E4407B spectrum analyzer, like other receivers, can be used for site monitoring to verify the transmitter signal strength. It works on the principle of super-heterodyne receiver and covers frequencies from 9 KHz to 26.5 GHz. It can also be used to monitor interference at specific frequencies of interest. It provides antenna isolation, co-channel interference, adjacent channel power, occupied bandwidth, intermodulation, microwave or satellite antenna alignment, and the characterization of components.

It provides a GPIB interface for communication with other devices like computer and printer etc. Through the GPIB interface, by using a predefined set of commands, the analyzers can be controlled remotely with a computer. More details about this analyzer can be found in [7].

Figure 2.3: Agilent E4407B Spectrum Analyzer [6].

2.1.3 Rohde & Schwarz ESMD

The ESMD is a wideband radio monitoring digital receiver which supports 9 KHz to 26.5 GHZ frequency range. It has a high resolution bandwidth of 20 MHz. It also provides very high frequency scans (up to 100 GHz/second) and memory scans (up to 1000 channels/second). It provides fast detection of signals with higher order of measurement and demodulation accuracy and a large (8.4") XGA colour display. It can also detect wideband and all types of interference sources reliably.

Figure 2.4: R&S ESMD Spectrum Analyzer [5].

The signal processing is carried out by means of powerful processors and FPGAs. It is done in real-time using high filter bandwidth (up to 20 MHz, which can be extended to 80 MHz) with FFT spectrum calculation and the results are displayed on a wide and coloured screen in the form of spectrum and waterfall plots. It can also be expanded to a direction finder by installing an additional direction finder kit. It has a separate receiving path for different frequency bands and antennas which can be controlled manually or automatically by the analyzer. The GX430 analysis software available with the analyzer is used for analyzing the complex signals. This software has a number of functions used for signal detection and analysis such as classification in terms of modulation mode, vector analysis, bit stream analysis and decoding. For online analysis, digital data are transferred in real-time via LAN from the analyzer to the computer. For offline analysis, the software accesses data which are saved internally in the receiver. All receiver functions can be controlled remotely via the LAN interface. All measurement results are transferred in digital format via this interface. The analyzer has two Gbit Ethernet interfaces and five antenna inputs for HF, VHF, UHF and SHF. Analog AM/FM data is transferred via fixed interfaces [5].

2.1.4 Comparison of Receivers

Though analyzers from Anritsu, Agilent and Rhode & Schwarz have been discussed briefly above with all their features, there are many other things that need to be compared as well. Table 2.1 below presents some key differences between these analyzers.

	MS2602A	E4407B	ESMD
Minimum Frequency	100 Hz	9 KHz	9 KHz
Maximum Frequency	8.5 GHz	26.5 GHz	26.5 GHz
Minimum Sweep Time	20 ms	1 ms	20 GHz/s
Maximum Sweep Time	1000 s	4000 s	100 GHz/s
Minimum RBW	10 Hz	10 Hz	100 Hz
Maximum RBW	3 MHz	5 MHz	20 MHz
RBW Steps	1/3/10	1/3/10	1/3/10
Minimum VBW	1 Hz	1 Hz	1 KHz
Maximum VBW	3 MHz	3 MHz	20 MHz
VBW Steps	1/3/10	1/3/10	1/3/10
Input Impedance	50 Ohm	50 Ohm	50 Ohm
Maximum Trace Points	1002	8192	2048
Display	7" Colour Green CRT	Colour 13.8-cm VGA TFT	8.4" XGA Colour Display

Table 2.1: Comparison of Radio Monitoring Receivers.

By looking at the features of the ESMD, it is evident that the ESMD is the best among the family of radio monitoring analyzers available. It has high resolution bandwidth and provides real-time signal processing with FFT spectrum calculation. Coloured display and the use of waterfall plots helps in locating the presence of RF interference more precisely.

2.1.5 FFTS Based Instruments for RFI Monitoring

Different hardware-based FFTS solutions have been proposed for RFI monitoring. They are flexible, cheap and consume low power. The IBOB is an FPGA-based processing board for digital signal processing. It has two Z-DOK connectors to which a variety of I/O boards like ADC and DAC can be connected. The IBOB has a Xilinx Virtex-II Pro 2VP50 FPGA and is used in radio astronomy applications primarily for digitizing data, down converting, filtering and FFT operations, and transferring these data over a 10Gbit Ethernet interface to computer. Recently, spectral kurtosis based solutions have been proposed using data (received signals) collected from IBOB receivers [3]. It is considered to be a very efficient method of detecting and mitigating RF interference from the astronomical data.

2.2 INSTRUMENTS USED FOR THESIS

Initially, it was planned to use the ESMD digital analyzer for the thesis work but due to unavailability of ESMD at OSO, I tested the system with the MS2602A and the E4407B analog analyzers. I used them to connect antenna controlling devices. Only one antenna is activated at the time, its polarization is selected and then the signals of that activated antenna are received at the analyzer. Data from the analyzer are transferred to a computer through a GPIB interface and then the data are checked for interference, saved and plots are generated for analysis. All this is done through a GUI-based application, developed in Matlab, which communicates with the analyzers through the same GPIB interface. This application can control different parameters of the analyzers by setting them in the GUI.

2.3 SETTING INTERFERENCE DETECTION CRITERIA

Interference is encountered when a signal with higher power arrives at a certain frequency. So there are many sources of interference. It could be due to another carrier carrying data of a different service or it could be noise. For detecting the interference, we have to measure the signal power at a certain frequency consistently at different times. If there is a sudden change in received power then it is considered to be interference. Setting interference criteria depends on differences of power levels at a certain frequency at different time instances. So it depends on the requirement. One can set a difference of 10 dBm in received power levels. Algorithms like GSK algorithm check the mean of the variance of the received power signals and help to remove the noise from the signal as well if the signal power is quite high. This is discussed in the next section below and in later chapters.

2.4 SPECTRAL KURTOSIS ALGORITHM

The GSK algorithm has been proposed in many solutions for interference detection and excision. Many variants of this algorithm have been presented so far. It is likely to become an ultimate solution for RFI excision for radio astronomy [12]. It is a statistical approach for detecting and removing RF interference in radio astronomy data. Recently, its integration with IBOB-based radio astronomy receivers has been tested and the results are quite impressive [4]. It not only removes interference but also removes noise from the signals as well [3]. It statistically checks the mean of the amplitude of variances of the received signal powers and calculates the upper and lower thresholds. If there is any deviation from the marked thresholds, it declares it as interference. The mean is always around 1. The algorithm considers interference-free signals as gaussian signals. Any interference is considered to be as non-gaussian interference.

CHAPTER 3

HARDWARE MANAGEMENT

3.1 ANTENNA MANAGEMENT UNIT

The antenna management unit consists of a RIO-47200 to generate TTL pulses of +5 V, LNAs for the omnidirectional antennas, a coaxial switch for activating the antennas, a relay driver board for providing 28 V DC to coaxial switch, and three power supplies. It is shown in Figure 3.1.

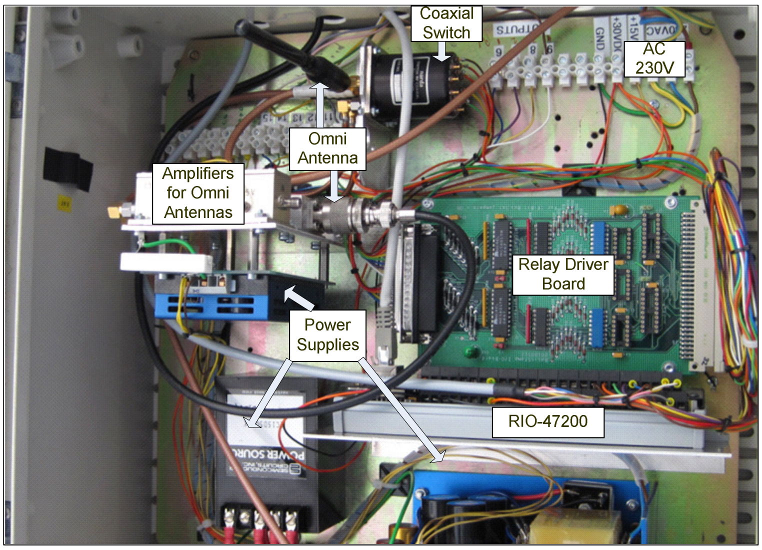


Figure 3.1: Main Antenna Management Unit with Power Amplification.

One power supply gives +5 V power to the RIO. The second provides +12 V to the LNAs and the third supply gives +28 V to the relay driver board. The relay driver board provides +28 V to the coil of coaxial switch. One LNA operates in VHF band (5-1000 MHz) and the second operates in UHF band of 1000-2000 MHz. There is no LNA for the HF band antenna. The Steerable antenna covers frequency band up to 18 GHz.

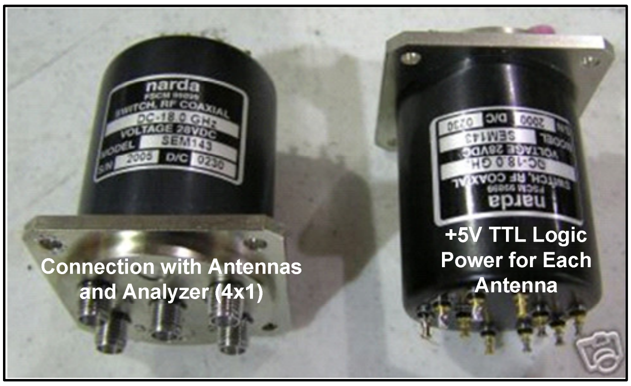


Figure 3.2: Coaxial Switch for Antenna Activation [14].

The relay driver board takes input in the form of TTL pulses from RIO and transfers them to the coaxial switch for antenna selection. Similarly, the polarization of the antenna is activated. The switch port selection is done by TTL logic high. The required current levels for the switch are from 0 to 1.6 mA [14]. The coaxial switch can support 0-18 GHz frequencies.

3.2 STEERING ANTENNA AMPLIFICATION UNIT

The antenna management unit can provide up to 1 A current. The rotating antenna has two motors, one motor for movement in the azimuth direction and the other for movement in the elevation direction. These motors cannot work on the +5 V power provided by the RIO. They need at least ±18 V (±13.8-24 V) with a continuous current of ±3-5 A and a peak current of ±4 A [15]. Therefore, a separate power amplifier unit is attached to the main unit to provide the power required for the antenna motors. This unit consists of two power supplies, one for each direction, and is shown in Figure 3.3. The ports DO11-DO14, OP1A and OP1B of RIO are connected with this power unit. Their connection arrangement is mentioned in Table 3.1. The front of the power unit has two connectors at the left side for the connection with the azimuth motor and two connectors at the right side for connection with the elevation motor. I have used the SALSA antenna amplifier box and more information on this can be found in [26]. By changing the polarity of the power supply, the direction of movement of the antenna motor can be changed. To rotate the motor clock-wise in north south direction (right), a control signal from RIO enables a positive polarity. When this signal is disabled, polarity is changed to negative and the motor starts moving in counter clock-wise (left) direction.

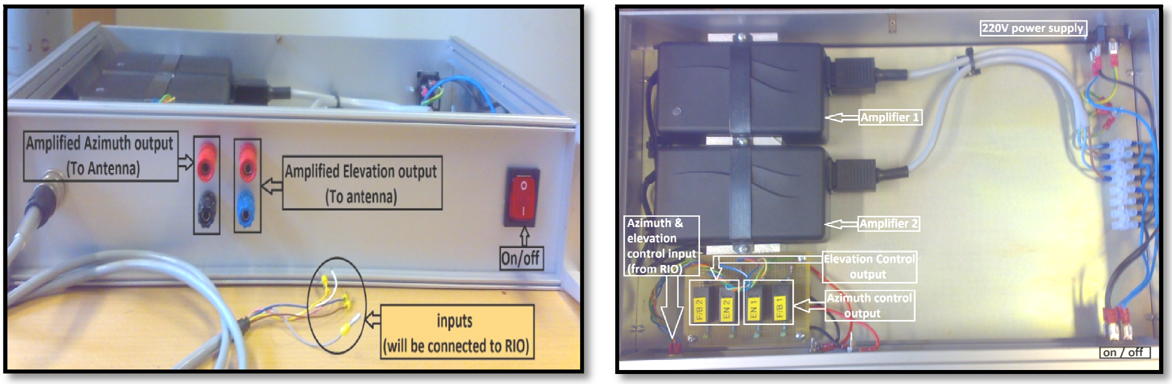


Figure 3.3: Front and Inside View of Amplifier for Antenna Rotator [26].

3.3 ANTENNA MOTORS

The AlfaSpid AZ/EL rotator is a heavy-duty antenna rotator which is designed to run large antennas. It can be mounted in different configurations [15]. Two windshield motors are capable of driving the antenna in azimuth and elevation direction. The motors need an input voltage of 13.8-24 V and input current of 3-5 A with peak starting current of ±4 A [15]. The complete rotation time in azimuth is 120 seconds with 12 V, and in elevation it is 80 seconds with 12 V. These motors have predefined limit switches which restrict the maximum rotation to 360^{o} in azimuth and 100^{o} in elevation. Each motor has a gearbox to drive it. A 12 leg wheel is mounted on a shaft of gearbox in each motor which moves with the movement of an antenna. Antenna rotation or reset depends on the feedback pulses generated by the motors. Feedback pulses are discussed in the Chapter 4.

3.4 RIO-47200 MOTION CONTROLLER

For controlling the motors and reading feedback pulses, RIO-47200 has been used in this thesis. It is a product from Galil Motion Control which provides low cost, intelligent and compact I/O solution. It has a 32-bit processor and NVRAM for storing the information. The unit is shown in Figure 3.4. It has 8 analog inputs and 16 optically isolated digital inputs and outputs. The digital outputs (+ 5 V TTL pulses) can be used for controlling motors, and digital inputs can be used for reading feedback pulses. RIO is used for arithmetic and logical processing, process control loops and timers. It can be communicated over Ethernet or with RS232 interfaces. It can receive power from Power-over-Ethernet (PoE) or from an external power supply of 18-36 V DC [16].

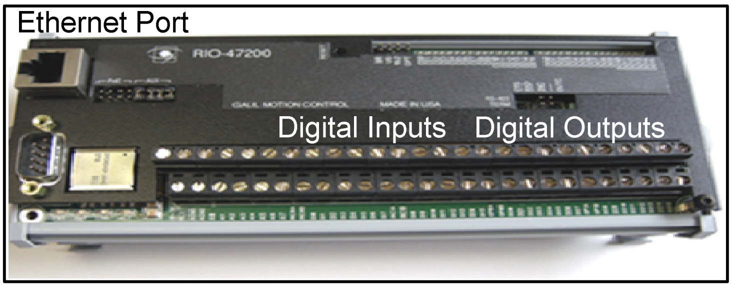


Figure 3.4: RIO-47200 for Antenna Control with TTL Logic.

3.4.1 Interfacing with RIO using MEX Function

The easiest way to interface with RIO is through Ethernet interface by assigning an IP address to it. RIO has built-in libraries which can be invoked through C++, VB or C# languages. It has a ***Galil.h*** file which is called in the C++ program to send commands and execute tasks on RIO. Normally, commands sent to RIO are to set, and clear the output port or to read from the input port. Some commands are given below.

Galil g("IP Address"); is used to make connection with RIO
g.command("SB8"); is used to set output port 8.
g.command("CB8"); is used to clear output port 8.
g.command("MG@IN[0]"); is used to read feedback pulses from an antenna at digital input port 0.

Using a command window in Matlab, Unix shell or Windows command prompt, C++ files implemented with a MEX function can be compiled as:

mex filename.cpp

If the program does not find RIO header files during compilation then the following command is used.

mex filename.cpp -lGalil

After the compilation, ***filename.mexglx*** is generated which is used by Matlab for interfacing with C++ code. We can change the compiler in the Matlab command prompt, Unix shell or Windows command prompt depending on the language, either C or C++, using the command:

mex -setup

3.4.2 Antenna Selection using Coaxial Switch

The output of RIO is TLL logic 1, which is sent for antenna selection. After instructions from Matlab, a C++ program communicates with RIO and RIO further sends TLL logic 1 of +5V to a coaxial switch for antenna activation. When the next antenna is selected, TTL logic 1 of the previously selected antenna is cleared first with TTL 0 and then a new antenna is selected with TTL 1. The input from the new antenna is displayed on the analyzer.

3.4.3 Antenna Polarization

For setting the horizontal or vertical polarization of the antenna, RIO sets or clears the output ports as instructed from the program. For horizontal polarization, it sets the port with TTL 1 and for vertical polarization it sets the port (clears the port) with TTL 0. This activation or clearance of ports can be checked on LEDs for each port on the RIO.

3.4.4 RIO Connection with Amplifier Unit

The RFI monitoring application works with different antennas, therefore, all the power supplying devices, relay driver board and the coaxial switch need to be connected with RIO perfectly. RIO ports and their connectivity with these devices are described in Table 3.1.

Wire Colour	RIO Connected PIN	Description
Black	AGND	Power Supply Ground
Black	AGND	Connected to Relay Driver Board
Brown	DO0	Coax Switch Pin 1 for Antenna 1
Red	DO1	Coax Switch Pin 2 for Antenna 2
Orange	DO2	Coax Switch Pin 3 for Antenna 3
Yellow	DO3	Coax Switch Pin 4 for Antenna 4
Green	DO5	Set Polarization for Antenna 1
Blue	DO6	Set Polarization for Antenna 2
Purple	DO7	Set Polarization for Antenna 3
Yellow Brown	DO8	Set Polarization for Antenna 4
Brown	DO11	Activate Azimuth Motor (from SALSA antenna amplifier unit)
Yellow	DO12	Move Left or Right Azimuth Motor. TTL 1 for Right, TTL 0 for Left. (from SALSA antenna amplifier unit)
Gray	DO13	Activate Elevation Motor (from SALSA antenna amplifier unit)
White	DO14	Move Left or Right Elevation Motor. TTL 1 for Right, TTL 0 for Left. (from SALSA antenna amplifier unit)
Gray	DI0	Feedback by Azimuth Motor on wire 4 with 0V Ground on wire 1 from Antenna to RIO on Green wire
Pink	DI1	Feedback by Elevation Motor on wire 2 with +5V Ground on wire 3 from Antenna to RIO on white wire
Red	OP0A	Output Power 5V for DO0-DO7
Black	OP0B	Output Power Ground DO0-DO7
Blue	OP1A	Output Power 5V for DO8-DO15 (from SALSA antenna amplifier unit)
Pink	OP1B	Output Power Ground DO8-DO15 (from SALSA antenna amplifier unit)

Table 3.1: Cable Connection Pattern with RIO.

3.5 PROLOGIX GPIB BOX

The connection between the spectrum analyzer and the computer is done through a Prologix GPIB to LAN converter box [13]. Through this box, SCPI commands are sent to the analyzer for remotely changing the configuration. It is shown below on Figure 3.5.

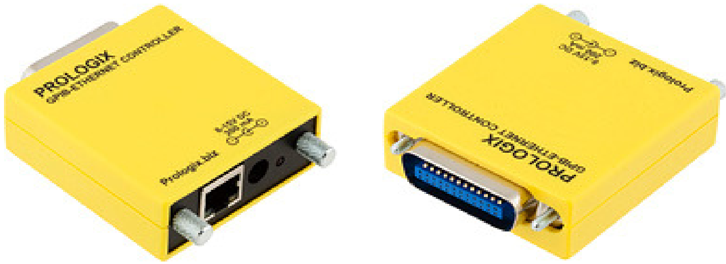


Figure 3.5: Prologix GPIB-Ethernet Converter.

These boxes are easy to use, affordable and a perfect replacement of expensive GPIB cards, which are installed in the computer have short cable length for connecting with the receivers.

For GPIB cards, the cable length is limited but by using this box, a long LAN cable can be used and the GPIB to LAN conversion is done at this box. The Prologix GPIB converter box can support static and dynamic IP address. No specific drivers are required to install for communication with this box. These boxes can operate in controller mode to send commands and in device mode to receive commands from other GPIB devices.

3.6 OMNIDIRECTIONAL ANTENNA

Three omnidirectional antennas have been used. So far the system was tested with available antennas. Later on HE314A1 (20-500MHz) [17], HF214 (500-1300MHz) [18] and HF902 (1-3GHz) [19] antennas from Rohde & Schwarz will be used with this system. These antennas operate in HF, VHF and UHF bands because astronomers are more interested in finding the interference in low frequency bands.

3.7 STEERABLE ANTENNA

The use of a steerable antenna is to find the direction of interference. The steering of the antenna is based on absolute angle movement instead of relative angle by saving the current position. To test the system, the SALSA antenna [26] and its amplifier were used but later it will be replaced with broadband dual polarized log periodic antenna (up to 18 GHZ) from TECOM [20]. This antenna has 6.5 dBi gain and higher angular resolution.

CHAPTER 4

RF INTERFERENCE MONITORING SYSTEM

4.1 SYSTEM OVERVIEW

The RFI monitoring system consists of three omnidirectional antennas, one directional antenna, a coaxial switch and RIO motion controller for connecting different antennas to the spectrum analyzer. The software application running on a Linux PC controls the hardware, logs the data and checks the interference levels. The system block diagram is shown in Figure 4.1. The rationale of this thesis is to reduce human interaction with all the hardware and provide RFI monitoring remotely from LAN or WAN environment as well. Computer, spectrum analyzer and RIO motion controller are connected through a LAN switch. The RFI monitoring program initiates a call to RIO-47200 for switching the control among the different antennas. RIO produces TTL pulses of 5 V each and in response to these pulses the coaxial switch activates one antenna at a time, and data from the active antenna are received at the analyzer. A relay driver board takes +5 V TTL pulses from RIO for each antenna, converts them to +28 V and transmits them to the coaxial switch.

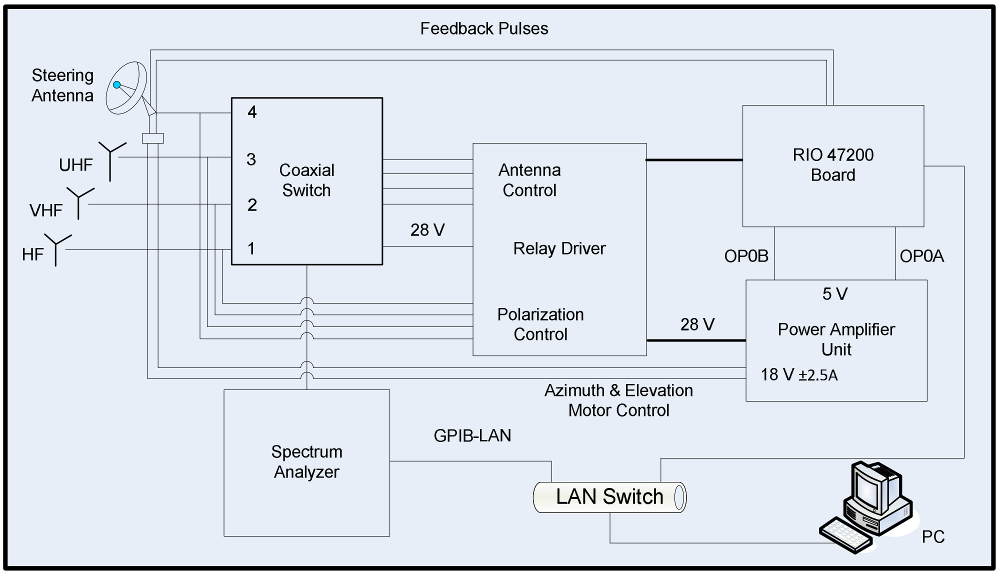


Figure 4.1: RFI Monitoring System Block Diagram.

4.2 RFI MONITORING APPLICATION

A screen shot of the RFI monitoring application is shown in Figure 4.2. A GUI provides a convenient way to set the start and end frequencies for each channel and calibrate each channel with calibrating data. A single antenna can be monitored with short frequency spans on all the channels. Each channel is dedicated for one antenna and we can set the polarization of the antennas. A steerable antenna is supposed to be used, in case of interference detection from omnidirectional antennas, to find the direction of interference from which the interfering signals arrive. The steering antenna can be moved by providing azimuth and elevation angle for finding the direction of interference. Though elevation movement is not required in this system, this application has this provision as well. This application also provides resetting the steerable antenna to its origin. If auto increase is checked, the steerable antenna moves by 6^{o} each time when its turn comes, and when it reaches 360^{o} it again comes back to its origin in azimuth and elevation direction. The beam-width or angular resolution of the antenna is 7^{o}, therefore the antenna moves in steps of 6^{o} to achieve some overlapping beam area each time. The steerable antenna has a diameter of 2.3 meters. This application also provides offline data analysis, saved in the database, in the form of different plots.

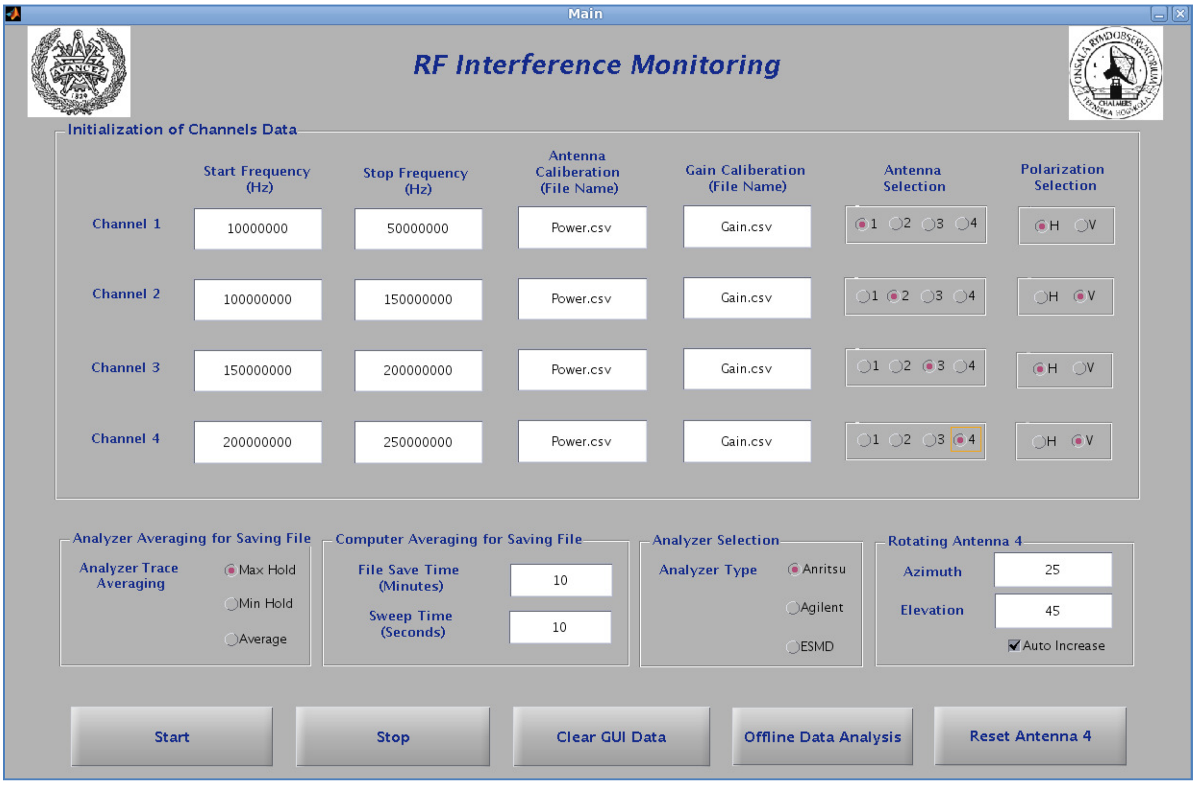


Figure 4.2: RFI Monitoring Application.

4.3 APPLICATION FLOW

The flow of the RFI monitoring system is shown in Figure 4.3. When the program is started after setting the necessary parameters like frequency spans, calibration data, antenna selection with polarization, file save time and averaging etc, it first checks the selected receiver type and then opens a socket connection with GPIB for talking to the analyzer and mapping the antenna on each channel. After that it switches between the different antennas to get data from a particular antenna at a certain frequency.

If the steerable antenna is used, then the RFI application calls the C++ program to change the antenna position. The reason for using the C++ program for antenna control is that the RIO only supports C++ to communicate with it. Therefore, Matlab initiates the C++ compiler by using a MEX function to communicate with RIO in C++ format.

After the antenna selection the data are temporarily received in ASCII format from the analyzer, are checked for interference and finally results are plotted for analysis. The main features of the RFI application are explained in detail in the below subsections.

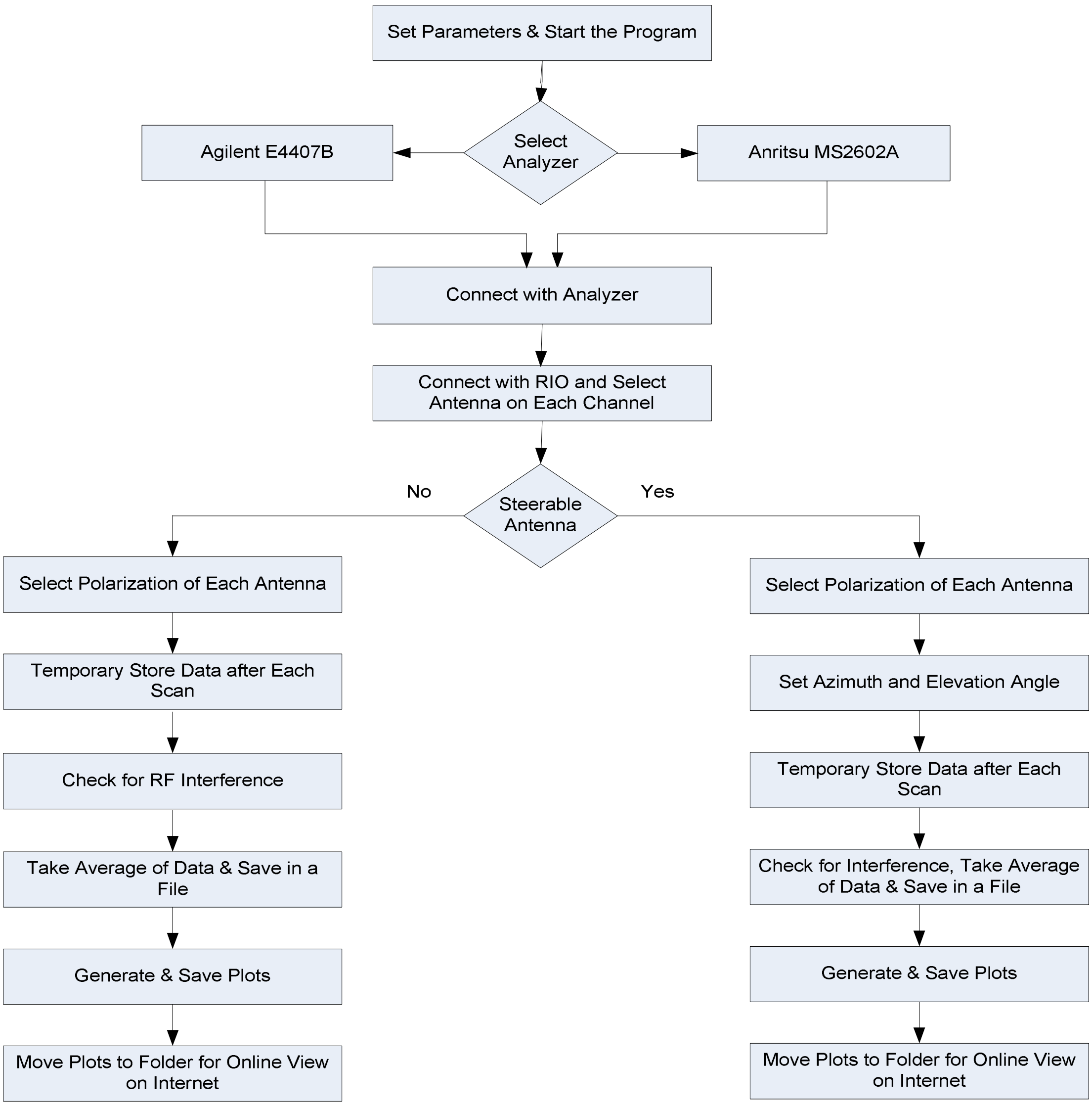


Figure 4.3: Flow Chart of the RFI Monitoring Application.

4.3.1 Analyzer Management

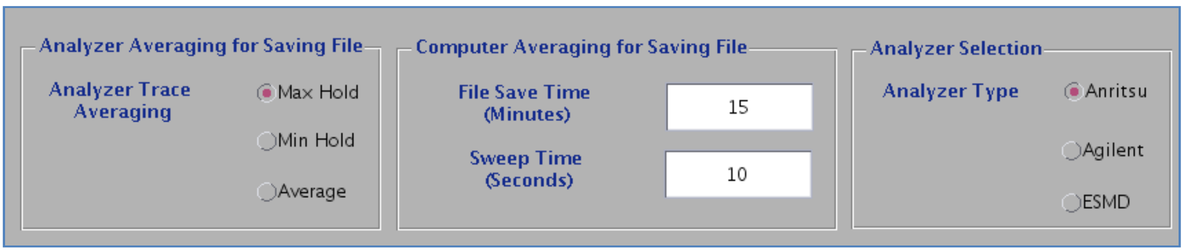


Figure 4.4: Analyzer Selection and Working Criteria.

The software provides flexibility to use different models of spectrum analyzers. This application can work on Anritsu and Agilent spectrum analyzers but its functionality can be extended to the ESMD analyzer for future use. So for running the application we have to select the right analyzer, sweep time to read the whole spectra for one channel and averaging used for sampling the received power levels. The three basic levels are MAXHOLD for taking maximum value, MINHOLD for minimum value and AVG for taking the average of the values. Programming manuals for E4407B and MS2602A can be found on [24] and [25]. The analyzer takes single sweep instead of continuous and after one complete sweep RFI monitoring application waits for 1 second to read all the ASCII values of power levels from the analyzer and saves them temporarily for further processing. Then control moves to next channel.

4.3.2 Setting Connection with Analyzer & RIO

The application creates a TCP/IP socket connection with analyzer through GPIB box which is used to send commands and receive data from analyzer. Similarly, a connection is established between application and RIO device.

4.3.3 Omnidirectional Antenna Selection

After connecting on TCP/IP socket with a selected analyzer the application checks for an antenna mapped on each channel. Once the antenna is selected on a particular channel, the polarization of the antenna is selected. Antenna and polarization selection in the RFI monitoring application is shown in Figure 4.5.

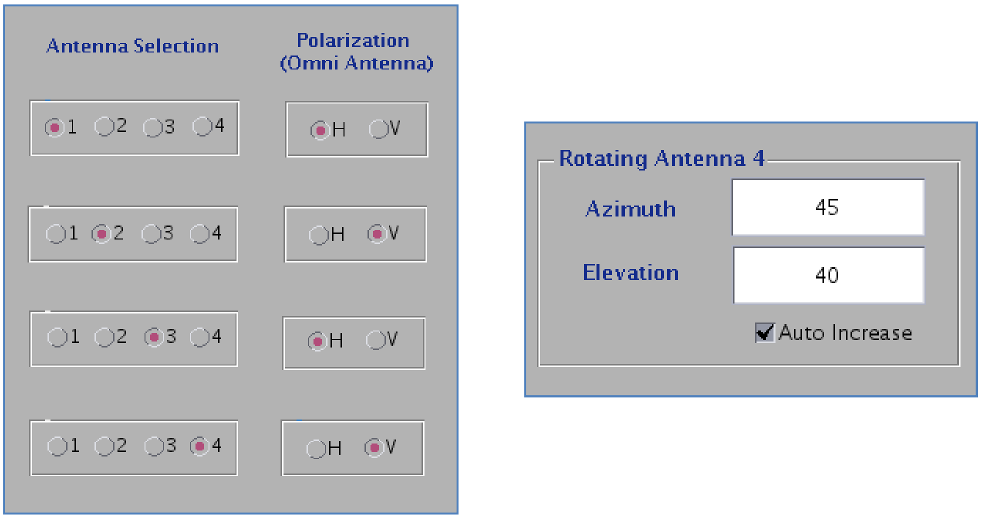


Figure 4.5: Antenna and Polarization Selection.

4.3.4 Steerable Antenna Selection and Auto Increase Option

The use of the steerable antenna is to find the direction of interference by providing azimuth and elevation angle in the application. The auto increase option, as shown in Figure 4.5 moves the antenna 6^{o} by each step. As 7^{o} is the angular resolution of the antenna, 6^{o} steps are used to have some overlapping in the coverage area of the antenna. The antenna moves automatically once the initial position is set. When it reaches at its maximum position it comes back to the origin and starts moving again automatically. Similarly, the polarization can be switched between horizontal and vertical.

4.3.5 Detection of Feedback Pulses

The position of the antenna is sensed by an opto-couple switch, which is located behind the 12 leg wheel. This opto-couple switch throws light on this wheel when this wheel rotates. As a result of that TTL pulses are generated. The frequency of these pulses varies from 8 Hz to 12 Hz. This is due to the wind speed and its resistance against motor movement. For 1^{o} movement, 3 pulses are generated (1 pulse = 0.333^{o}). These pulses are sent to RIO at port DI0 for azimuth pulses and at port DI1 for elevation pulses. The RFI monitoring application counts the number of feedback pulses. The application looks for consecutive 1s and 0s. On each 1 and 0 combination, one pulse is counted. It is shown below in Figure 4.6 where each pulse is marked with a rectangular box.

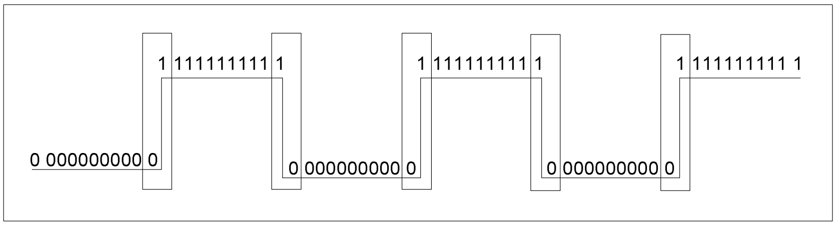


Figure 4.6: Feedback Pulses Detection.

4.3.6 Antenna Movement Control

The antenna can move in azimuth direction up to 360° (north) and in elevation direction up to 90° (zenith). On the basis of feedback pulses, the application knows about antenna movement in either direction. Figure 4.7 shows the steps taken by the application to control the movement of the rotating antenna. It takes decisions based on the feedback pulses.

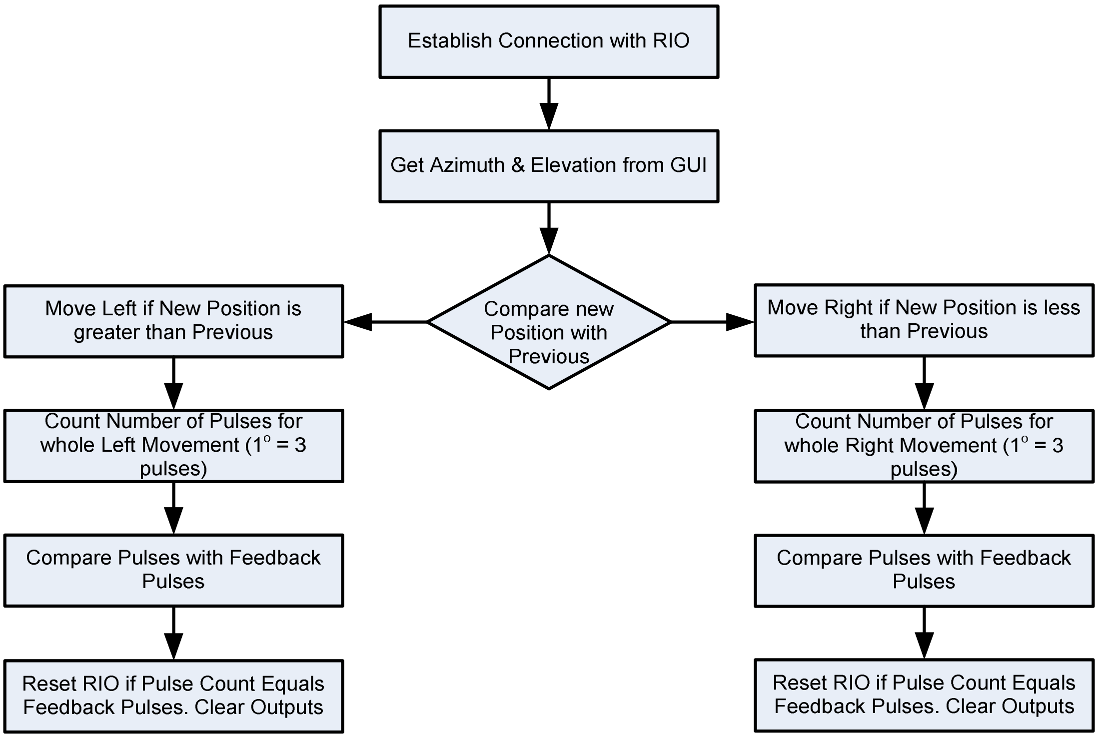


Figure 4.7: Antenna Movement Decision Based on Feedback Pulses.

Feedback pulses are received at the digital input of the RIO motion controlling hardware. For each degree rotation, 3 pulses from the motors are counted by the application. For instance, for 10 degree rotation, 30 pulses are counted and then program stops after saving the current position.

4.3.7 Resetting Steerable Antenna

When the RFI monitoring application is closed, it loses the current position of antenna. So to rotate the antenna to some specific direction, we should know the current position of the antenna. If we rotate the antenna without resetting it, the application will consider its current position as its origin and the rotation will not be precise. Therefore, a reset of the antenna is required. By resetting the antenna, it moves to its origin at 0° in azimuth and at 90° in elevation (in zenith direction). For this purpose the main application has the “reset antenna 4 button”. The steps required to reset the antenna are shown in the form of flow diagram below in Figure 4.8.

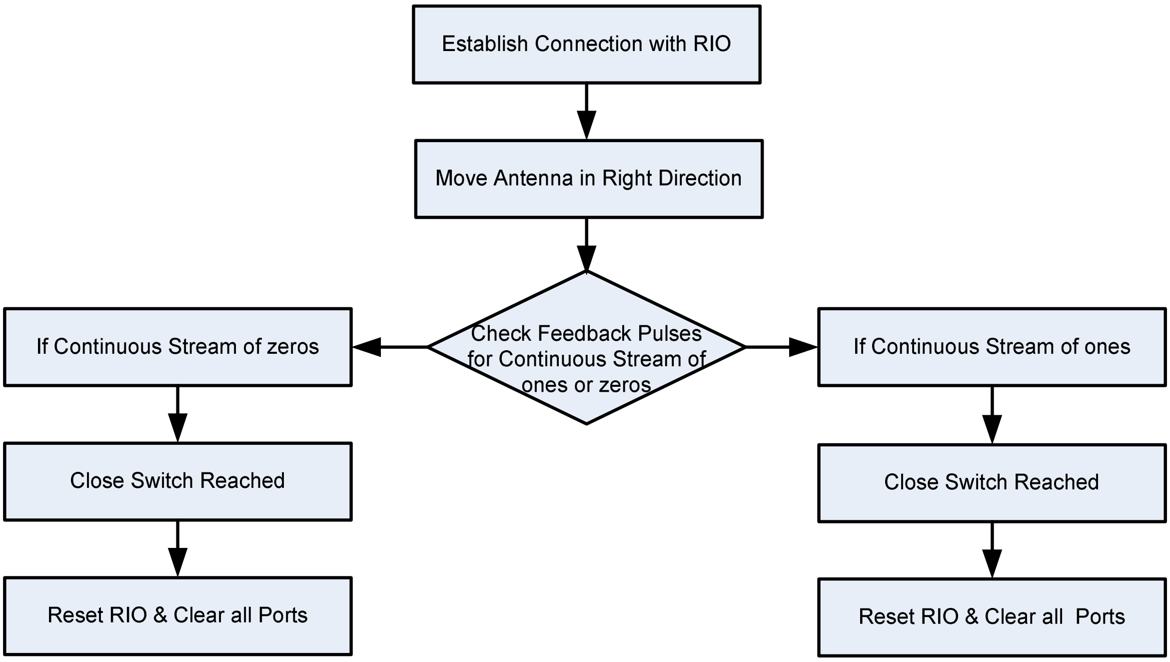


Figure 4.8: Reset Decision Based on Feedback Pulses.

When there is no movement, a continuous stream of zeros is received. On movement, a long stream of ones and zeros is received. If the application receives a long stream of ones or a long stream of zeros then it means limit switch in azimuth (north) or in elevation (zenith) direction is reached. It means that the reset is completed. The program then resets (clears) all the RIO ports.

4.3.8 Data Saving Criteria

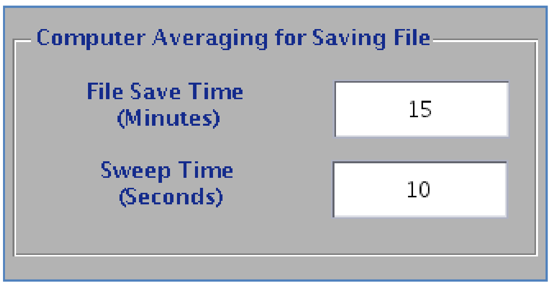


Figure 4.9: File Saving Criteria.

The RFI monitoring application temporarily saves the data and when the file save time is reached (as shown above in Figure 4.9) it saves the data based on the averaging used by the analyzer. The file save time can be changed. If the analyzer uses MAXHOLD then the application also selects the maximum value of power (in dBm) in the row against one frequency point as an averaging mechanism.

This application is optimized for 1002 data points in one file for each analyzer in use but data points can be changed with minor changes in the program at initializing the frequency and data points.

4.3.9 Adding Calibration Files

Calibration files are required to calibrate the received data and these files are provided by the vendors. Antenna power and gain calibration files can be added by specifying the filename in the text box in two ways. One way is to add the calibration files manually by specifying the path and filename. But this is not an efficient way and it involves careful filename mentioning. The second method is by pressing the “enter” (return) key after clicking on the textbox. It gives a Windows method of selecting file name, and allows pressing “open” to add the filename in a textbox, as shown below in Figure 4.10. The complete path and name of file will appear in the textbox. During execution of the program, the calibration data are added with the received power from antennas. When the file save time is reached, the average calibrated data are saved in the database.

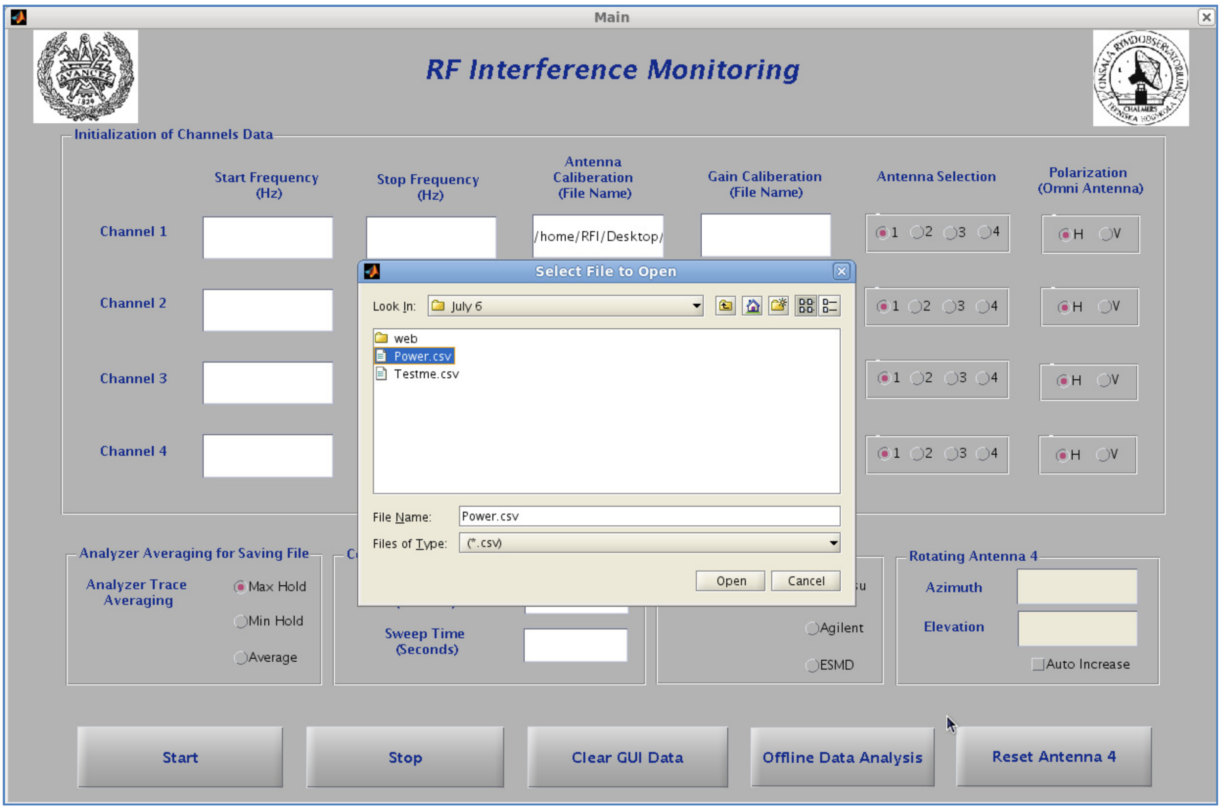


Figure 4.10: Entering Calibration Files in the Main GUI.

4.3.10 Setting Interference Criteria

The interference detection criteria must be accurate so that application could mark any new interference or increase of the level of the known interferences at OSO. Initially, I set the criteria on the basis of difference in received power levels at a particular frequency. If it is greater than, for instance, 10 dBm then it marks 1 against that frequency point in the file after taking the averaging of data. This criterion is not helpful as it needs manual setting of decision thresholds. Therefore, I have used GSK estimator which is the latest solution for finding interference and setting the decision thresholds, in the field of radio astronomy.

The steps taken by this algorithm to find interference at the OSO are shown below in Figure 4.11.

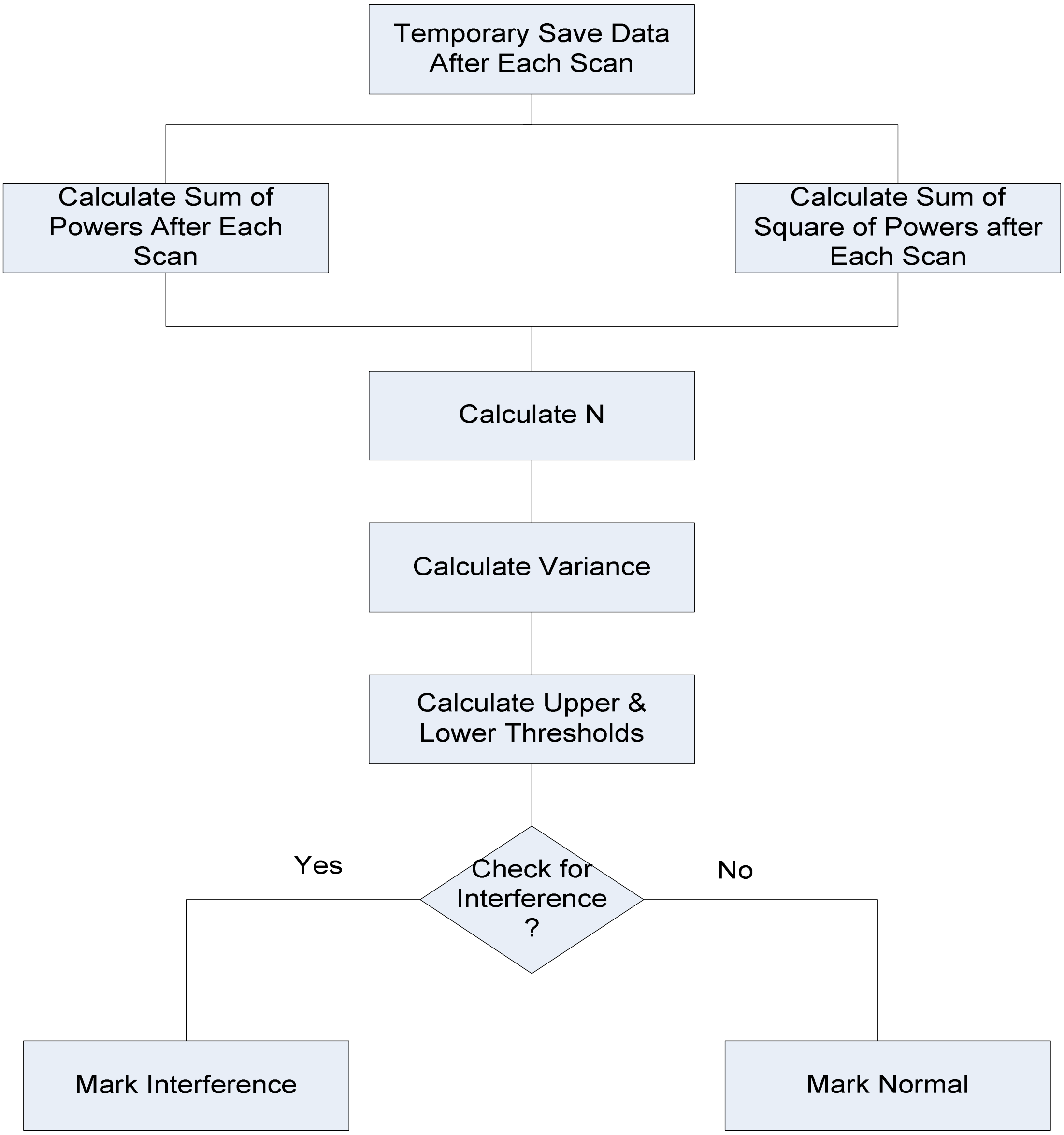


Figure 4.11: Flow of Steps for SK Estimator Algorithm.

This algorithm computes the sum of signal powers (S_1) and sum of square of powers (S_2) received for each channel during one file save time and calculates the variance (V_K) based on S_1 and S_2. The mean of the variance of the received data should be around 1.

$$S\_1 = \sum_{K=1}^{M} P_K \qquad (3.1)$$

$$S\_2 = \sum_{K=1}^{M} {P_K}^2 \qquad (3.2)$$

$$V_k = \frac{M}{M-1}\left(\frac{M \cdot S\_2}{S\_1^2} - 1\right) \qquad (3.3)$$

$$N = \frac{1}{mean\,(V_K\ )} \qquad (3.4)$$

$$New\_V_k = \frac{(M \cdot N \cdot d)+1}{M-1}\left(\frac{M \cdot S\_2}{S\_1^2} - 1\right) \qquad (3.5)$$

$$Mean = Mean\ (New\_V_k) \qquad (3.6)$$

Here ***M*** is the number of scans for each channel during a file save time. The number of power levels accumulated when the power for one frequency point is saved in the analyzer is called ***N***. It is calculated empirically in Equation 3.4 and ***d*** is the duty cycle which in my case is 1. Once the mean (Equation 3.6) and variance (Equation 3.5) are calculated, the decision thresholds (upper and lower bounds) are calculated to mark the interference. The GSK estimator does this automatically and adjusts the thresholds according the mean and the variance. The calculation of upper and lower thresholds can be seen in [12].

4.3.11 File Naming and Directory Management

A file is saved when the time to save the file is reached. The file name starts with the current system date and time. It has some more identification parameters as well. The format of the file name is:

Current Date Time_Channel_Antenna_Polarization_Analyzer Name_Azimuth_Elevation_Warning

Below are the two files with all the parameter. In the first file, 999 represent no particular value of azimuth and elevation since the omnidirectional antenna 1 is used. Antenna 4 (steerable antenna) has 40 and 45 degree azimuth and elevation angle in second file.

June.02.2010 15.18.49_CH1_Ant1_H_Anritsu_999_999_W.csv

June.02.2010 15.18.50_CH4_Ant4_V_Anritsu_040_045_W.csv

Table 4.1 below shows some parameters used in filename along with their description.

Parameter	Description
CH1, CH4	Channel 1 or Channel 4
Ant1, Ant4	Antenna 1 or Antenna 4
H, V	Horizontal or Vertical Polarization
Anritsu, Agilent	Analyzer Name
W	Warning in case of Interference

Table 4.1: Parameters used in the Filename.

When a file is created, it needs to be stored in a proper folder so that it could be located easily in the future. The RFI monitoring application creates different folders and arranges the files in those folders. The sequence of created folders is year/month/date. In the date folder, all the files on that particular date are stored. For the next day, a new folder is created under the same month folder, and files for that day are stored in that folder.

For a new month, a new folder under the same year folder is created and date-wise files are stored in that month's folder. At the start of a new year, a new folder with the year name is created and similarly data are stored accordingly. In the Figure 4.12 below, the complete path with the created folders is shown and is marked with a circle.

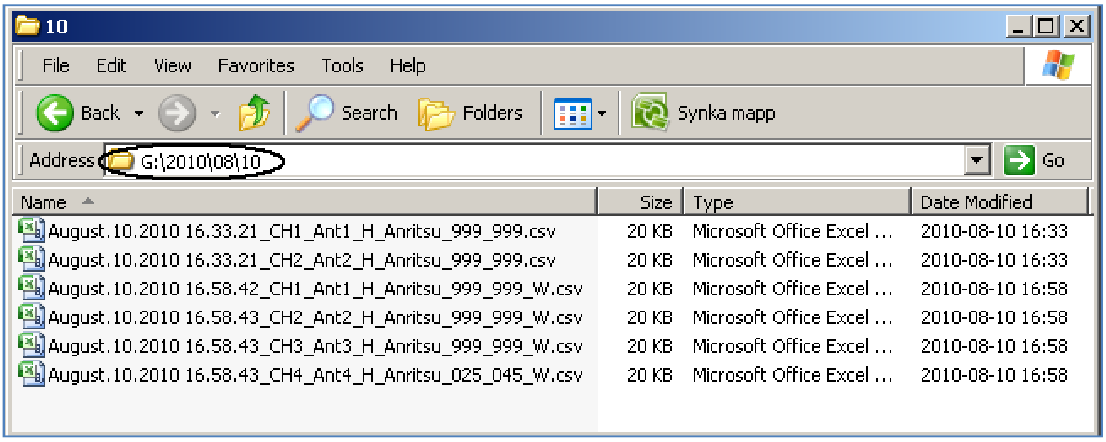


Figure 4.12: File Saving Directory Database.

For each channel, a separate file is generated. The first row of each file consists of the resolution bandwidth of the analyzer which is used for offline data analysis for conversion to Jansky units. Each saved file consists of 1002 data points. A file is saved in comma separated value (csv) format which is the standard format for saving the data. It consists of frequency, received power in dBm and interference columns. For interference presence 1 is marked otherwise 0 is marked in that column.

4.3.12 Plots Generation & Plots Saving

The RFI monitoring application can be used to generate different type of plots after saving the data. These plots include spectra plots, waterfall plots, interference plots and spectra plots in Jansky units. These plots will be discussed in detail in Chapter 5. After generating the plots, the application saves the plots (in jpeg format) and moves the plots in other folder where these plots are used for HTML view on a web server. HTML presentation of plots is discussed in Chapter 6.

4.3.13 Conversion to Jansky Units

In radio astronomy, received power is usually expressed in spectral power flux density. Since the received power is very low therefore it is specified in terms of Jansky (Jy).

$$1\,J_Y = 10^{-26}\,W\,m^{-2}Hz^{-1} \simeq -260\,dB(W\,m^{-2}Hz^{-1})$$

For the conversion to Jansky units, the calculation of the antenna's area is required.

For the short dipole,

$$Area = \frac{\lambda^2}{4\pi} \qquad (3.7)$$

$$\lambda = \frac{Velocity\ of\ Light}{Carrier\ frequency} \qquad (3.\ 8)$$

$$Where\ (\frac{\lambda}{50} \leq length\ of\ dipole\ < \frac{\lambda}{10})$$

$$Carrier\ Frequency = \frac{Start\ Frequency + Stop\ Frequency}{2} \qquad (3.9)$$

For an infinitesimal dipole,

$$Area = \frac{3\lambda^2}{8\pi} \qquad (3.10)$$

$$where\ the\ length\ of\ the\ dipole\ \leq\ \frac{\lambda}{50}$$

For half-wavelength dipole,

$$Area = 0.13\lambda^2 \qquad (3.11)$$

$$where\ the\ length\ of\ the\ dipole\ \leq\ \frac{\lambda}{2}$$

For a reflector antenna,

$$Area = \frac{\pi \cdot D^2}{4} \qquad (3.12)$$

Where, D is the diameter of the reflector antenna.

$$Power\ in\ Jansky\ = \frac{Received\ Power}{area \cdot \Delta f \cdot 10^{-26}} \qquad (3.13)$$

Here Δf is the resolution bandwidth of the spectrum analyzer. From the above expression we get the received power in Jansky units. The infinitesimal dipoles are not very practical antennas. In this thesis, only short dipole or half-wavelength dipole antennas will be used.

CHAPTER 5

RFI SYSTEM RESULTS

Results from any system reflect the success or failure in implementation of that system. The performance of the RFI monitoring system has been analyzed with different plots. The system has been tested indoors for the GSK estimator and outdoors for an overall testing. Data taken from the analyzer are plotted in dBm or in Jansky units. The interference is monitored by the GSK estimator. The behaviour of the received signals is studied using waterfall plots. In this chapter, the results of the implemented system are discussed with different types of plots.

5.1 INDOOR TESTING FOR GSK ESTIMATOR

To check the performance of the GSK estimator, a test was done by using a signal synthesizer (10 KHz-2112 MHz) and a noise diode (10 MHz-26 GHz) attached with a low noise amplifier of 28 dB gain at 1420 MHZ and a narrow band pass filter (1000-2000 MHz with 24 dB gain). The arrangement of the devices to test the GSK estimator is shown in Figure 5.1. First, the synthesizer and the small antenna were connected to the spectrum analyzer with a 3 dB coupler. The analyzer frequency span was 100 MHz to 1000 MHz and the synthesizer was set on 800 MHz. When the synthesizer signal strength (-80 dBm) was less than the signal received (-65 dBm) by the antenna, the amplitude variations were quite low. There was low deviation from the mean of the GSK estimator. But this deviation increased when the synthesizer power was increased. When the noise diode was used instead of the synthesizer, the result was the same as using the synthesizer with higher power than received signal. So the higher variance amplitude levels of the GSK estimator are considered as interference.

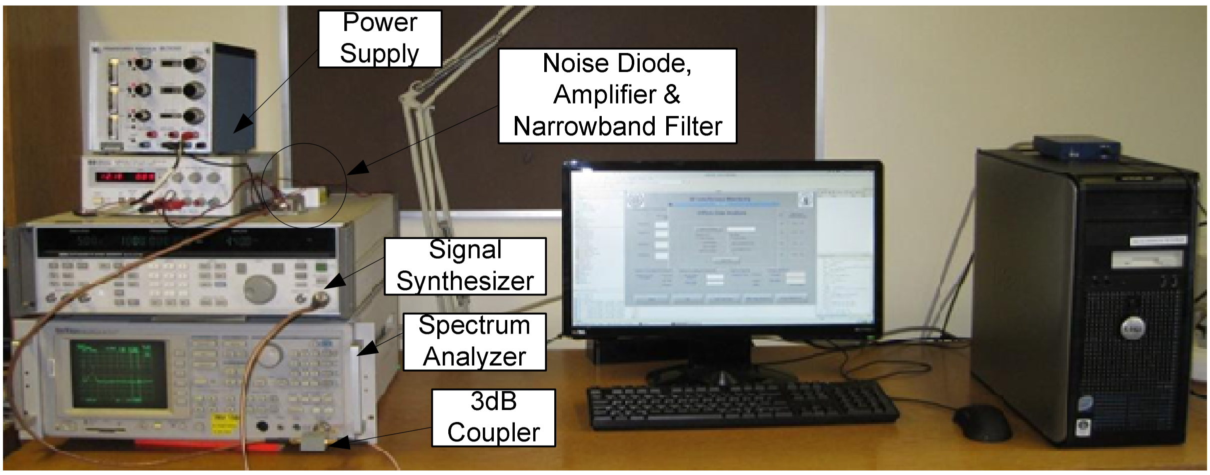
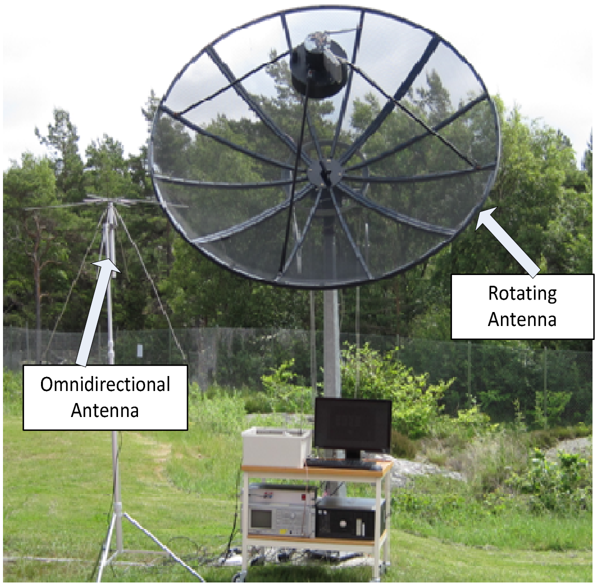


Figure 5.1: Indoor Testing Setup for GSK Estimator.

5.2 OUTDOOR TESTING

The RFI monitoring system was tested with three omnidirectional antennas and the SALSA antenna in outdoor environment. All antennas were connected to the antenna management unit and the power amplifier unit. Different frequency bands were assigned to the channels in the application where each channel corresponded to one antenna. The system was tested with different sweep and save times and the results were saved in files. During the test, different types of interference signals were detected at the observatory, especially signals belonging to FM radio or mobile communication. The complete system with all the antennas and power amplification unit is shown in Figure 5.2. Results of the testing are discussed in the next sections.



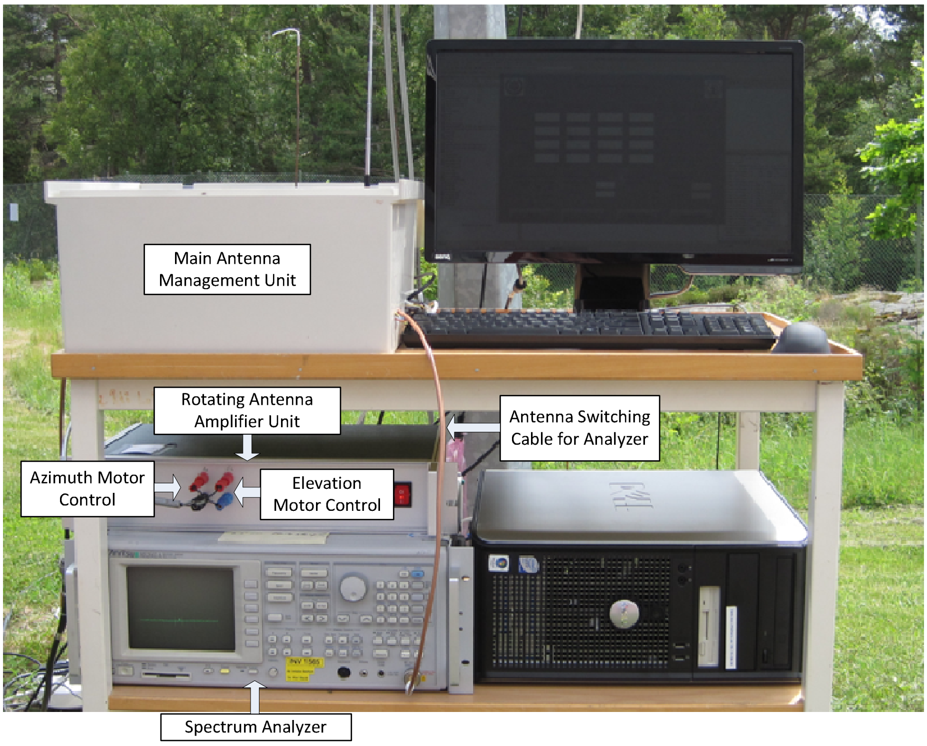


Figure 5.2: RFI Monitoring System for Outdoor Testing.

5.3 SPECTRAL REPRESENTATION OF PLOTS

Spectral plots represent the received power levels for all the four channels with different frequency spans. The power levels are in dBm and in Jansky units, as shown in Figure 5.3 and 5.4. Conversion between dBm and Jansky is discussed in Chapter 4. These plots show the averaged data depending on the averaging used by the analyzer and the application as discussed earlier in Chapter 4. The

Maximum signal power received was -51 dBm, or 138 dB-Jansky (dBJy) and the minimum received signal strength was -71 dBm, or 97 dB-Jansky (dBJy). These high power signals are considered to be the interference signals which can deteriorate or completely mask the astronomical signals. The interference signals are shown in Figure 5.6.

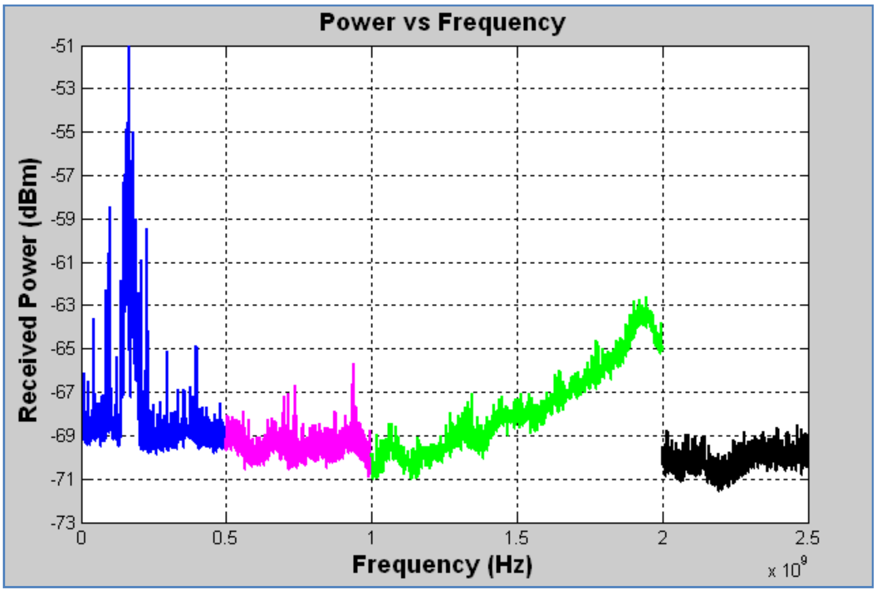


Figure 5.3: Received Power Spectral Plot in dBm after Averaging.

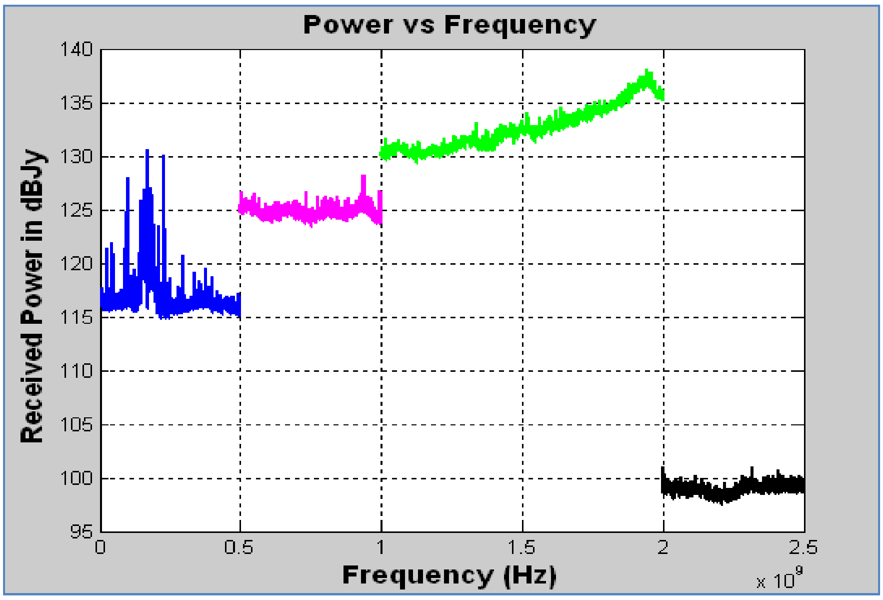


Figure 5.4: Received Power Spectral Plot in dBJy.

5.4 INTERFERENCE REPRESTATION OF PLOTS

By looking at the high power signals shown in Figures 5.3 and 5.4, it is difficult to mark interference at a particular frequency. Detection of interference depends on the applied criteria. The criteria can be set on the basis of a comparison of received power at a particular frequency or by a statistical analysis of the channel power. In the first case, if high power signals are received at a particular frequency during different scans of the same channel, interference is marked on that frequency if the power difference goes beyond a certain power difference (assuming 10 dB difference between the minimum and the maximum signal strength). This criterion is not flexible and needs manual adjustment of the power difference according to the requirements. In the second case, the GSK estimator algorithm is used.

5.4.1 Interference Detection using the GSK Estimator

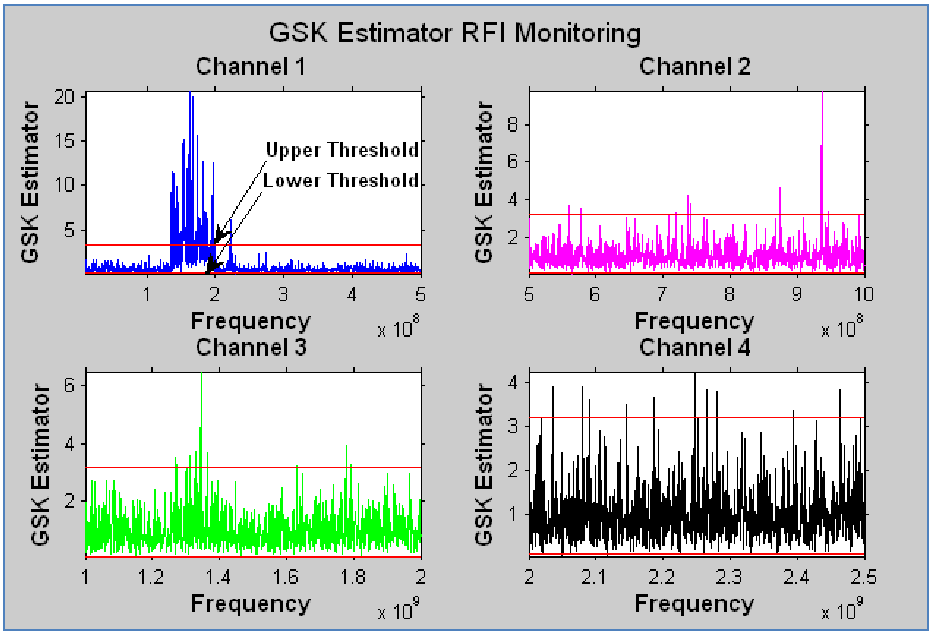


Figure 5.5: Setting Thresholds for Interference using the GSK Estimator.

Figure 5.5 shows the GSK estimator plots for all the four channels. To avoid the manual adjustment and calculation of threshold, the GSK estimator is implemented which does this automatically. After finding the variance of all the power levels, it calculates the upper and lower thresholds. Variances of particular frequencies are marked as interference if they exceed the boundaries of the upper and lower thresholds.

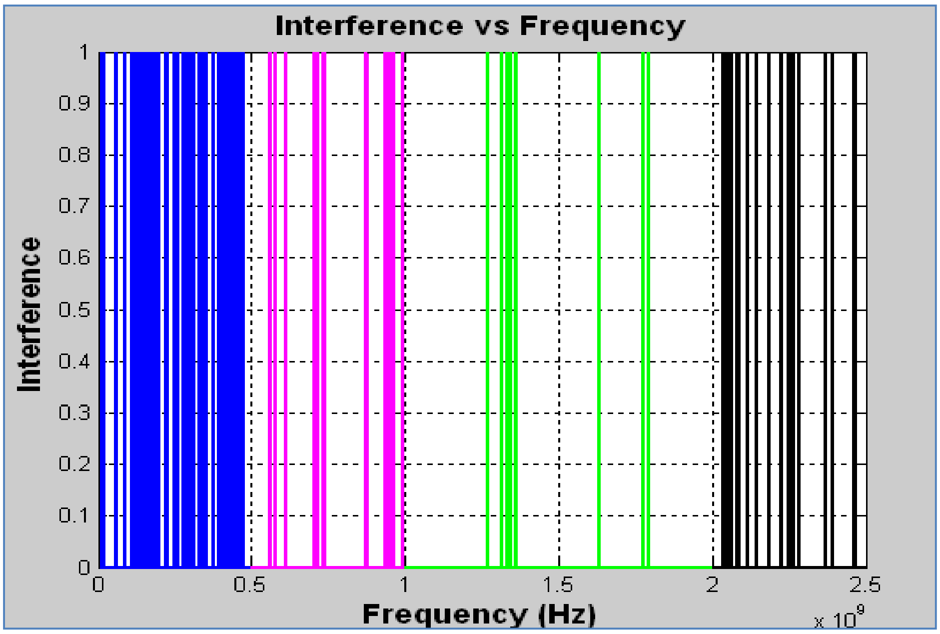


Figure 5.6: Interference Detection Plot.

Figure 5.6 shows the interferences marked by the GSK estimator using thresholds, shown in Figure 5.5. The GSK estimator analyzes the signal statistically and marks a new signal as an interference even with a small variation in power. Most of the interferences are marked at the upper threshold side but GSK looks for interferences at the both thresholds.

There are some limitations when using the GSK estimator. The parameter ***M*** (number of scans) should not be less than 5, since the GSK algorithm works best for small number of scans (***M***). If we increase the number of scans per channel the difference between the thresholds reduces and more signals are marked as interference [3].

5.5 WATERFALL PLOT

Waterfall plots are 3D plots which show the trend of received power levels of different frequency spans at different times. They are not averaged plots like spectral plots. They show the actual powers before averaging.

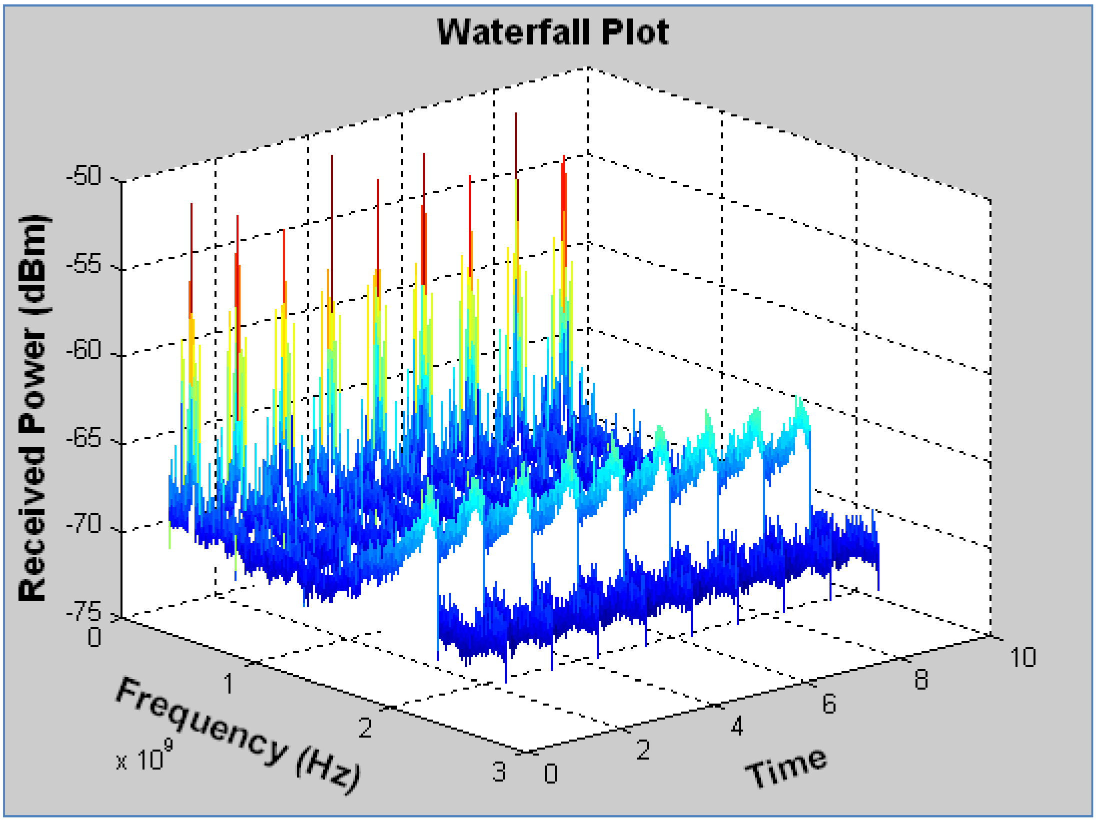


Figure 5.7: Waterfall Plot of Received Power before Averaging.

Several variations in power are clearly visible in the Figure 5.7 for the frequency span less than 1 GHz in channels 1 and 2. These variations in received power levels are not visible in the spectral plots. Therefore, these plots are helpful in identifying the new interferences during different scans of the same frequency spans.

CHAPTER 6

DATA ANALYSIS

6.1 OFFLINE DATA ANALYSIS

Once the application saves data, analysis of the saved data is required for future use to see any interference or to see the behaviour of received data. The below sections describe how to use the offline data analysis application.

6.1.1 Opening Offline Data Analysis Application

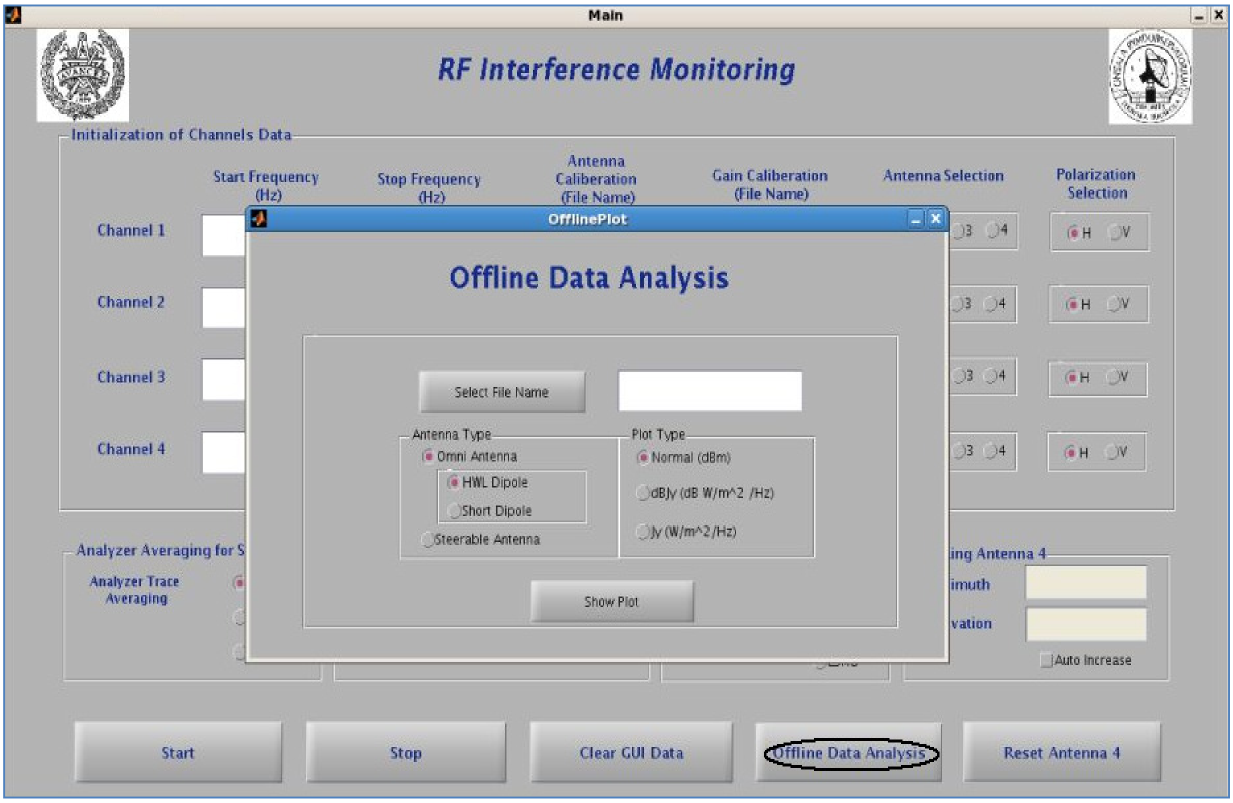


Figure 6.1: Offline Data Analysis Application Opening.

To open the offline data analysis application, the main RFI monitoring application is used. By pressing the “offline data analysis” button the offline data analysis application is opened as shown in Figure 6.1. When the application is opened, it can be used to analyze the saved data for any channel.

6.1.2 Flow of Application

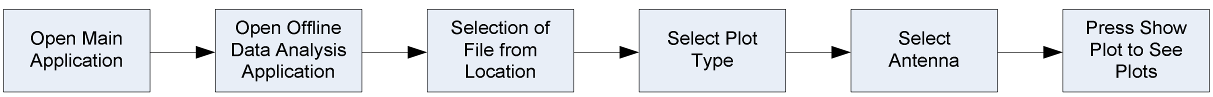


Figure 6.2: Offline Data Analysis Application Flow.

To analyze the offline data, the application needs to select some parameters in order to generate the plots. The flow chart of the application is shown in Figure 6.2. It needs the offline data source file, the antenna type and the type of plot. The antenna type is required for Jansky plots as it needs calculation of area of the antenna. For normal spectral plots, the area calculation is not needed.

6.1.3 File Selection

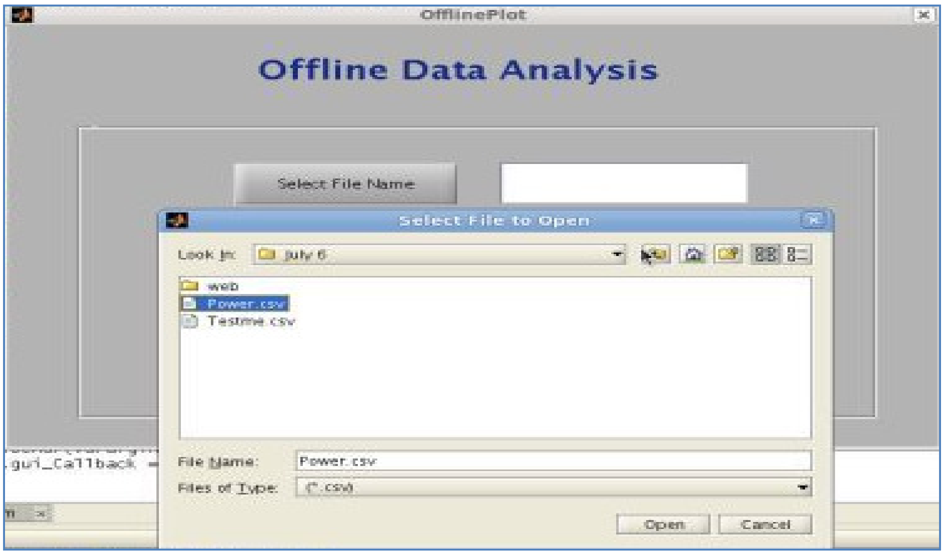


Figure 6.3: File Selection for Offline Analysis.

After opening the offline data analysis application, we have to provide the name of the saved data file along with its complete path. It can be either provided by writing the path and name of the file in the text box, or by pressing the select "file name button" in the application. After pressing the button, a Windows method of file section is invoked to show it in the application. A dialogue box appears where we can navigate to a particular folder to select the desired file as shown in Figure 6.3.

6.1.4 Plot Selection

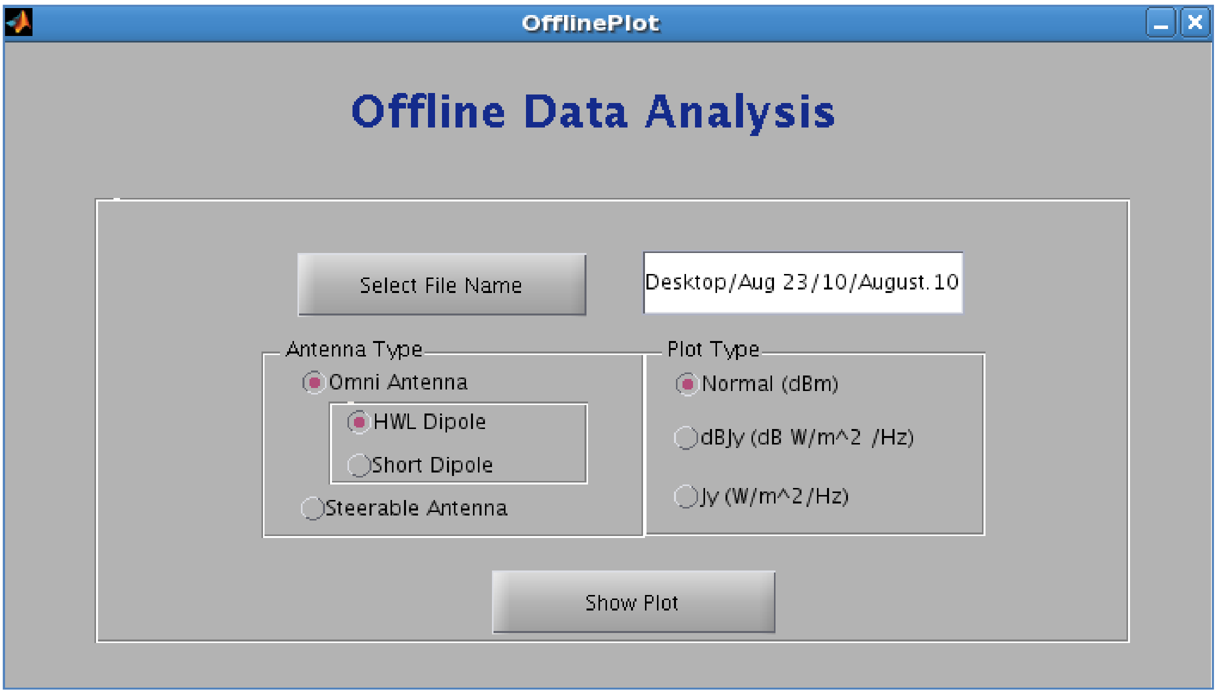


Figure 6.4: Antenna and Plot Selection for Offline Analysis.

Once the file is selected, the type of the plot needs to be selected. It is shown in Figure 6.4. If a normal plot is selected then plot of power spectra in dBm units is generated. If a Jansky plot is selected then the application converts the received power in Jansky using the criteria mentioned in Section 4.3.13 and displays the plot of the received spectra in units of Jansky (Jy) as $\boldsymbol{W\,m^{-2}Hz^{-1}}$ and in dB-Jansky (dBJy) as $\boldsymbol{dBW\,m^{-2}Hz^{-1}}$.

6.1.5 Antenna Selection for Jansky Plots

The antenna selection is needed for Jansky plots. For Jansky plots, the application needs to know the area of the antenna. For omnidirectional antennas, we need to select either an infinitesimal or a short dipole antenna. It is shown in Figure 6.4. For a rotating antenna, a steerable antenna is selected. Depending on the antenna type, the application calculates the antenna area and uses it to convert received power into Jansky units.

6.1.6 Available Plots for Offline Data Analysis

After selecting all the parameters, the received power plots either in dBm units or in Jansky units and interference plot are generated by pressing the “show plot” button. If there is any interference at a particular frequency, it would be visible on the interference plot with amplitude 1. With the spectral plot, we can confirm the presence of interference if there is any change in the behaviour of the plot.

Example plots are shown in Figures 6.5-6.8. These plots show the results of one channel as in the database, for each channel data is saved separately. Each channel consists of 1003 rows of data with frequency, power and interference columns. These plots are generated based on the saved data.

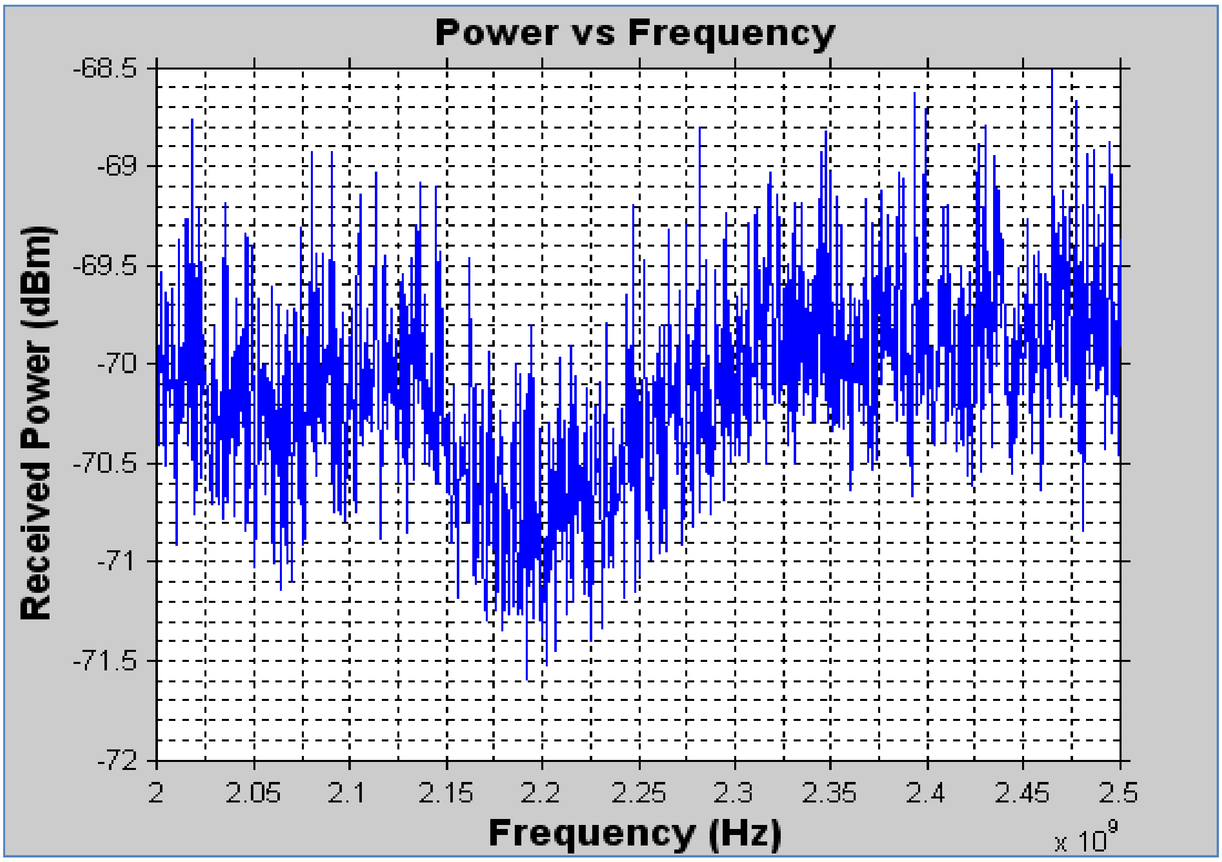


Figure 6.5: Received Power (dBm) vs Frequency Plot.

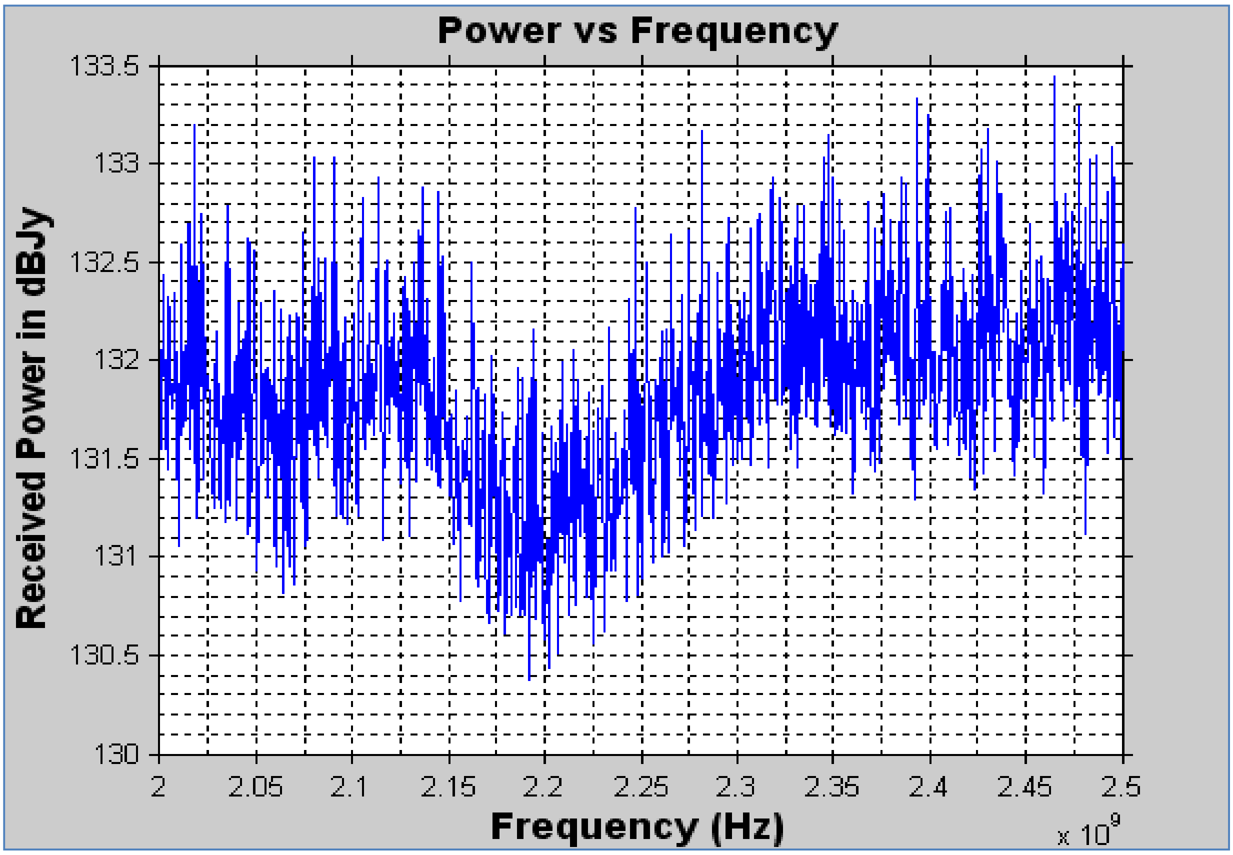


Figure 6.6: Received Power in dB-Jansky (dBJy) vs Frequency Plot.

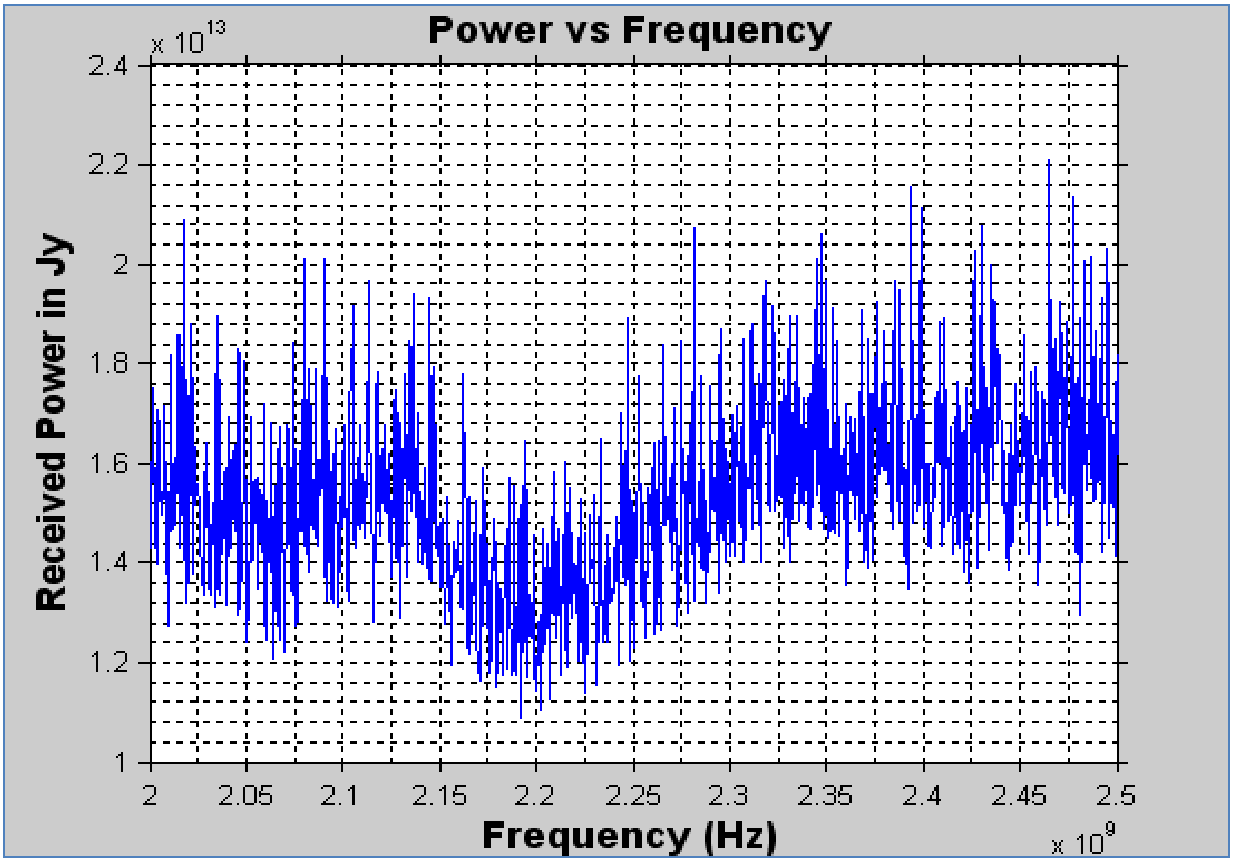


Figure 6.7: Received Power in Jansky (Jy) vs Frequency Plot.

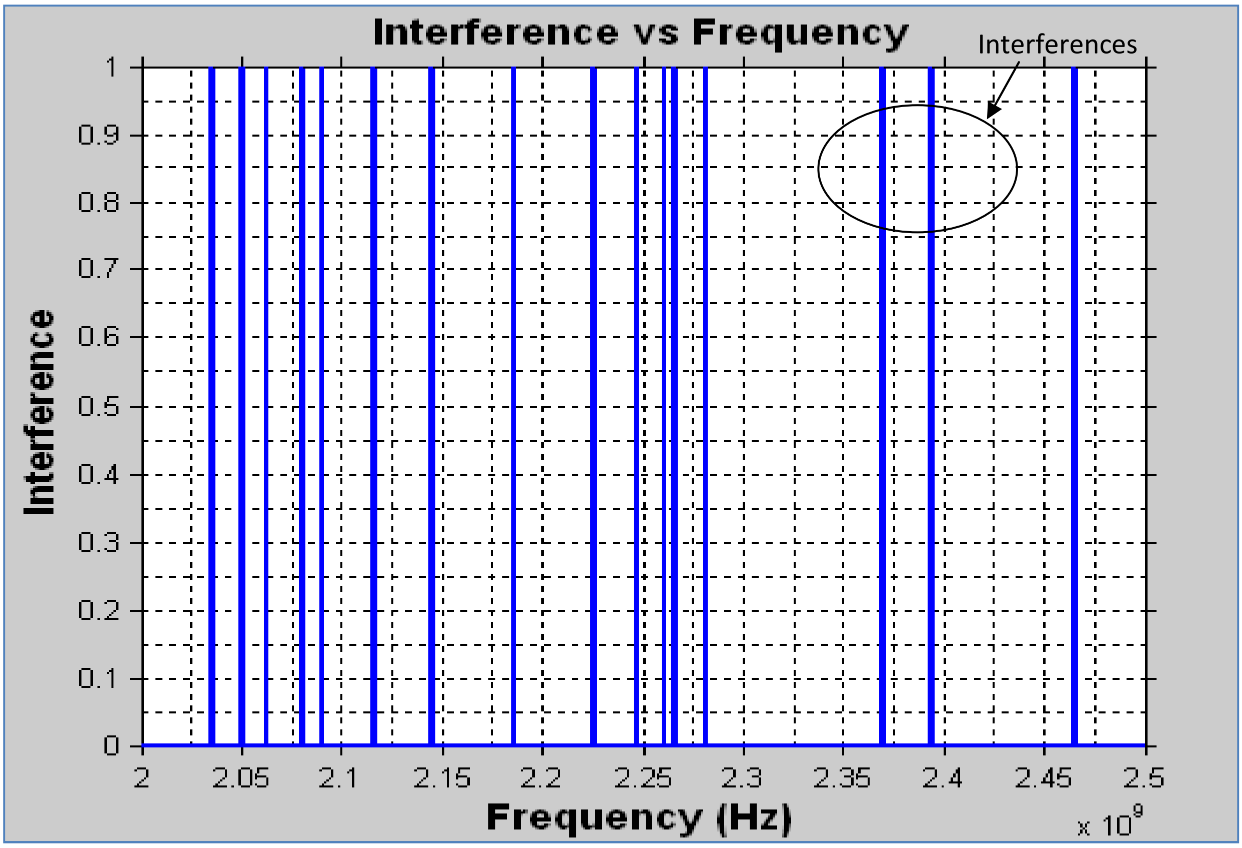


Figure 6.8: Interference Detection Plot.

6.2 WEB BASED ONLINE MONITORING

The RFI monitoring application provides online monitoring of interferences through an HTML web page. This web page will be a part of the Chalmers main website and it will be linked with the OSO webpage where, for example, temperature sensor monitoring is done. Anyone who can access the web page via the internet will be able to see the results.

The online monitoring involves five HTML pages, which are:

- RFI Main.html
- dbm.html
- jansky.html
- gsk.html
- interference.html
- wfall.html

The RFI Main.html is the main file which will be accessed from internet. The remaining HTML files are linked with the main file to show different plots.

6.2.1 Replication of Plots on a Web Server

When the RFI monitoring application saves data at the end of each measurement or when file save time expires, results are plotted as discussed in Chapter 5. The application saves these plots in jpeg-format and copies them to the folder where all the HTML files, mentioned above, are located. The right path of the folder should be mentioned in the code of the application so that the files could move in the correct folder. If the path is wrong the application will generate an error. Whenever new plots are generated, they are replicated in the web server folder from where they will be accessible from internet. Each generated plot is labelled with date and time at the top of it so that reader can know the time when any interference is experienced or the latest results are available.

6.2.2 Representation of Results

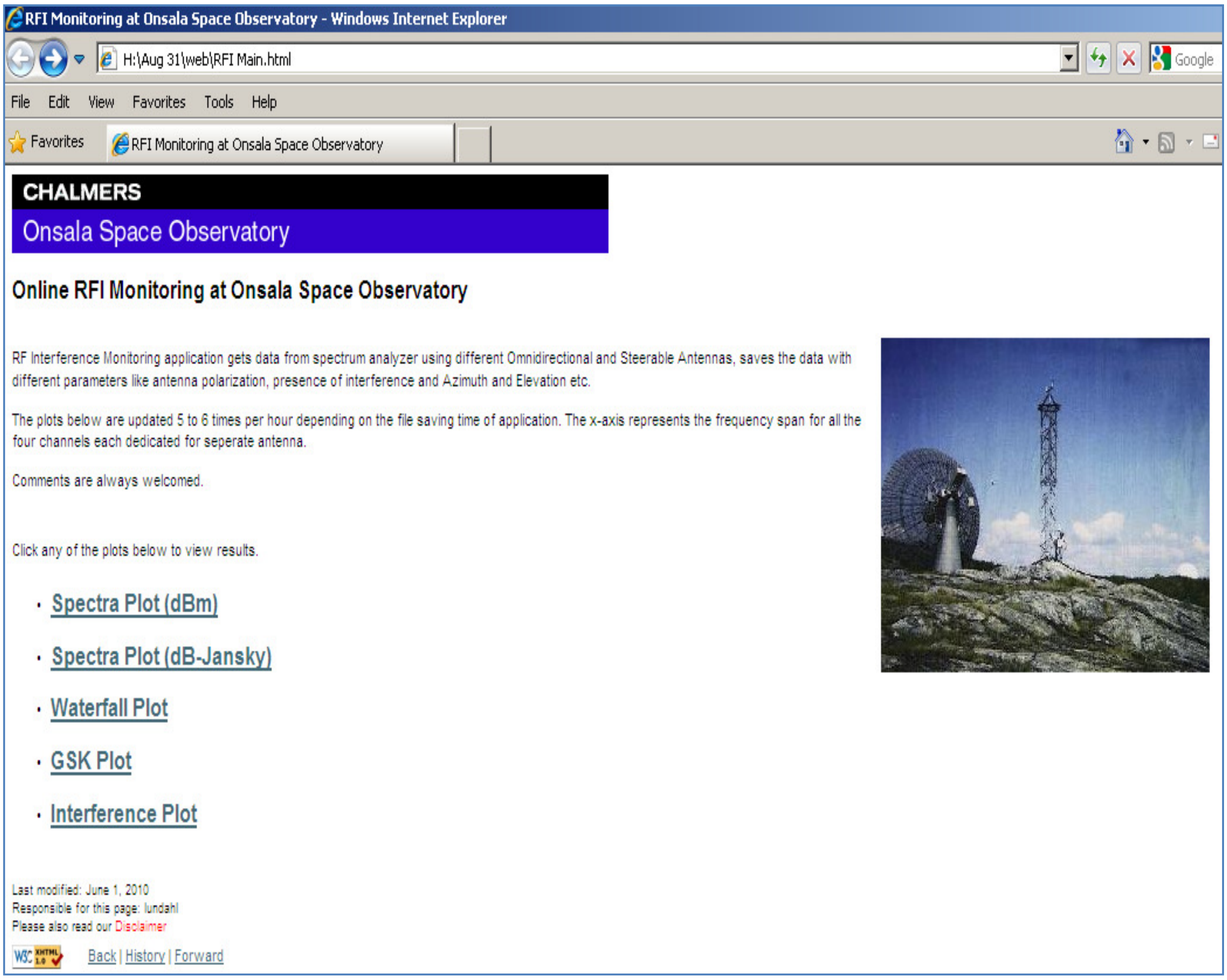


Figure 6.9: Main Web Page for Online Monitoring.

A screen shot of the online RFI monitoring web page is shown in the Figure 6.9 above. This page is accessed when ***RFI Main.html*** is opened in the browser. On this page, links to other web pages are available where the latest power spectra and interference related plots can be seen. These plots are the same as discussed in Chapter 5 but here they have been shown for online monitoring purpose.

Figures 6.10-6.14 show the screen shots of the web pages which show different spectral, interference and waterfall plots. The web pages refresh after some time and show the latest plots copied to their folder by the RFI application.

When the RFI monitoring application copies the new plots to the web server folder, it first removes the old plots and then copies the new plots to that folder so that the latest plots are available for the viewer to see.

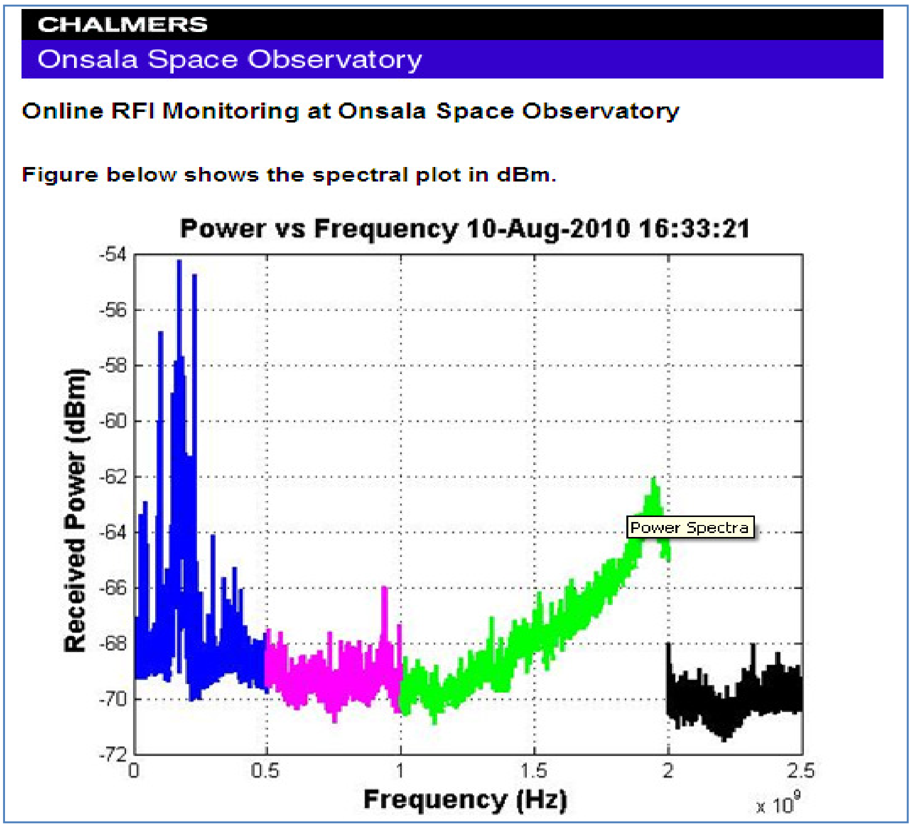


Figure 6.10: Spectral Plot in dBm units.

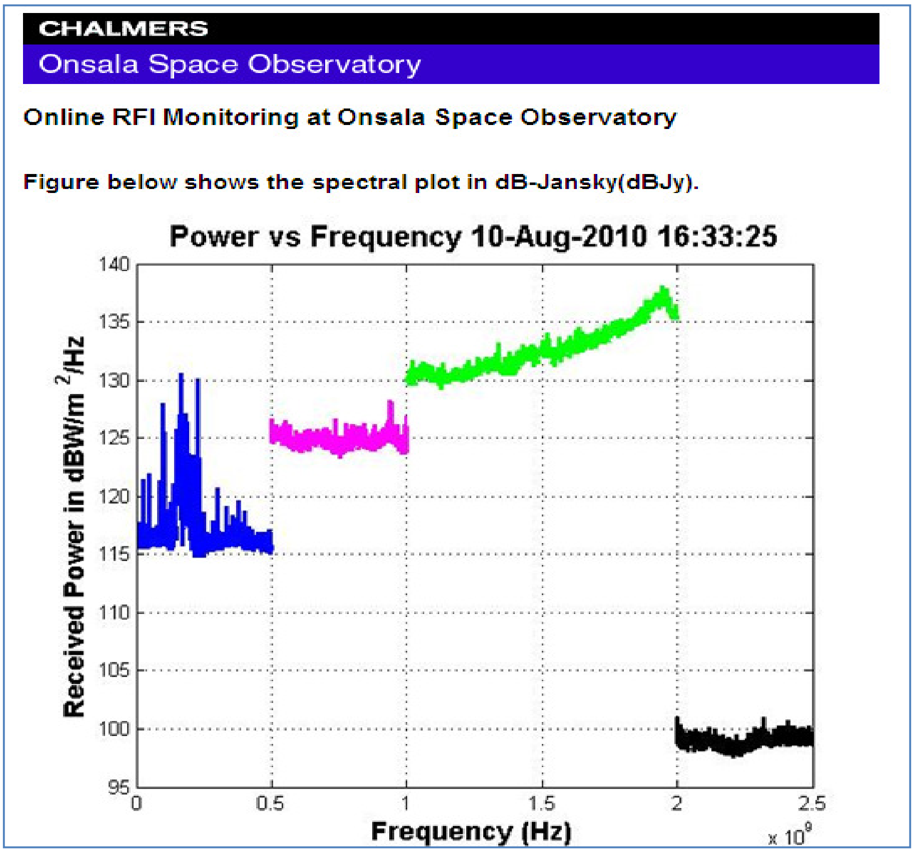


Figure 6.11: Spectral Plot in dB-Jansky (dBJy) units.

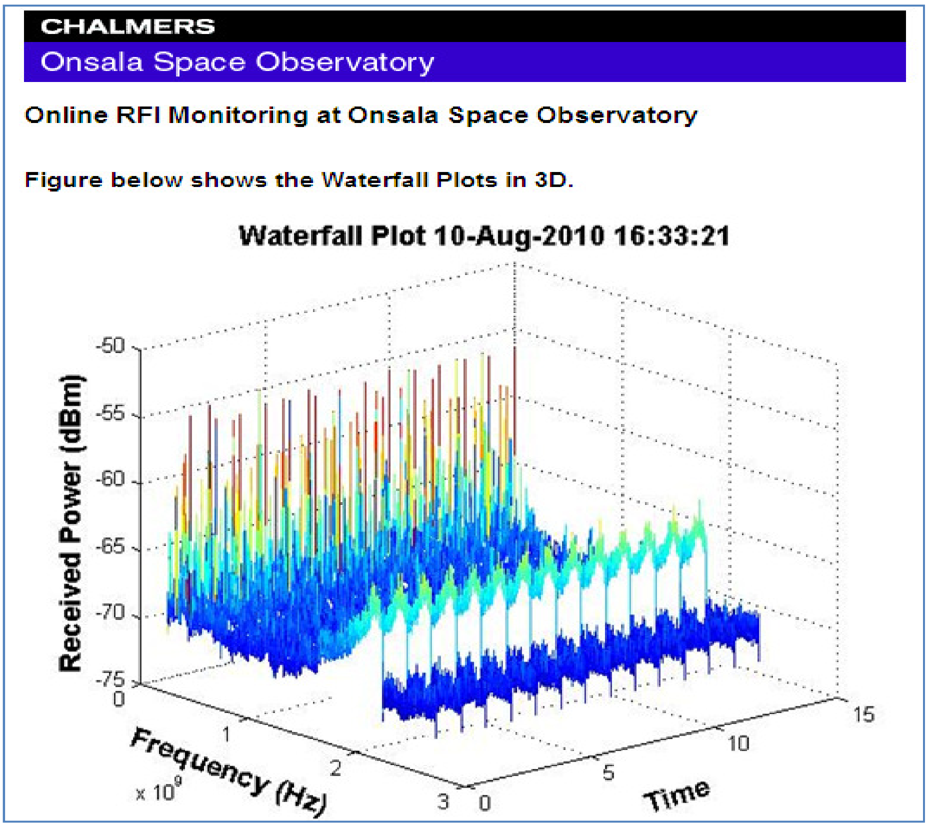


Figure 6.12: Waterfall Plot (in 3D).

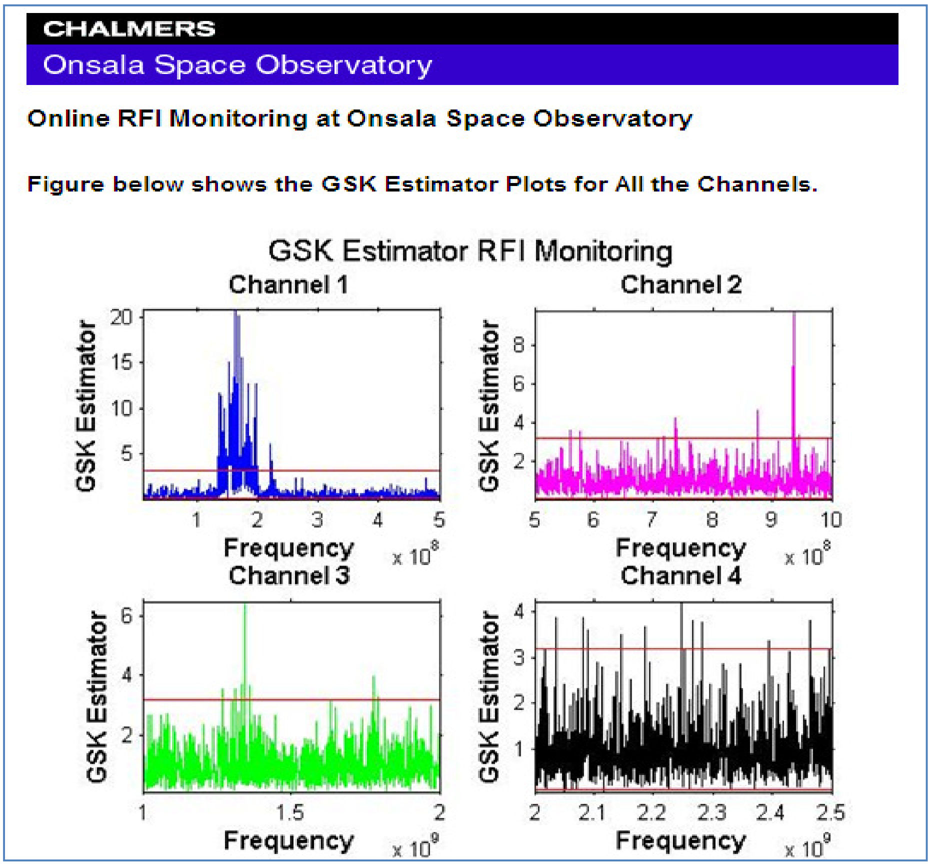


Figure 6.13: GSK Estimator Plot.

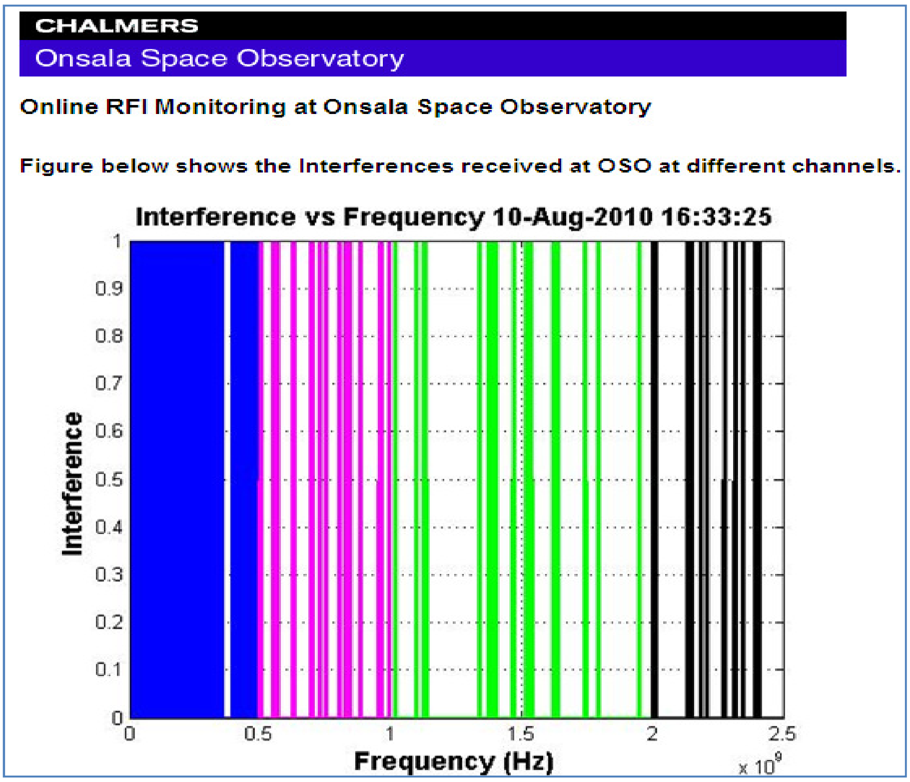


Figure 6.14: Interference Detection Plot.

CHAPTER 7

CONLUSION & FUTURE WORK

In this thesis work, a complete RFI monitoring system has been developed in a Linux environment. It works with different type of antennas like omnidirectional and steerable antennas. These antennas are used to find different type of new signals or interferences which could be a potential threat for radio astronomical observations at OSO.

This system has been implemented in C++ and Matlab R2010. The RFI monitoring application is very flexible, user friendly and easy to use. There are four channels available in the application. We can specify any frequency span, which is supported by the analyzer and the antenna, to any channel. The polarization of the antenna can be set using this application. A rotating antenna can be controlled by providing azimuth and elevation angles in the application. The purpose of using the rotating antenna is to find the direction of new signals. Omnidirectional antennas just find interferences but not the direction of the interference source. The application can switch between the antennas using a coaxial switch and a RIO motion controller which is implemented in C++. This system can support multiple receivers like Anritsu MS2602A and Agilent E4407B. The communication between the analyzer and RIO is TCP/IP based. The communication between the analyzer and the computer is implemented in Matlab while the communication between the computer and other hardware control is implemented in C++. In the later case, Matlab just forwards the request sent by the application to C++ using MEX function.

Detection of new interference signals has been done using GSK estimator which is state of the art methodology for detecting interferences in radio astronomical observatories. Many variants of this algorithm based on FFTS solutions have been proposed.

The RFI monitoring system saves the results in the form of files as a database for later use. Each channel has a separate file to be saved in the database. If there is any interference in the channel a warning is marked in the file name. Files are arranged in proper date-wise folders. The application generates different plots before saving the data in files. These plots are also saved in jpeg-format and they are replicated to a web server for online monitoring via the internet. An offline analysis of saved data in the database is also provided by this system. Data analysis is done by different plots.

Though this system meets all the requirements of OSO, still enhancements can be made in this system to meet global requirements. In this system, files are saved for each channel. It would be better to maintain a database like PostgreSQL in Linux. All the records should be saved in that database. The offline analysis application should just access the data of particular data and time from the database. Similarly, for the online monitoring on a web page, the viewer should be able to select the plots of particular date and time and a web server should generate the plots on run-time by accessing the data from the database. Currently, the latest available plots are viewable on the website. But it would require resources (software licensing, high computer resources, DBA etc) to implement a database for offline analysis and online monitoring.

Currently, this system can support Anritsu MS 2602A and Agilent E4407B analyzers. Support of this system can be extended to the latest state-of-the-art analyzers like the Rhode & Schwarz ESMD receiver. Some more features can be added to the application to set more parameters of the analyzers.

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APPENDIX A
APPLICATION OPERATION MANUAL

To run the RFI monitoring application, Matlab R2010 and a C++ compiler should be installed on a Linux based system. All the Matlab and C++ files should be located in the same folder. The Matlab files for RFI monitoring system are:

- Main.m
- Main.fig
- OfflinePlot.m
- OfflinePlot.fig
- calc_thres.m
- lower_root_x.m
- upper_root_x.m

The hardware management is done through files developed in C++, which are:

- Antenna.cpp
- Omni.cpp

The files ***Main.m*** and ***Main.fig*** are the main files for this system. The user should run either of these two files. The rest of the files are linked with ***Main.m***. To calculate the interference thresholds using the GSK estimator, ***calc_thres.m*** is used. The files ***lower_root_x.m*** and ***upper_root_x.m*** are used to calculate upper and lower thresholds for marking interference.

In order to compile the C++ files, the following command is used in a Linux shell or in a Matlab command window:

mex Antena.cpp -lGalil

After compiling the CPP file, an executable file is generated which is:

Antenna.mexglx

This file links the Matlab code with the C++ code.

The file ***Omni.cpp*** takes six parameters from the ***Main.m***. First three parameters are for selecting three omnidirectional antennas one at time and last three parameters are used to set the polarization of the selected antenna. The file ***Antenna.cpp*** is used to rotate the steerable antenna and resetting the steerable antenna. First two parameters are to for azimuth and elevation angles and the third parameter is used either for rotating the antenna or for resetting the antenna. The last parameter is used to set the polarization of the antenna.

The main considerations before running the application are:

- The PC, RIO and Analyzer should be connected properly in LAN environment.

- The IP addresses for Prologix box and RIO should be the same as specified in the code. IP for RIO is specified in C++ files and IP for Prologix box is specified in Matlab. Currently the IP for RIO is **129.16.208.166** and IP for Prologix box is **129.16.208.167**.
- The RIO, coaxial switch, rotating antenna amplifier unit should be connected according to the Table 3.1 and Figure 4.1.
- When the GUI is opened after running the ***Main.m*** file in Matlab, fill in all the text boxes and start the application by pressing the Start button.
- Sometimes RIO does not respond to Matlab requests. As a result the Matlab application crashes. By resetting the RIO we can resolve this issue.
- We need to specify the path in the code for each channel where data or files will be saved. This should be done prior to running the application. Otherwise the application will save the data in the current working directory by defining new folder and sub folders.
- We should specify the path in the code where the plots will be saved for online monitoring. These plots should be saved in the folder where all the HTML files are located.
- We need to specify the antennas area in the ***Main.m*** and ***OfflinePlot.m*** files for different antenna types like half-wavelength or short dipole and steerable antenna. Because based on these antenna areas, both the offline analysis application and the main application generate dB-Jansky and Jansky plots.

The start and stop frequencies can be specified in RFI monitoring system by different ways. We can specify the start and stop frequencies like 10000000 or 10e6 for 10 MHz in the application.

To add the calibration files, click on the text boxes and press the “enter” key. A dialog window will appear where we can select the file saved on the particular path and press the “open” to add the file with its path location in the text boxes. If the calibration files are saved in the same folder where the main RFI monitoring system files are saved, we can just write the name of the file in the text boxes. Both methods can be used for adding the calibration files in the data.

For online monitoring, all the HTML files and plots should be in the same folder. The main HTML files are:

- RFI Main.html
- dbm.html
- jansky.htm
- gsk.html
- interference.html
- wfall.html

The file ***RFI Main.html*** is the main file which should be opened through a web browser. On this page, there are links to view different plots. The remaining five files are used to show different plots currently available.

There are two jpeg-files in the folder where all the Matlab and C++ files are located. These files are used as a logo of Chalmers and OSO at the top of main application.