DIGITAL RECEIVER FOR SALSA

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ABSTRACT

The SALSA receiver uses a 2.3m parabolic antenna steerable in azimuth and elevation by motor driven mount. A horn with a probe integrated with a Low Noise Amplifier (LNA) is mounted in the focus of the parabola. The horn and the antenna are optimized for 1420 MHz, which is the frequency at which atomic hydrogen in the Milky Way is emitting.

This Master thesis, entitled "Digital Receiver for SALSA", describes the upgrade of the existing receiver and antenna control. We designed the new digital receiver system that use a reconfigurable I/O (RIO) FPGA in conjunction with antenna control software and a software receiver (Software-Defined-Radio or SDR).

The purpose of upgrading the system was to include some enhancements in the antenna controller as well as in the receiver. In the previous system a C program just worked as a GUI for the user, taking data and sending it to a microcontroller based hardware system, which decodes this data signal and sends appropriate signal to the antenna mount and then reads feedback encoder. In this project, a flexible and scalable software is realized to replace this complicated hardware. In the upgraded receiver, a Antenna Motion Controller software completely controls antenna. The software is designed in such a way that it does not miss even a single feedback pulse (there are 4 feedback pulses in one degree). The accuracy factor of software is 0.25 degrees.

The old receiver was hardware-based, thus every new configuration required new hardware. However, in our case, the software receiver is highly flexible in which a wide range of configuration is possible without changing or upgrading existing hardware. The new receiver also works in real-time mode (real-time signal processing) while the old one used to do store-and-process. This upgrade reduces the user interaction to continuously obtain signal spectra, and also minimizes the hardware needs.

ACKNOWLEDGEMENTS

First of all we would like to thank Almighty **ALLAH**, the most merciful and beneficent, who always shows us path of success and helps us in every moment of life and to whom we have to return one day. We would also like to honor our **parents** who always pray for us and give us courage to work hard in every step of studies.

Special thanks to our supervisor **Miroslav Pantaleev** and our examiner **Vincent Desmaris** for supervising us in every single stage of work and managing their time from their tight schedule. Many Thanks to **Lars Peterson** and **Michael Olberg** (in OSO) for providing a great software support and to **Magne** (in OSO) who not only helped us in initial antenna controller design but also gave us time to troubleshoot during the final testing stages. Thanks to **Cathy Horellou** (in OSO), **Rune Bystrom** (in OSO) and **Per Bjorklund** (in OSO) for providing help regarding antenna pointing towards source, regarding existing receiver, providing feedback on final results and regarding amplifier design. Thanks to all of the OSO people for their moral support and for providing a good working environment.

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CHAPTER 1

INTRODUCTION TO RADIO ASTRONOMY RECEIVERS

1.1 TRANSMISSION AND RECEPTION

In typical scenario, Radio Frequency or RF signals are used to communicate information (Audio, Voice, Video, Data etc) from one place to another. The Information signal is modulated on a RF carrier wave and transmitted using antennas (wireless case) which convert electrical signals into electromagnetic waves that can travel though a wireless medium. On the receiver side, the same frequency signal is received using the antenna and fed to the receiver consisting of filters, amplifiers, down converters and demodulated to retrieve the transmitted information. In radio astronomy, since there are no man-made transmissions, it is usually required only to amplify very weak signals from sky and introduce some techniques to remove noise to get some sort of profile (frequency, shape, bandwidth etc) of the incoming signal.

1.2 RADIO ASTRONOMY RECEIVERS

Radio astronomy is a subfield of astronomy that studies celestial objects at radio frequencies. The initial detection of radio waves from an astronomical object was made in the 1930s, when Karl Jansky observed radiation coming from the Milky Way. Subsequent observations have identified a number of different sources of radio emission. These include stars and galaxies, as well as entirely new classes of objects, such as radio galaxies, quasars, pulsars, and masers. The discovery of the cosmic microwave background radiation, which provided compelling evidence for the Big Bang, was made through radio astronomy [1].

Radio astronomy is conducted using large radio antennae referred to as radio telescopes [1] that detect weak signals from the sky. There are two types of receivers: direct detectors and heterodyne detectors. In heterodyne detectors one or more mixer stages are involved to down-convert the incoming RF signal to reduce processing overheads. After detecting a signal, its power spectrum is calculated using correlators or FPGA based Fourier Transform receivers and is used to further process the signal in order to read and get information about source of emission. These types of receivers are usually termed as **spectrometers.**

Figure 1-1 and **1-2** show typical and simplified low frequency (lower than 100 GHz) Radio-Astronomy-Receiver (RAR) or Spectrometer. For higher frequencies and for more sensitive receivers with ultimate performance the first stage of LNA is not present [2]. As shown on **figure 1-1**, a correlator calculates the power spectrum based on Wiener-Khinchin-Theorem which states that the power spectrum of a signal is the Fourier transform of its autocorrelation function (ACF). The correlator might be analog or digital. For a digital correlator, the signal is first digitized using analog-digital converter (ADC). **Figure 1-2**, shows a digital receiver, which incorporates an A/D down-conversion. This type of receiver is built using modern high speed ADCs and powerful FPGAs. This works on the principle that the magnitude square of the Fourier transform is the power spectrum.

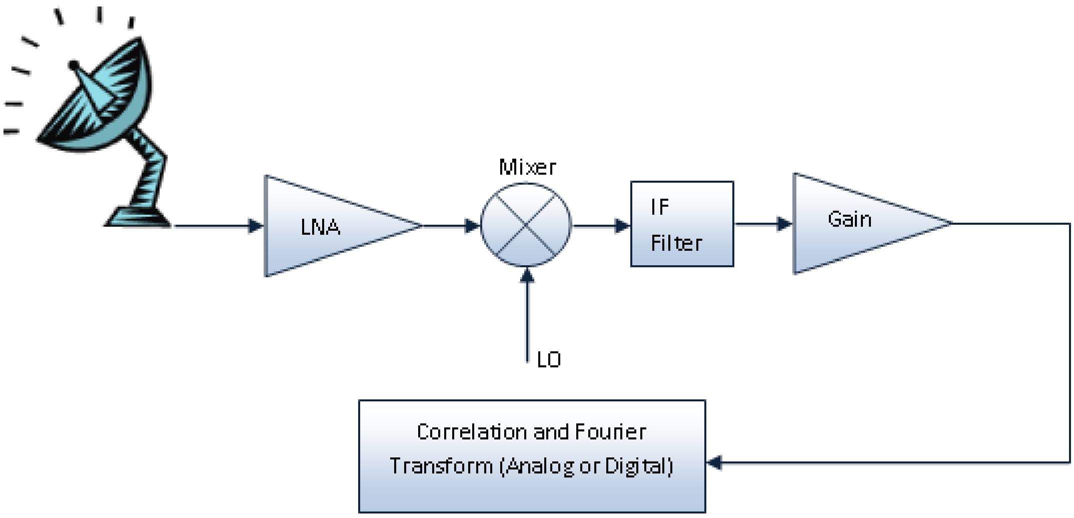


Figure 1-1: A typical block diagram of a hardware-based Radio-Astronomy-Receiver with analog or digital Correlator

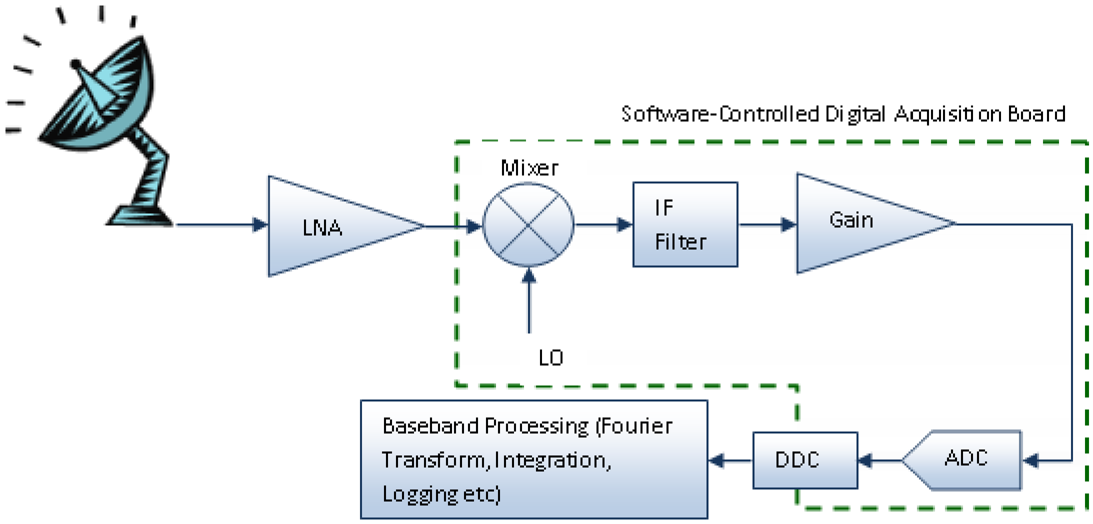


Figure 1-2: A typical block diagram of a hardware-based Radio-Astronomy-Receiver with digital processing to calculate Power Spectrum

The existing SALSA receiver is based on what is shown in **figure 1-1**. **Figure 1-2** shows the system that is implemented in software and will be discussed in detail.

After being received from antenna (typically parabolic reflector), the incoming signal is amplified by a high gain Low Noise Amplifier (LNA) which is down converted to Intermediate Frequency (IF) using mixers in order to facilitate further processing. Then, the Analog-to-Digital conversion takes place so that the signal can be digitally processed in modern receivers. A Digital-Down-converter down converts the IF signals into baseband for processing by dedicated or general purpose (PC) processors. The output can be in the form of display showing some spectra and/or data files.

1.3 OBSERVING TECHNIQUES

There are different observation techniques to observe weak signals from the sky. These are defined below.

- **Frequency-Switching,** in which the spectrum at exactly the frequency of interest is observed/calculated first for a certain period of time and stored. Then the local oscillator frequency of the mixer is changed to a few MHz away from frequency of interest and then the spectrum is calculated at that frequency. The spectrum at exact frequency of interest is termed **Signal** and the spectrum at some offset frequency is termed **Reference**.
- **Position-Switching,** in which first for a few moments the spectrum at exactly the frequency of interest and exactly at the right position on the sky is observed/calculated and stored. Then the direction of the antenna is changed only to some other position from where there is no emission at the frequency of interest and then the spectrum is calculated at the same frequency of interest. The spectrum at exact frequency of interest observed from the exact position of interest is termed **Signal** and the spectrum observed from offset position is termed **Reference**.
- A signal processing technique is employed to make the weak signal at frequency of interest further detectable within the noise which in mathematical form is

$$\frac{Signal - Reference}{Reference}$$

1.4 THESIS MOTIVATION

The usual approach (hardware-based) to detect signals has some limitations like to adapt to new services and standards. Each element in the receiver usually works for a particular specification and needs to be changed or re-designed or re-purchased if there is some change in the receivers' pecifications (Frequency, Gain, Bandwidth, Weight etc). This increases the hardware cost and is time-consuming (design, purchase and installation). Software-Defined-Radio (SDR), as described later, can do almost all of the said processing using software running on PCs with a general-purpose single-piece device. Re-designing the software is time and cost effective. Considering **figure 1-2,** the section in dotted lines (a digital acquisition device) is usually integrated into a single device (USRP2 in our case) with configurable parameters and all the remaining signal processing is done in software which gives more flexibility over the entire-hardware-based approach.

The second part of the project deals with steering of the antenna, saving and loading antenna position in some file (Antenna Motion Controller Software). In the existing system, the control of antenna is divided into two parts; the C program and Q-radio (microcontroller based hardware). With the upgrade, the antenna is completely controlled by a single C program. This program is flexible enough to easily change the number of pulses per degree, position of the closed switches both in azimuth and elevation directions, initial position of antenna etc. Also if one wants to reconfigure the interface between antenna and the C program for future extensions, one would just need to change some parameters in the program (clearly commented). The antenna motion controller software is flexible enough to be used with different antenna mounts due to the use fast sampling to read feedback pulses from antenna.

1.5 THESIS ORGANISATION

The report comprises of two parts, **Antenna Steering and Control Software** and a **Software-based Digital Receiver**. These two tasks were completed by **Nabeel Ahmed Durrani** and **Umair Naeem** respectively and their reporting is organized as follows,

Chapter 2 gives an overview of the existing system and currently available Software-Defined-Radio (SDR) architectures. **Chapter 3** covers the design analysis done for the receiver using GNU Radio and future possibilities and extension in the system. **Chapter 4** covers hardware configuration, physical interfaces connected to different hardware and characteristics of hardware components used in this project. **Chapter 5** deals with different aspects of the antenna motion controller software. **Chapter 6** includes conclusions and suggests future work of this thesis.

CHAPTER 2

OVERVIEW OF EXISTING SYSTEM AND SOME OF THE SOFTWARE-DEFINED-RADIO (SDR) ARCHITECTURES

2.1 OVERVIEW OF THE EXISTING SYSTEM

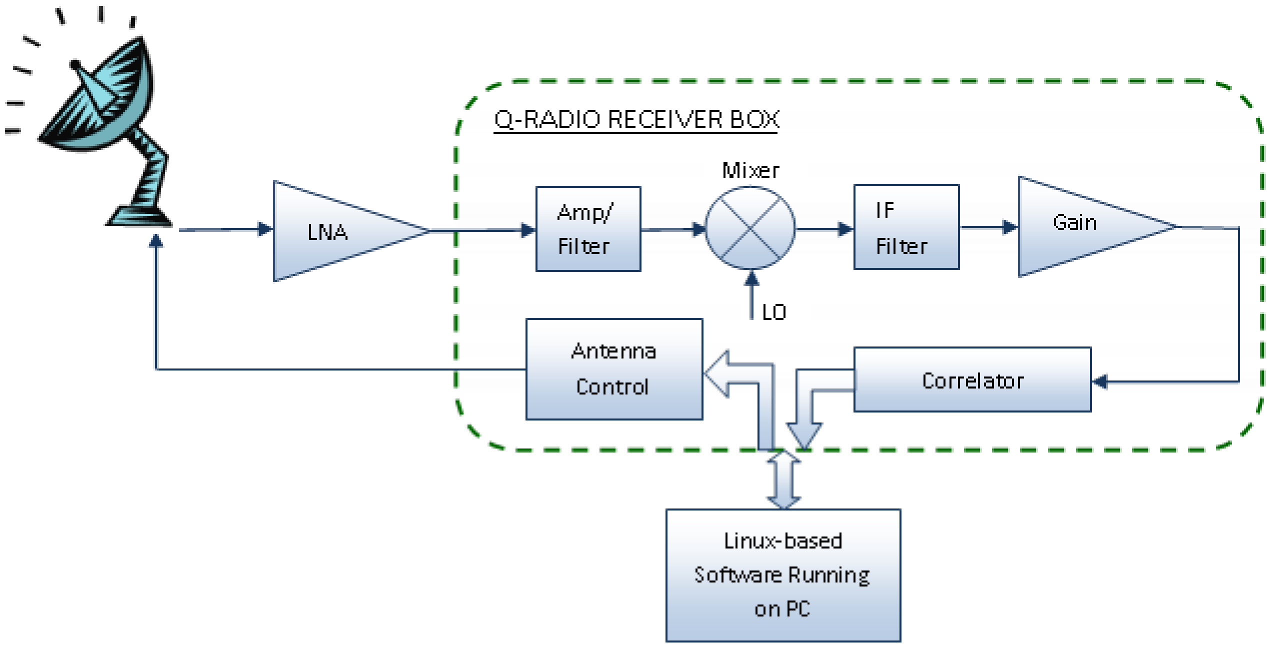


Figure 2-1: Block Diagram of the Existing System

Figure 2-1 shows the existing system used for the observation of the hydrogen line. After the amplification in the LNA the signal is carried by coaxial cable to a preamplifier box where it is further amplified and filtered in a narrow bandwidth filter to remove interference signals around the 1420MHz line. The receiver box (named Q-Radio) accommodates the down-conversion circuitry, the driving IC's for the antenna motors, the correlator and a micro-controller which controls all functions and communicates with a PC.

In the receiver box, the signal from the preamplifier box is further amplified and then down-converted to an Intermediate Frequency (IF) and a total bandwidth of 2,4 MHz using Side Band Separation technique. The microcontroller performs auto-correlation of the signal with a resolution of 12,5 kHz and also gives the possibility to integrate over a certain period of time. This pattern is sent to the PC via serial port. A Linux based software calculates the frequency spectrum and logs the data. The user enters the azimuth and elevation coordinates for the observation in the software and then the computer communicates with the microprocessor which commands the mount motors and reads its current position. **Figure 2-2** shows the detailed block diagram of the existing receiver in Onsala Space Observatory developed by Rune Byström (Åre Elektronik). It can be seen that the RF signal is split in two branches and are mixed with a sinusoidal signal from a local oscillator with a frequency of about 1418 MHz which are phase shifted with 90 degrees. After mixing, both signals are digitized and then added together after introducing additional 90 degrees phase shift in the corresponding channel to cancel the unwanted side band.

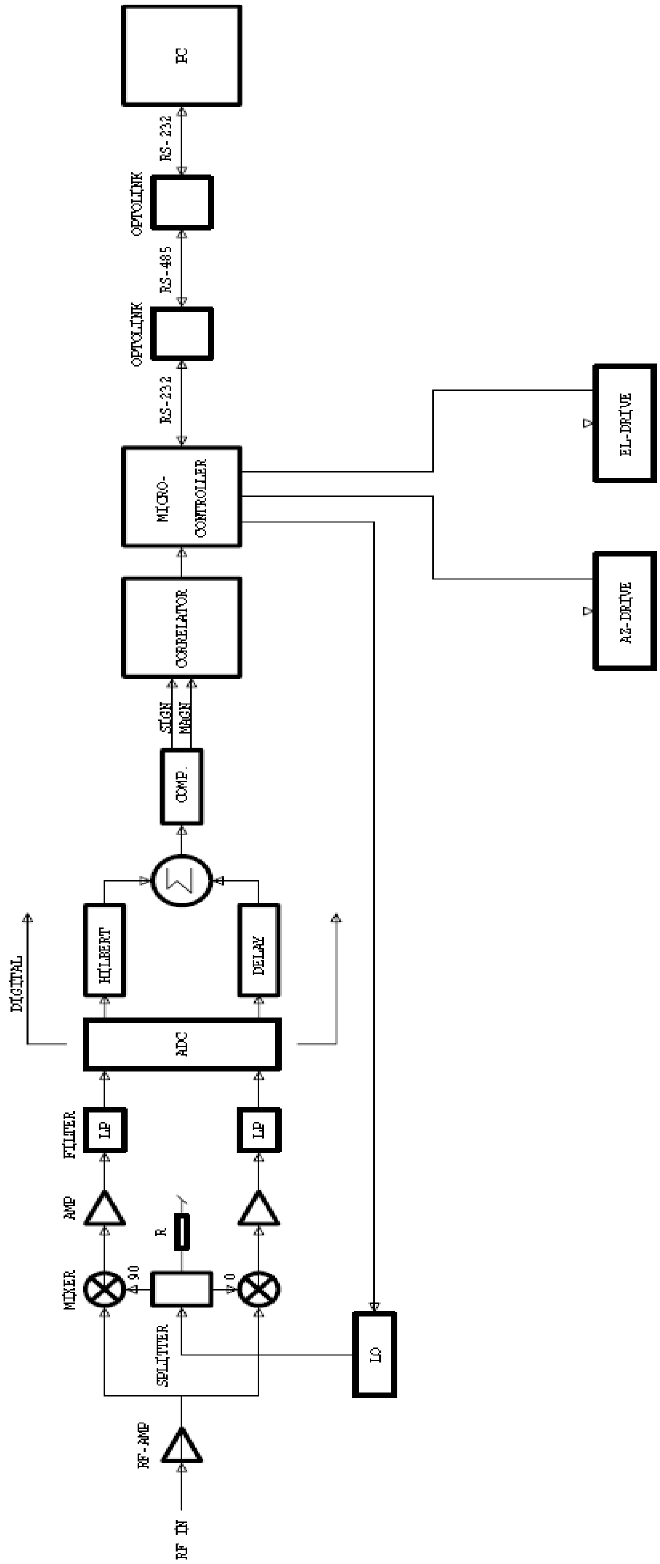


Figure 2-2: Existing SALSA Receiver (Q-Radio) Block Diagram [3]

One of the main objectives for this thesis is to replace the correlator with a general purpose digital front-end device named USRP2 from Ettus Research and implement a new software for data analysis based on GNU radio. The hardware specifications of the existing system available for the project, are summarize in the table below.

Table 2-1: Specification of the existing system for use in the project

Components	Specification
2.3m Antenna	F/D : 0.4
LNA	Gain: 28 dB, NF: 0.34 dB, 1420 MHz
Amplifier/Filter	Range: 1000-2000 MHz, Gain: 24 dB
Feed Horn	Inner Dia: 15.5 cm/0.733 λ, 1420 MHz

2.1.1 Feed horn

Figure 2-3: Feed horn used mounted over the antenna

The feed horn is a corrugated aperture-controlled horn in which the phase variation over the aperture is small. By referring the design graph in [4, page 339], the directivity was calculated to be about 6 dB.

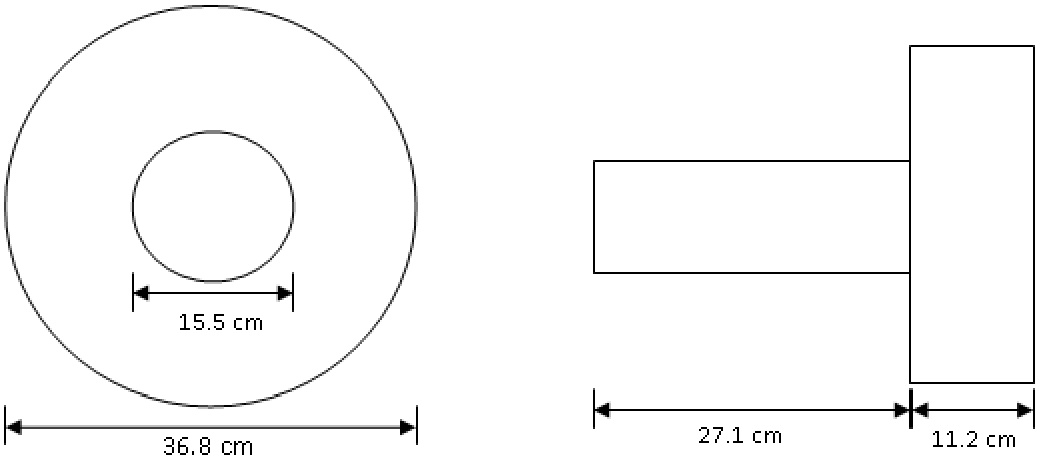


Figure 2-4: Top and Side View of the Feed Horn

2.1.2 Parabolic Reflector Antenna

Figure 2-5: Parabolic Reflector Antenna

The Antenna is a parabolic mesh-surface reflector having the diameter of 2.3 meters. Following is the parabola arc of the reflector. From this graph, the F/D ratio was calculated to be about 0.4.

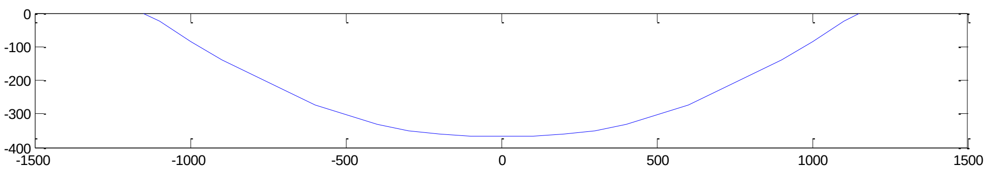


Figure 2-6: Parabola Arc of the Reflector Antenna

2.2 SOFTWARE-DEFINED-RADIO (SDR)

A software-defined radio (SDR) system is a hardware-cum-software-based radio communication system which can tune to any frequency band and decode different modulations/encoding schemes across a large frequency spectrum by means of a programmable hardware, which is controlled by software. An SDR performs significant amounts of digital signal processing in a general purpose computer (PC), or a reconfigurable piece of digital electronics [5]. SDR has evolved with advancement in computing machines and high-speed analog-digital (A/D) and digital-analog (D/A) converters. Thus SDR allows a single device to support a wide range of capabilities previously available only through multiple products.

Usually it is required that signals received by an antenna should be digitized so that SDR may use these digitized samples at RF frequencies (around GHz frequencies) to perform further signal processing steps (IF conversion, filtering, baseband conversion etc). But due to certain limitations like unavailability of A/D converters at very high frequencies (starting from a few GHz) and very high speed general purpose computers, digitization takes place after the IF or baseband demodulator stage. That typically means that hardware is still required to convert the signals of interest into and out of the "baseband" frequencies in the digital domain, but all of the complex processing performed at baseband is handled in the digital software domain [6]. Yet, such hardware is usually fairly simple comprising of a local oscillator and mixer, and a pair of low-pass filters.

2.3 REVIEW OF AVAILABLE SDR PLATFORMS

There are many platforms or architectures available to perform signal processing together with software domain. A brief introduction to some of the devices that use SDR is given below:

2.3.1 NI PXIe-5641R [7]

The NI PXIe-5641R uses LABView software to develop signal processing algorithms and applications. The NI PXIe-5641R is an intermediate frequency (IF) transceiver for applications such as radio-frequency identification (RFID) tests, spectral monitoring, real-time spectrum analysis, RF dynamic test, and software-defined radio (SDR). It features:

- 100 MS/s A/D converters with 20 MHz bandwidth digital down-converters (DDCs).
- 200 MS/s D/A converters with 20 MHz bandwidth digital up-converters (DUCs).
- Radio frequency (RF) applications at frequencies up to 2.7 GHz with bandwidths up to 20 MHz.

2.3.2 WinRadio [1]

WiNRADiO is the name of a manufacturer of radio communication equipment as well as a brand name of applied software radio receivers, antennas and accessories. Applications of WiNRADiO receivers include general purpose radio, radio astronomy, or SETI (Search for Extraterrestrial Intelligence).

WinRadio has developed its own receivers (G303 etc) with software to digitize the signal coming from antenna and process it in software domain. This includes tuning the receiver, controlling the attenuator and gain, as well as reading the signal strength. To complete a third-party software-defined receiver based on hardware platform, all that is needed is DSP software (running on the PC), to filter and demodulate the low IF (12 kHz) signal made available by the receiver. This 12 kHz IF signal is available at the output of the receiver, and is usually externally connected to the line input of the sound card. For standard USB-connected G303e receivers, the IF signal is available via the USB interface.

2.3.3 Vanu [8]

Vanu is a software radio that is primarily used for mobile communication. It utilizes a software radio base station to form software RAN (Radio Access Network) solutions. Vanu also developed **MultiRAN** to support multiple virtual base stations (vBTS) running on a single BTS hardware platform. Different resources like antennas, BTS electronics, and backhaul can all be shared. MultiRAN allows multiple operators to virtually share a single physical network. This allows operators to experience the cost benefit of shared infrastructure without the cost, complexity and risk associated with traditional network sharing arrangements.

2.3.4 Pentek Model 7142-428 [9]

Digital transceiver with digital down converter and interpolation filter is a complete software radio system in a PMC/XMC module with a decimation range from 2 to 65,536 and interpolation range from 2 to 32,768. It includes four A/D and one D/A converters with bandwidths up to 40 MHz and above for connection to HF or IF ports of a communications or radar system.

2.3.5 USRP and GnuRadio

GnuRadio (http://www.gnu.org/software/gnuradio) provides a comprehensive toolkit for the experimentalist in SDR to produce applications in a variety of disciplines. The work originated at MIT, with Eric Blossom shepherding its emergence as a GPL-licensed toolkit that is seeing significant usage by RF experimenters and engineering students worldwide [6].

The GnuRadio project resulted in the Universal Software Radio Peripheral (USRP) which is a digital acquisition (DAQ) system containing four 64 MS/s, 12-bit A/D converters (ADCs), four 128 MS/s, 14-bit D/A converters (DACs), and supports USB 2.0 interface. The USRP is capable of processing signals with 16 MHz of bandwidth.

The USRP takes daughter-cards to map the frequency ranges of interest into the “baseband” that is visible by the A/D hardware. Several different daughter-cards are available, but the cards of most interest to amateur radio astronomy enthusiasts would be [6]:

- DBS_RX - RX only, covers 850-2250 MHz
- TV_RX – RX only, covers 50-800Mhz

The DBS_RX converts the incoming RF into complex signals in a direct-conversion approach (with the signals extending from DC up to the low-pass cut-off of the receive converter) [6].

The TV_RX converts the incoming signal into a 5.75MHz IF. The desired frequency and bandwidth are settable using the GnuRadio toolkit and GUI [6].

The USRP was developed by Matt Ettus [1]. Later on the USRP2 was built on the success of the original USRP, and added new features [10] like Gigabit Ethernet, 25 MHz bandwidth etc.

GnuRadio is an open-source SDR toolkit which contains a library of signal processing blocks (like in Simulink/Matlab) which are interconnected like a flow graph. Each signal processing block is written in C++. The processing blocks in GnuRadio are arranged or organised with a Python-based applications framework. The Python code manages interconnection of processing blocks, and also provides user-interface functions. **Table 2-2** shows the comparison between different SDR platforms.

Table 2-2: Comparison between different SDR platforms

NI PXIe-5641R	WinRadio	Vanu	Pentek Model 7142-428	USRP2 and GNURadio
• 2 IF inputs and 2 IF outputs • 20 MHz real-time IF bandwidth • Xilinx Virtex-5 SX95T FPGA optimized for DSP • 100 MS/s 14-bit ADC • 200 MS/s 14-bit DAC • Built-in digital upconverters and downconverters • >76 dB input SNR • 250 kHz to 80 MHz IF center frequency • -143 dBm/Hz input noise density	• IF of 12 kHz • USB interface • Extraordinary sensitivity • Real-time spectrum analyzer • Spot-on tuning in 1Hz steps • Accurate signal strength indicator • Very low phase noise • DRM decoder option • Continuously variable IF bandwidth 1Hz - 15kHz • User adjustable filter selectivity • Built-in test and measurement instrumentation • Interactive block diagrams	• Frequency: 850 MHz, 1800 MHz, 1900 MHz • Output Power: 20W per carrier • Backhaul: IP over Ethernet or E1/T1 • Interfaces: Antenna ports (50 ohm N female), GSM – BTS to BSC (GSM A-bis over IP), • CDMA – BTS to BSC (CDMA A-bis over IP) • Supported Standards: GSM/GPRS/Edge/CDMA2000 1xRTT • Sensitivity: GSM (-112 dBm), CDMA (-126 dBm) • Capacity: GSM (upto 48 carriers), CDMA (upto 24 carriers)	• Full scale input: 10 dBm into 50 ohms • 3 dB passband: 250 kHz to 300 MHz • ADC: Sampling rate (1 MHz to 125 MHz) • Resolution: 14 bits • Decimation: 1 to 4096 • Input B/W: 40 MHz • Upconverte Sample Rate: 500 MHz max. and resolution 16 bits • Interface: PCI Bus (64-bit, 66 MHz), DMA: 9 channel demand-mode and chaining controller	• Gigabit Ethernet interface • 25 MHz of RF bandwidth • Xilinx Spartan 3-2000 FPGA • Dual 100 MHz 14-bit ADCs • Dual 400 MHz 16-bit DACs • 1 MByte of high-speed SRAM • Locking to an external 10 MHz reference • 1 PPS input • Configuration stored on standard SD cards • The ability to lock multiple systems together for MIMO

2.4 CHOICE OF SDR PLATFORM

Comparing the different SDR platforms available, GnuRadio with USRP2 was chosen in this thesis to develop SDR for the astronomical spectrometer for the detection of Hydrogen line at 1420 MHz. For this purpose, DBS_RX daughterboard is used to get RF and convert it to IF and baseband for further processing. USRP2 and Gnuradio were chosen for the following reasons,

- Input signal frequency from 800 MHz to 2.4 GHz
- Largest Single Sided bandwidth of 25 MHz
- Open-Source (Cost-effective and expandable) solution

CHAPTER 3

DESIGN FOR THE SOFTWARE RECEIVER USING GNURADIO

3.1 INTRODUCTION

Keeping in mind the main goals of the project, the whole existing correlator receiver was converted into software receiver using the GnuRadio software platform. The USRP2 serves as an RF front end to get the digital signals for GnuRadio.

3.2 DESIGN ANALYSIS

The signal flow in the existing receiving system was as follows,

- The RF signal coming from the antenna, amplified through the LNA (and pre-amplified as necessary), is fed into an IF stage which converts RF into IF.
- This IF is used to calculate the frequency content of the signal hence the power spectrum is calculated in the correlator and fed into an accumulator to integrate several spectra for averaging purpose. This averaging ensures the removal of as much random noise as possible.
- The observations were done using **frequency-switching.** The spectrum at exactly the Hydrogen line (1420MHz) is calculated and stored for a certain period of time. Then the local oscillator frequency of the mixer (IF stage) is changed to a few MHz away from Hydrogen line and then spectrum is calculated at that frequency. The Spectrum at exact the Hydrogen line is termed **Signal** and spectrum at some offset frequency from Hydrogen line is termed **Reference**.
- A signal processing technique is employed to make the weak Hydrogen line signal further detectable within the noise which in mathematical form is

$$\frac{Signal - Reference}{Reference}$$

3.3 IMPLEMENTATION IN GNURADIO AND USRP2

According to the above methodology for the receiver, the digital software receiver was implemented in the chosen SDR architecture as follows,

- The RF signal coming from Antenna, amplified through LNA (and pre-amplified as necessary), is fed into USRP2 which has a DBS_RX daughter board that contains an IF stage for converting RF into IF and then baseband with a maximum bandwidth of 50 MHz. This baseband signal is available through Ethernet interface to GnuRadio running on a PC for further processing. GnuRadio makes use of software filters and FFT to calculate and display the power spectrum.
- There is some limitation in GnuRadio. It works well in real-time, not in store-and-process method. In order to have two slightly different frequency signals (Signal and Reference), frequency switching is not used. Instead, the whole band consisting of the signal as well as the reference was obtained for processing. In our case this was as follows
  - Signal at 1420.4 MHz with 2.5 MHz bandwidth (1419.15 – 1421.65) MHz.

  - Reference at 1417.9 MHz with 2.5 MHz bandwidth (1416.65 – 1419.15) MHz.
  - Total bandwidth comprising of Signal and Reference thus became 5 MHz.
- The signal and reference signals are then filtered through separate filters, their FFT is calculated, averaged and finally the above mathematical equation is applied to detect the required signal.

Figure 3-1 Functional block diagram of the developed software receiver.

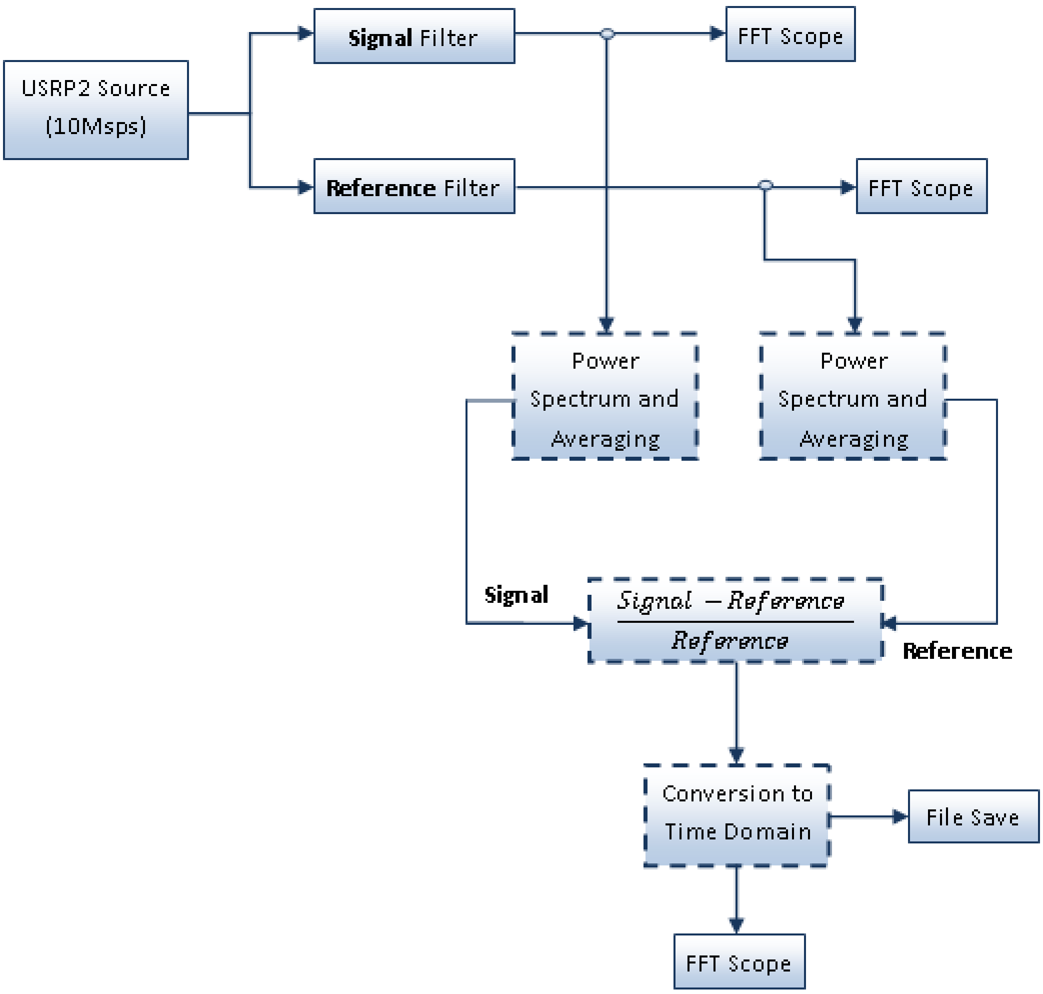


Figure 3-1: Functional Block Diagram of Software Receiver

3.3.1 USRP2 Source

This source block defines the parameters to get signals from USRP2. “Source” refers to the signal flow starting from USRP2 as seen from the GnuRadio point of view. Parameters are defined below,

Frequency: This is the frequency which will be down-converted to 0 Hz (baseband). It was set to the center of Reference frequency band i.e. 1417.9 MHz.

Decimation: This parameter sets the decimation that USRP2 should perform. Normally since the USRP2 provides a bandwidth of 50 MHz it means that the sample rate of the output signal from USRP2 is at 100 Msamples/sec (twice of bandwidth according to Nyquist Theorem). We require 5 MHz of bandwidth so we need 10 Msamples/sec of sample rate. Therefore decimation should be 100/10 = 10.

3.3.2 FFT Filters

There are two FFT filters to filter out Reference and Signal. The FT filter performs filtering in frequency domain which is faster than time domain filtering.

3.3.3 Power Spectrum and Averaging

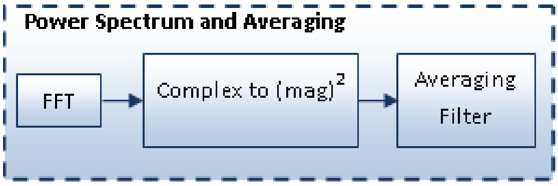


Figure 3-2: Power Spectrum and Averaging Block

These blocks calculate the Fast-Fourier-Transforms (FFT) of both Reference and Signal and then take the square of the magnitude to get the power spectrum. Averaging filters perform averaging to smoothen the signals and remove as much random noise as possible.

3.3.4 (Signal-Reference)/Reference

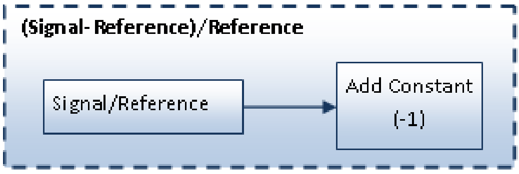


Figure 3-3: Observation Block

These blocks actually perform the mathematical operation described above. They are implemented with the following simplification,

$$\Rightarrow \frac{Signal - Reference}{Reference} = \frac{Signal}{Reference} - \frac{Reference}{Reference}$$

$$\Rightarrow \frac{Signal - Reference}{Reference} = \frac{Signal}{Reference} - 1$$

3.3.5 Conversion to Time Domain and FFT Scope

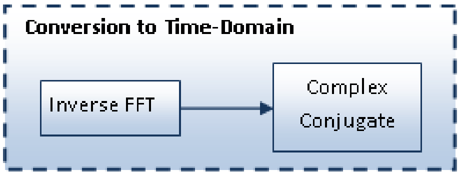


Figure 3-4: Conversion to Time-Domain Block

This block converts the frequency domain signal back into time domain. For this, it takes the inverse FFT, since we need to display the power spectrum of (Sig - Ref)/Ref and the FFT scope does this on time domain signal. The FFT Scope also provides with additional averaging options to smoothen the signal as much as required.

The complex conjugate block takes the complex conjugate of the incoming time domain signal. This is to invert (flip) the spectra. The previous blocks actually process the signals and the resultant signals' spectra is flipped to negative side of the frequency scale. In order to re-flip it to positive side of the frequency scale, this block is added here.

3.3.6 File Save

This sink block is used to store the time domain signal in binary file format. This file can be read by a **File Source** block.

Following figure shows the software receiver made in a tool (named GnuRadio Companion or GRC) of GnuRadio which provides graphical user interface to design systems.

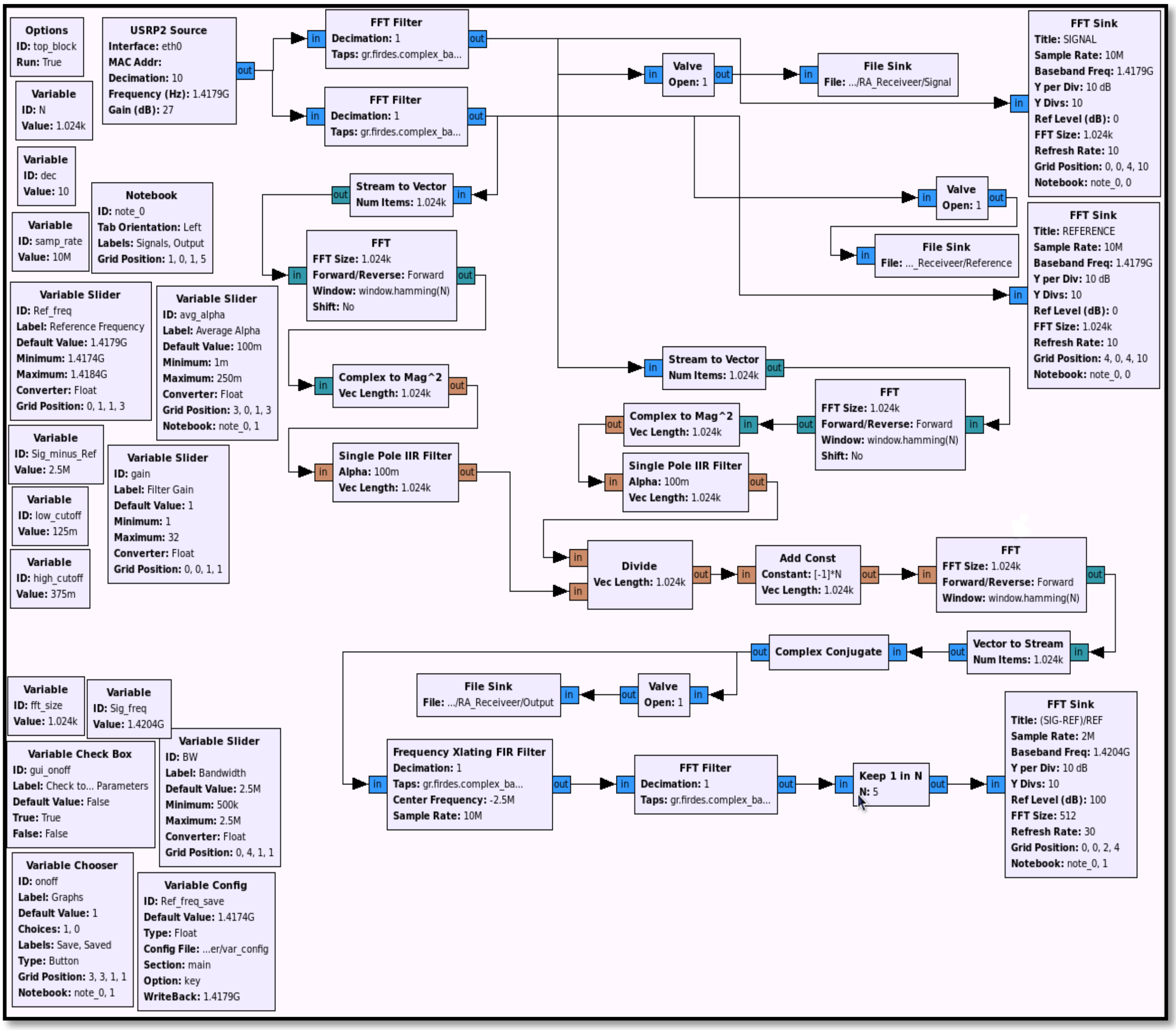


Figure 3-5: Software Receiver Snapshot

3.4 LAB VERIFICATION

Before testing the receiver in real environment, a setup was made to test the software receiver for eventually debugging the software, checking each of the receiver blocks and investigating the sensitivity issues since it would be a cumbersome job to setup the PC with all the wiring connections in real outdoor environment directly. The purpose of this setup was to test the USRP2 for its sensitivity to weak signals and to check whether a weak signal hidden in the noise is detectable by the software receiver or not. The USRP2 was seen to have a sensitivity of around -60 dBm which means it cannot detect signals below this level. For detecting lower level signals (that would be the case for astronomical objects) we need pre-amplifiers and set some gain of USRP2 device as well to amplify the incoming signal as much as it can be seen by the receiver (to have the signal greater than -60 dBm).

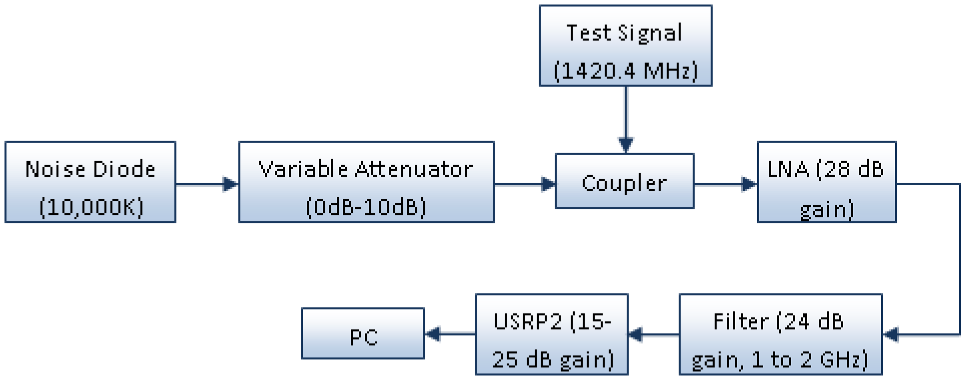


Figure 3-6: Block Diagram of Simulation

Figures 3-6 and **3-7** show the block diagram and the photograph respectively, of the setup in which a noise diode (10,000° K). In addition a test signal at 1420.4 MHz was injected through pre-amplifier(s) to have a total gain of around 70 dB including the USRP2 gain. The noise floor showed up above the -60 dBm which means that the incoming signal has been provided sufficient with gain to cross the -60 dBm sensitivity limit and is detectable. The weak test signal (around -125dBm) was not detectable from within the noise diode's noise as it has very low level (see **figure 3-8**). To detect this test signal the (sig-ref)/ref method (see **figure 3-9**) was performed and the test signal appeared, verifying that the new system is now ready to test for Astronomical sources.

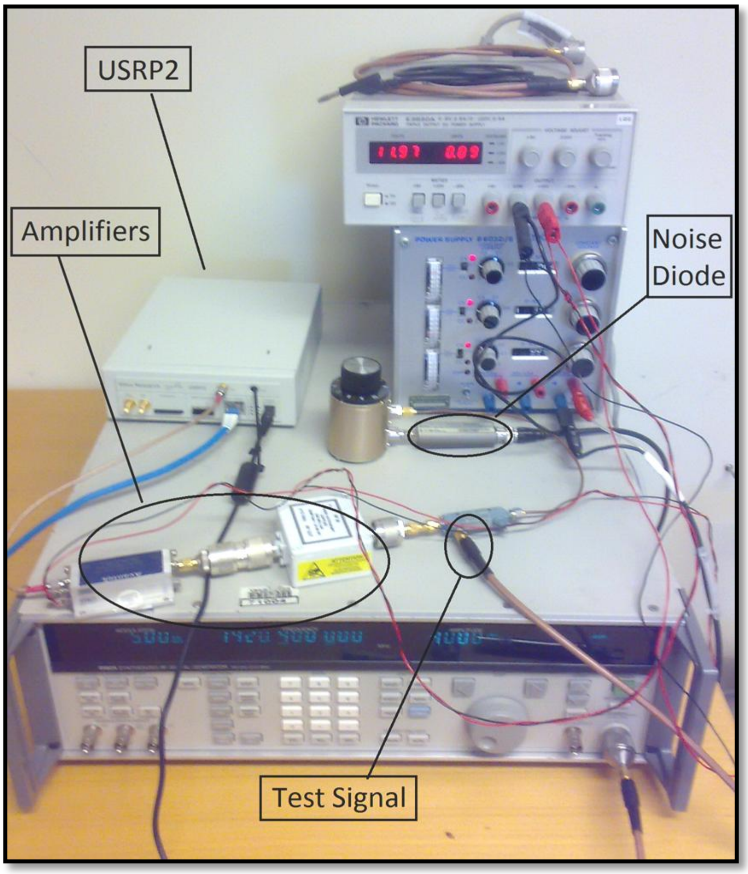


Figure 3-7: Test Setup

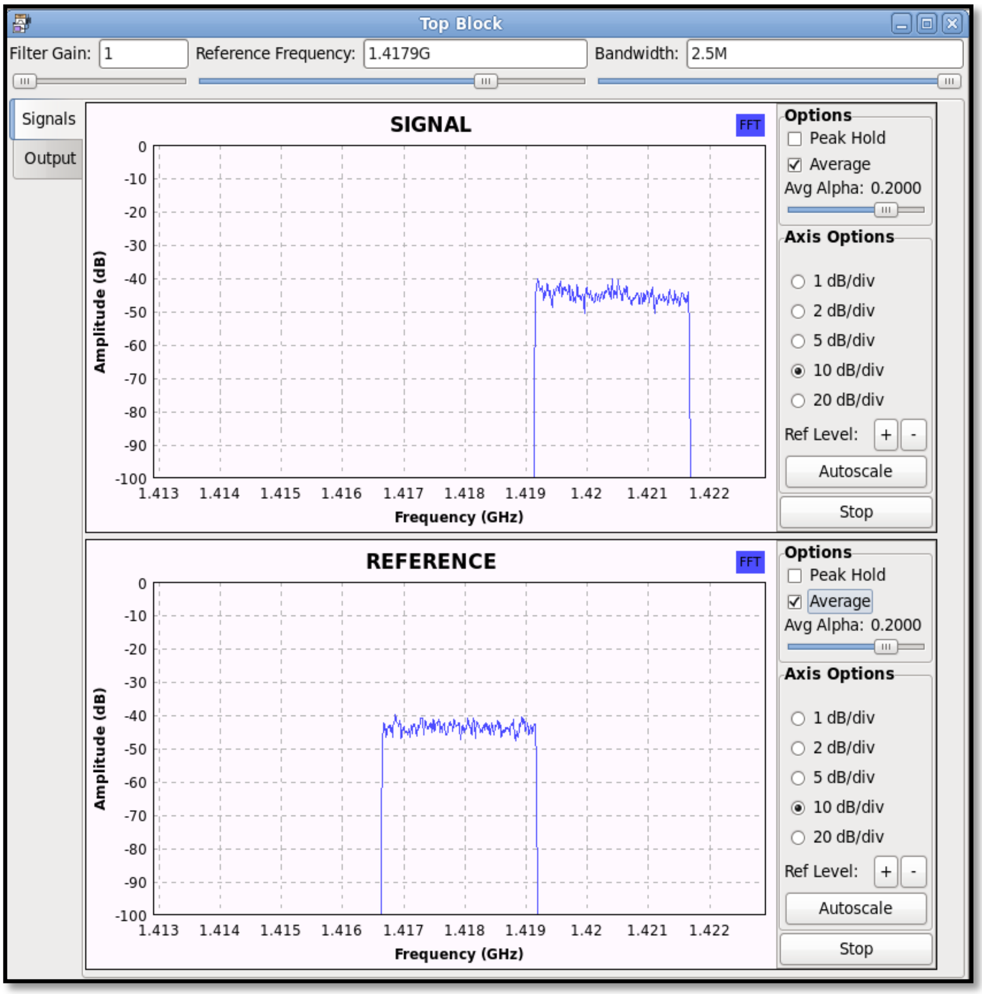


Figure 3-8: SIGNAL and REFERENCE Spectra Observed in Testing

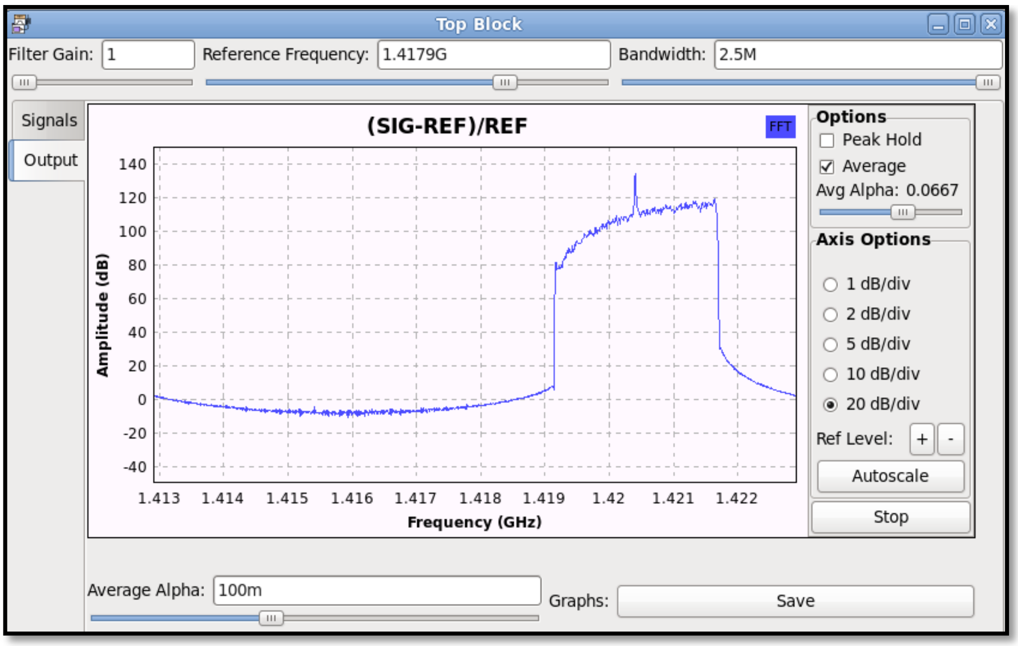


Figure 3-9: Observation of Signal within Noise using (SIG-REF)/REF Technique

3.5 TESTING IN REAL ENVIRONMENT

The whole setup was assembled outdoor in order to test the system for Hydrogen line detection. This testing in real environment would be validating that all the components are placed in the right order. (antenna, LNA, power supply etc).

First the antenna was pointed in a random direction and the power level of the signal was noted. Then the antenna was pointed towards the sun and power spectrum lifted a little showing that all the connections were fine and that the pre-amplifier and software receiver is working properly in accordance with the lab test results. Then the antenna was pointed towards the hydrogen line source. **Figures 3-10, 3-12, 3-13** show the setup and the difference in the spectrum of (sig-ref/ref) without and with the antenna pointed towards the Hydrogen line source respectively. It can be seen from the **figures 3-12** and **3-13** that the receiver worked properly as the signal is differentiable from noise.

Comparing the spectrum taken with the old configuration of SALSA ([11], **figure 3-11**) pointed toward the same direction of the galactic plane (Galactic longitude l=120 degrees, Galactic latitude b = 0) and the spectrum (**figure 3-13**), obtained with the upgraded digital software receiver pointing in the same direction, clearly shows the functionality of the upgraded digital receiver. The difference is spectrum can be explained by the approximate pointing during our experiment, but it certainly looks like a detection! It would also have been useful to observe in a slightly larger or shifted (towards right) band [11].

The observed spectrum range seems far wider than the actual spectrum band needed to observe (within red circle in **figure 3-13**). This is due to the FFT Scope block of the GnuRadio, where no zooming on a particular section of the spectrum is possible; hence we have to see the whole band which is being translated from analog to digital domain through sampling. To observe only a small part of spectrum, one could decimate the (SIGNAL-REFERENCE)/REFERENCE signal to a point where the bandwidth is half the decimated sampling rate (Nyquist Theorem). Actually, a small decimation is performed here if we compare **figures 3-13 and 3-9** to see the difference.

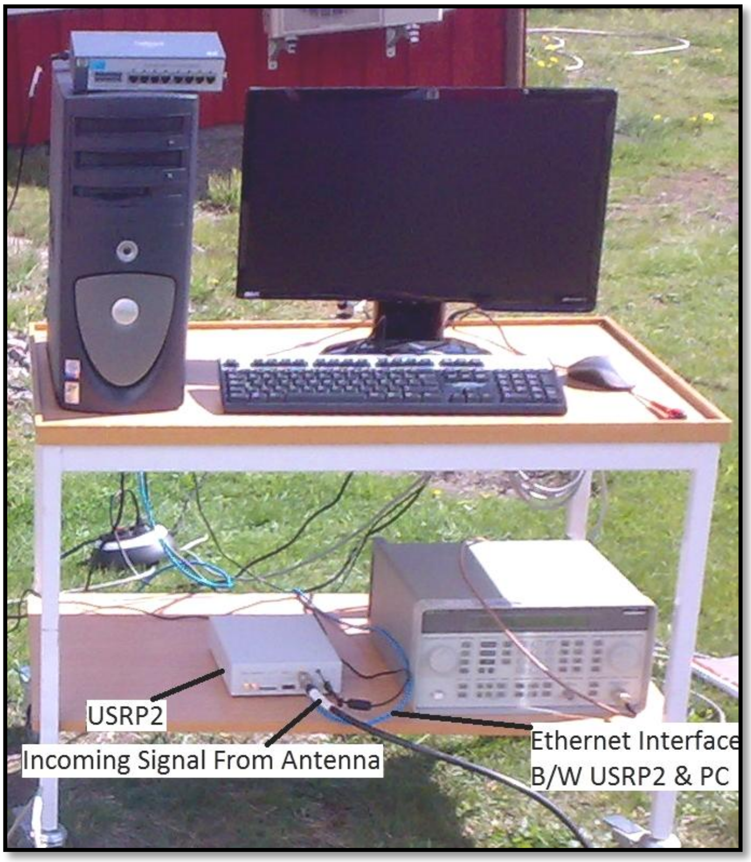


Figure 3-10: Testing in Outdoor Environment

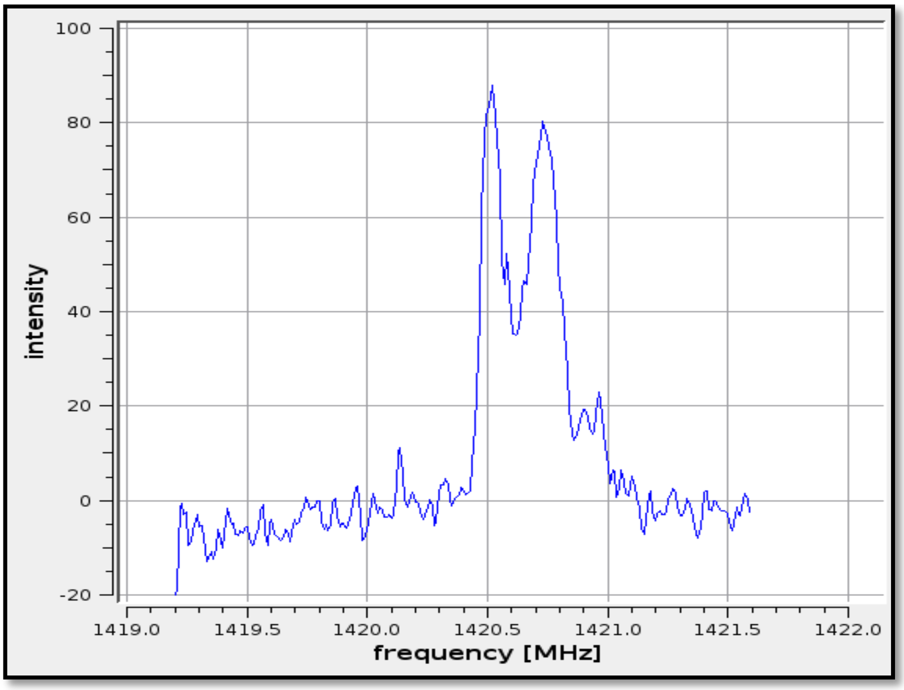


Figure 3-11: Spectra of Hydrogen Line Taken From Existing System (in Units of Temperature)

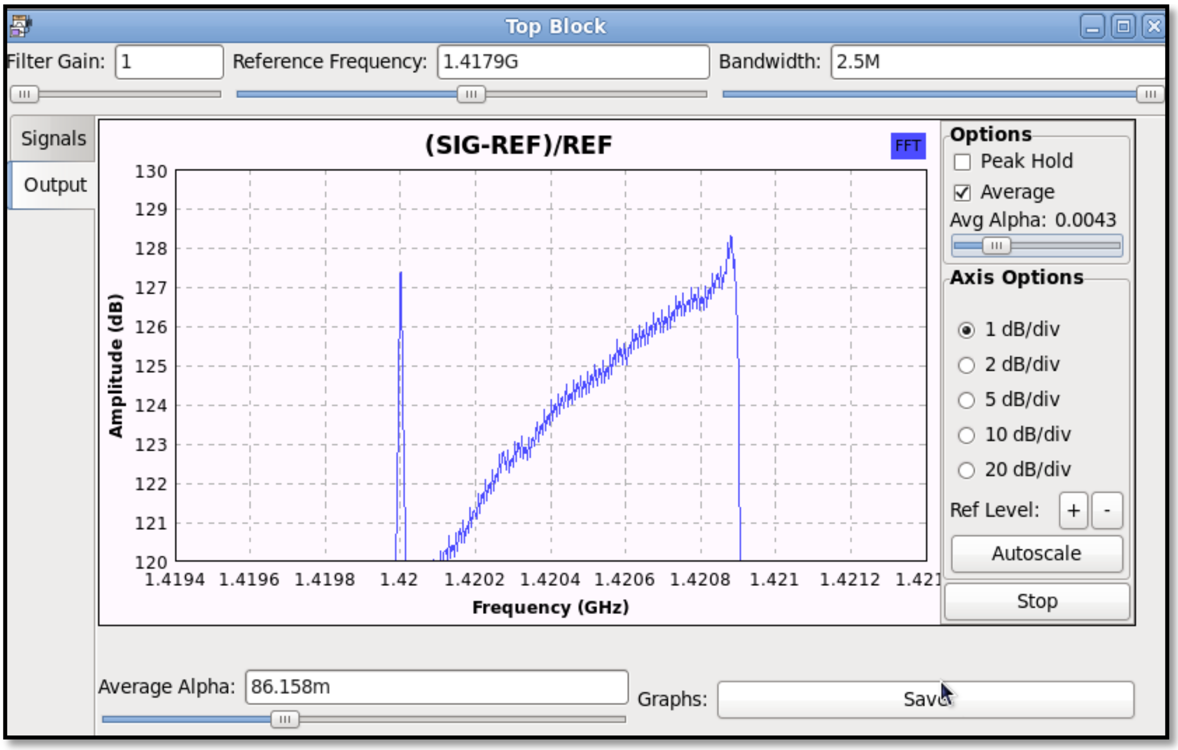


Figure 3-12: Spectra When Antenna is Misaligned towards Hydrogen Source

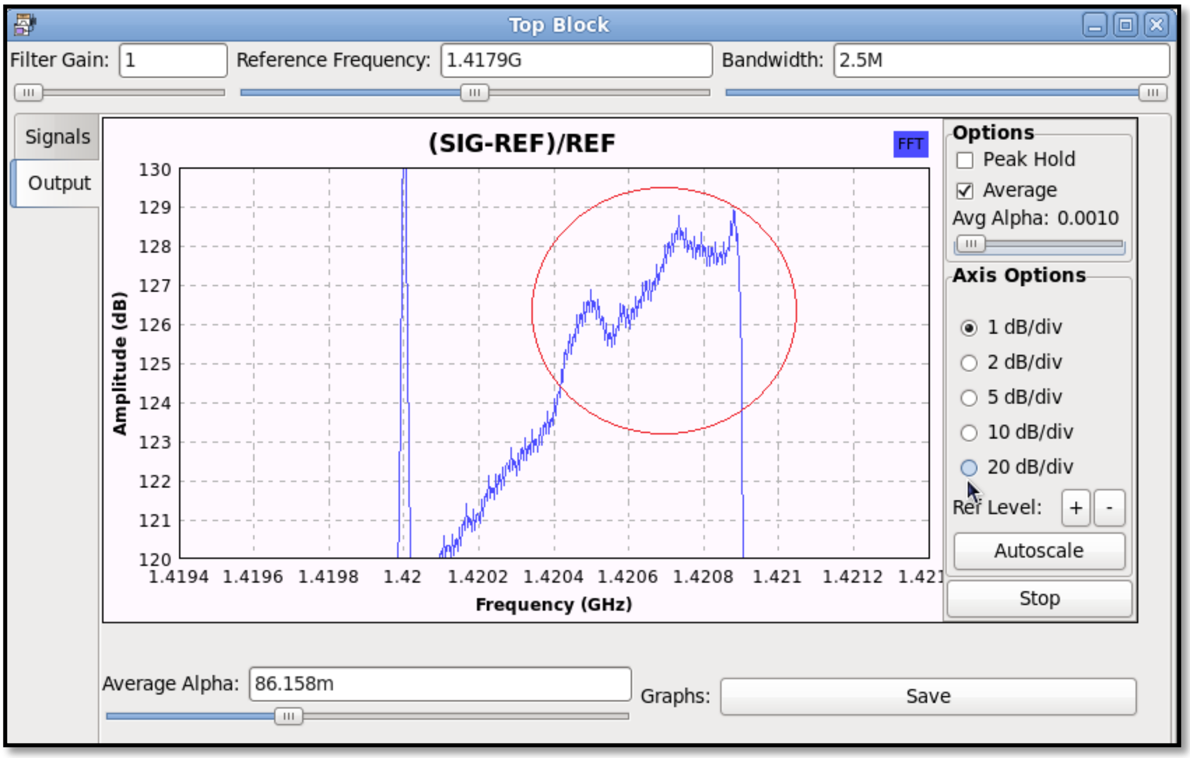


Figure 3-13: Spectra When Antenna is aligned from the Hydrogen Source

CHAPTER 4

ANTENNA MOTION CONTROLLER HARDWARE CONFIGURATION

4.1 REVIEW OF THE AVAILABLE HARDWARE

In our application, there were many options for choosing hardware for controlling the motors and reading the feedback encoders. Different vendors provide such hardware with different features. This section describes some of the available hardware and motivates our choice of Galil RIO 47200 because of its advantages over other available hardware.

4.1.1 Rabbit op 7210 eDisplay

Rabbit provides op 7210 eDisplay Ethernet/intelligent operator interface. It provides 16 digital inputs and 8 digital outputs. Digital outputs are individually configurable in software for different current and voltage outputs. Current and voltage can be set up to 350mA and 36VDC respectively. It provides Ethernet as well as two RS-232 or one RS-232 (with CTS/RTS) interfaces. Programs are developed for the op 7210 using Rabbit's industry-proven Dynamic C software development system. This development system offers almost all the capabilities like pop-up menus, onscreen keypads, data transmission/reception over TCP/IP and serial connections, analog volt meter display, and many more [12]. The main disadvantage of op 7210 is its number of digital outputs; it has only 8 digital outputs. This project utilizes 5 digital outputs, but such a short number of digital outputs will limit the possibility of future expandability.

4.1.2 Trio Motion CAN 16-I/O

The CAN 16-I/O module from Trio Motion Technologies allows the 24volt digital inputs and outputs of the Motion Coordinator to be extended in blocks of 16 bi-directional channels. It provides its own made Motion Perfect software for programming and analyzing I/O status. However, this module does not provide the flexibility to be used with most widely used languages like MATLAB, C++ etc. It supports G code, which is one of the standard languages that is widely used in CNC machines [13].

4.1.3 NI compactRIO Series

National Instruments provide a series of compactRIO components. These series provide the control to a variety of hardware types with the integration of the very popular LabView software. The main drawback in NI compactRIO series is that it only supports single axis devices while the antenna mount used in this project utilizes two axes motion. Using these compactRIO just increases un-necessary components and so the cost will also increase [14].

4.1.4 Galil's DMC family

Galil's DMC family is also a strong candidate for our application. The DMCs are specialized motion controlling boards. They have 32 bit processor and provide standard PCI and ISA slots for communication. They also provide different modes of motion like point to point positioning, jogging etc [15].

4.2 Choice of hardware for Antenna Motion Controller

The main reason for choosing the RIO family is its simplicity. It provides number of digital outputs which are perfectly matching our application in which we have to give commands to the azimuth and elevation motors. It also has digital inputs which makes easy to read feedback encoders to get azimuth and elevation pulses from the motor. It also provides standard 100Base-T Ethernet and RS-232 options to interface with PC. Galil provides its own made C++ communication library which makes it really easy to communicate with RIO and interrogating about its I/O status. It provides on board programming which can be a very important feature when using RIO as standalone motion controller. It provides flexibility to add more RIO units with it via Ethernet or RS232 port [16].

4.3 SYSTEM BLOCK DIAGRAM

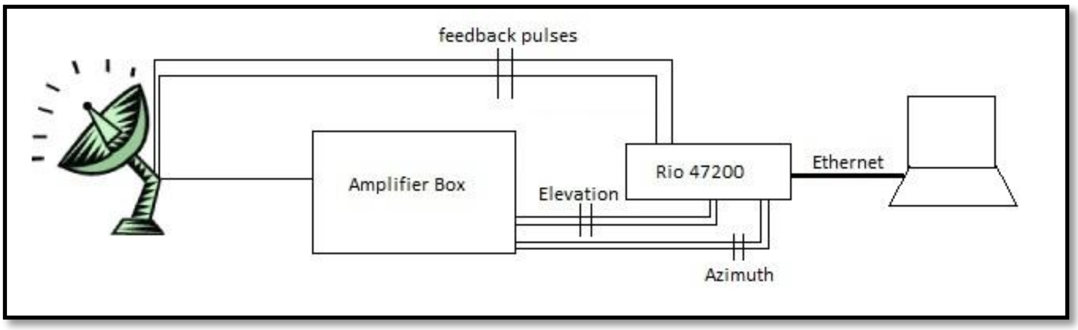


Figure 4-1: Block diagram for antenna motion controller

One of the main goals of this master thesis is to minimize the hardware used in the previous system (Q-radio). In the previous system, a C program just provides GUI to the controller (Q-radio). The C program, which controls Q-radio, sends commands in string format to the Q-radio, in which a microcontroller decodes these commands and send appropriate signal to antenna motors. Then Q-radio reads feedback pulses from the antenna feedback mechanism and sends the number of feedback pulses to the C program (again in string format). The main idea of this master thesis is to replace this complicated hardware by simplified software and to minimize the hardware needs; therefore the system block diagram is very simplified.

The mount of the antenna is provided by Alfa Radio Ltd. It's a heavy duty antenna rotator. Each axis uses a double worm gear drive system. Two windshield motors are used as drivers. Motors operate on ±12-24V, 2,5A, with peak starting current of 4A. Motors have two limit switches in each axis. One limit switch is at a complete rotation in azimuth (360 degree) and the other is on 95-100 degrees in elevation [17].

4.3.1 Rio 47200

Rio 47200 has multiple digital inputs and multiple digital outputs. As shown in block diagram, Rio is connected to the PC via Ethernet 100Base-T, which takes care of the communication part between the PC and the Rio board. Two wires for azimuth control and two wires of elevation control of the motor are connected to the digital outputs of the RIO and these outputs are controlled by the Antenna Motion Controller software (defined in next chapter). To control the rotation of the antenna, there are feedback pulses for azimuth and elevation from the motors which rotate the antenna. These feedback pulses wires are connected to the digital input of the Rio, as these are TTL pulses of 8-12Hz frequency.

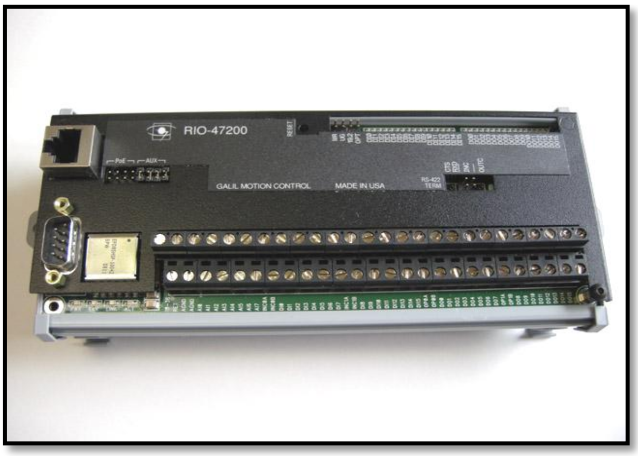


Figure 4-2: Rio 47200

4.3.2 Amplifier Box

The output from the Rio are TTL levels, but the motors which rotate the antenna requires at least ±18V with a continuous current of ±2.5A and a ±4A peak current, so there is an considerable need of amplifier between Rio and antenna motor.

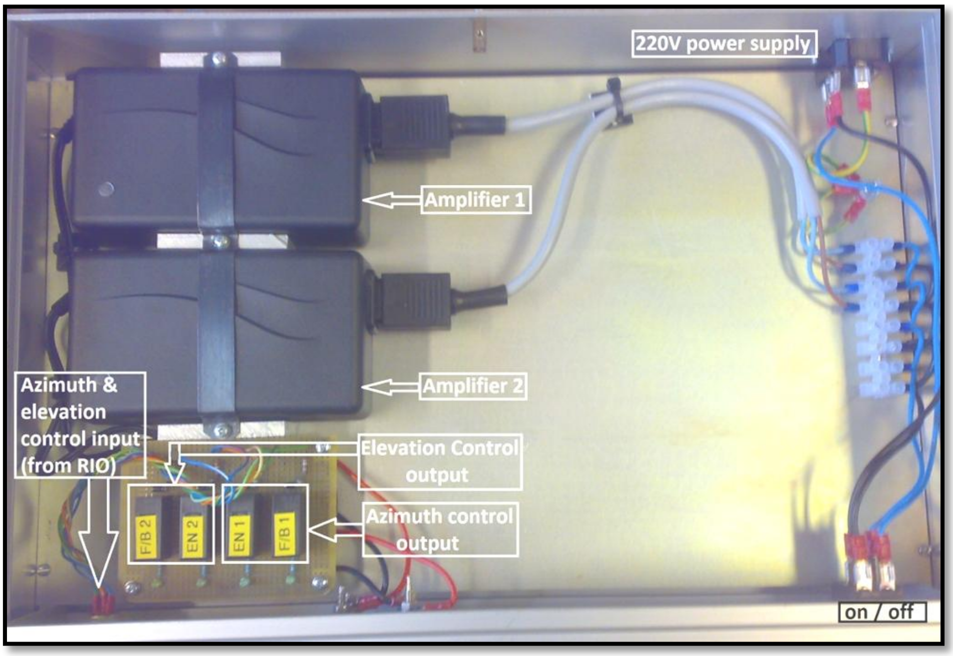


Figure 4-3: Amplifier Box (inside view)

Furthermore, the direction of steering is changed by changing the polarity of the power supply, and this is accomplished by creating a control signal with the power supply, which when enabled, delivers power with positive polarity and when disabled, delivers power with negative polarity.

The amplifier front panel contains discrete input connection from Rio to the amplifier and amplified output azimuth and elevation control signals (marked by solid black boxes in **figure 4-4**) to the antenna motors.

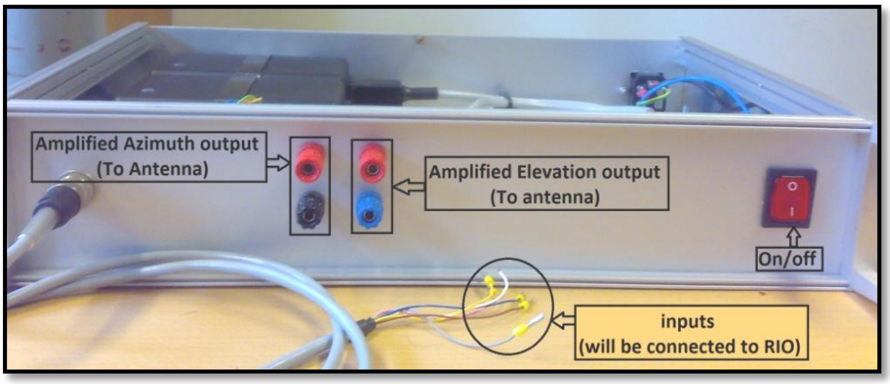


Figure 4-4: Amplifier box (front view)

4.3.3 Antenna Motor

The antenna motors which rotate the antenna have a feedback mechanism, which is fairly simple. A 12 leg wheel (as shown in **figure 4-5**) is mounted on a shaft in one of the gearboxes of antenna motor, so whenever the antenna moves, it also rotates this wheel. There is an opto-couple behind this wheel, so that TTL pulses are created when light from the opto-couple falls on it. These are TTL pulses and have frequency ranges from 8 to 12Hz. One degree rotation in azimuth or elevation generates 4 feedback pulses, which gives an angular accuracy of 0.25 degree (the full moon has an angular diameter of about half a degree [18]). The angular resolution of the 2.3m SALSA antenna is about 7◦ at the frequency of the HI line, 1420 MHz [18]. These pulses directly go to the digital input of the Rio which is then read by the antenna motion controller software.

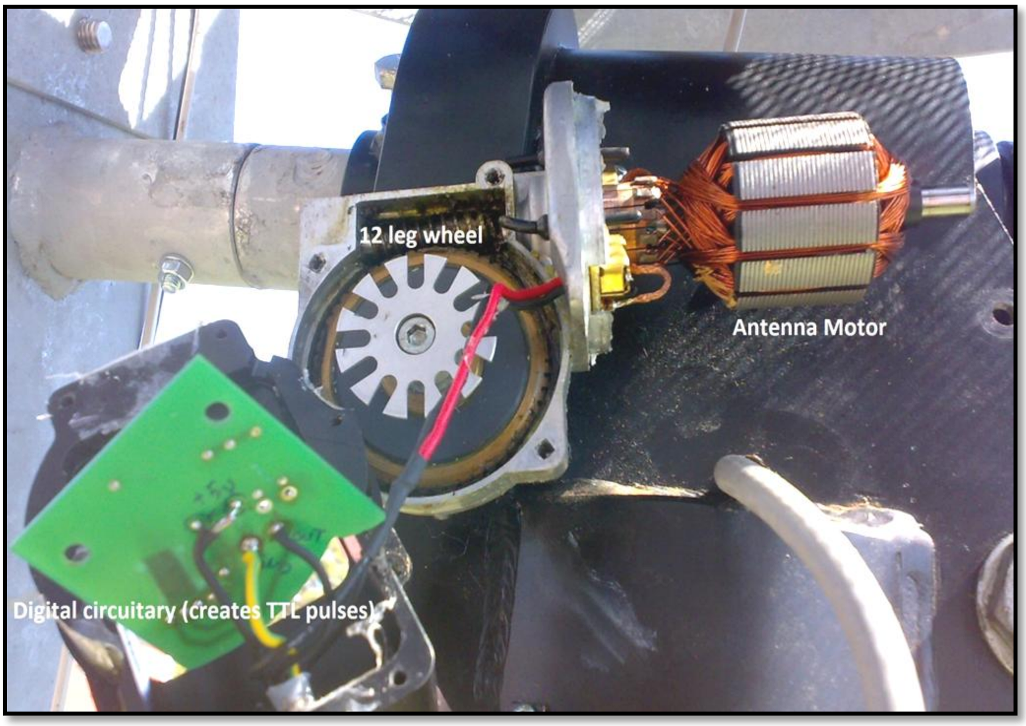


Figure 4-5: Opto-couplers and the Wheel Providing Feedback of Antenna Position

4.4 CONFIGURATION OF RIO

The following table contains physical interfaces which are connected to Rio. A small description of every interface is also given in the table below.

Table 4-1: Physical Interfaces Connected to RIO

Wire colour/number	Connected to	Description
Red	RET	+18-36V Power Supply
Black	AGND	Ground for Power Supply
Blue	Op0A	+12-24V Output Power Supply for DO[0-7]
Pink	Op0B	Output Power GROUND for DO[0-7]
Brown	DO5	Direction signal for azimuth
Yellow	DO6	Motion signal for azimuth
Gray	DO7	Direction signal for elevation
White	DO8	Motion signal for elevation
Wire # 1	INC1B	To enable IN jumpers
Wire # 2	DI9	Elevation feedback
Wire # 3	INC1A	Input common DI[8-15]
Wire # 4	DI8	Azimuth feedback
Noise diode	D02	Noise diode control

Rio has two power options; external power supply and PoE (Power over Ethernet). When external power supply is used then four jumpers are placed at pins labelled as AUX on Rio (default setting) and when power over Ethernet is required then instead of placing 4 jumpers on AUX, 4 jumpers are placed at pins labelled as PoE on Rio.

The INC jumpers can be used when an external power supply is not desired for digital inputs 0-15. These inputs can use the internal +5V from the RIO instead. To do this, place a jumper on the pins labelled INC [16].

CHAPTER 5

ANTENNA MOTION CONTROLLER SOFTWARE

5.1 OVERVIEW

Antenna motion controller software is developed using C++ language and used for steering of the antenna in azimuth and elevation directions, resetting the antenna to the north and zenith positions, enabling and disabling noise diode, saving azimuth and elevation coordinates in a .txt file. The User can also load the coordinates from a saved file. The GUI (Graphical User Interface) is built mainly by means of the C++ Qt library which is specially developed for graphics in C++ language.

5.2 PROGRAM FLOW

5.2.1 Steering of Antenna

The antenna motion controller software enables the user to steer antenna in both azimuth and elevation directions from GUI. The user can give azimuth values form 0-360 degrees and elevation values from 0-90 degree in double spin box created using Qt library. The flow graph of the program to steer the antenna in desired directions is presented below.

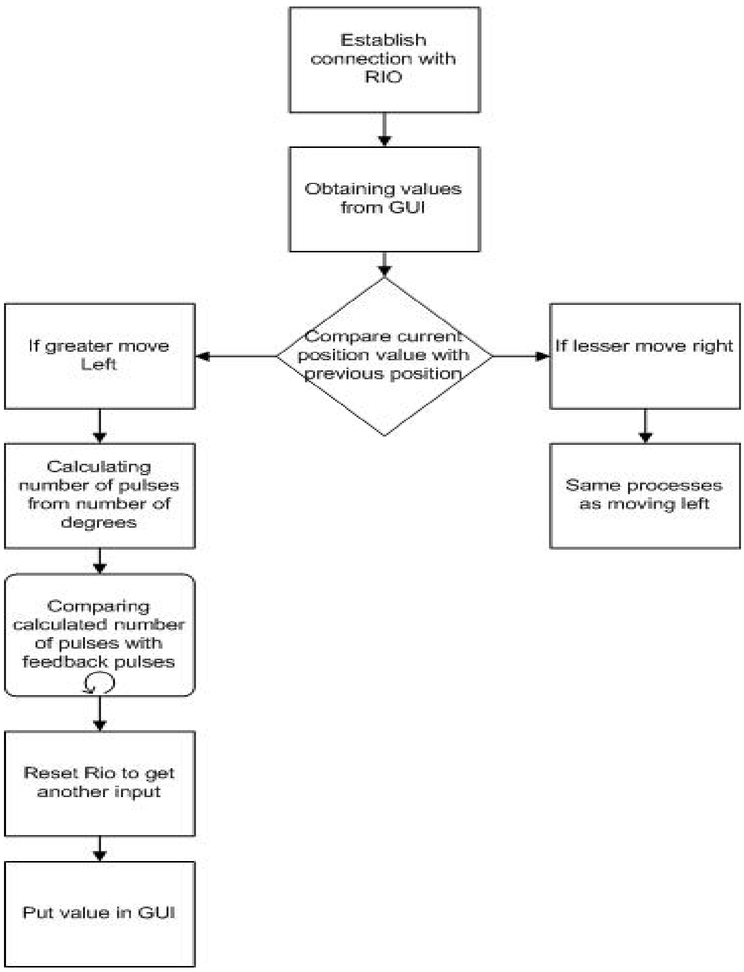


Figure 5-1: Flow Graph of Antenna Steering

5.2.2 Initialization of Antenna Position

The software enables the user to the reset antenna to the north direction in azimuth (i-e 0 degree) and to the zenith in elevation (i-e 90 degree). The antenna has its close switches both in horizontal and vertical directions. The antenna is mounted so that it has its horizontal close switch at North and vertical close switch at zenith direction. Indeed the vertical close switch is not exactly at 90 degree, it is around at 95 degree elevation, so when performing the reset function, software moves the antenna 5 degrees from its close switch to get the actual zenith position. The flow graph of reset function, is presented below.

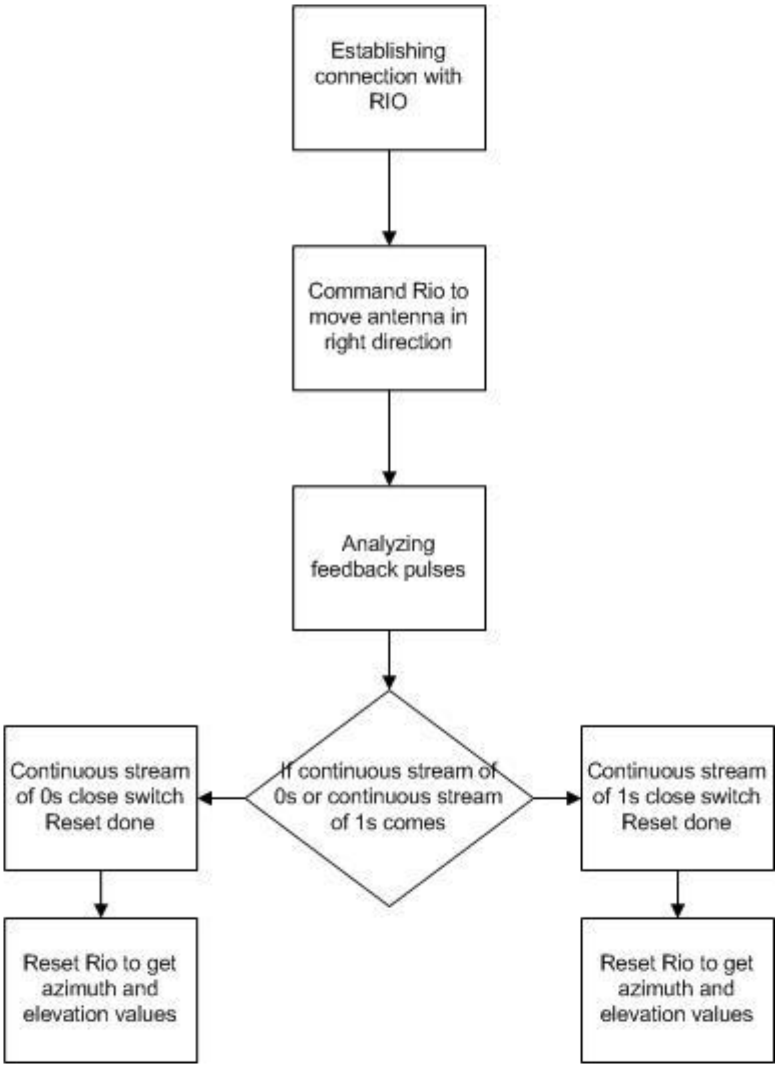


Figure 5-2: Flow Graph of Resetting Antenna

5.2.3 Noise Diode

A noise diode is a device used to simulate the atmospheric noise. It is turned on for calibration and simulation purposes. The control signal of the noise diode is connected to one of the outputs of the Rio board, and it can be turned on or off just by sending 0 or 1 at this output. A Boolean variable is declared for the noise diode, whenever the GUI sends this Boolean variable as true, a 1 is sent to the output of the RIO and the noise diode is turned on, and when it is false, a 0 is sent to the output of RIO and noise diode is turned off.

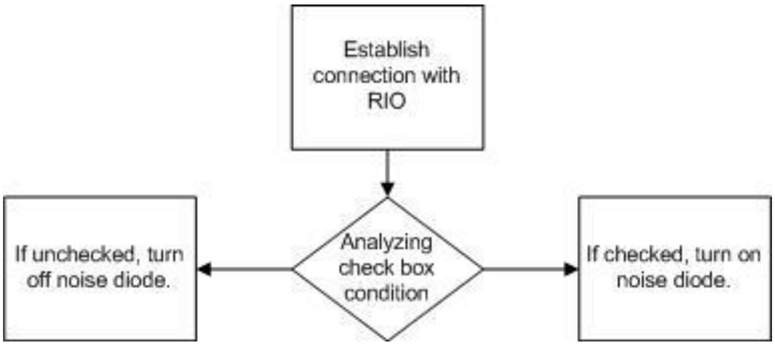


Figure 5-3: Flow Graph of Noise Diode

5.2.4 Saving Coordinates in a File

The antenna motion controller software enables the user to save the current coordinates (azimuth and elevation values) to a text file, as illustrated in the flow chart below.

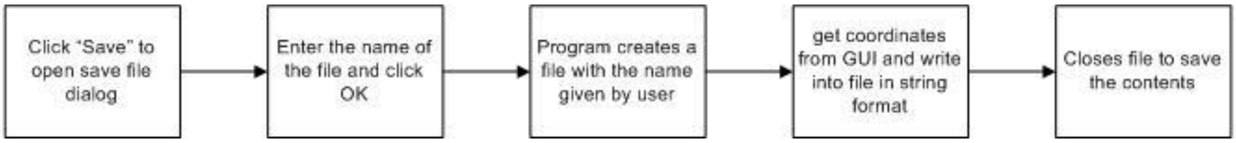


Figure 5-4: Flow Graph of Saving File

5.2.5 Loading coordinates From File

The software also has an option of loading coordinates (azimuth and elevation) from a saved text file; Flow of the procedure is illustrated below.

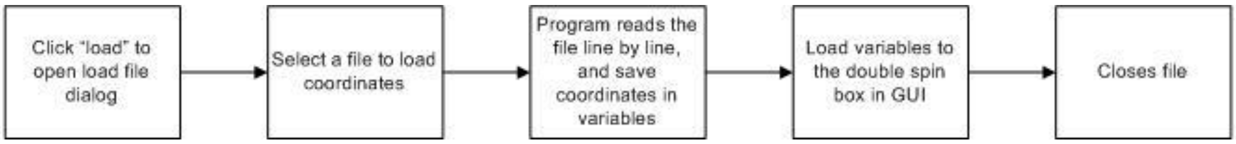


Figure 5-5: Flow Graph of Loading File

5.2.6 Graphical User Interface

The GUI of the software is developed by using the C++ Qt library. The main window of the software has double spin boxes for getting the azimuth and elevation values. Text boxes are used to show the actual values after steering of the antenna. Push buttons are used to perform several tasks like saving and loading of file etc. A check box is used to activate and deactivate the noise diode.

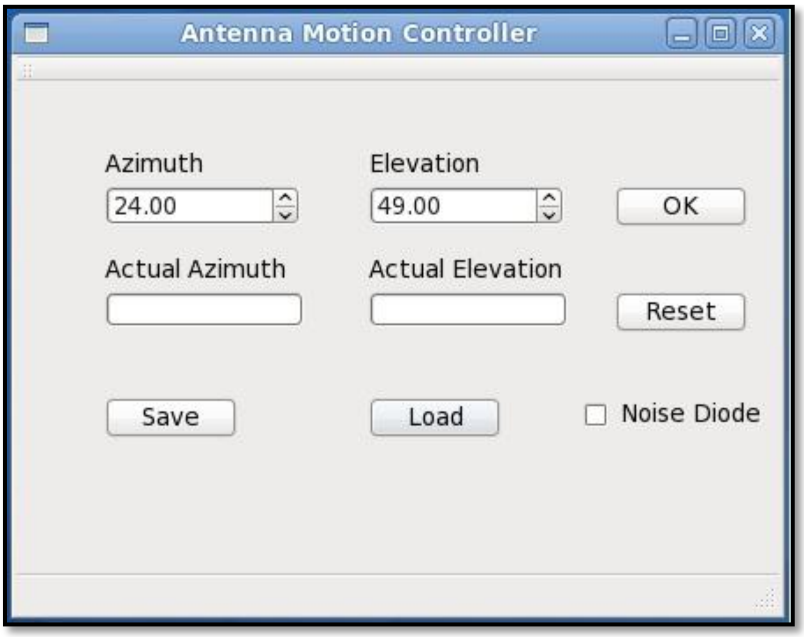


Figure 5-6: The Main GUI of Antenna Motion Controller Software

When the user clicks on the save button, a windows method is invoked which shows a dialog window whose parameters are set so that the file is saved to the specified folder.

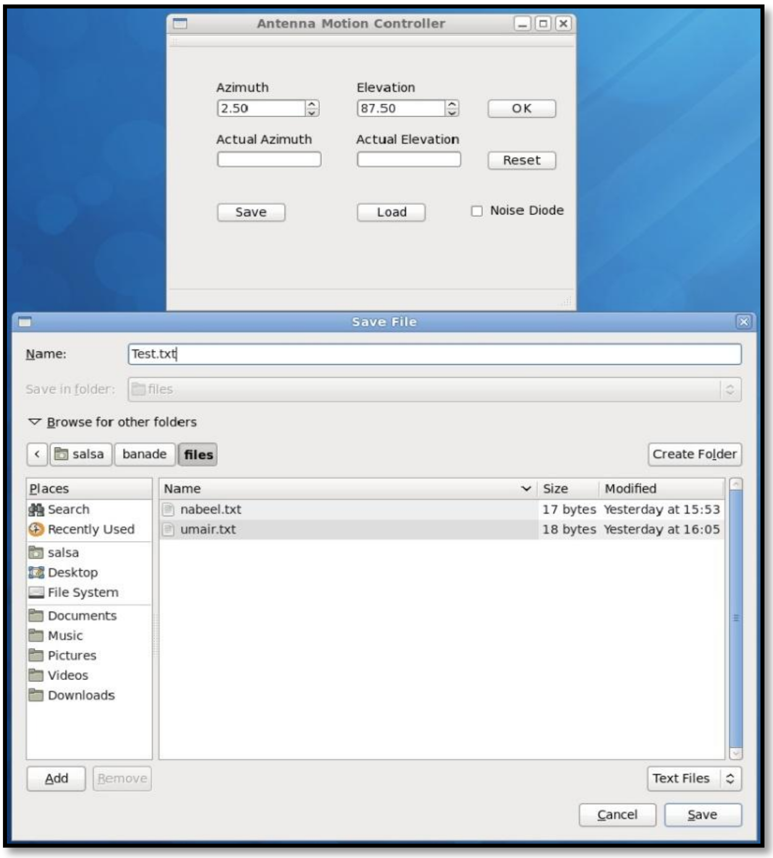


Figure 5-7: GUI When Saving Coordinates to a .txt File

The following window is shown when user clicks load button. Again a windows method is invoked whose parameters are set to show only .txt files.

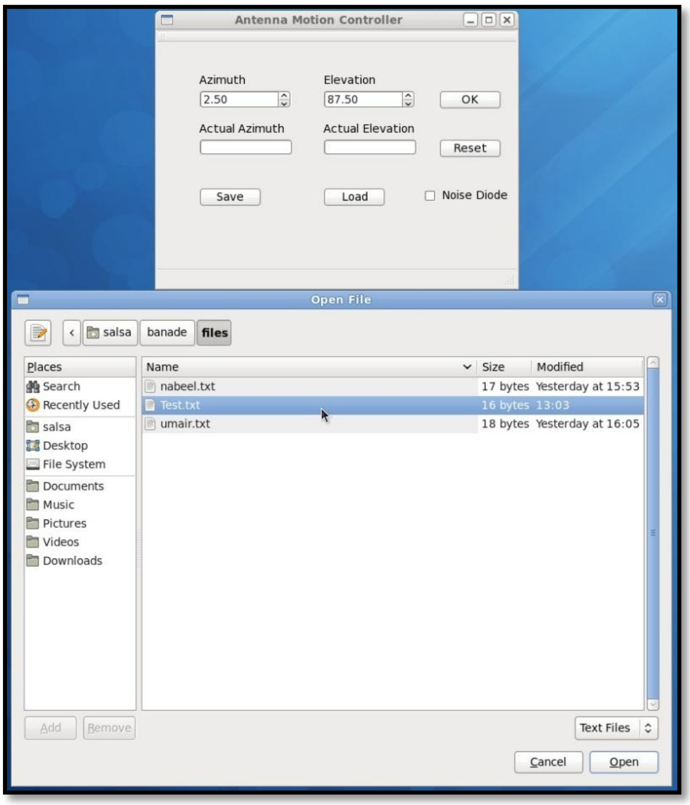


Figure 5-8: GUI When Loading Coordinates From a .txt File

5.3 PROGRAM'S MAIN PARTS

5.3.1 Interfacing With RIO

Rio uses Ethernet 100Base-T to interface with a PC. The manufacturer provides the libraries to use Rio with languages like C++, C#, VB etc. Galil.h is used to interface and interrogate RIO in Linux environment. This library function provides simple functions to perform complicated tasks. Like a simple command "g.command ("SB4")" is used to set high the digital output 4. A simple command like "Galil g("ip address")" is used to perform a very complicated part of connecting the PC with Rio. This command takes care of all the overhead information used to connect the PC Ethernet port to the RIO. The user does not have to take care of these overhead and flag information. This library function eases the programming of RIO.

5.3.2 Detecting feedback Pulses

The main problem in the project is to detect feedback pulses, as the frequency of the feedback pulses is not constant. It varies from 8 to 12Hz, and it depends upon the motor speed which can vary due to wind speed and direction. The solution to this problem is to sample the incoming pulses as fast so that not a single pulse would be missed.

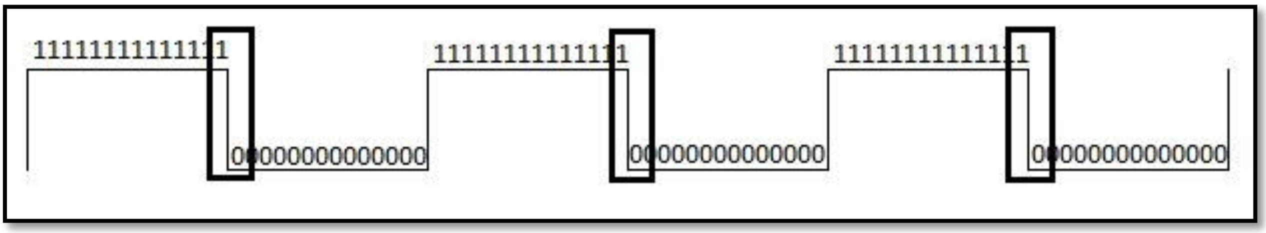


Figure 5-9: Figure Elaborating Detection of Feedback Pulses

In the program the incoming pulses are sampled so fast that there would be a stream of around 70 ones or zeroes under normal conditions. Then the program looks for the consecutive 1 and 0 or in order words going down pulses (as marked by a bold square in **figure 5-9**). The sampling is so fast that we are confident that not even a single feedback pulse is missed; therefore the program and pointing are so accurate.

5.4 Outdoor Testing

The software was tested thoroughly in lab with real antenna mount but without the antenna load on it. After completing all the coding and testing all the software parts in lab, an outdoor testing was conducted. An antenna mount with a parabolic antenna (shown in **Figure 2-7**) was placed in a windy environment and hardware is setup (as shown in **Figure 5-10**) to test the Antenna Motion Controller Software in real environment.

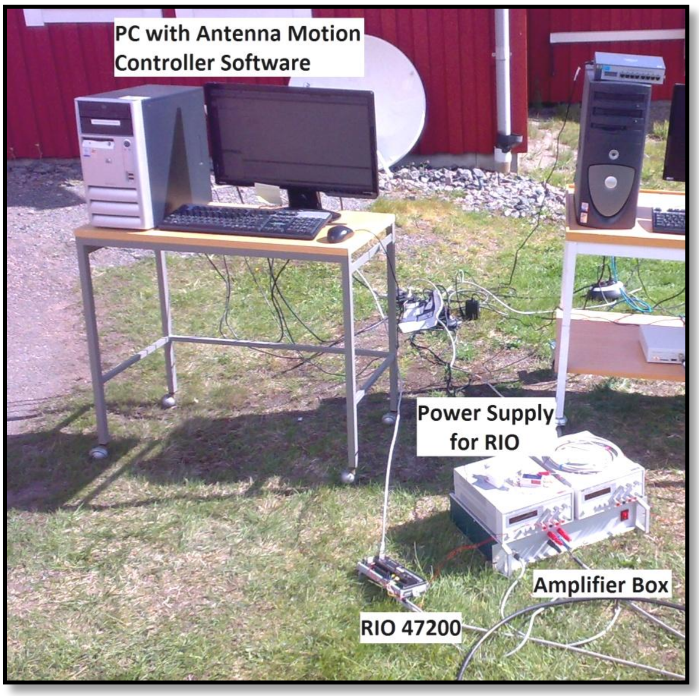


Figure 5- 10: Antenna Motion Controller software testing in real environment

The antenna is mounted in such a way that the horizontal close switch is in north direction and vertical close switch is in zenith direction. The main problem in the outdoor testing is the windy environment. In order to compensate the behaviour of the windy environment, the sampling of the incoming feedback pulses is kept very fast so that, even not a single feedback pulse would be missed. Every part of the software was thoroughly checked, tested and verified in the lab, so the software worked perfectly in real conditions.

CHAPTER 6
CONCLUSION AND FUTURE WORK

A software receiver for SALSA and a new antenna motion controller we designed, realised and successfully tested under real operation condition. The antenna motion controller is fully functional and flexible, the software receiver is performing far better than the existing one with real-time signal processing, less hardware resources and with the advantage of re-configurability. All the parts of the project/thesis are now to be integrated to have a fully functional operating system with Software Receiver and Antenna Control Software running on a PC and to have a single piece of enclosure for all the necessary hardware. This will ensure maximum integrity and minimum parts in the surroundings of the antenna.

The software receiver shows real time signals (**Signal and Reference**) which can also be set by the user. Observations can be made using the (**Signal-Reference**)**/Reference** technique which is shown in separate tab in the software. The software receiver is highly flexible in terms of changing frequency, gain, bandwidth without changing hardware components. It is not required to switch the frequency from **Signal** to **Reference** because both are shown simultaneously in real time.

In the antenna motion control software, the user enters azimuth and elevation to direct the antenna in the proper direction (towards Hydrogen line source). The software controls completely the steering of the antenna, initializing the antenna position, controlling of noise diode and saving and loading antenna position in some file. In the previous system, the control of antenna is divided in two parts; the C program and Q-radio (a microcontroller based hardware). But now the antenna is completely controlled by a single C program. This program is flexible enough that most of the things like number of pulses per degree, position of the closed switches both in azimuth and elevation directions, initial position of antenna etc can be easily changed. Further, if one wants to reconfigure RIO for future extensions, one would just need to change some numbers in program (clearly commented). Antenna motion controller software is also sufficiently flexible to be used with different antenna mounts because sampling which is used to read feedback pulses is fast enough to accommodate high frequency feedback pulses as well.

The current receiver system has an option to save the spectrum in a binary format. There are a few extensions that could also be made to make it a little more versatile. Currently the GnuRadio itself is in development stage and the save data procedure could be optimized, keeping smooth running of the program when saving data. The software could also be upgraded for supporting different file formats, save the spectrum that is currently shown etc, by the use of Python or C++ programming.

The current receiver is designed for the detection of the Hydrogen line and may be slightly modified to detect some other lines. A new receiver can be built to detect Pulsars based on either filter-bank or employing a reverse channel filter. A filter-bank consists of a number of narrow-band filters or channels, the output of each of which is delayed separately by different amount and then are added. This is to remove dispersion effects that are caused to pulsar signals during their journey through dispersive medium. The other way to remove dispersion is to employ and anti-dispersive or reverse channel filter that has the characteristics just opposite of the dispersive medium or channel and will reshape the Pulsar signals. Finally, since Pulsar signals arrive in the form of pulses with highly accurate timing, one has to take each pulse and add them together to have enough energy to be detectable.

The following consideration could be taken into account for the extension of the antenna motion controller software.

First, in the current software files can be saved in standard .fits format, but because of the time limitation of the project, reading the antenna positions from this standard .fits format is not implemented yet. Second, the interface between the software receiver developed in GNU radio and the antenna motion controller software, could be improved even though it is functional as it is. Third, a tracking part could be included in the software which can lock an object and then track it automatically. Last, there is a possibility of creating interferometer with two antennas.

REFERENCES

[1] http://en.wikipedia.org/wiki/

[2] Bhushan Billade, "Design of Dual Polarization Sideband Separation Mixer for ALMA Band 5", Department of Radio and Space Science, Chalmers University of Technology, Sweden, 2009

[3] Courtesy of Onsala Space Observatory

[4] Per-Simon Kildal, "Foundations of Antennas", Spring 2009

[5] Naveen Manicka, "GNU RADIO TESTBED", University of Delaware

[6] Marcus Leech, VE3MDL, "GnuRadio and USRP: Solderless Breadboarding for the 21st Century"

[7] http://sine.ni.com/nips/cds/view/p/lang/en/nid/207050

[8] http://www.vanu.com/technology/sdr.html

[9] www.pentek.com

[10] www.gnuradio.org

[11] Private Communication with Cathy Horellou, Onsala Space Observatory

[12] http://www.rabbit.com/products/op7200/

[13] www.triomotion.com

[14] http://sine.ni.com/np/app/main/p/ap/motion/lang/en/pg/1/sn/n17:motion,n24:cRIO/

[15] http://www.galilmc.com/products/dmc-17x0.php

[16] User manual for 74xxx series.

[17] http://www.alfaradio.ca/

[18] http://www.oso.chalmers.se/~horellou/OUTREACH/SALSA/radiosweden.pdf

APPENDIX A

ANTENNA MOTION CONTROLLER C++ CODE

A.1: mainwindow.h

```
#ifndef MAINWINDOW_H
#define MAINWINDOW_H
#include <QMainWindow>
namespace Ui {
    class MainWindow;
}
class MainWindow : public QMainWindow {
    Q_OBJECT
public:
    MainWindow(QWidget *parent = 0);
    ~MainWindow();
protected:
    void changeEvent(QEvent *e);
private:
    Ui::MainWindow *ui;
private slots:
    void on_load_clicked();
    void on_azimuth_valueChanged(double );
    void on_save_2_clicked();
    void on_track_clicked();
    void on_noise_clicked(bool checked);
    void on_OK_clicked();
};
#endif // MAINWINDOW_H
```

A.2: main.cpp

```
#include <QtGui/QApplication>
#include "mainwindow.h"
#include "Galil.h"

int main(int argc, char *argv[])
{
    QApplication a(argc, argv);
    MainWindow w;
    w.show();
    return a.exec();
}
```

A.3: mainwindow.cpp

```
#include "mainwindow.h"
#include "ui_mainwindow.h"
#include<stdio.h>
#include<stdlib.h>
#include <math.h>
#include <ctype.h>
#include <unistd.h>
#include <string.h>
#include <fcntl.h>
#include<iostream>
#include<sstream>
```

```
#include<cstring>
#include<cstdlib>
#include<fstream>
#include<qfile.h>
#include<qtextstream.h>
#include<qdir.h>
#include<qapplication.h>
#include<QFileDialog>
#include<fstream>
#include "Galil.h"
float actual_az = 0;       // CLOSE SWITCH AZIMUTH
float actual_el = 95;   // CLOSE SWITCH ELEVATION
using namespace std;

MainWindow::MainWindow(QWidget *parent) :
    QMainWindow(parent),
    ui(new Ui::MainWindow)
{
    ui->setupUi(this);
}

MainWindow::~MainWindow()
{
    delete ui;
}

void MainWindow::changeEvent(QEvent *e)
{
    QMainWindow::changeEvent(e);
    switch (e->type()) {
    case QEvent::LanguageChange:
        ui->retranslateUi(this);
        break;
    default:
        break;
    }

}

/*------------------------------- Steering Part-------------------------------------*/

void MainWindow::on_OK_clicked()
{
    /*------------connection with Rio-------*/

    Galil g("192.168.0.24"); // check whether works with global dec

    /*-----------getting values from form (.ui)--------- */

    float az;   //Azimuth
    float el;   //Elevation
    az = ui->azimuth->value();      // picking azimuth value from form
    el = ui->elevation->value();    // picking elevation value from form


    /*---------------- Azimuth Tracking-------------*/

    float totalP_az;    //for checking with 3 pulses
    int feedbackP_az = 0;
```

```
int i = 0;
double feedback_az [99999]; //feedback pulses for azimuth
//if (az >  360.0) az -= 360.0;
//if (az <    0.0) az += 360.0;
//totalP_az = (az-actual_az) * 4; // 4 feedback pulses in 1 degree
totalP_az = (az-actual_az) * 3; // 3 feedback pulses in 1 degree (change to any
                                     number when known)
if (totalP_az<0)
{
totalP_az = totalP_az*(-1);
}
int totalP_az1 = static_cast <int> (totalP_az + 0.5); // converting float to the
                                                         nearest integer
while(totalP_az1 != feedbackP_az){
    if (az < actual_az){
        g.command("SB4"); // Right movement
        g.command("SB5");
    }
    else{
        g.command("SB4"); // Left movement
        g.command("CB5");
        }

    std::string num = g.command("MG@IN[8]");// acquiring feedback pulses from RIO
    feedback_az[i] = ::strtod(num.c_str(),0);// converting std::string into float
    cout<<feedback_az[i];
    if ((feedback_az[i-1] == 1) & (feedback_az [i] == 0))//detecting feedback
                                                              pulses
    {
        feedbackP_az++;     // counting feedback pulses
        cout<<endl;
    }
        i++;
        }
cout<<feedbackP_az<<endl;
actual_az = az;     // storing current value of azimuth in actual azimuth
g.command("CB4"); // resets Rio
g.command("CB5"); // resets Rio

/*------------putting values in form---------*/

ui->actualaz->setText(QString::number(actual_az, 'f',2));



/*--------------------elevation Part---------------------*/

float totalP_el;       //for checking with 3 pulses
int feedbackP_el = 0;
int j = 0;
double feedback_el [99999]; // feedback pulses for elevation
    //if (el >  90.0) az -= 90.0;
    //if (el <    0.0) az += 90.0;
    //totalP_el = (el-actual_el) * 4; // 4 feedback pulses in 1 degree
    totalP_el = (el-actual_el) * 3; // 3 pulses per degree (change to any number
                                          when known)
    if (totalP_el<0)
    {
    totalP_el = totalP_el*(-1);
```

```
        }
        int totalP_el1 = static_cast <int> (totalP_el + 0.5);
        while(totalP_el1 != feedbackP_el){
            if (el > actual_el){
                g.command("SB6"); // counter clock wise
                g.command("SB7");
            }
            else{
                g.command("SB6"); //clockwise
                g.command("CB7");
                }

            std::string num2 = g.command("MG@IN[9]");
            feedback_el[j] = ::strtod(num2.c_str(),0);
            cout<<feedback_el[j];
            if ((feedback_el[j-1] == 1) & (feedback_el [j] == 0))
            {
                feedbackP_el++;
                cout<<endl;
                cout<<feedbackP_el<<endl;
            }
                j++;

                }
        cout<<feedbackP_el<<endl;
        actual_el = el;
        g.command("CB6"); // resets Rio for elevation
        g.command("CB7"); // resets Rio for elevation

        /*------------putting values in form---------*/

        ui->actualel->setText(QString::number(actual_el, 'f',2));
        cout << "end" << endl;

}

/*-------------------------------- Noise diode Part----------------------------------*/

void MainWindow::on_noise_clicked(bool noise)
{
    /*------------connection with Rio-------*/
    Galil g("192.168.0.24"); // check whether works with global dec
    if (noise)
        g.command("SB2"); //noise diode is on on DO2
    if (!noise)
        g.command ("CB2"); // noise diode is off on DO2
}

/*--------------------------------------Reset Part--------------------------------------*/

void MainWindow::on_track_clicked()     // when reset button clicked (It resets
                                           antenna to 0 degree azimuth (North)
                                           and 90 degree elevation (zenith))
{
    /*-------------connection with Rio--------*/

    Galil g("192.168.0.24"); // check whether works with global dec

    /*---------------azimuth reset ----------------*/
```

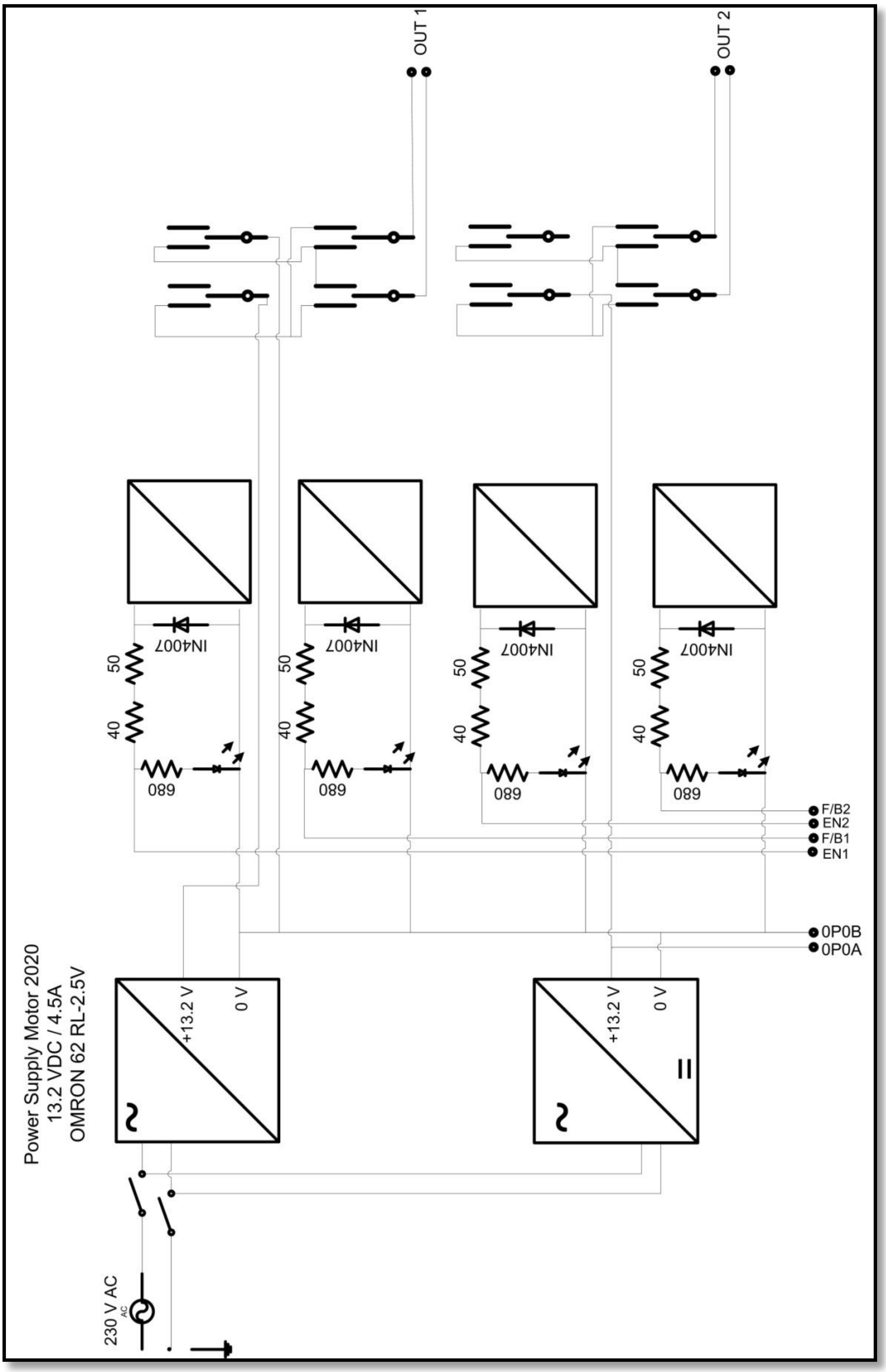
```
double reset_az[99999];
int k = 0;
int sum = 1;    // making do-while in this way
g.command("SB4"); // right movement
g.command("SB5"); // right movement

while((sum != 0) & (sum != 48))     // if a contineous stream of 0s or
                                       contineous stream of 1s occurs,
                                       it comes out of loop
{

std::string num3 = g.command("MG@IN[8]");//acquiring azimuth pulses
reset_az[k] = ::strtod(num3.c_str(),0);// converting std::string into double
cout<<reset_az[k];

if (k>50)       // counting number of zeros or ones at close switch
{
sum = 0;
for (int l=50; l>1; l--)
{
    sum += reset_az[k-l];
    cout<<sum<<"    ";
}

}
g.command ("WT5");

k++;

}
g.command("CB4"); // resets Rio for elevation
g.command("CB5");

cout<<"azimuth is reset to 0 degree"<<endl;


/*-------------- Elevation reset --------------*/

double reset_el[99999];
int m = 0;
int sum2 = 1;
g.command("SB6"); // right movement
g.command("SB7"); // right movement
while((sum2 != 0) & (sum2 !=48))
{
std::string num4 = g.command("MG@IN[9]");
reset_el[m] = ::strtod(num4.c_str(),0);
cout<<reset_el[m];

if (m>50)
{
sum2 = 0;
for (int n=50; n>1; n--)
{
    sum2 += reset_el[m-n];
    cout<<sum<<"    ";
}

}
```

```
        g.command ("WT5");
        m++;

        }
        g.command("CB6"); // resets Rio for elevation
        g.command("CB7");

        cout<<endl<<"elvation is reset to 100 degree"<<endl;

        /*-----------Moving 5 degrees more--------*/


        float totalP_el;
        int feedbackP_el = 0;
        int j = 0;
        double feedback_el [99999]; //can be array of bool
        float el = 90;
        float actual_el = 95;
        totalP_el = (el-actual_el) * 3; // 3 feedback pulses in 1 degree (change to
                                           any number when known)
        //totalP_el = (el-actual_el) * 4; // 4 feedback pulses in 1 degree
        totalP_el = totalP_el*(-1);
        int totalP_el1 = static_cast <int> (totalP_el + 0.5);
        while(totalP_el1 != feedbackP_el){
                g.command("SB6"); //clockwise
                g.command("CB7");

            std::string num2 = g.command("MG@IN[9]");
            feedback_el[j] = ::strtod(num2.c_str(),0);
            cout<<feedback_el[j];
            if ((feedback_el[j-1] == 1) & (feedback_el [j] == 0))
            {
                feedbackP_el++;
                cout<<endl;
            }
                j++;

                }
        cout<<feedbackP_el<<endl;
        actual_el = el;
        g.command("CB6"); // resets Rio for elevation
        g.command("CB7"); // resets Rio for elevation
        cout <<endl<<"the actual elevation is 90 now"<<endl;

}

/*-------------------------------Save file Part-------------------------------------*/

void MainWindow::on_save_2_clicked()
{

    //opening file dialog to save file
    QString fileName = QFileDialog::getSaveFileName(this,tr("Save File"),
                                                 "/home/salsa/banade/files",
                                                 tr ("Text Files (*.txt)"));
    // creating file with the name given by user
    QFile file(fileName);
    file.open(QIODevice::WriteOnly | QIODevice::Text);
    QTextStream out(&file);
```

```
    // putting data in file
    double d1=(ui->azimuth->value());
    double d2 = (ui->elevation->value());
    QString s1;
    QString s2;
    s1.sprintf("%.5f", d1);
    s2.sprintf("%.5f",d2);
    out<<s1<<endl<<s2;
    //close file to save
    file.close();

}

/*-------------------------------load file Part-------------------------------------*/

void MainWindow::on_load_clicked()
{
    // opening file dialog to load file
    QString fileName;
    fileName = QFileDialog::getOpenFileName(this,
         tr("Open File"), "/home/salsa/banade/files", tr("Text Files (*.txt)"));
    FILE *in = fopen(fileName.toAscii(), "rt"); //converting Qstring into c string
    // read the first line from the file
    char buffer[100];
    char buffer2[100];
    fgets(buffer, 50, in);
    fgets(buffer2, 50, in);
    // display what we've just read
    printf("first line of \"fred.txt\": %s\n", buffer);
    printf("first line of \"fred.txt\": %s\n", buffer2);
    double f = atof(buffer);
    double f2 = atof(buffer2);
    cout<<f<<endl;
    cout<<f2<<endl;
    //putting values in form
    ui->azimuth->setValue(f);
    ui->elevation->setValue(f2);
    // close the stream
    fclose(in);
}
```

APPENDIX B

ELECTRICAL DIAGRAM OF AMPLIFIER BOX



APPENDIX C

INSTALLATION OF SOFTWARES

GnuRadio was installed on Linux-Fedora Core operating system. Following links were used to install and configure GnuRadio and GRC.

- http://gnuradio.org/redmine/wiki/gnuradio
- ftp://ftp.gnu.org/gnu/gnuradio/gnuradio-3.2.2.tar.gz
- http://gnuradio.org/redmine/wiki/1/GNURadioCompanion

Once everything is installed, the file receiver.grc can be open in GRC and can be run from there. Alternatively, the python code that is also generated, can be run directly from terminal by typing (in the directory "RA_Receiver")

- python top_block.py

Following are the instructions to install Antenna Motion Controller software on computer.

- Pre-requisite is a personal computer on which Linux (any version) is already installed.
- Copy and paste antenna motion controller software along with all of its files in to home folder (copy folder "banade").
- To download Qt SDK, go to http://qt.nokia.com/downloads. Choose LGPL open source license. Click the version which suits your machine type (32 or 64 bit) and start download.
- After downloading, install QT SDK on your machine. Installation instructions are given on download page.
- This will install Qt library 4.6 and also an editor Qt creator 1.3.1 on your computer. This Qt creator have already added all the paths and libraries, you don't have to worry about it anymore.
- Now install Galil Tools. Go to http://www.galilmc.com/support/software-downloads.php and click on link install files under Linux tab. It will lead you to the registration page. Register yourself, its free.
- After registration, download and install the latest version of GalilTools. Installation instructions are available on the same page.
- After installation search for "Galil.so", copy it and paste it in to /usr/lib. This is the easiest way to locate Galil communication library, otherwise you have to give complete path of "Galil.so" in banade.pro
- Now Antenna Motion controller software is ready to run on this computer. You can directly run executable file "banade" in the folder "banade" which you have pasted in home folder in step 2 OR you can load file "banade.pro" in Qt creator and then press Ctrl+R to run the project.
- Now you are ready with Antenna Motion Controller Software.