TOTAL POWER RADIOMETER

A Project Report Submitted in Partial Fulfillment of the Requirement of the Degree

Of

BACHELOR OF TECHNOLOGY

in

ELECTRONICS AND COMMUNICATION ENGINEERING

by

SANKHA SUBHRA DEBNATH

(201600331)

Under the guidance of

Dr. Abhirup Dutta	**Dr. Swastika Chakraborty**
Head of Department,	**Associate Professor,**
DAASE,IIT Indore	**ECE Dept, SMIT**

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING
SIKKIM MANIPAL INSTITUTE OF TECHNOLOGY
MAJITAR, EAST SIKKIM-737136, JUNE 2020

TOTAL POWER RADIOMETER

A Project Report Submitted in Partial Fulfillment of the Requirement of the Degree

Of

BACHELOR OF TECHNOLOGY

in

ELECTRONICS AND COMMUNICATION ENGINEERING

by

SANKHA SUBHRA DEBNATH

(201600331)

Under the guidance of

Dr. Abhirup Dutta	**Dr. Swastika Chakraborty**
Head of Department,	**Associate Professor,**
DAASE,IIT Indore	**ECE Dept, SMIT**

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING
SIKKIM MANIPAL INSTITUTE OF TECHNOLOGY
MAJITAR, EAST SIKKIM-737136, JUNE 2020

CERTIFICATE

This is to certify that the project report entitled "**TOTAL POWER RADIOMETER**" submitted by **Sankha Subhra Debnath** (**201600331**) to Sikkim Manipal Institute Of Technology, Sikkim in partial fulfillment for the award of degree of Bachelor of Technology in Electronics And Communication Engineering, is a bonafide record of the project work carried out by him under my guidance and supervision during the academic Session January– May, 2020.

Dr. Swastika Chakraborty
Associate Professor
Dept. Of Electronics & Communication
Sikkim Manipal Institute of Technology
(Internal Supervisor)

Dr. Sourav Dhar
Head of Department
Dept. Of Electronics & Communication
Sikkim Manipal Institute of Technology

ABSTRACT

In this project we have designed and constructed a radio telescope by assembling the required gain chain and horn antenna which can be used to detect 21cm Hydrogen lines from astronomical sources. The receiver part consists of low noise amplifiers, Galen Amplifier, attenuator, band pass filter. The components are tested individually as well as a whole system after assembling in order to check whether the system is able to detect anything from sources. The sun is used as an initial test as on and off for the system. When we use our radio telescope for on and off detection of sun there is a abrupt change in the noise floor of spectrum analyzer on detection of sun within the directivity of the Horn antenna. The detection of 21cm Hl is one of the most important aspect of Radio astronomy. The components of the gain chain are thoroughly checked and tested multiple times so that we can get as much as accurate values for the gain of our system.The gain measurement is done both practically ad theoretically for the best results. When both the measurements are almost equal each time we can generally conclude that our components are yielding good results. The S11 parameter must be checked for both the gain chain and the horn antenna. The right power supply is also needed for the gain chain. The hardware setup for testing is generally done outside where the horn antenna is pointed directly to the source we will try to observe and detect. The frequency at which our gain chain will work is 1.42 GHz.

ACKNOWLEDGEMENT

I sincerely take this opportunity to express my thanks and deep gratitude to all who extended their whole hearted cooperation, opinion and gracious hospitality to me in doing the work on the project for the time period.

It was a pleasure working under the guidance of **Dr. Abhirup Dutta** as an external guide**,** however I'm also indebted to **Dr.Swastika Chakraborty** who was my internal guide and without her incredible support and guidance to the project work would have been insurmountable.

I am exceptionally grateful to **Dr. Sourav Dhar,**Head of Department, Electronics and Communication Engineering, Sikkim Manipal Institute of Technology for his constant support and fortitude throughout the process.

I am also grateful to **Prof. (Dr.) A. Sharma,** Director, Sikkim Manipal Institute of Technology and the **Training & Placement cell** of the Institute for their kind co-operation through the process.

I also like to thank to my acquaintance **Pranoy Ghosh** with whom I have worked daily on my duration on the project at the Institute for his great support in this project. I would also like to thank all the staff members and lab manager of Radio astronomy lab, DAASE,IIT Indore without whose help the work would have been futile

And, lastly most grateful to my family and friends for their constant support in my endeavours during the hard times.

Sankha Subhra Debnath

SANKHA SUBHRA DEBNATH

(201600331)

Dept. Of Electronics and Communication

Sikkim Manipal Institute of Technology

Table of Contents

List of Abbreviations

Hz	Hertz
CO	Carbon Monoxide
LGM	Little Green Man
ISM	Interstellar Medium
UHF	Ultra High Frequency
RF	Radio Frequency
RAS	Radio Astronomy Supplies
LNA	Low Noise Amplifier
BPF	Band Pass Filter
HP	High Power
USB	Universal Serial Bus
VNA	Vector Network Analyzer
SNR	Signal to Noise Ratio
CSV	Comma Separated Values
HL	Hydrogen Line
SDR	Software Defined Radio
RBW	Resolution Band Width
RFI	Radio Frequency Interference

List of Figures

List of Tables

A. INTRODUCTION

The project I have undergone for my final semester is based on Radio Astronomy where with the help of a Horn antenna and making a receiver system for the antenna we will detect the 21 cm hydrogen lines or the radio waves at the 1420 MHz frequency that is for 21cm wavelength Hydrogen lines. The project achieved is the hardware implementation of the receiver system of the radio telescope necessary for observation and detection of the radio waves from sources. Radio Astronomy is the study of celestial objects that emits radiation in radio frequency of electromagnetic spectrum. Radio Astronomy allows us to see the hidden or invisible astronomical phenomenon of the universe because the radio waves are not blocked by the interstellar medium but the electromagnetic waves of optical frequency are opaque to the medium. Radio telescopes are antennas which are used for reception of radio waves coming from an astronomical source. These telescopes are either used singularly or with multiple antennas using techniques called interferometry and earth’s rotation aperture synthesis to achieve higher angular resolution and be able to observe distant astronomical radio sources.

I carried out most of the work of the project in Radio Frequency laboratory at IIT Indore alongside **Pranoy Ghosh** who has guided me and helped me on my journey. The project was for a duration of 6 months but due to the 2020 Global CoVid-19 Outbreak we had to halt our project till midway, the full pledged of the project was not possible to carry out.

B. MOTIVATION

- To understand and get the basic underlying ideas of Radio Astronomy
- To explore the current working area in the research areas of Observational astronomy
- To develop a project for deeper understanding of the technical workings in the field with the underlying Engineering knowledge of Microwave, digital signal processing, Image processing, Antenna, Digital and Analog Communications, Electronics.
- To get more on hand experience on Hardware involved in the field
- To get more insight of the theoretical approach and observation measurements of such projects.

C. LITERATURE REVIEW

SNO.	AUTHOR	TITLE	YEAR	FINDING	RELEVANCE TO PROECT
1	A.W. Love	Electromagnetic Horn Antennas	1976	The basic structural designs of horn antennas and the general use of horn antennas from communication to astronomy.	To develop and understand the relevant antenna required for our work
2	Gart Westerhout	THE EARLY HISTORY OF RADIO ASTRONOMY	1972	The basic principles that laid the foundation of modern day astronomy	To understand why we are using the radio spectrum to understand and observe the astronomical sources
3	N. Gopalswamy	Radio Astronomy at Long Wavelengths	2000	Radio Astronomy at Long Wavelengths	Important for calibrating the gain of the antenna and the amplification required for the system to detect minimal radio waves from sources.
4	A. Richard Thompson, James M. Moran, George	Interferometry and Synthesis in Radio Astronomy	2017	The basics of the setup of radio astronomy	To know about the hardware components we are using

	W. Swenson				
5	A. D. Olver, P. 1. B. Clarricoats, A. A. Kishk, L. Shafai	Microwave Horns and Feeds	1994	The fundamentals of microwave and waveguides	Study of reflection coffecients,waveguides and dimensions
6	Roslan Umar1,2, Zamri Zainal Abidin1, Zainol Abidin Ibrahim1, Zulfazli Rosli1and Noorkhallaf Noorazlan	Selection of radio astronomical observation sites and its dependence on human generated RFI	2013	Study about the Radio Frequency Interferences when observations are done	The RFI is an important factor that needs to be studied discreetly to make observations with minimal errors

Table 1.1 – Literature survey

D. PROBLEM DEFINITION & SOLUTION

- We have to know about the components and what should be the gain of the system in order to have the components accordingly. The horn Antenna should be also of the specific dimensions as per the theoretical value proposes.

- Power supply should be different for the spectrum analyser and the gain chain for amplifiers. We should always be cautious while giving the power supply as required for the components without damaging. For that we need different power supplies.

- Without a proper mount it is difficult to navigate the antenna beamwidth or the radiation pattern. We have to manually place the antenna

- For detecting 21cm hydrogen line radio telescopes are our best shot for ground observations. As radio waves can penetrate and reach us to ground through atmosphere unlike the X Ray waves.

- We have to cross check the hardware design theoretically and practically several times in order to determine the functionality of the Receiver system.

- We have to check for the impedance mismatching and the exact gain required so that we can detect the signals for a particular range. In this case our initial frequency range is taken 1.42 GHz.

E. CHAPTER WISE PROJECT DISCUSSIONS

CHAPTER 1

THEORY

1.1 INTRODUCTION TO RADIO ASTRONOMY

Radio Astronomy is the study of celestial objects that emits radiation in radio frequency of electromagnetic spectrum. Radio Astronomy allows us to see the hidden or invisible astronomical phenomenon of the universe because the radio waves are not blocked by the interstellar medium but the electromagnetic waves of optical frequency are opaque to the medium.

Radio astronomy has changed the way we view the Universe and dramatically increased our knowledge of it. Traditional optical astronomy is great for studying objects such as stars and galaxies that emit a lot of visible light. Individual stars, however, are normally only weak emitters of radio waves. Radio waves were first detected from space in the 1930s but few scientists took the discovery seriously. The development of radar in the Second World War led to improvements in antennas and electronics. After the war many of the scientists involved started to use this equipment to investigate the radio signals coming from space. Radio waves are a form of electromagnetic radiation, just like the visible light you are used to seeing with your eyes. The difference in radio waves is that they have a longer wavelength and are lower in frequency than visible light. They also carry less energy. Visible light is energetic enough to help plants produce their own food through photosynthesis. Radio waves are far weaker than this so we need electronic amplifiers to help us boost their signal.

Radio telescopes are antennas which are used for reception of radio waves coming from an astronomical source. These telescopes are either used singularly or with multiple antennas using techniques called interferometry and earth's rotation aperture synthesis to achieve higher angular resolution and be able to observe distant astronomical radio sources.

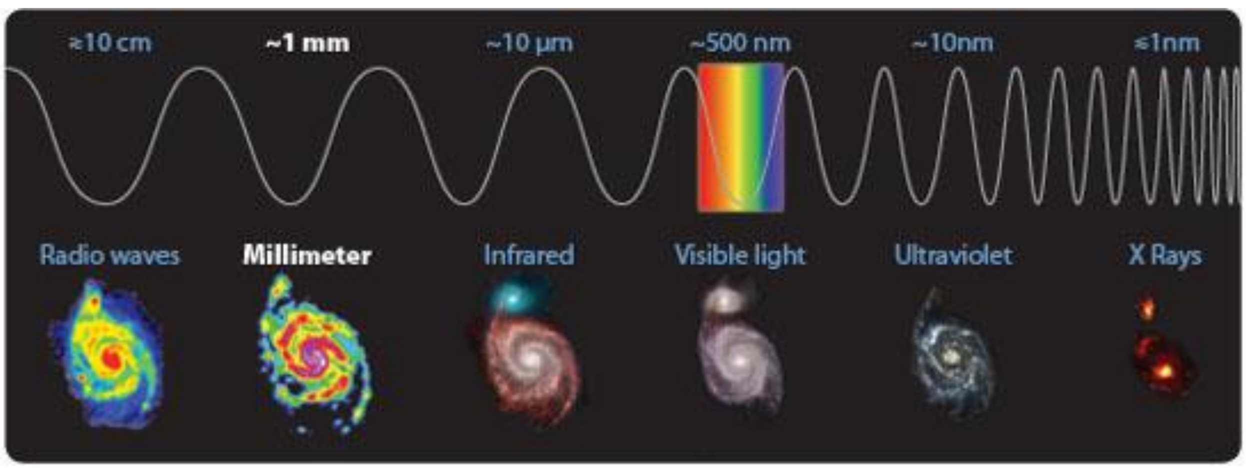


Figure 1.1 Spectrums of wavelengths at different category and where Radio waves lies on the spectrum, source: www.khanacamedy.org

1.2 IMPORTANT TERMS IN RADIO ASTRONOMY

Flux: The radiation power we detect depends on the size of our telescope. The larger the cross-sectional area, the more radiation will be detected and again we normalize our measurement by dividing the area of the telescope. This gives us a measure of flux which is defined as the amount of energy per unit time per unit area. The SI units of flux are J s-1 m-2 or W m-2.

Flux density can be measured directly. The amount of power the telescope receives depends on the collecting area and the bandwidth. The amount of power the telescope gathers from a source of given flux density is P = F v A eff Δv Radio astronomers have defined a unit for flux density after the father of Radio astronomy, Karl Guthe Jansky. 1 jansky (Jy) = 10-26 W m-2 Hz-1 in SI units.

Intensity: The surface intensity is often referred to as surface brightness is defined as the flux density per unit solid angle. If one knows the solid angular size of the source, one can calculate the average intensity of the source by dividing the measured flux by solid angle of the source. Iv = Fv/ Ω Several of the important aspects of intensity are:

1. Flux density does not distinguish the direction from where the photons come from whereas Intensity does.

2. Intensity is independent of distance.

3. Intensity is a direct measure of an objects' surface brightness

Luminosity: The amount of energy that a star emits per unit time. It is independent of distance or how bright or dim the star appears from Earth. It is measured in Watts (Joules/seconds) and is often given in terms relative to our Sun, L⊙ (about 3.846×10^26 W).

Radio Galaxy: A galaxy that emits radio waves from its central core. The energy to produce these emissions is generated by a supermassive black hole, which sends out massive jets of radio energy many millions of light-years into interstellar space.

Radio Source: A point or small portion of the sky giving stronger radio emission than other parts of the sky surrounding it.

Radio Telescope: Like an optical telescope, a radio telescopes receives, focuses, and analyzes light to form an image or study a celestial object. The longer wavelengths of radio waves mean that these telescopes use dish antennas to reflect and focus radio light, a receiving system to amplify and measure the signal, and a computer to process the data and develop an image.

21-cm Hydrogen Line: Radio emission by a neutral hydrogen atom when its electron flips its spin. This causes the electron to emit a single photon with a wavelength of 21 centimeters.

Hertz: A unit of measurement of a wave's frequency. Hertz are measured by the number of oscillations that occur per second. 1 Hertz (Hz) = 1 cycle or oscillation/second.

Sensitivity: The sensitivity of a telescope is the smallest signal that it can clearly measure from a source in space. It is the minimum brightness that a telescope can detect. A telescope with high sensitivity can detect very dim objects, whereas a low sensitivity telescope can only detect the brighter objects in space.

Sidereal Day: The time required for Earth to revolve 360 degrees with respect to a celestial object outside the solar system. This equals about 23 hours 56 minutes duration in terms of solar time

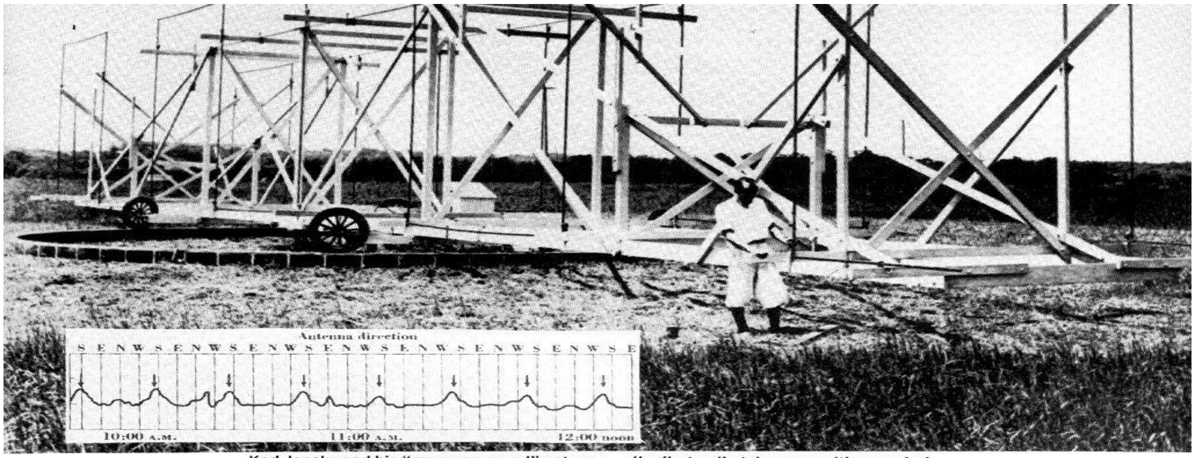
Spectrum: A plot or distribution of light intensity at different frequencies and wavelengths.

Spectral Line: Light given off at a specific frequency by an atom or molecule. Every different type of atom or molecule gives off light at its own set of frequencies. Therefore, astronomers can look for gas containing a particular atom or molecule by tuning the radio telescope to one of the gas's frequencies. One example would be tuning the radio telescope to 115 gigahertz to find carbon monoxide (CO) which has a spectral line at 115 gigahertz (or a wavelength of 2.7 mm).

Molecular Cloud: An interstellar gas cloud where molecular formation occurs. Over 125 different molecules from molecular clouds have now been discovered in interstellar space through radio wavelength observations.

1.3 Major works and development in Radio Astronomy

Radio astronomy was born early in the 20th century. In 1932, a young engineer for Bell Laboratories named Karl G. Jansky tackled a puzzling problem: noisy static was interfering with short-wave radio transatlantic voice communications. After months of tracking the source, he noticed that it shifted slowly across the sky. Jansky had discovered something at the heart of the Milky Way Galaxy. His work led to one of the most important papers in the history of astronomy in the 20th century, called “Radio Waves from Outside the Solar System”, published in 1933. His work laid the foundation for the science of radio astronomy.



Karl Jansky and his "merry-go-round" antenna — the first radio telescope with record of hiss noise he detected from our galaxy as indicated by small bumps, one for each revolution of the antenna every 20 minutes.

Figure 1.2- The Merry-go-round antenna and Karl Jansky- first radio telescope to detect hiss noise from our galaxy, source: https://public.nrao.edu

Another famous radio astronomy discovery occurred in 1967 when a young graduate student named Jocelyn Bell noticed a strange signal in a printout from a radio telescope she helped to build. At first the signal wasn't clear. The object produced strong radio pulses at a regular rate, about 30 times a second. Bell and her colleagues first called the object LGM-1, since they joked that the regular pulses could be from "Little Green Men," though they understood that it was an as-yet-unexplained natural phenomenon.The signals turned out to be flashes of radio emissions from a weird object called a pulsar. Pulsars are what remains after a massive star collapses and then explodes as a supernova.

Figure 1.3- Jocelyn Bell infront of a radio telescope,Source: https://public.nrao.edu

March 25, 1951, Harold Ewen and Edward Purcell detected the 21-cm line of neutral hydrogen in the Milky Way with a horn antenna. In 1963, Arno Allan Penzias and Robert Woodrow Wilson discovered the residual radiation of the Big Bang under George Gamow trying to eliminate background noise in their transmission equipment. In 1967, Jocelyn Bell Burnell detected the first pulsar and was credited with "one of the most significant scientific achievements of the 20th Century.

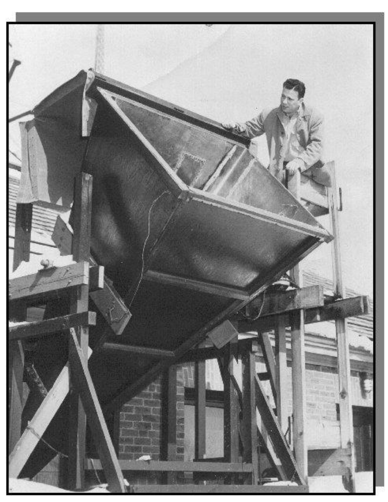


Figure 1.4 -Harold Ewen and Edward Purcell detected the 21-cm line of neutral hydrogen in the Milky Way with a horn antenna, Source: https://public.nrao.edu

1.5 21cm Hydrogen Lines

Hydrogen is the most abundant element and hence these neutral hydrogen atoms are ubiquitous in our universe. They are found plentiful in low density regions of Interstellar Medium (ISM). These Hydrogen atoms are observed in a spectral line called H1 or 21cm line. It emits at a frequency of 1420.4MHz which lies in the UHF band of microwave window and this is a protected band in Radio Astronomy. This 21cm line is a result of "spin-flip" transition which is a result from magnetic interaction between quantised spins of proton and electron in the Hydrogen atom. Parallel spin has a higher energy than anti-parallel spin. The transition occurs when the proton-electron spin states change from parallel to antiparallel emitting energy of 5.9µev. This spontaneous transition is highly forbidden and has a radioactive lifetime of around 11Myrs. Though we cannot observe this in our lifetime, there is a vast amount of hydrogen out there and hence we are able to detect this transition. We cannot detect any spectral lines at RF for molecular Hydrogen as it has no permanent dipole moment. The red shifted 21cm line is a very useful probe of galaxy formation in the early universe. The redshift occurs due to the expansion of the universe. The 21cm line is used to map the distribution of Hydrogen in our Galaxy. About 99% of the interstellar medium (ISM) is gas which consist of about 90% atomic or molecular hydrogen, 10% helium, and traces of other elements. Dust scatters and absorbs visible light much more than a gas. The interstellar gas can be seen when you look at the spectral lines of a source. Among the broad lines that shift as the two stars orbit each other, there are narrow lines that do not move. The narrow lines are from much colder gas in the interstellar medium between us and the source. The hydrogen gas is observed in a variety of states: ionized, neutral atomic and molecular forms.

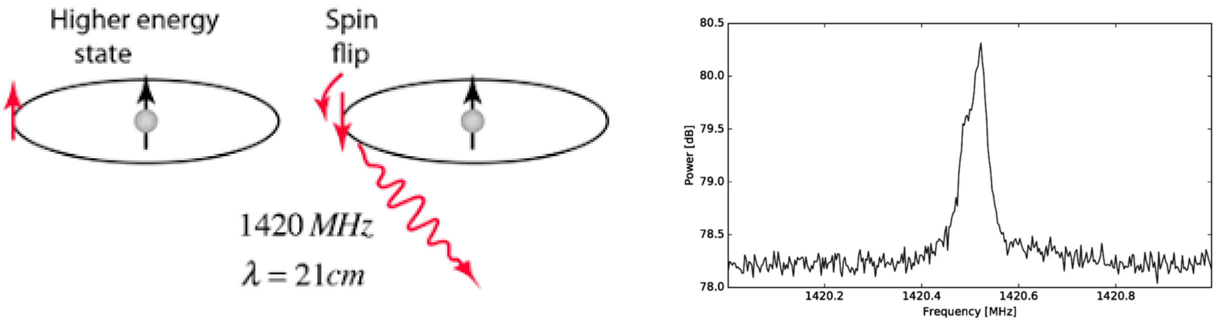


Figure 1.5 -21cm Hydrogen line spectrum as seen in a spectrum analyzer, Source: source: Wikipedia.org/wiki/Hydrogen_line

CHAPTER 2

SYSTEM DEVELOPMENT

2.1 BLOCK DIAGRAM OF RECEIVER SYSTEM

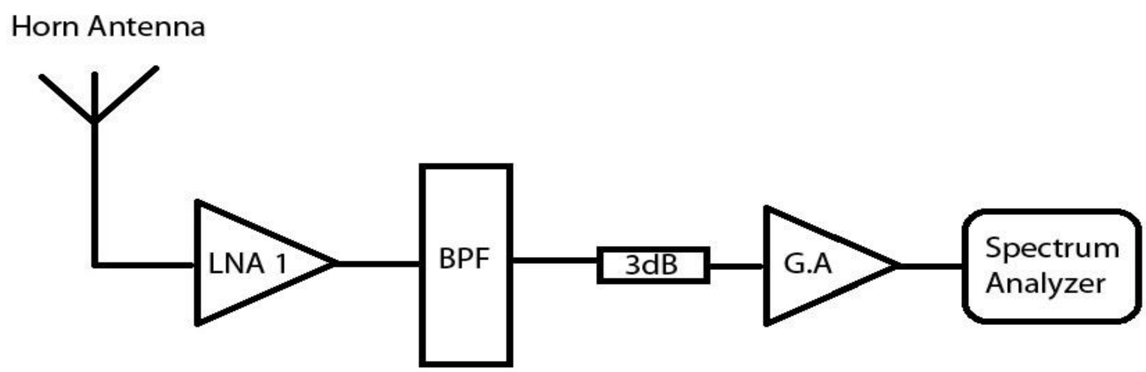


Figure 2.1 Block diagram of the gain chain

The above block diagram is the representation of the system we have used in developing the receiver system that is our gain chain. The gain chain is connected to the feed of the Horn Antenna. The System comprises of a Horn antenna, the gain chain and the spectrum analyzer.

We also need the necessary power supply for the gain chain as well as to operate the spectrum analyzer. We have used both Hand- held Spectrum Analyzer and Digital Spectrum Analyzer for the system observations and testing.

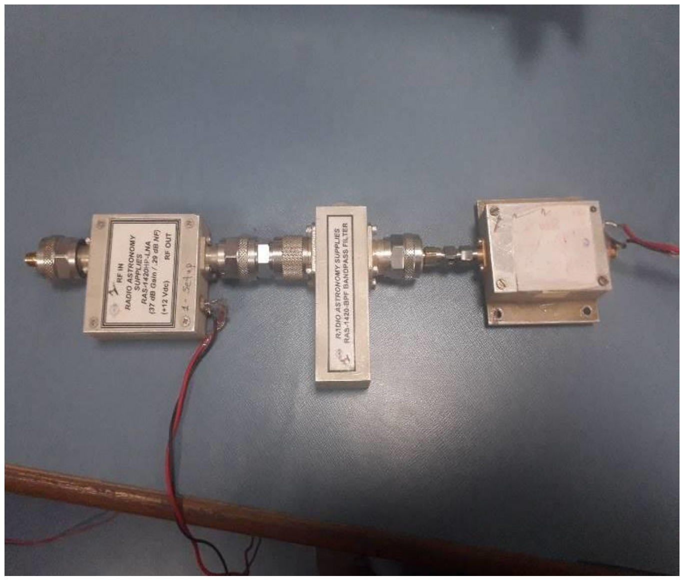


Figure 2.2 The Hardware setup of the gain chain of our Receiver System

2.2 COMPONENTS USED IN THE SYSTEM

Main Key Components that we have used in the Gain Chain:

- RAS- 1420-BPF- Band pass filter
- RAS- 1420 HP-LNA (Amplifier 1)
- RAS-1420 HP- LNA (Amplifier 2)
- Galen Amplifier
- 3 dB attenuation

Other Components required for the Hardware Setup :

- Horn Antenna
- Hand Held Spectrum analyzer/ Spectrum Analyzer

- Power Supply -30V/12V
- Valon Synthesizer

Different types of connectors used in our gain chain:

1. SMA
2. N-Type
3. F type

A brief description of the components of the gain chain is given below:

A) *RAS- 1420 HP-LNA (Amplifier 1)*

The low noise amplifier is the first active component of receiver chain. It is an electronic amplifier that amplifies very feeble and low power signals without significantly degrading it signal to noise ratio. These are one of the most important circuit components present in radio and other signal receivers. , in electronics circuits when an amplifier is used noise is introduced in circuitry due to passive elements like resisters present in it. LNA is a critical component regarding the overall noise figure.

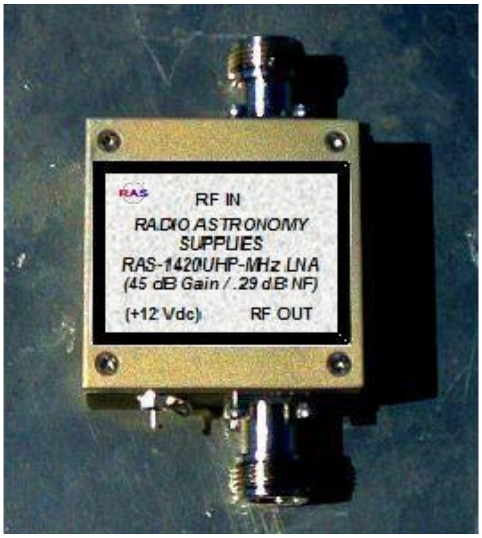


Figure 2.3- Same RAS- 1420 HP-LNA (Amplifier 1) used in the system,source: radioastronomysupplies.com

B) *RAS- 1420-BPF- Band pass filter*

It is a device that allows frequencies of within a certain range and attenuates frequencies outside the specified range. It is combination of low pass and high pass filter. Ideal BPF would resemble a step function, with a perfect cut-off high and low frequency boundaries and a flat response in between. No band pass filter is ideal, that is, is cannot completely attenuate all frequencies outside the desired frequency range. LNA is a critical component regarding the overall nose figure. The bandwidth of the BPF is difference between the upper and lower cut-off frequencies. In a receiver, its main function is to limit the bandwidth of signal to the required frequency band.

Figure 2.4- Same RAS- 1420-BPF- Band pass filter used in the system,source: radioastronomysupplies.com

C) 3 dB Attenuator

Attenuators are passive devices. It is convenient to discuss them along with decibels. Attenuators weaken or *attenuate* the high level output of a signal generator, for example, to provide a lower level signal for something like the antenna input of a sensitive radio receiver. In the case of a stand-alone attenuator, it must be placed in series between the signal source and the load by breaking open the signal path. In our system we are using a 3dB attenuator. In the gain chain the attenuator is placed right after the Band Pass Filter and before the Galen Amplifier.

Figure 2.5 3dB attenuator, source: techtoolsupply.com/3dB-attenuator-5MHz-3GHz-p

D) Horn Antenna

The dimensions of the Horn antenna used for the =0.43 x 0.33 m. The horn antenna we used in the project was preordered beforehand. It is also possible to make a separate Horn antenna from scratch provided the right components and the horn design for our requirement is available to us. In our project we have not used any automated mount for the rotation or movement of the antenna rather it was done manually The gain chain is connected to the feed of the antenna and then according to our requirement we manually locate the source we want to observe.

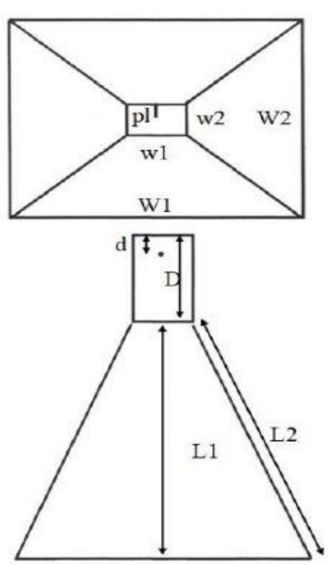


Figure 2.6 (L)- Horn Antenna parameters, (R)- Horn antenna we used for our project

E) Hand Held Spectrum Analyzer

Spectrum analyzers are found in many laboratories and other areas where test instruments are needed to test and verify radio frequency RF performance. Spectrum analyzers are widely used test instruments for applications where RF testing is needed: in RF design, general electronic circuit design, testing; electronics manufacturing; base service and repair, and increasingly in field installation and service. Hand held spectrum analyser can come with different frequency range as requirement. The more the frequency range the costlier the device gets due to the complexities of the devices. Hand held SA are portable devices and can be used at testing sites and outdoors easily with the provided power supply.

Figure 2.7- Hand held Spectrum Analyzer used in our project, source: keysight.com

F) Valon Synthesizer

The 5009 from Valon Technology is a dual-channel frequency synthesizer module that operates from 23 MHz to 6 GHz. There are two independent RF sources contained within the same module, which can be used at the same by using the USB serial port to control frequency of Source 1 and the TTL port to control the frequency at Source 2. The synthesizer provides an output power of up to 15 dBm and has an attenuation range of 31.5 dB with 0.5 dB steps. The internal TCXO provides ± 2ppm stability over the -20 °C to +70 °C temperature range.

The 5009 is capable of fast sweep modes and has a FLASH based non-volatile memory. It can save up to 16 synthesizer frequency configurations which can be recalled using logic signals on the convenient user port without the need of a controller or computer.

Figure 2.8 -The 5009 valon synthesizer that is used in the project, source: valonrf.com

2.3 HARDWARE TESTING AND ASSEMBLING

With the components we have now have to test for individual components for their gain. This is achieved with the help of a power supply , Valon Synthesizer, cables, spectrum analyzer, LNA1, BPF, G. Amplifier. The Valon syntheziser is used to give an output Frequency of 1420.20 Mhz that simulates our radio source from astronomical sources. The LNA 1 is connected from the output port to the Input of the Valon Synthesizer and the RF out of the LNA 1 is connected to the spectrum analyzer for the spectrum to be visualized. We have to know the settings of the

Spectrum analyzer in order to calculate correctly the gain of the LNA 1. The power supply used for LNA 1 is 12v max. The Valon synthesizer is connected to a computer where we use some programming for generating the desired frequency for the system. In our project we have to generate the 1.42039 GHz.. We use the following commands with pre-requisite packages installed for various purposes. Once the Valon Synthesizer is connected by USB to the computer, we open the linux terminal for further commands, the commands are :

Sudo bash (enter)

Password for system- _(enter)

Minicom (Enter)

F 1420.4 Mhz

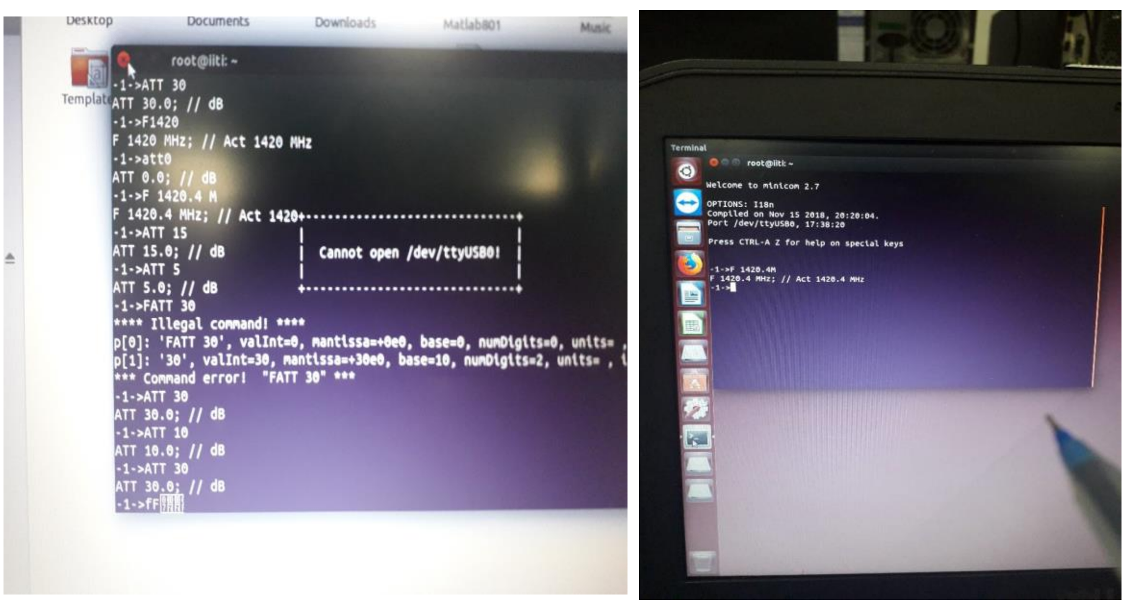


Figure 2.9 -Ubuntu Terminal where code for Valon synthesizer is executed for frequency generation

The frequency is generated to the input of the LNA 1 and we get the Spectrum correspondent to it and the gain achieved from the spectrum analyzer.

The same process is being repeated by LNA 2,G. Amplifiers and Band pass filter and we know their spectrums and the relevant data we needed to with the help of spectrum analyzer. In this way we get the gain of the individual components initially.

After the measuring of gain of individual components we have to measure the gain of the gain chain that has to be made according to the block diagram mentioned before. By theoretical measures we have an estimated gain that will enable us to compare whether the gain chin we hve assembled is giving us the correct measurement of gain power or at best the gain power nearest to the estimated theoretical value. The theoretical and the observed data is given in the next chapter where all observations and calculations are given in details.

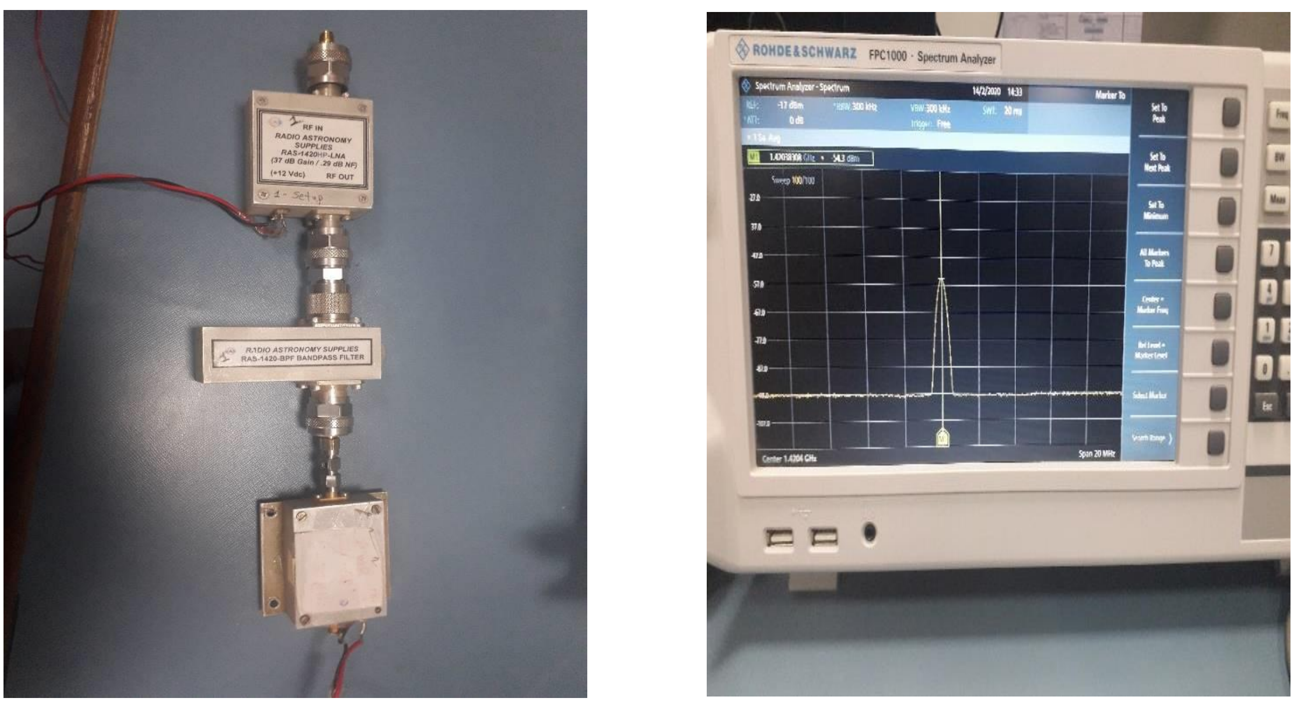


Figure 2.10 -Gain chain and its spectrum on a Spectrum Analyzer.

2.4 VECTOR NETWORK ANALYZER (VNA)

The Vector Network Analyzer, VNA is a test instrument that measures the response of a network as vector: real & imaginary parameters so that its performance can be characterised. The primary use of a VNA is to determine the S-parameters of a myriad of passive components, including cables, filters, switches, diplexers, duplexers, triplexes, couplers, bridges, transformers, power splitters, combiners, circulators, isolators, attenuators, antennas, and many more. In addition, VNAs can also characterize active devices such as transistors and amplifiers using S-parameters, as long as they are operating in their linear mode of operation. High-frequency devices can have one or two or more ports. In our project we need the VNA in order to determine the S11 parameters of the gain chain as well as the Horn antenna. Before connecting the Gain chain or the Horn antenna with the VNA it is must that we have to calibrate the VNA first. Once Calibration is done we connect the gain chain via several modes along the ports. We have to use Short, throughput and E.Cal for different port connections.

Figure 2.11- Calibration before using the VNA.

The Red light on the calibration module indicate it is calibrating. The Green light indicates it has been calibrated. It generally takes a few minutes to calibrate.

2.5 S11 PARAMETER

Measuring of S11 parameter:

S-parameters describe the input-output relationship between ports (or terminals) in an electrical system. For instance, if we have 2 ports (intelligently called Port 1 and Port 2), then S12 represents the power transferred from Port 2 to Port 1. S21 represents the power transferred from Port 1 to Port 2. In general, SNM represents the power transferred from Port M to Port N in a multi-port network.

A port can be loosely defined as any place where we can deliver voltage and current. So, if we have a communication system with two radios (radio 1 and radio 2), then the radio terminals (which deliver power to the two antennas) would be the two ports. S11 then would be the reflected power radio 1 is trying to deliver to antenna 1. S22 would be the reflected power radio 2 is attempting to deliver to antenna 2. And S12 is the power from radio 2 that is delivered through antenna 1 to radio 1. Note that in general S-parameters are a function of frequency (i.e. vary with frequency). In practice, the most commonly quoted parameter in regards to antennas is S11. S11 represents how much power is reflected from the antenna, and hence is known as the **reflection coefficient** (sometimes written as gamma: Γ or **return loss**. If S11=0 dB, then all the power is reflected from the antenna and nothing is radiated. In our system,the S11 parameter of the whole system i.e Antenna + Gain chain is -21.571dB.Our requirement for the detection should be good if the s11 parameter is greater than -14 dB (Preconditioned). The VNA is used for the measurement of the s11 parameter hence it is very crucial to understand how to use the

VNA fully and its calibration beforehand in order to measure the S11 parameters of the Horn Antenna as well as the gain chain.

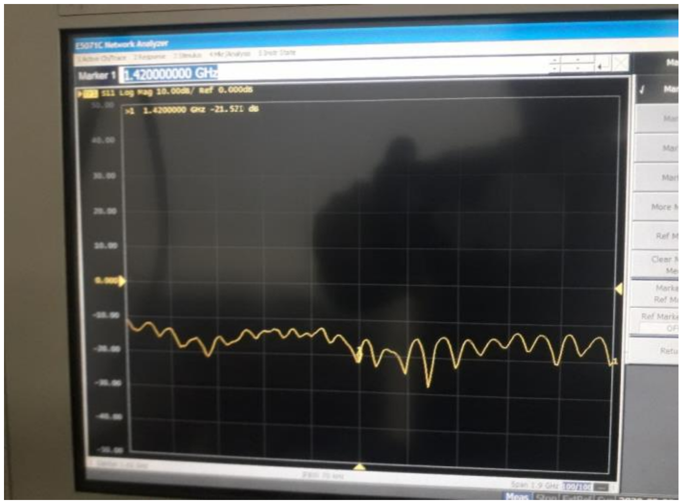


Figure 2.12- The S11 parameter of the Horn Antenna and gain chain

The result we get for our system is pretty good of what we have expected in theory. Thus our chain should be be able to detect 1420 MHz from astronomical sources provided enough noise floor for our detected signals. The above s11 parameter can be saved in a file formal of CSV using USB from the VNA an can be plotted using python or Excel. The following is the plotted CSV file for the S11 parameter.

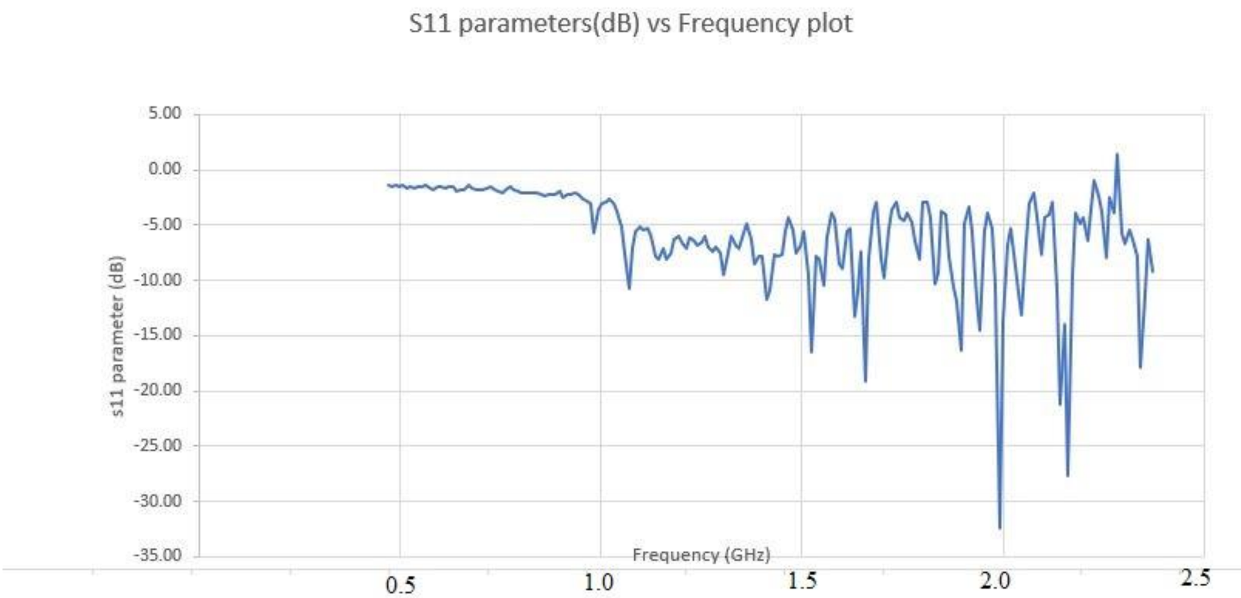


Figure 2.13- Graph obtained from the CSV file of the S11 parameter from Vector Network Analyzer, s11 parameters (dB) vs Frequency (GHz)

2.6 COMPRESSION POINT

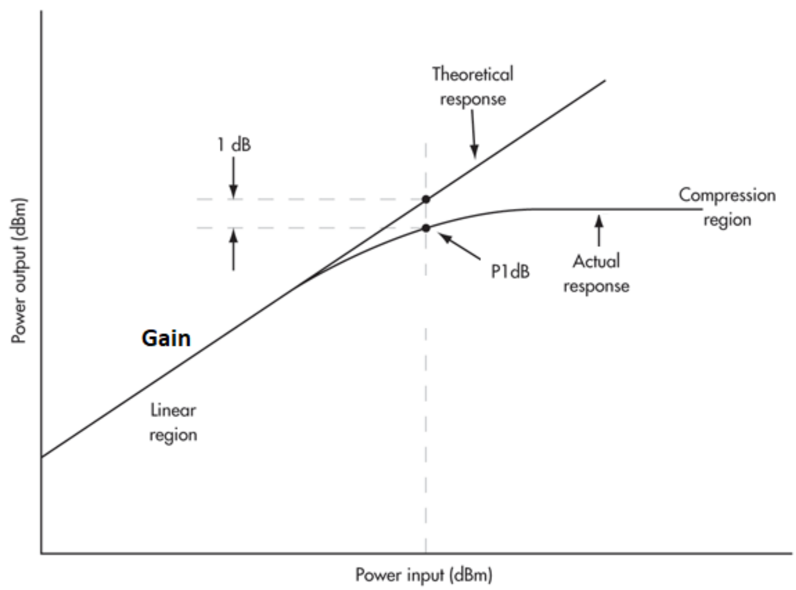


Figure 2.14- Graphical representation for 1dB compression point,source: www.rfcomp.com

The **1 dB compression point (P1dB)** is the output power level at which the gain decreases 1 dB from its constant value. Once an amplifier reaches its P1dB it goes into compression and becomes a non-linear device, producing distortion, harmonics and intermodulation products. Amplifiers should always be operated below the compression point. P1dB is one of the most important specifications for power amplifiers, as it is up to this point that we consider an amplifier to operate linearly. For our project we have to find the compression points for LNA1, LNA2, G.Amplifier. For finding Compression point we have used the analog function generator, the components for which the compression points are to be tested and spectrum analyzer. The data of the compression points will be described in the next chapter.

In our system the 1 dB compression points are:

1. LNA1 = -35 dBm

2.LNA2= -95 dBm

3. Galen Amplifier= -55 dBm

Figure 2.15- Analog Function Generator

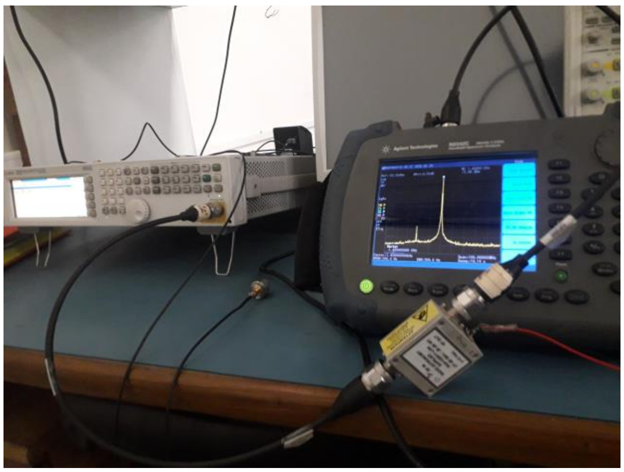


Figure 2.16- Measuring the 1dB compression point for LNA 1

2.7 ANTENNA BEAM

An important point to bear in mind is that radiation received by the telescope can come from many different directions, but the ability of the telescope to capture the power of that radiation is not the same in all directions. Hence, the antenna temperature we measure will depend on both the intensity of the radiation from the astronomical source, which is a function of position on the sky, and on the sensitivity of the telescope—also a function of position on the sky.

The sensitivity of a telescope as a function of angle relative to the pointing direction is known as the telescope's beam pattern, or power pattern, and is a fundamental characteristic of the telescope. The beam pattern has a significant impact on the observations.

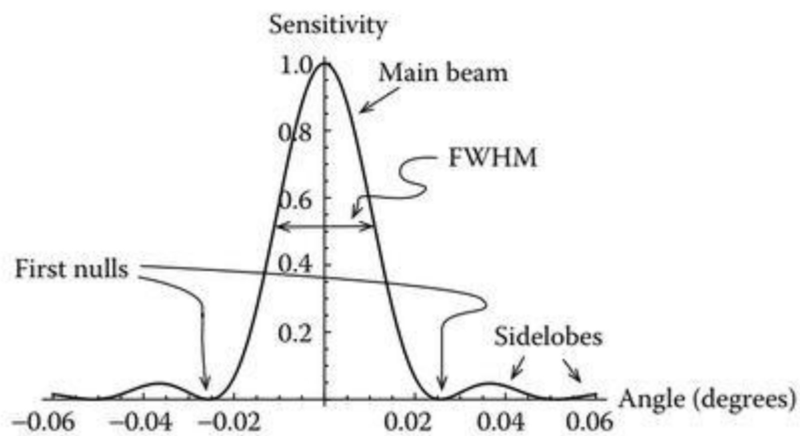


Figure 2.17- Sensitivity function, in one dimension for a 1.4-cm observation with a 40-m diameter, source: www.rfcomp.com

CHAPTER 3

OBSERVATIONS & CALCULATIONS

3.1 OBSERVATIONS OF THE COMPONENTS

The components of the gain chain that has been tested using the Spectrum Analyzer**:**

1. RAS- 1420-BPF- Bandpass filter
2. RAS- 1420 HP-LNA (Amplifier 1)
3. RAS-1420 HP- LNA (Amplifier 2)
4. Galen Amplifier

	Input	**Valen synthesizer power (op power)**	**Δ Gain**
LNA 1	-54.8 dBm/Hz	-89.6 dBm/Hz	34.8 dB
LNA 2	-43.6 dBm/Hz	-67.1 dBm/Hz	23.5 dB
Galen Amplifier	-50.3 dBm/Hz	-83.9 dBm/Hz	33.5 dB

	Centre Frequency	**Start frequency**	**Stop Frequency F2**	**Bandwidth**	**Power F1**	**Power F2**

		F1				
Band Pass Filter	1420.4 MHz	1414.4 MHz	1439.4 MHz	25Mhz	-57 dBm	-56.9 dBm

Galen Amplifier	**Length**	**Gain**	**Attenuation**
	1m	-52.0dBm	-2 dBm
	2m	-52.3 dBm	-3.2 dBm

N type cable (L<2m) Gain= -58.7 dBm	**Direct Valon synthesizer** Gain= -61.8 dBm
N type cable loss (<2m)= -3.1 dB	

Table 3.1- Gain measurements of Individual components

We have calculated the gain expected from the chain theoretically from individual components and then after assembling the gain chain as whole we have checked the gain with the help of spectrum analyser. From the gain chain the gain value for individual components from spectrum analyser we have gains as such:

LNA1=34.8 dB

Galen Amplifier=33.5 dB

BPF= -2.5 dB

3 dB attenuation

Cable, N type connector < 2m= -3.1dB

RF connector cables 1m: -2dB

2m=-3.2dB

Total gain=34.8-5.5+33.5-5 =57.8 dB

The theoretical gain value of the Chain we have calculated from the values of the gain of components:

Total gain= 34.8+33.5 -5.5 -2 =60.8 dB

We have to compare the theoretical gain values and the practical gain values in order to see if any mistakes is made and it also full fill the testing of the components. Now gain of the total chain using spectrum analyser we got:

Total gain = 62.8 dB

We have to use specific setting in the spectrum analyser for the observations to be measured correctly.

Centre frequency- 1.420 GHz

RBW- 300 kHz

Span= 2 MHz

Attenuation - 0 – 30 dB

Reference- 5 dBm

3.2 FINDING OUT THE 1 dB COMPRESSION POINT

We have used the RF Analog signal generator and spectrum analyser for finding out the 1dB compression points of individual components. The cable used for the input of the analog Signal generator has a loss of -12.28dBM, which is the called as offset and must be taken into consideration when calculating the total gain for specific I/P.

A) LNA 1 Observation table

I/P (dBM)	O/P (dBM)	Gain, (O/P-(I/P – offset)
-90	-76.42	25.86
-85	-71.72	25.56
-80	-66.74	25.54
-75	-61.83	25.45
-70	-56.87	25.41
-65	-51.92	25.36
-60	-46.93	25.35
-55	-41.95	25.33

-50	-36.94	25.34
-45	-31.97	25.31
-40	-27.01	25.27
-35	-21.98	25.3
-30	-18.06	24.22
-25	-12.16	25.12
-20	-7.47	24.81
-15	-4.47	22.81

Table 3.2- 1 dB compression point for LNA 1

B. Observation table for Galen Amplifier

I/P (dBM)	O/P (dBM)	Gain, (O/P-(I/P – offset)
-90	-71	34.13
-85	-65.97	34.16
-80	-60.96	34.17
-75	-56.01	34.12
-70	-51.02	34.11
-65	-46.03	34.1

-60	-41.03	34.1
-55	-36.06	34.07
-50	-31.03	34.1
-45	-26.03	34.1
-40	-20.97	34.16
-35	-16.01	34.12
-30	-11.01	34.12
-25	-6.06	34.07
-20	-3.85	31.28

Table 3.3- 1 dB compression point for G.Amplifier

C. Observation table for LNA 2:

I/P (dBM)	O/P (dBM)	Gain, (O/P-(I/P – offset)
-100	-93.86	18.42
-95	-88.82	5.28
-90	-83.77	6.05
-85	-78.81	6.09
-80	-73.89	6.17

-75	-68.90	6.18
-70	-63.88	6.16
-65	-58.90	6.18
-60	-53.880	6.16
-55	-48.90	6.18
-50	-43.85	6.13
-45	-38.88	6.16
-40	-33.90	6.18
-35	-28.88	6.16
-30	-23.88	6.16
-25	-18.89	6.17
-20	-13.90	6.18
-15	-8,93	6.21

Table 3.4- 1 dB compression point for LNA 2

The compression point observed from the data :

- The compression point of LNA 1 is at -35dBm
- The compression point of LNA 2 is at -100dBm
- The compression point of G.Amp is -25dBm

For a linear device, output power is merely a fixed fraction of the input power. This includes most passive devices such as connectors, cable, waveguides, etc. Nonlinear devices exhibit complex behavior when input power is compared to output power. However, most nonlinear devices tend to become lossier with increasing input power. Devices such as amplifiers, mixers and switches tend to fall into this category.

3.3 OBSERVATIONS AFTER HARDWARE IMPLEMENTATION

The initial process after the hardware is setup is that we can test on and off the sun as the source body to detect in signals and observe the noise floor change in spectrum analyser. Theoretically when we point the horn antenna to the Sun directly there must be a change on the noise floor abruptly when the power supply is given to the gain chain connected to the feed of the Horn Antenna.

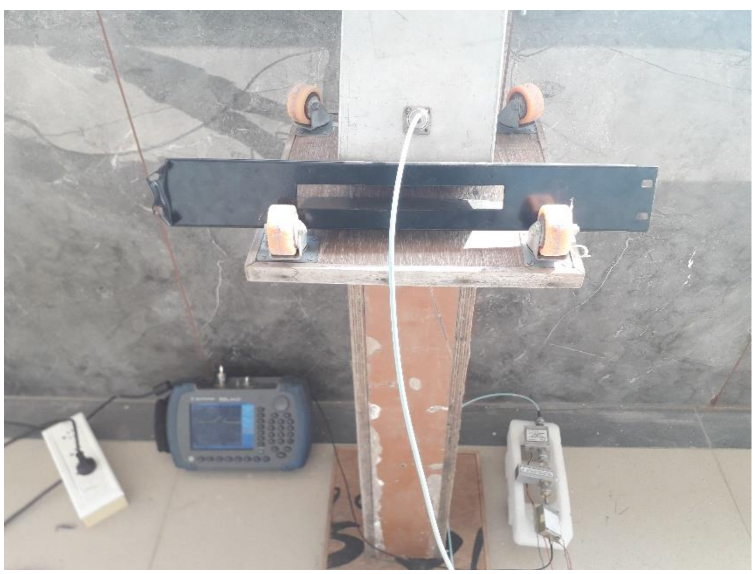


Figure 3.1- Hardware setup of the system

The Observations after the hardware setup for different periods :

Attempt 1:

Noise floor kept at -88.4 dBM

Horn antenna directed towards sun we get, -56.4 dBM

Horn antenna directed away from sun, -56.4 dBM

There is no significant difference ON and OFF sun

Integration time -30 sec

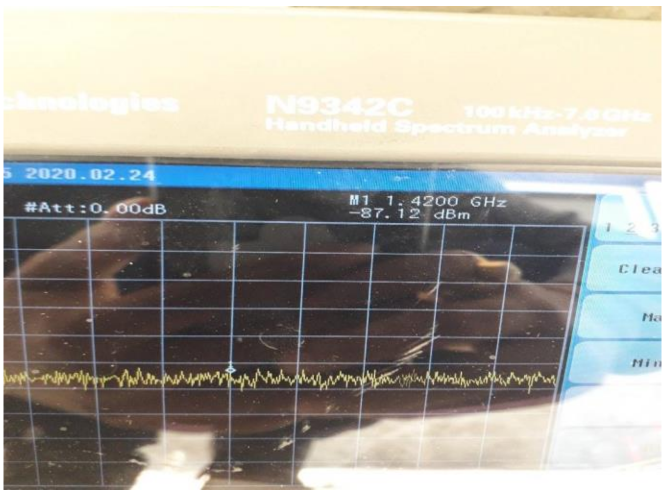


Figure 3.2- Noise floor of the Spectrum Analyzer

Attempt 2:

Noise floor kept at -119.6 dBM

Directed towards sun- 59.57 dBM

Without directed towards sun- 59.57 dBM

Integration time – 30 sec

- Settings of Handheld spectrum analyser used for the observations:

  Centre frequency: 1420 Mhz

  Span:50 Mhz

  RBW: 100 Hz

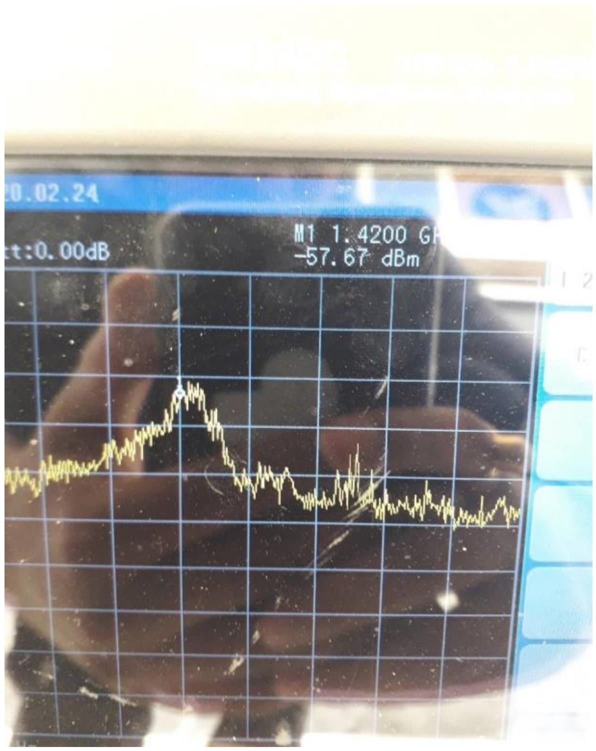


Figure 3.3- Change in the noise floor to some extent on detection of sun

No significance difference is observed in the spectrum analyser between ON and OFF sun

The main reasons initially there were no desired output can be the oscillation in the amplifier or the noise floor should be much more lower in order to detect the sun. The testing is thus one of the important phase of the procedure where we have to check the system and components again and again in order to debug the fault in our system.

After carefully scrutinising the gain chain and individual components again and again to see if there was any discrepancy within the hardware parts and cross checking the total gain value of the system. New observations are taken after connecting the LNA1 directly from the feed :

<u>Attempt 3</u>:

Noise floor kept at -86.1 dBM

Directed towards sun- 67.62 dBM

Without directed towards sun- 61.80 dBM

Integration time – 30 sec

<u>Attempt 4</u>:

Noise floor kept at -133.26 dBM

Directed towards sun -93.57 dBM

Without directed towards sun -93.41 dBM

Integration time – 30 sec

- Settings of Handheld spectrum analyser used for the observations:

  Centre frequency: 1420 Mhz

  Span:50 Mhz

  RBW: 100 Hz

A difference has been observed in the spectrum analyser between On and OFF sun. But the difference can be much higher theoretically. The reasons for the following problem can be the integration time , RFI oscillation in amplifier or any other discrepancy in the gain chain.

Other factors that has been studied for improving the signals detected from the ON and OFF position switching can be the antenna temperature for SNR 3, 5. The Antenna System temperature for SNR=3,5 is to be determined practically and the Observation time can be the important factor for solving the problem. RFI is also another important factor to be determined.

3.4 RADIO SOURCES FOR PLAUSIBLE OBSERVATIONS

- Sun: From observations in a narrow band around 21 cm we find estimates for the peak temperature of the chromosphere of the sun and doppler shifted 21 cm from following constellations:
- Cassiopeia
- Sagittarius
- Scutum
- Aquila
- Among which Cassiopeia has very suitable rise and set time in this, next month (rise: 4 am set: 11 pm) and following month therefore making it easy for adjusting angle & time for observation.

Astronomical sources are often referred to as either being resolved or being unresolved. A resolved or extended source has an angular size larger than the main beam of the telescope. Observing such a source is intrinsically a very different situation from observing an unresolved source (sometimes called a point source), that is, one whose angular size is much smaller than the main beam.

CHAPTER 4

FUTURE SCOPES, CONTINUATION & CONCLUSION

4.1 ASTRONOMICAL OBSERVATIONS

The Horn Antenna that is tested and has substantially detected radio waves from Sun can be now used for detecting 21 cm lines from astronomical sources. For such detections we need the location and time of observations of the sources with accurate data. Sources that can be observed with this Radio telescope easily are Sagittarius, Scutum, Cassiopeia.

One of the major results the project can yield moving forward is the measurement of the galactic curve rotation that can be deduced with the help of the collected data and radio waves from the mentioned sources. Such system can be used vastly in observation of radio objects that is emitting the radio wave at the specific frequency of 1.42 GHz. We can also change the power of the amplifier in case we need more rise in the detection of the signal generated within the gain chain. The amplifier helps us to detect the signals that can be almost negligible or is very low in its power.

As we saw a very abrupt change on the noise floor of spectrum analyzer indicating that we have successfully detected the Sun using our Rx system and Horn Antenna thus this will be used for detection of 21cm HL from astronomical sources.

For further continuation of the system, we can use RTL-SDR dongle to connect to the system to computer for generating pictorial representation and also create animations with the help of data if collected in large amounts.

Radio components such as modulators, demodulators and tuners are traditionally implemented in analogue hardware components. The advent of modern computing and analogue to digital converters allows most of these traditionally hardware based components to be implemented in software instead. Hence, the term software defined radio. This enables easy signal processing and thus cheap wide band scanner radios to be produced. The RTL-SDR can also be used as a wide band radio scanner.

Figure 4.1 -RTL SDR that will be used in the system further, source: www.rtl-sdr.com

4.2 EXPECTED OUTCOME OF OBSERVATIONS OF SOURCES

As we have discussed earlier that the most plausible easy observations we can make with the help of the system are:

- Cassiopeia
- Sagittarius
- Scutum
- Aquila

We have to understand the measuring of the rise time and set time, coordinate system, azimuth angle, horizontal angle in order to know when we need to use our horn antenna for how much time period to a particular direction that will detect the signal of the specific astronomical sources. We can also use the software like Stellarium that can guide us about the time schedule, angles and coordinates of our astronomical sources throughout the sky.

We can determine and get the Frequency spectra of all the astronomical sources we have mentioned previously but there can be a whole lot of other sources emitting radio waves which can also be detected for 21cm Hydrogen lines provided we have to know their coordinates, time periods and angles very accurately for yielding result. The frequency for the detection of the HL will always be at 1420 MHz..

4.3 CONCLUSION

The Horn antenna system that has been made during this period has been used tested for its components individually and as system all together.It is important that all the components for any type of system must be tested again and again in order to ensure that it is working with the most efficient result. Our horn antenna and the gain chain has been setup without any typical radio telescope stand that can regulate automatically rather we have managed to perform manual movements according to our sources. The observations an the calculations documented in this project has been tested several times for the best results. The detected signal for the sun till the period of the project done on site has been slightly less then expected. We have focused more on the debugging of the issue after that. The possible solutions that can be the reason behind this is RFI, antenna temperature, integration time of the observations done previously. On practical grounds the gain achieved for the Radio telescope has been fruitful and has yield good results as compared to the expected theoretical estimation. Along with the making of the system I have also learnt in great details on working with sophisticated equipment like that of VNA, Spectrum Analyzer, Valon Synthesizer and also Analog Radio Frequency generator that was essential for each step along the way for the project. With the gain chain and the horn antenna that is made it is can be used to detect the 1420 MHz for Sun and other astronomical sources that emits the same radio wave frequency. This project is a direct recreated experiment from the Harold Ewen and Edward Purcell experiment of detecting 1420 MHz for 21cm hydrogen lines which is refereed as one of the most important experiment in the Radio Astronomy history.

REFERENCES

Papers

[1] N. Gopalswamy, Radio Astronomy at Long Wavelengths, vol. 119, pp. 123, 2000.

[2] Gart Westerhout, "THE EARLY HISTORY OF RADIO ASTRONOMY", Annals of the New York Academy of Sciences, vol. 198, pp. 211, 1972.

[3] Donald James McLean, Solar System Radio Astronomy, pp. 117, 1965.

[4] A. Richard Thompson, James M. Moran, George W. Swenson, Interferometry and Synthesis in Radio Astronomy, pp. 1, 2017.

[5] A. D. Olver, P. 1. B. Clarricoats, A. A. Kishk, L. Shafai, Microwave Horns and Feeds, London:lee, 1994.

[6] A. W. Love, Electromagnetic Horn Antennas, New York:IEEE Press, 1976.

[7] Roslan Umar1,2, Zamri Zainal Abidin1, Zainol Abidin Ibrahim1, Zulfazli Rosli1and Noorkhallaf Noorazlan,Selection of radio astronomical observation sites and its dependence on human generated RFI,2013

[8] A. D. Olver, P. 1. B. Clarricoats, A. A. Kishk, L. Shafai, Microwave Horns and Feeds,1994

Books

[1] Jeff Lashley,The Radio Sky and How to Observe It, Springer ,2010

[2] J. Marr, R. Snell, S. Kurtz Fundamentals of Radio Astronomy: Observational Methods, CRC Press, 2016

Reports

[1] A low-cost home-built horn antenna for 21 cm astronomy,R. N. Patel and N.A. Patel, 2013.

[2] A TRAINING PROJECT REPORT ON OBSERVING 21CM LINE WITH HORN ANTENNA, Joshi Yogesh Kumar D and Krishna Prajapat, 2018

[3] The Horn Antenna in Radio Astronomy (A History and Use) By Jeffrey M. Lichtman Radio Astronomy Supplies

www

[1] https://public.nrao.edu/glossary/

[2] https://www.everythingrf.com

[3] https://www.microwaves101.com/encyclopedias/compression-point

[4] http://rishi-patel.blogspot.com/2013/10/summary-of-horn-antenna-project.html

[5] https://en.wikipedia.org/wiki/Hydrogen_line

[6] http://www.astronomytrek.com/top-astronomical-discoveries-made-by-radio-telescopes

[7] https://www.rfcomp.com