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Surface Properties of Maxwell Montes region of Venus using Arecibo Dual-Polarization Radar Data

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Abstract

In the post-midterm part, we started with studying various types of antennas from the Scientech-2261 Antenna Kit. We plotted the field patterns of simple dipole, folded dipole and Yagi-Uda antennas and compared them with the actual patterns. Later, we calculated the beam-width and a directivity-analogous for 2d field pattern. The directivity increases for Yagi-Uda antennas, as it is supposed to. Standing Wave ratio for some of the antennas were also measured, however, they are not impedance matched. For the 21-cm Hydrogen line, we assembled the electronics (LNA, BPF and SDR) and checked the antenna and the electronics with a VNA. However, we could not detect any signal at the 21 cm from the galactic anticenter.

Chapter 1

Antenna Trainer Kit Experiments

1.1 Objectives

1. To plot the field patterns of different antenna
2. To measure the beam-width and Standing Wave Ratio for the antennas
3. To compare the directivity of different antennas

1.2 Introduction

In the pre-midsemester part, different antenna parameters, antenna types and two different antennas- dipole antenna and horn antenna were discussed. Some of the important antenna parameters are bandwidth, field pattern, beam width, directivity, gain and standing wave ratio. Bandwidth of an antenna is defined by its working frequency region. Field pattern is the variation of power radiation as a function of direction. In this part, we took a few antennas of our choices and plotted the field pattern in 2d Cartesian and polar coordinates. Half Power Beam Width (HPBW) is the angular separation in which magnitude of the radiation is decreased by 50% or 3 dB. We derived the half power beam width from the 2d polar plots. Directivity of an antenna is a measure of how directional the antenna is at a particular direction. Usually by directivity, we mean the peak directivity at the direction of the major lobe[1] [2] [3] [4]. Directivity is given by,

$$D(\theta,\phi) = \frac{U(\theta,\phi)}{U_I} \tag{1.1}$$

Although, directivity is a measure in the three dimensional field pattern, but we tried to estimate the value of it for a two dimensional field. It gives a comparative parameter value for different antennas and it can be used to compare how directive two or more different antennas are. Antenna gain is given by the product of the directivity and efficiency of an antenna, where efficiency corresponds to the ohmic loss of the antenna.

$$G = k \times D \tag{1.2}$$

Standing Wave Ratio (SWR) or Voltage SWR (VSWR) is another measure of how efficiently power is transmitted from a source into a load through a transmission line. It is given by the maximum to minimum voltage ratio of the signal on the transmission line. A detailed explanation of SWR and calculation of SWR are given in a later section.

1.3 Apparatus Required

- RF generator
- Transmitting mast
- Transmitting antenna
- Receiving mast
- Detector Antenna
- Matching Stub
- Directional Coupler
- Multimeter
- BNC Cable
- Wires and Power Supply

1.4 Theory (in addition to pre-midterm part)

1.4.1 Working Principle of a Wire Antenna

An antenna can be as simple as an open-ended wire, connected to an AC source. In case of this system, the current changes direction at the end point of the wire as the direction of the AC source changes. In other terms, there occurs an 180° phase change at the end point of the wire. However, the entire current cannot change its phase by 180° instantaneously. Although, the direction of overall current changes. As a result, the rest of the current that cannot allow an 180° phase change is transmitted in the free space.

The current that we supply to the antenna is called the forward current, while the current that is reflected back is known as the reverse current. For an antenna to observe maximum transmittance, we need the reverse current to be zero. An wire with forward current equal to the reverse current will not transmit any signal at all. This is the main working principle of an wire antenna.

1.4.2 Dipole Antenna

The general structure and construction of a dipole antenna was discussed in pre-midsem report. Here we talk about the direction of current in a dipole antenna.

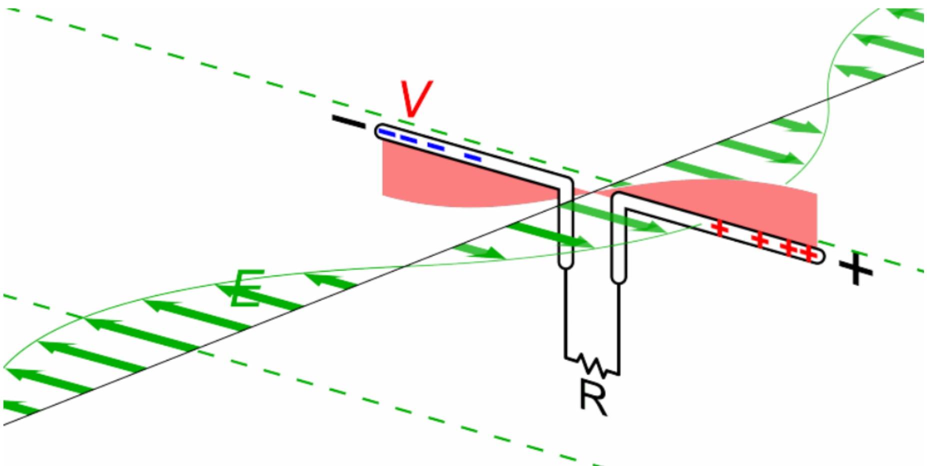

Figure 1.1: Instantaneous current flow in dipole antenna (Fig: stack-exchange)

Dipole Antenna uses the same technique as discussed before. Here there are two wires bent in 90° and kept in parallel to each other. Current flows in anti-parallel direction in the two wires, i.e.

if current is flowing outwards in one of the wires, then it flows towards the source in the other one. The direction of current keeps on switching as the source is AC [1]. The direction of electric and magnetic fields are shown in Figure 1.1.

In case of half-wave dipole antenna, the transmitted current from both end of the wires make a half-wave. This pattern exists when the length of the antenna is $l \leq \lambda/2$ (Fig. 1.2). Now, dipole antennas can be formed with length $n\lambda/2$. The change of current diagram for a $3\lambda/2$ antenna is shown in Fig 1.3.

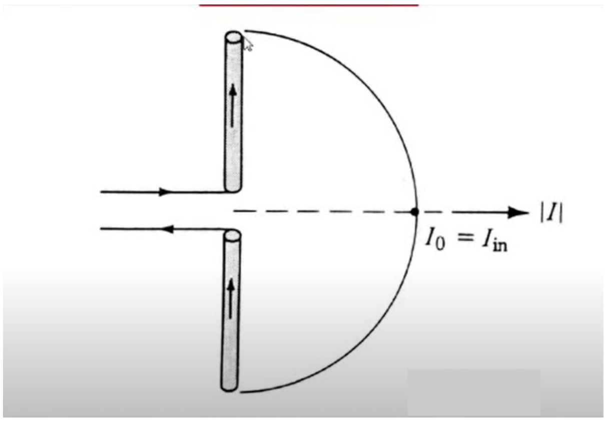

Figure 1.2: The transmitted current in Half-wave dipole antenna forms a half wave at the end points of the wires. The length of the antenna should be $l \leq \lambda/2$

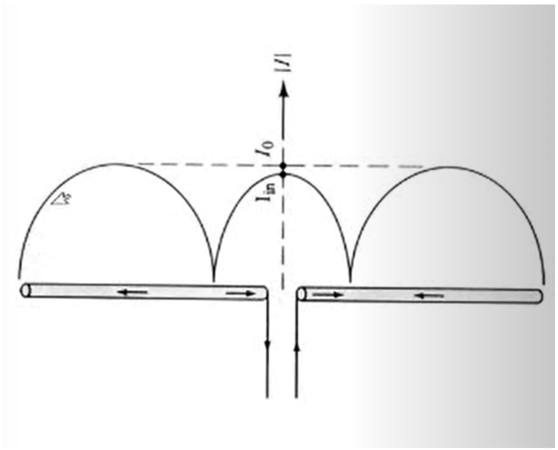

Figure 1.3: Transmitted current in $3\lambda/2$ antenna. Here, $\lambda < l < 3\lambda/2$ (Fig. Colorado University)

1.4.3 Folded Dipole Antenna

The folded dipole antenna consists of a basic dipole, but with an added conductor connecting the two ends together. As the ends appear to be folded back, the antenna is called a folded dipole antenna. The working principle of a folded dipole is similar to the basic dipole, the folded dipole antenna is a balanced antenna, and needs to be fed with a balanced feeder. The most common version of a folded dipole is a half-wave one, which is centre fed, i.e. it is fed where the impedance is low and current is high.

Figure 1.4: Typical Half-wave folded dipole antenna

1.4.4 Yagi-Uda Antenna

Yagi-Uda antenna or aerial antennas are famous for their uses in the communication industry. A typical Yagi-Uda has three major elements, one centre driven element, which is either folded dipole or simple dipole, there is a reflector at the back side and a series of directors at the other direction. The main centre element is connected to the power source. The reflector stops the current to flow in the back side of the antenna, thus avoiding extra power loss towards any other direction. The other directors are placed in series to make the antenna highly directional. Depending upon the number of directors, the Yagi-Uda can be further classified.

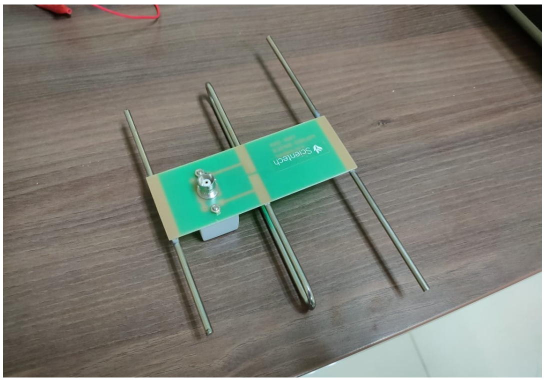

Figure 1.5: 3-element folded dipole Yagi-Uda antenna

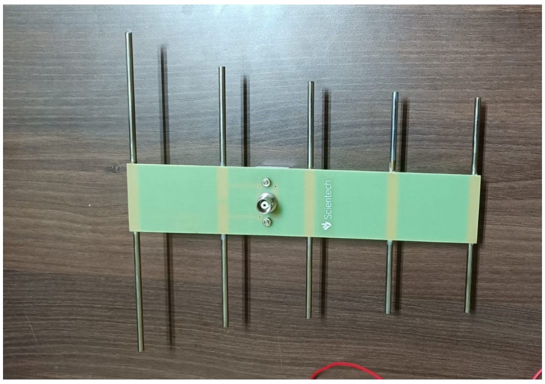

Figure 1.6: 5-element simple dipole Yagi-Uda antenna)

1.4.5 detector Antenna

Figure 1.7: Detector Antenna with ammeter

The detector antenna is a folded dipole antenna with a reflector at the back. The folded dipole is used because it has better gain than the other simple dipole antennas and it has fairly higher beam-width. The reflector prevents any extra power loss.

1.4.6 Directional Coupler

The directional coupler separate metering of power flowing in the forward direction (generator to antenna) and the reverse direction (antenna to generator). This is used during the experiments as an aid to match the generator to the load and also as a means to measure the Standing Wave Ratio in the transmission line to the antennas. In the following circuit diagram (Fig. 1.8), line trunks are placed in parallel to the transmission line from generator to load. The power travelling from input to output of the device will cause induced voltages in the upper and lower loops. In the lower loop, the voltage will build across the sensing devices due to the forward conducting diode. As for the power travelling from load to generator, the situation is reverted and the upper loop will sense the current due to the other diode, the lower one will not. A scale adjustment is required at the end because the measured currents are from induced current and not the original current.

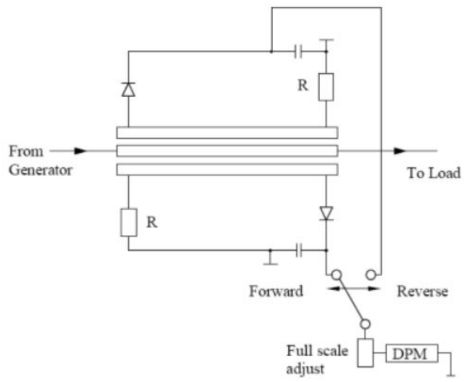

Figure 1.8: Directional coupler circuit diagram

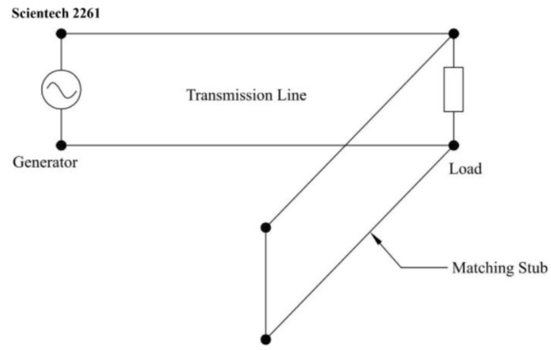

Figure 1.9: Matching Stub circuit diagram

1.4.7 Matching Stub

The junction of RF generator and antenna is the highest voltage and zero current point. The other end of the antenna is a maximum current and zero voltage point. In other words, the transmission line acts as an infinite impedance line. Since the line is loss less, the impedance must be purely reactive. In fact, the line from length 0 to $\lambda/4$ has inductive impedance while $\lambda/4$ to $\lambda/2$ has purely capacitive impedance. A handy way to match these impedances is to use a matching stub in parallel which has a adjustable reactive impedance, varying with length.

1.5 Results

1.5.1 Field Patterns

The output current is calculated at different angles between the transmitter and receiver antennas by rotating the transmitting antenna. The plot between angle and output current in dB gives us the antenna field pattern. Field Pattern in Cartesian Coordinate, Polar Coordinate and Polar dB Coordinates are given for half-wave simple dipole, $\lambda/4$ simple dipole, half-wave folded dipole and 3-element folded dipole Yagi-Uda antennas are attached below. The scripts for plotting could be found here.

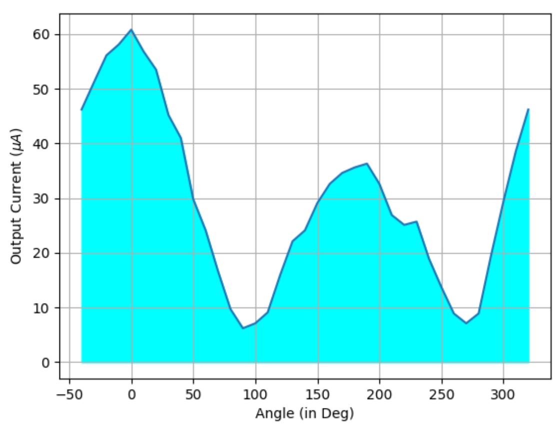

Figure 1.10: Field Pattern of Half-wave Dipole Antenna in Cartesian Coordinate

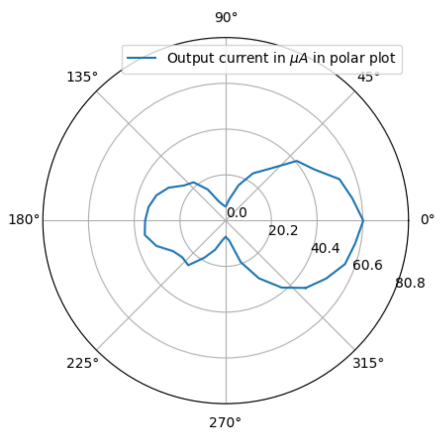

Figure 1.11: Field Pattern of Half-wave Dipole Antenna in Polar Coordinate

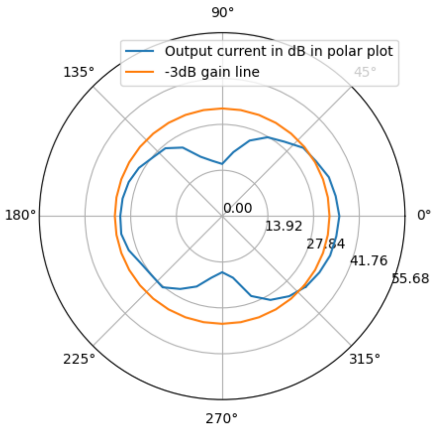

Figure 1.12: Field Pattern of Half-wave Dipole Antenna in dB in Polar Coordinate

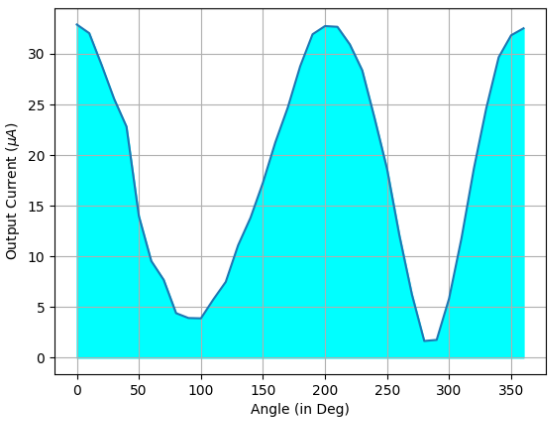

Figure 1.13: Field Pattern of $\lambda/4$ Dipole Antenna in Cartesian Coordinate

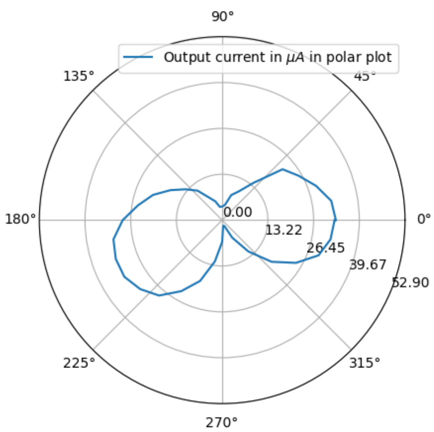

Figure 1.14: Field Pattern of $\lambda/4$ Dipole Antenna in Polar Coordinate

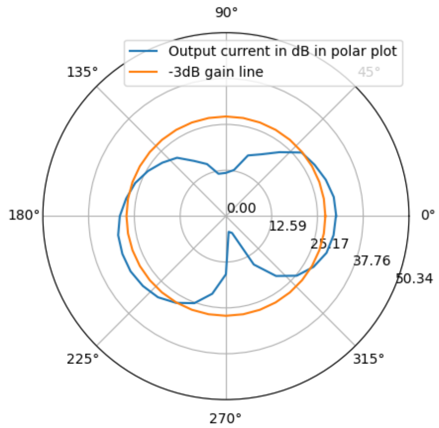

Figure 1.15: Field Pattern of $\lambda/4$ Dipole Antenna in dB in Polar Coordinate

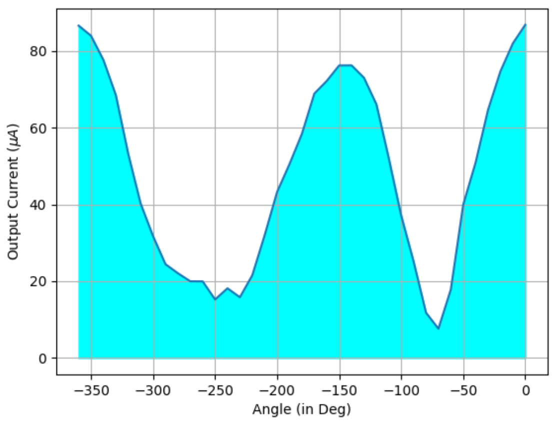

Figure 1.16: Field Pattern of Folded Dipole Antenna in Cartesian Coordinate

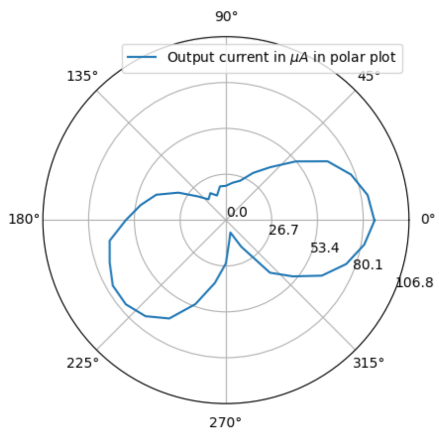

Figure 1.17: Field Pattern of Folded Dipole Antenna in Polar Coordinate

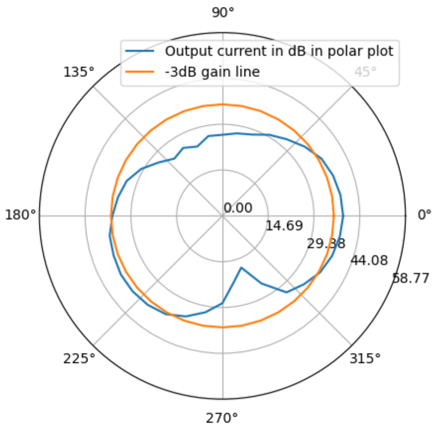

Figure 1.18: Field Pattern of Folded Dipole Antenna in dB in Polar Coordinate

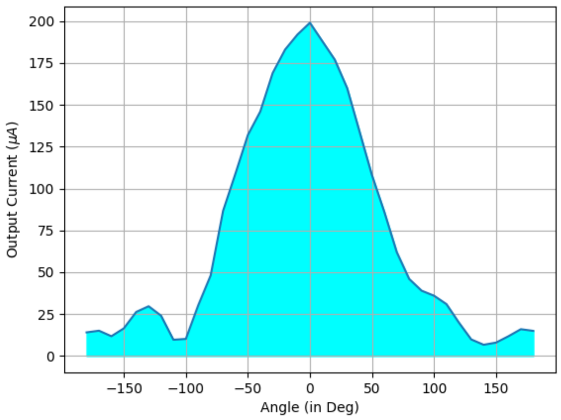

Figure 1.19: Field Pattern of 3-element Folded Dipole Yagi-Uda Antenna in Cartesian Coordinate

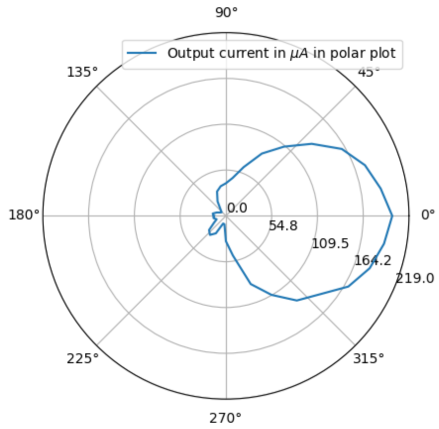

Figure 1.20: Field Pattern of 3-element Folded Dipole Yagi-Uda Antenna in Polar Coordinate

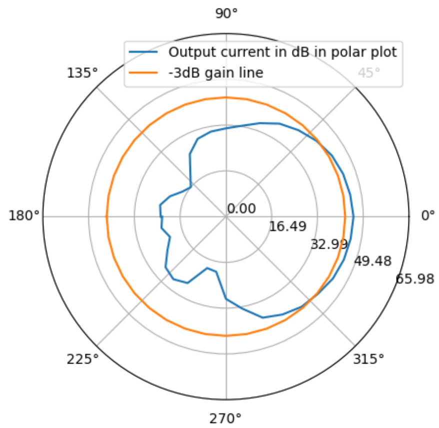

Figure 1.21: Field Pattern of 3-element Folded Dipole Yagi-Uda Antenna in dB in Polar Coordinate

1.5.2 Half-power Beam Width

Beam width of an antenna is commonly defined in two ways. The most well known definition is the -3dB or half-power beam width, but the 10dB beam width is also used, especially for antennas with very narrow beams. The -3dB or half-power beam width of an antenna is taken as the width in degrees at the points on either side of the main beam where the radiated level is 3dB lower than the maximum lobe value. We calculate that from the polar plots of field pattern in dB.

Table 1.1: List of antennas with their calculated HPBW

Antenna	HPBW		Antenna	HPBW
Half-wave simple dipole	80.21		$\lambda/4$ simple dipole	70.70
Half-wave folded dipole	66.20		3-element folded dipole Yagi-Uda	81.70
5-element simple dipole Yagi-Uda	48.70		7-element simple dipole Yagi-Uda	50.01

1.5.3 Directivity

The directivity of an antenna is defined as the ratio of power density of the antenna in its direction of maximum radiation to the power density averaged over a sphere. We calculate a physical parameter which is analogous to directivity in 2D space. So, we average it over a rectangle in Cartesian coordinates and calculate the directivity analogous in 2D plane. The scripts for the calculation could be found here

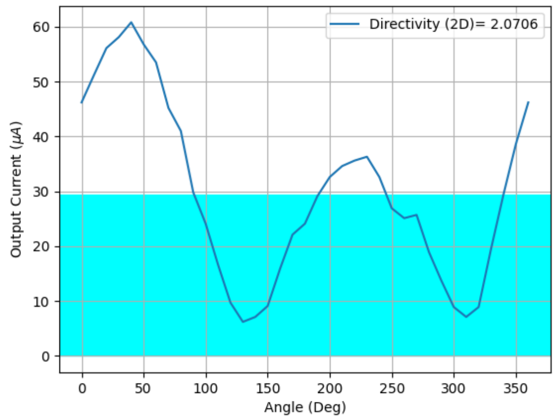

Figure 1.22: Directivity calculation for half-wave dipole antenna

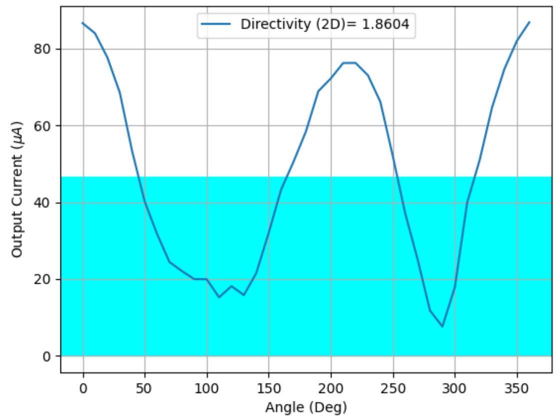

Figure 1.24: Directivity calculation for half-wave folded dipole antenna

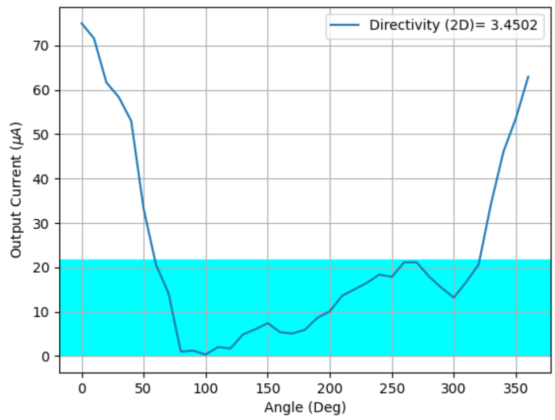

Figure 1.23: Directivity calculation for 5-element Yagi-Uda antenna

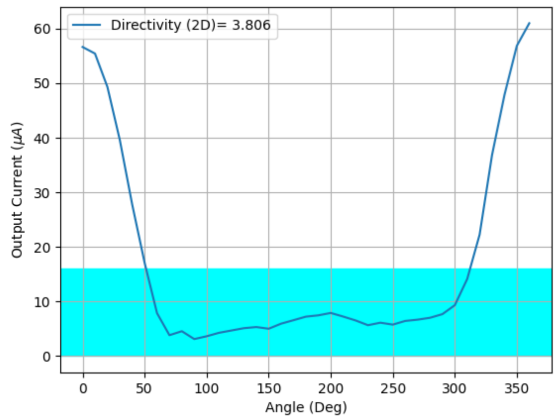

Figure 1.25: Directivity calculation for 7-element Yagi-Uda antenna

The directivity of half-wave simple dipole is higher than that of folded dipole. As expected the directivity of both the Yagi-Uda antennas are much higher than the dipole antennas. While comparing between a 5-element and a 7-element Yagi-Uda antennas, we can see that the later one has slightly higher directivity. It is simply because of the reason that 7-element dipole antenna has more number of directors in the direction of main lobe.

1.5.4 SWR Measurement

As defined in previous section, the SWR is calculated as the ratio of sum of forward and reverse current and difference between the two.

$$SWR = \frac{F+R}{F-R}$$

Reflection Coefficient is defined by,

$$\Gamma = \frac{SWR-1}{SWR+1}$$

We first use the matching stub with the folded dipole antenna as the transmitter. However, the matching stub returns the same values of SWR (within error range) for each length

Table 1.2: SWR of Folded Dipole Antenna for different matching stub lengths

Stub length	RF Detector current	Forward Current	Backward Current	SWR
(cm)	(μA)	(μA)	(μA)	
10	110.4	83.0	50.8	4.155279503
0	72.5	93.2	58.1	4.310541311
2.5	112.0	87.8	54.5	4.273273273
5	120.7	84.0	51.6	4.185185185
7.5	92.6	86.6	53.3	4.201201201
10	112.5	85.3	52.2	4.15407855
12.5	122.2	82.2	50.4	4.169811321
15	91.9	90.6	56	4.23699422
17.5	92.1	88.7	54.3	4.156976744
20	106.0	87.0	52.5	4.043478261
22.5	72.2	88.9	54.8	4.214076246
25	76.1	89.7	55.2	4.2
29	103.8	90.5	56.2	4.27696793

SWR for different antennas:

Antenna types	Forward Current	Backward Current	SWR
Yagi uda folded 3 element	80.6	49.7	4.216
Yagi uda simple 5 element	92.9	56.5	4.1044
Phase array $\lambda/2$	97.1	60.7	4.335
Loop antenna	99.9	64.1	4.581
Zip line antenna	95.1	56.9	3.979
Ground plane antenna	87.8	56.5	4.610
Simple dipole $\lambda/4$	79.4	53.2	5.061
Simple dipole $\lambda/2$	89.3	54	4.059

Table 1.3: SWR calculation for different antennas (without matching SWR)

Antenna types	Γ	Reflected power(%)	Ref.power (dB)	Mismatch loss
Yagi uda folded 3 element	0.617	38.069	4.194	2.081
Yagi uda simple 5 element	0.608	36.966	4.322	2.004
Phase array $\lambda/2$	0.625	39.063	4.082	2.151
Loop antenna	0.642	41.216	3.849	2.307
Zip line antenna	0.598	35.76	4.466	1.922
Ground plane antenna	0.63	39.69	4.013	2.196
Simple dipole $\lambda/4$	0.644	41.474	3.822	2.326
Simple dipole $\lambda/2$	0.67	44.89	3.479	2.588

Table 1.4: (Continuation of the above table)

1.6 Possible Further Improvements

The SWR measurements are coming in vicinity to each other as they are not calculated after matching the impedance. If we can make electrical circuit instead of a mechanical system and vary the reactive impedance in the range of impedance along transmission line, then the impedance could be matched. In that way, we can match the impedance first and then calculate the SWR.

Chapter 2

Observing 21 cm Hydrogen line from anti centre of Galaxy

2.1 Objectives

- To check the antenna and electronics with a VNA
- To detect 21-cm line from galactic anticenter

2.2 Introduction

In the pre-midterm part, we talked about the 21 cm Hydrogen line, its abundance, importance and detection with Horn Antenna. We also talked about the dimension of the waveguide and flare of the horn, required for our specified wavelength. In this section, we discuss the electronics required and used to get the analog signal into digital.

2.3 Apparatus Required

- Horn Antenna
- Tripod
- Low Noise Amplifier
- 12V DC adapter for LNA
- Band-pass Filter
- RTL-SDR
- GNU Radio Software
- BNC Cable
- Polyurethane flexible cables for antenna
- Wires and Power Supply
- Vector Network Analyser

2.4 Theory (in addition to pre-midsem part)

2.4.1 Study Area

The Milky Way is a barred spiral galaxy, that is, a galaxy composed of a core crossed by a bar-shaped structure from which the spiral arms branch off. The stellar disk of the Milky Way has a diameter of about 100000 light years and a thickness, in the region of the arms, of about 1000 light years. Our star, the Sun, is located in the outer part of the Galaxy, at a distance of about 8.5 kpc (about 25000 light years) from the galactic center. Our target area was direction of galactic anticenter of Milky Way, Sagittarius (location: RA 05h 46m, dec +28° 56').

2.4.2 The detection system

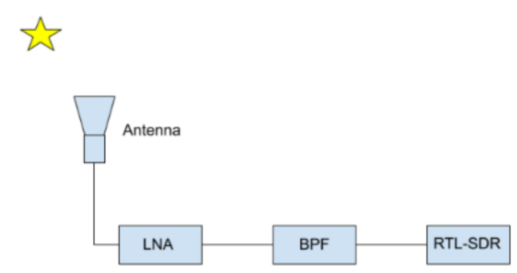

Figure 2.1: Electronics associated with the antenna

We use a series combination of Low Noise Amplifier, Band-pass Filter and a Software Defined Radio. We take the analog data from Horn, feed it through the circuits and the SDR is connected to a Radio range. The SDR is connected to the laptop. It converts the analog to digital signal. The digital signal is visible in PC on GNU radio software. The LNA is an electronic amplifier that amplifies a very low-power signal without significantly degrading its signal-to-noise ratio. A bandpass filter is a device that passes frequencies within a certain range and rejects (attenuates) frequencies outside that range. The GNU Radio software works on a block-based circuit system. Figure 2.2 shows the block diagram. Sample rate determines how fast data is processed, while bandwidth is defined by the centre frequency and start frequency. The code for blocks could be found here.

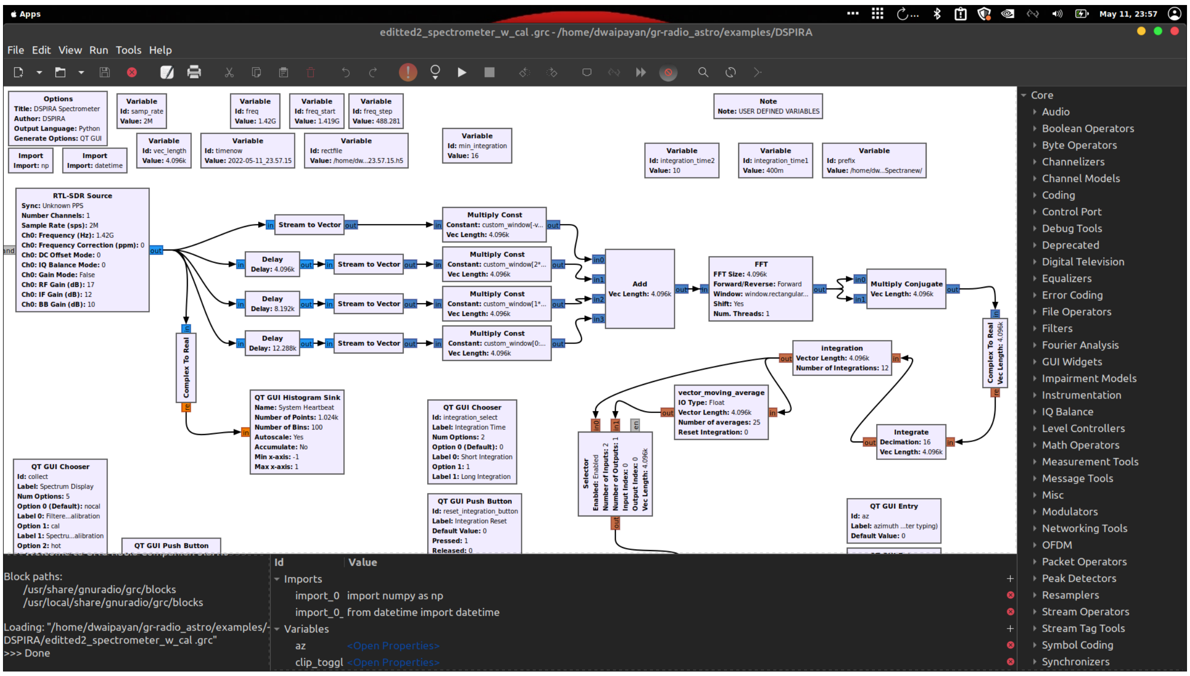

Figure 2.2: Block diagram of the GNU Radio Software

2.5 Experiment

To do the experiment, we first use a Vector Network Analyser and generate radio waves at our desired frequency. We make the setup with the antenna and the tripod. The signal generated by the frequency generator was well detected by the antenna and the SDR. Change in the centre frequency ($\pm 100 MHz$) of the generator does not affect the accuracy of the detection. The SDR and GNU-radio can detect and digitalize the signal as long as it is within a provided bandwidth.

Figure 2.3: Vector Network Analyser

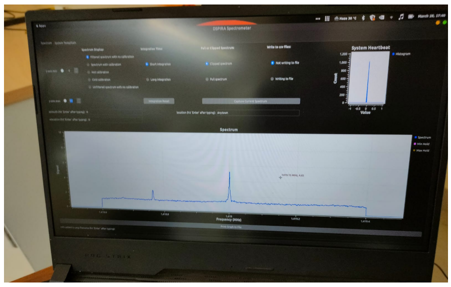

Figure 2.4: Detected signal from VNA

Later we took the antenna to the rooftop of the animal house to observe the 21-cm line from the Milky way anticentre. We faced the antenna towards the direction of the study area, which is discussed before. However, we could not detect the 21-cm line.

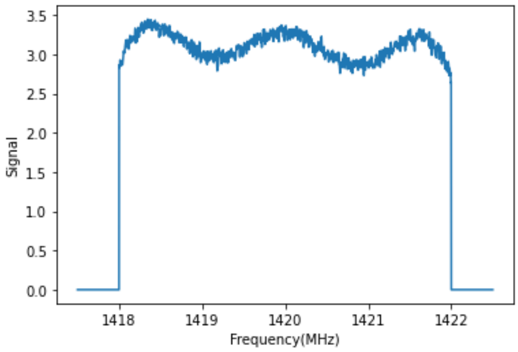

Figure 2.5: Noise signal in the range 1418 MHz to 1422 MHz, detected by the SDR and GNU radio software.

2.6 Scopes of further improvements

The signal which was detected by the detector was purely a noise signal. Supposedly, the expected signal from Milky Way is fainter than the received noise. In order to observe the line, we could improve the circuit to further amplify the noise.

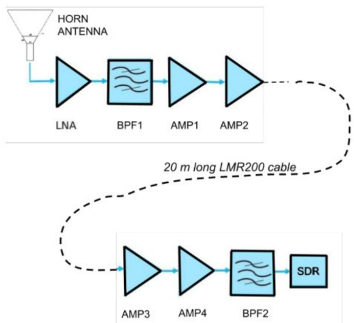

Figure 2.6: Circuit used in *Pandian et. al. (2022)* [5]

- **Adding more amplifiers in series:** The LNA we used could not be added in series with other LNAs, as it actually lowers the signal. However, other amplifiers could be compatible with each other. For example, *Pandian et. al. (2022)* [5] has used Mini-circuits ZX type of LNA and amplifiers in series.
- **SDR and BPF:** The SDR could be improved and another Band pass filter could have been used as in *Pandian et. al. (2022)* [5].
- The part of sky we are intending to observe rises only after 2am/ 3am in the night. That time is really windy and it is necessary for the antenna to remain stable during the observation. Post-cyclone time could be a good time to redo the experiment.

We plan to continue the experiment during this summer when the sky is relatively clear and it is less windy.

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