Open Lab P443-444
Post-midsem Lab report

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Detecting 21 cm H_2 line and Antenna trainer experiments

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Abstract

Post-midsem, we started off with studying various types of antenna on table-top using scientech kit, calculating a number of parameters. Study involved impedance matching using matching stub. Then we move on to detection of 21 cm H_2 line. In the pre-midsem part, we talked about the theory or the origin of the H_2 line. Though we failed to get a signal but it opened many ways for us to try and troubleshoot the issues.

Objective

- **Antenna Trainer experiments**
  To understand and study various antennas, in terms of SWR, Reflection coefficient and Directivity.
- **Detecting 21 cm H_2 line**
  To observe the 21 cm Hydrogen line using Horn antenna.

Antenna Trainer Experiments

Setup elements

The trainer setup consists of:

1. Main unit
2. Transmitting mast
3. Receiving mast
4. RF detector
5. Matching stub

The main unit consists:

1. RF generator
2. Modulation Generator
3. Directional Coupler

Figure 1: Transmitting mast

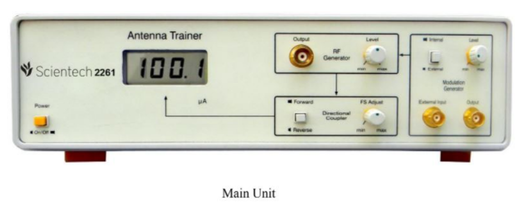

Figure 2: Main unit

RF generator

It sends signal to the transmitting antenna at frequency around 750 MHz. Due to this high frequency the sizes of the antennas are reduced and made suitable for table-top experiments.

Directional coupler

It is a component which allows us to measure forward and backward current separately, which helps in tuning the generator and load resistance.

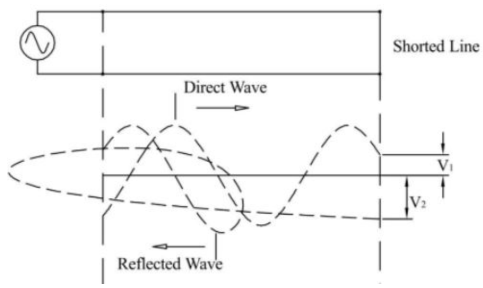

Figure 3: Forward and backward currents

Consider the above circuit which is short circuited. The power supplied by the generator has to go somewhere, but there is no power draining load. So returns back along the transmission line. Now instead of short circuit, we use antenna which dissipates some power to the free space hence acting as a load. In a mismatch condition(impedance mismatch), it will have some reflected power. Hence we will have forward and backward currents corresponding to input and reflected power.

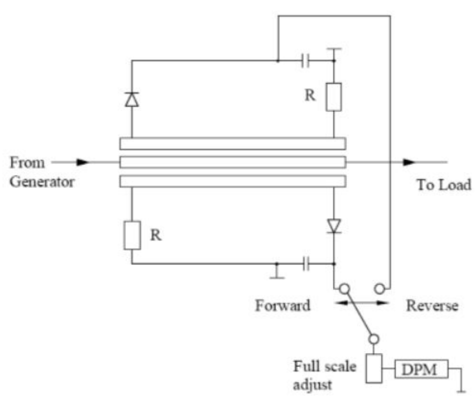

Figure 4: Directional coupler

The above figure demonstrates the circuit of the directional coupler. It has two circuits connected to the main line using line trunks. Both circuits have diodes but connected in opposite fashion. For one circuit, the forward current will create a forward bias and backward current will create forward bias for another circuit, hence we can calculate the two currents separately. We calculate SWR, reflected power and other parameters from the readings.

Matching stub

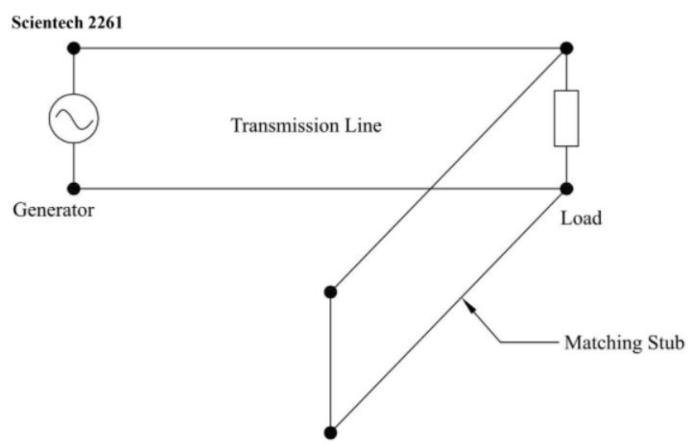

Figure 5: Matching stub circuit

This is a device used to match the load and generator. In our experiment it is connected on one end only and the free end is short circuited. The stub is separated from the load by a distance. This distance is chosen so that the resistive portion of the load impedance is equal to the resistive component of the characteristic impedance at that location due to the main line's impedance transformer operation. The length of the stub is chosen to negate the reactive part of the impedance presented perfectly. That is, depending on whether the main line has an inductive or capacitive impedance, the stub is rendered capacitive or inductive.
In our experiment, we have tried impedance matching using the matching stub but couldn't because of insufficient length. We tried creating a separate circuit for impedance matching, but failed to come up with a suitable arrangement.

Transmitting mast, Receiving mast and RF detector

Transmitting mast has the antenna mounted on it, on a rotatable platform and connected to RF generator. The mast has a Goniometer on the base. It is to measure the rotation of antenna and get polar graph in degrees.
Receiving mast has the receiver antenna, which catches the signal and sends them to RF detector in form of current.
RF detector is used to detect and measure the radiation pattern of the antennas, in the units of μA.

Parameters

Some of the important antenna parameters where discussed in the previous report, like - Directivity, Gain and Standing Wave Ratio. We have computed a few other parameters alongside these:

- **SWR:** If F is forward current and R is reverse current, then,

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

- **Directivity:** Ratio of power density of the antenna in its direction of maximum radiation in 3D space divided by its average power density.

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

- **Gain:** Gain is the product of the antenna efficiency(k) and directivity(D).

$$G = k.D$$

- **Reflection Co-efficient:**

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

- **Reflected power:**

$$\text{Reflected power}(\%) = 100 \times \Gamma^2$$

$$\text{Reflected power}(\text{dB}) = -20 \log \Gamma$$

- **Mismatch loss:**

$$\text{Mismatch loss}(\text{dB}) = -10 \log\left(1-\Gamma^2\right)$$

Results

SWR with different antennas:

Antenna types	Forward Current (μA)	Backward Current (μA)	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: SWR calculation in a few types of antennas(Note: Impedance are not matched)

Antenna types	Γ	Reflected power (%)	Ref.power (dB)	Mismatch loss (dB)
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 2: Continuation of the above table, for reflected power and mismatch loss calculation

We plotted the polar graph manually for the following antennas. The transmitting mast was rotated and the reading was recorded in RF Detector at every 10 degree interval on the Goniometer. Directivity was calculated as ratio of the maximum output intensity(from the RF detector) and radiation intensity averaged over a 2D circle (from the polar graph). The Half-power Beam Width (HPBW) is also calculated from the graph. It was done with a python code uploaded here on GitHub.

Simple $\lambda/4$ dipole:

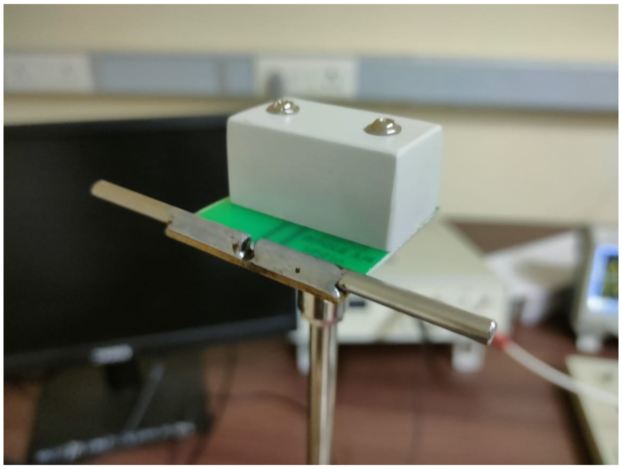

Figure 6: Simple $\lambda/4$ dipole

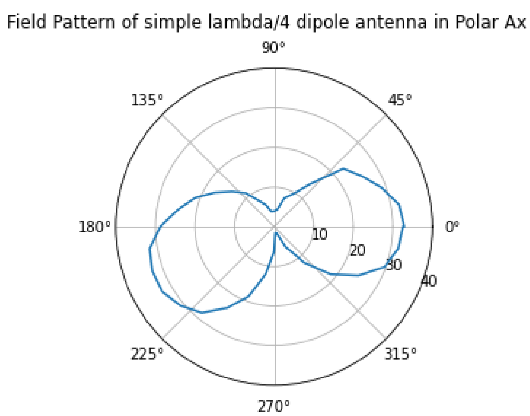

Figure 7: Polar graph

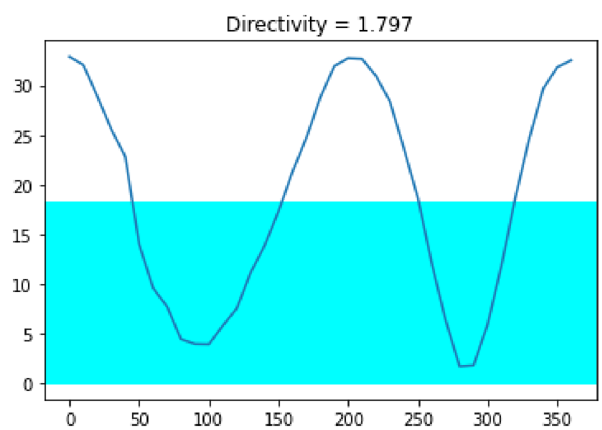

Figure 8: Cartesian graph (Output current vs degrees)

Half-power Beam Width $= 70.7\,\mathrm{deg}$

Simple $\lambda/2$ dipole:

Figure 9: Simple $\lambda/2$ dipole

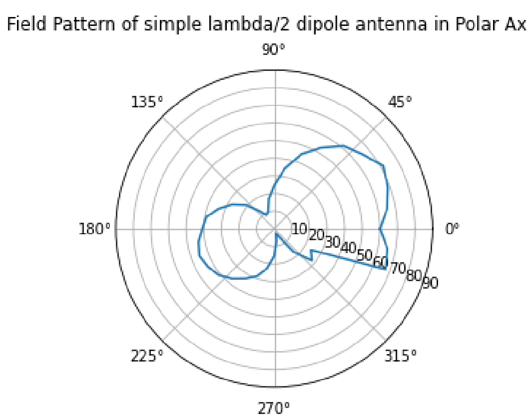

Figure 10: Polar graph

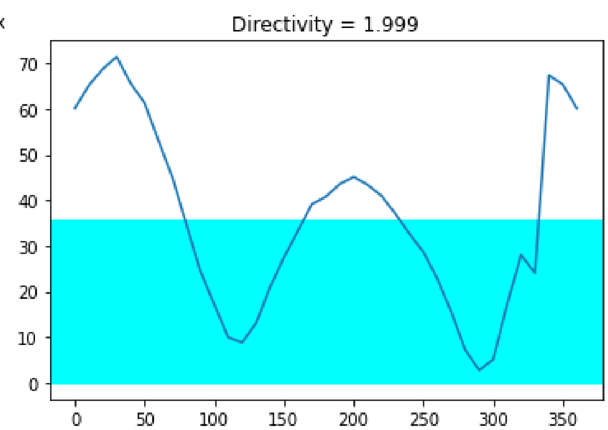

Figure 11: Cartesian graph (Output current vs degrees)

Half-power Beam Width $= 80.21\,\text{deg}$

Half-wave folded dipole:

Figure 12: Half-wave folded dipole

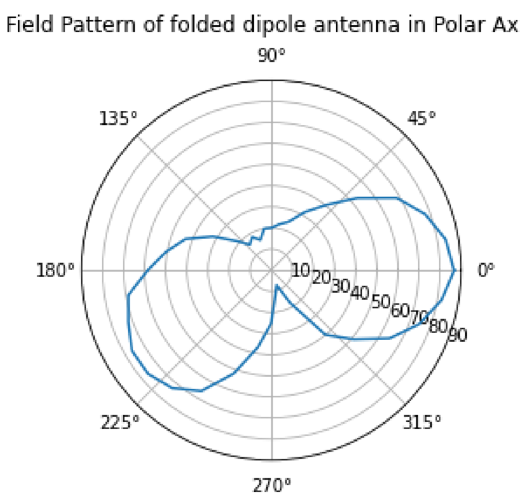

Figure 13: Polar graph

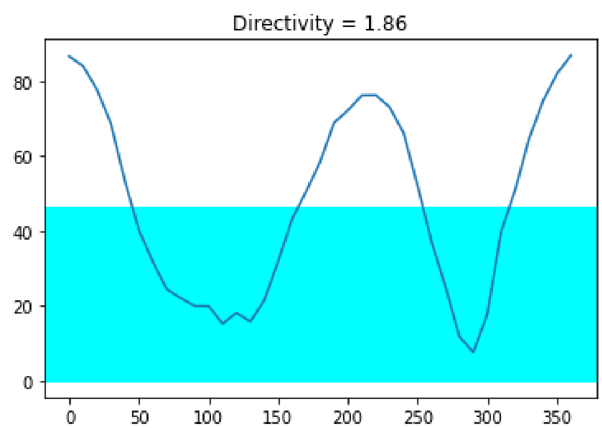

Figure 14: Cartesian graph (Output current vs degrees)

Half-power Beam Width = 66.2 deg

Yagi-Uda folded dipole 3 element:

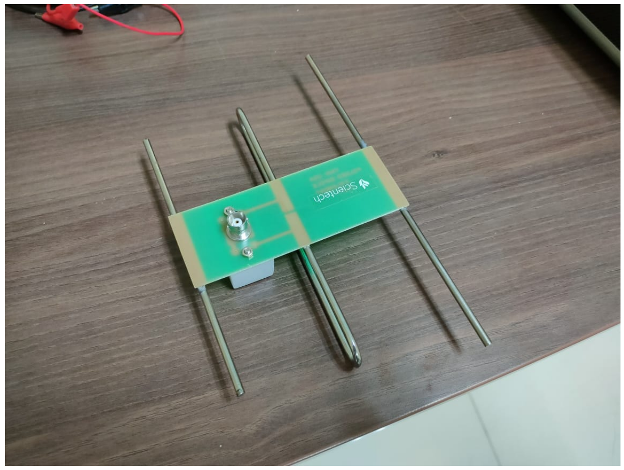

Figure 15: Yagi-Uda folded dipole 3 element

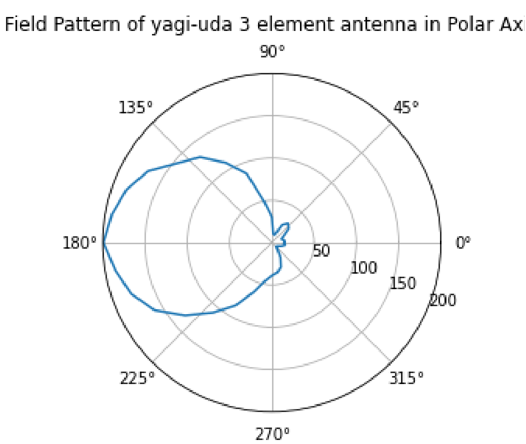

Figure 16: Polar graph

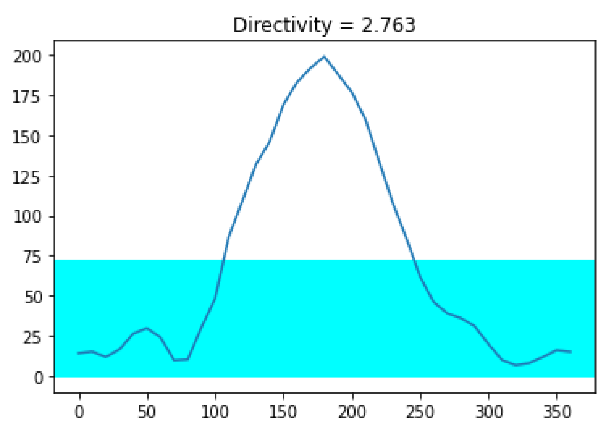

Figure 17: Cartesian graph (Output current vs degrees)

Half-power Beam Width = 81.7 deg

Yagi-Uda simple dipole 5 element:

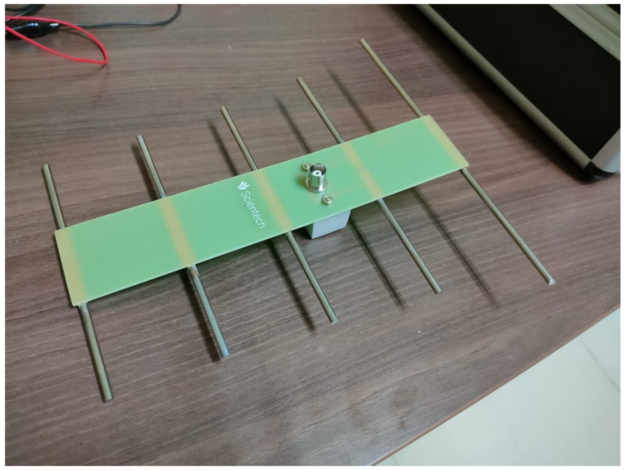

Figure 18: Yagi-Uda simple dipole 5 elemen

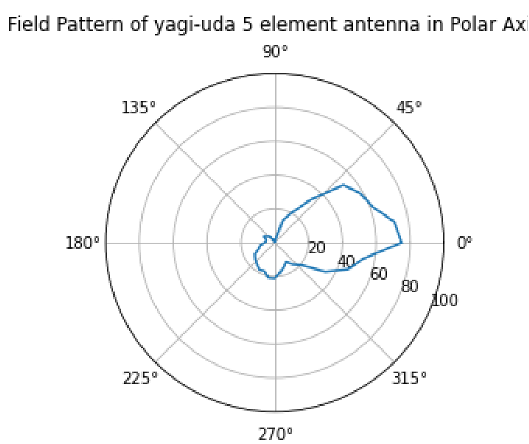

Figure 19: Polar graph

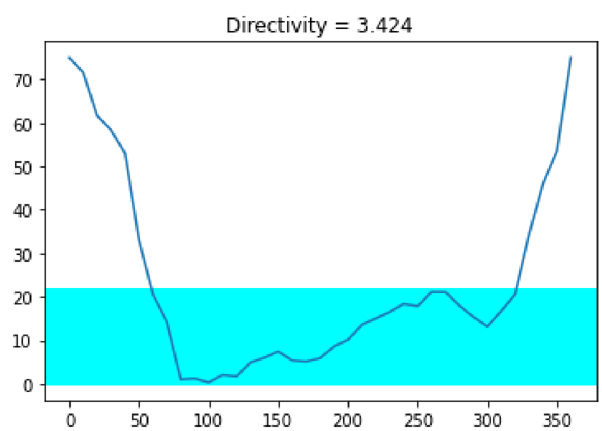

Figure 20: Cartesian graph (Output current vs degrees)

Half-power Beam Width = 48.8 deg

Detection of 21 cm Hydrogen Line

Setup

- Horn antenna
- Telescope mount and tripod
- A Low Noise Amplifier (LNA) (requires 12 V adapter)
- A Band Pass Filter (BPF)
- Software Defined Radio (SDR)

Experiment

Figure 21: Horn Antenna mounted on the tripod

The first step was assembling the circuit. The Horn antenna was set on the tripod, connected to the LNA and BPF, and to SDR. The SDR is connected to the laptop. It converts the analog to digital signal. The digital signal is seen in PC using GNU radio software. We worked with already existing blocks and some new (which is available here). After successful installation of GNU radio, we run spectrometer_w_cal.grc and get no errors.

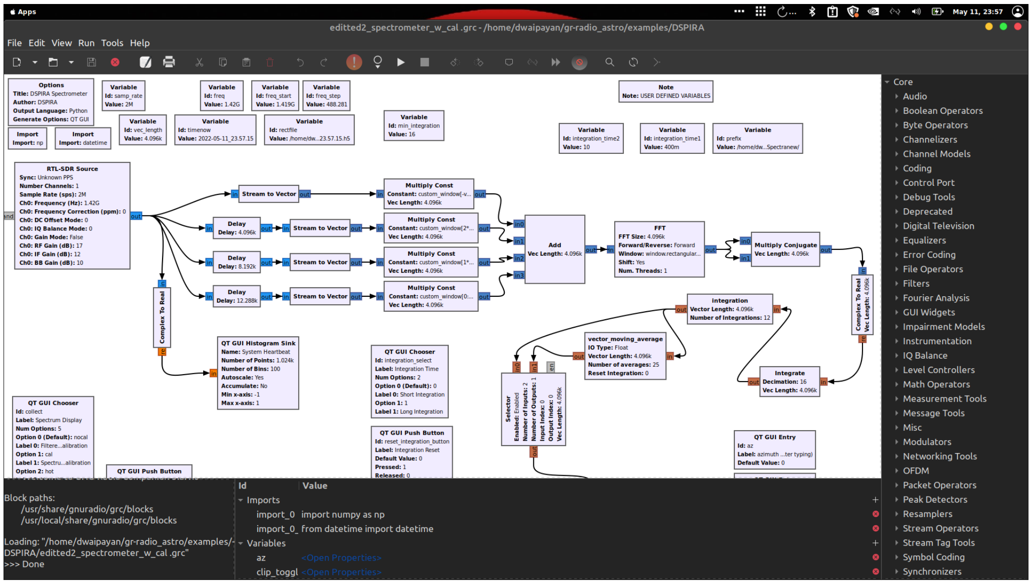

Figure 22: GNU radio companion

The above picture is a screenshot from the software. The .grc file contains various blocks to read the digital feed from the SDR. The first block, RTL-SDR source, reads directly from SDR. In that we can set frequency at which we want to study and the gain we need. We took sample rate to be 2 MHz, this determines how fast the data is updated on the spectrum. The center frequency is 1420 MHz and start frequency is from 1419 MHz.
We used Vector Network Analyser (VNA) to test our setup. We set VNA to emit signal at frequency 1420 MHz at 14.1 dB through a rectangular waveguide (containing dipole).

Figure 23: Vector Network Analyser

After trying a few combinations of LNA and BPF, we managed to get the received signal on the GNU radio companion. We took a few readings to calibrate the readings.

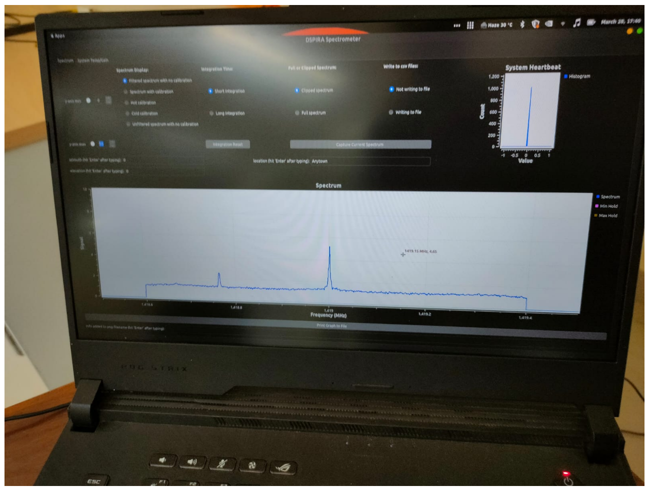

Figure 24: Received signal from Horn antenna

The setup was then carried to animal house terrace. We had to observe 21 cm in the direction of galactic anticenter of Milky Way, Sagittarius (location: RA 05h 46m, dec +28° 56'). But we could not record any signal as it was very faint. The recorded signal in the software is all noise (shown in the figure below), generated from internal components and external factors like wind. The noise is clearly more than the actual faint signal.

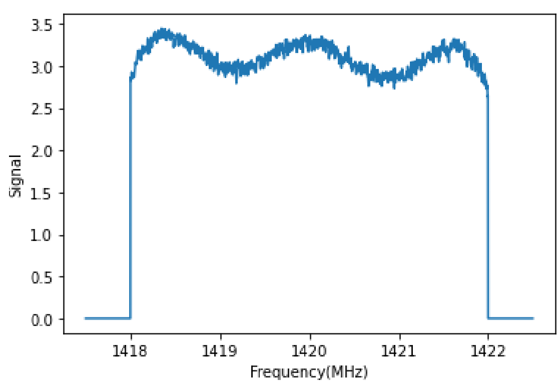

Figure 25: Received signal in GNU radio

Conclusion

There are some possible reasons for not getting signal:

- Something may have gone wrong with the circuit during the transportation. The possible way to fix this is to recheck with VNA to see if its working.

- A reference to a recent paper by Arul Pandian B et al.(5), they have built a working 21cm Radio telescope. They have used one set of low-noise amplifiers (LNA), bandpass filters (BPF1 and BPF2), post amplifiers (AMP1 to AMP4). This is to amplify the very faint signal coming from the galaxy.

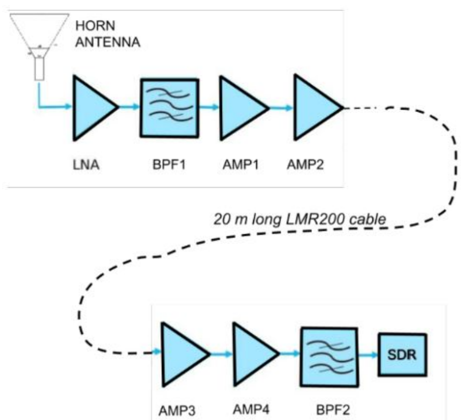

Figure 26: The whole circuit used in the paper

  We have used two LNAs in series but didn't observe any increase in the signal. In future we can use multiple amplifiers to check the signal.

- The time when we observe the galactic anticenter is around 2-3 am, and it is very windy at night. This might have caused some discrepancies in the recording of the signal.

Figure 27:

References

[1] Balanis, C. A. (2015). *Antenna theory: analysis and design*. John wiley & sons.

[Bevelacqua] Bevelacqua, P. J. Antenna theory. `https://www.antenna-theory.com/`. Accessed 2022.

[Bombay] Bombay, I. Antenna theory. `https://nptel.ac.in/courses/`. Accessed 2022.

[4] Orfanidis, S. J. (2002). Electromagnetic waves and antennas.

[5] Pandian, B. A., Ganesh, L., Inbanathan, S., Ragavendra, K., Somashekar, R., and Prabu, T. (2022). Galaxy rotation curve measurements with low cost 21 cm radio telescope. *Sādhanā*, 47(2):1–13.

[RF] RF, N. Return loss to mismatch calculator. `https://northeastrf.com/return-loss-calculator/`. Accessed 2022.

The code is uploaded here on Github.