# Two Element Interferometer with TV antennas observing the transit of the Sun at 10 – 12 GHz


**RADIO ASTRONOMY SUMMER PROGRAM 2022**

**INSTRUMENTATION GROUP**



## Abstract

The aim of this project is to develop a 2- Element Radio Interferometer using 2 similar parabolic dishes separated by a baseline length of 3m. The target under study for this project is the Sun and the frequency focused is in the range of 10 - 12 GHz. The receivers

The output from the dishes is passed through LNBs and Hybrid Networks for processing and correlating the signals. Finally, they are digitized using an Arduino controller and analyzed. This project has been carried out at Gauribidanur Radio Observatory which is located at Gauribidanur Taluka, Karnataka. The block diagram and the components of the Interferometer are explained below.


## Introduction

It was in the experiments of Karl G. Jansky that radio astronomy had its beginnings in the early 1930s. Jansky was an engineer at the Bell Telephone Laboratories and was assigned the problem of studying the direction of arrival of thunderstorm static. In the first results Jansky reported, he identified three groups of static: (1) static from local thunderstorms, (2) static from distant thunderstorms, and (3) "... a steady hiss type static of unknown origin." The third type showed peaks occurring in 20-min intervals as the antenna beam swept through the plane of our galaxy. Finally one discovered that the signal actually came from the center of the Milky Way. Shortly after that one also realized that the sun was a strong radio wave emitting object too.

Grote Reber, another pioneer of radio astronomy, did very significant work in repeating Jansky's work and conducting the first sky survey in the radio frequencies. After World War II substantial improvements in radio astronomy technology were made especially in Europe, the United States, and Australia, and the field of radio astronomy began to blossom. One of the most notable developments came in 1946 with the introduction of radio interferometry. An interferometer out of radio telescopes is used to reach a higher angular resolution such that pictures of closely situated or spatially broad radio sources get a higher resolution. The signals from all radio telescopes are then brought together and superimposed and can then be evaluated by Fourier transformation. The following work would be to demonstrate the interferometry using 2 elements for which one needs two telescopes or as in the case of this work two TV antennas, which obviously receive radio waves in the Ku Band. The entire setup was assembled at the Gauribidanur Radio Observatory workshop and the experiment was conducted at the same location in an appropriate area which allowed us to have a clear measurement of the Sun transit at Zenith.

For observing a moving object in the sky, such as the sun, one can either follow it, i.e. the telescopes move and are always directed towards the object, or one can stay fixed on a point of its path - mostly the highest point above the horizon. In this experiment the second possibility was used which expects an interferometer pattern that changes in intensity, rising when the object is moving towards the point the telescopes are fixed on and decreasing when moving away, to achieve this the 2 Dishes needed to be mounted exactly in the east-west axis in order to simplify the interpretation of the data and required a fixed baseline i.e, the distance between the two dishes should remain constant.  Keeping this in mind a mount was assembled() and was given a degree of freedom to change its elevation by + or – 15 degrees with respect to the horizon, This was done to increase the no. of measurements for the transit by the Sun.  The report further presents a detailed construction and working for the receivers() shown in the block diagram(). The specifications and experiments conducted to test each component individually have been discussed in detail().

With these interferometer patterns, one is able to draw conclusions about the size of the object and the length of the baseline on which the telescopes are situated(). Finally, the shortcomings in the experiments performed are explained in the conclusions() and how one can possibly improvise and ……in a better fashion is discussed thoroughly in the Future Scope of the report.

# Theory

An Interferometer or an Interferometer array combines the data from many small antennas to produce results that are, in part, equivalent to those from a large single antenna, using correlation techniques(Burke). Interferometry has proven to be crucial in attaining high angular and spectral resolution for certain classes of observation, particularly in mapping at radio frequencies and measuring the angular sizes of stars. In this experiment, the Sun was observed with a two-element interferometer and in the following, a brief section shall introduce the theory.

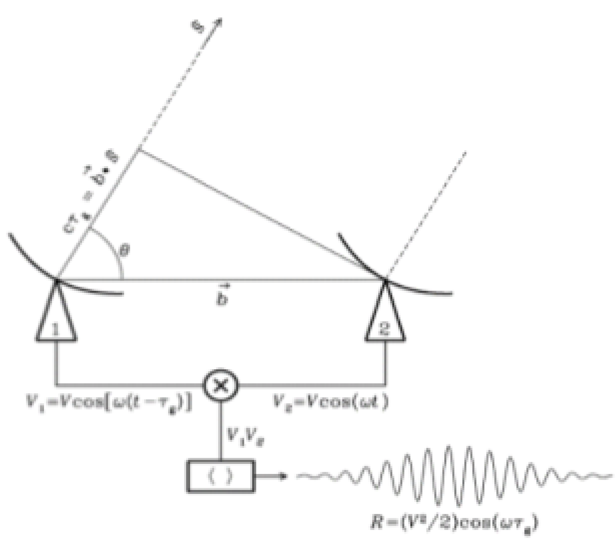



*Figure :Geometry of the two-element interferometer*

The interferometer constructed is a simple adding interferometer where we do not correct for the phase delay between 2 antennas. The Figure 1 above illustrates a simple two-element interferometer, where *b* is the length of the baseline θ is the angle between the baseline and the wavefront from the source. Assuming one had a point source and monochromatic radiation of wavelength λ the voltage at the two antennas would be:

$$v_A = E_0 e^{i(\omega t - \Theta)}$$

*( 1)*

$$v_B = E_0 e^{i\omega t}$$

*( 2)*

Where, $\Theta = \frac{2\pi\Delta s}{\lambda} = \frac{2\pi \sin sin\,(\phi) b}{\lambda}$ is the phase difference. The two antenna signals are first added, then quadratically detected and fed through the integrator with the integration time τ. In the case of the experiment, square law detectors were used. For the output voltage $V_R$ one gets:

$$V_R \,\alpha\, s = \frac{1}{\tau}\int_0^{\tau}\left(v_A(t) + v_B(t)\right)\cdot\left(v_A(t) + v_B(t)\right)^* dt$$

*( 3)*

From ( 1),( 2) and ( 3) we get ,

$$V_R = 2E_0^2\left(1 + \cos cos\left(2\pi \sin sin\,(\theta)\frac{b}{\lambda}\right)\right)$$

*( 4)*

Therefore, the output voltage depends on θ and we get a interferometer pattern which looks like the

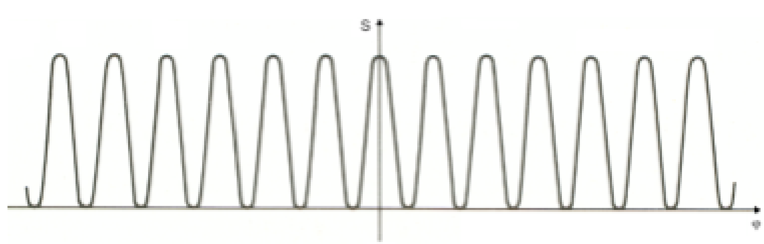
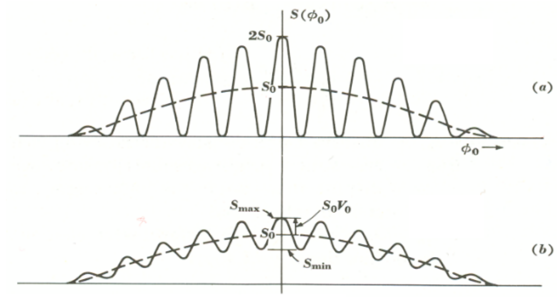



*Figure : Interferometer pattern*

But this is only the case if the antennas track the source. When the antennas are fixed to one point in the sky, hence a transit instrument, the interferometer pattern will be as shown in Figure 3. Since in this experiment the sun will be observed, an interferometer pattern such as (b) is expected.




The values indicated in (b) enable the calculation of the visibility function and consequential the angular size of the sun.

# 1 Experimental Work

In this section, the overall assembly of the interferometer is explained in detail. Before the Interferometer was ready to take observations it was necessary to check individual components and if they are maintaining its characteristics for the required bandwidth. The working of each component in the setup has also been discussed in this section.

## 1.1 Setup

The aim of this project is to develop a 2- Element Radio Interferometer using 2 similar parabolic Dishes separated by a baseline length of 3 m. The target under study for this project is the Sun and the frequency focused is in the range of 1 - 2 GHz. The output from the dishes is passed through LNBs and Hybrid Networks for processing and correlating the signals. Finally, they are digitized using an Arduino controller and analyzed.

### 1.1.1 Components Required

| Component | Specification |
|---|---|
| Two Similar Parabolic Dishes | NA |
| Low Noise Block Converter (LNBC) | • Input - 10.70 - 12 GHz<br>• Noise - 0.1dB<br>• O/P Gain - 60dB |
| RF Amplifiers | Gain of Amp_1 = 30 dB<br>Gain of Amp_2 = 15 dB |
| Half Wave Hybrid Network | NA |
| Square Wave Detector | NA |
| Operational Amplifiers | NA |
| Arduino - ADC | Arduino uno - 10 bit adc |

*Table 1*

### 1.1.2 Block Diagram

The entire setup can be outlined in the form of a block diagram given below,

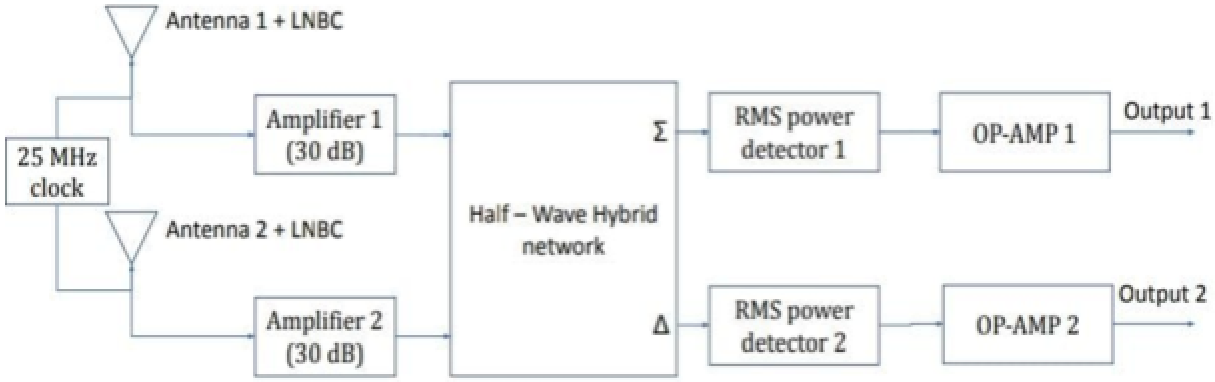



*Figure : The Block Diagram of the Interferometer setup*

***1. LNBC***

A **Low-Noise Block** (**LNB**) is the receiving device mounted on satellite dishes to collect radio waves from the dish and convert them to a signal which is sent to the receiver unit. The LNB is a combination of a low-noise amplifier, frequency mixer, local oscillator, and intermediate frequency (IF) amplifier. The specification of the LNB used is given below. To make sure that they actually receive in the expected range, they were measured with the spectrum-Analyser and confirmed that there is good reception. The measurements for both antennas are shown in ()

- Input - 10.70 - 12 GHz
- Noise - 0.1dB
- O/P Gain - 60dBtest results)

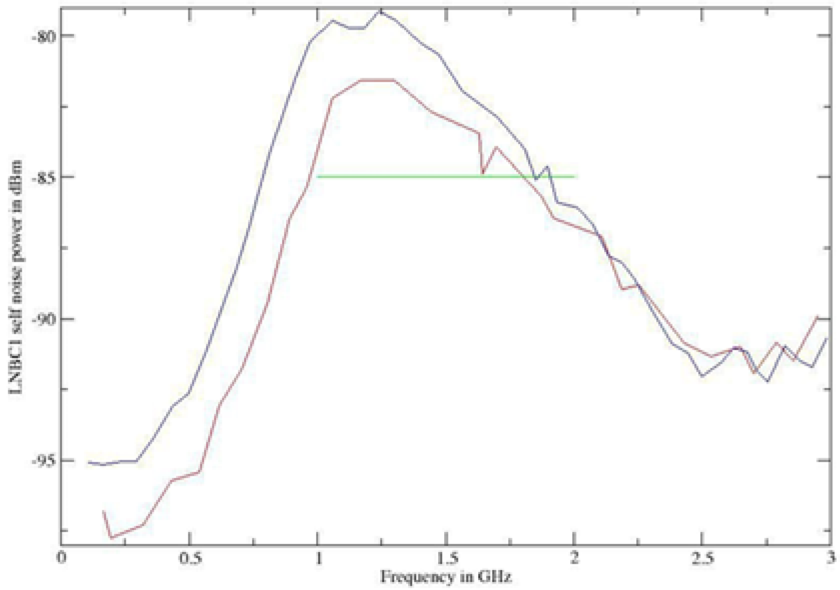


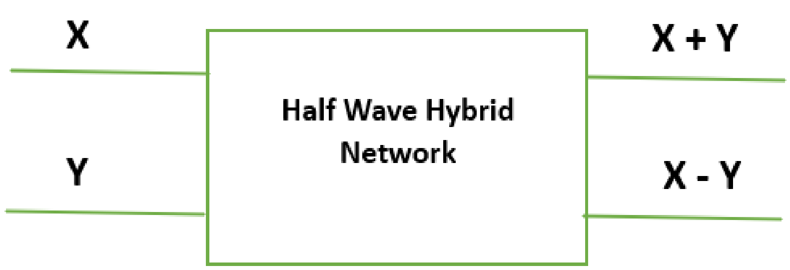

*Figure 6: Performance of both the LNBC's*

***2. RF Amplifiers***

RF Amplifiers are used here to convert the low-power radio frequency signals received from the LNB to high-power signals for better processing. The gain of both the amplifiers used is 30 dB each however during the testing one of the amplifiers wasn't functioning so it was replaced by a 15dB amplifier, the testing for each has been written in detail in () ().

***3. Half Wave Hybrid Network***

The Half Wave Hybrid Network is used for the purpose of correlation. The output from the 2 Amplifiers is given to the 2 input ports of the Hybrid Network (X and Y respectively). The 2 output ports namely Σ and Δ carry the operation (X+Y) and (X-Y).




The S – Parameters of the Half Wave Hybrid Network using the Field Fox Portable Vector Network Analyzer to study the transmission and reflection coefficients of the Hybrid Network.

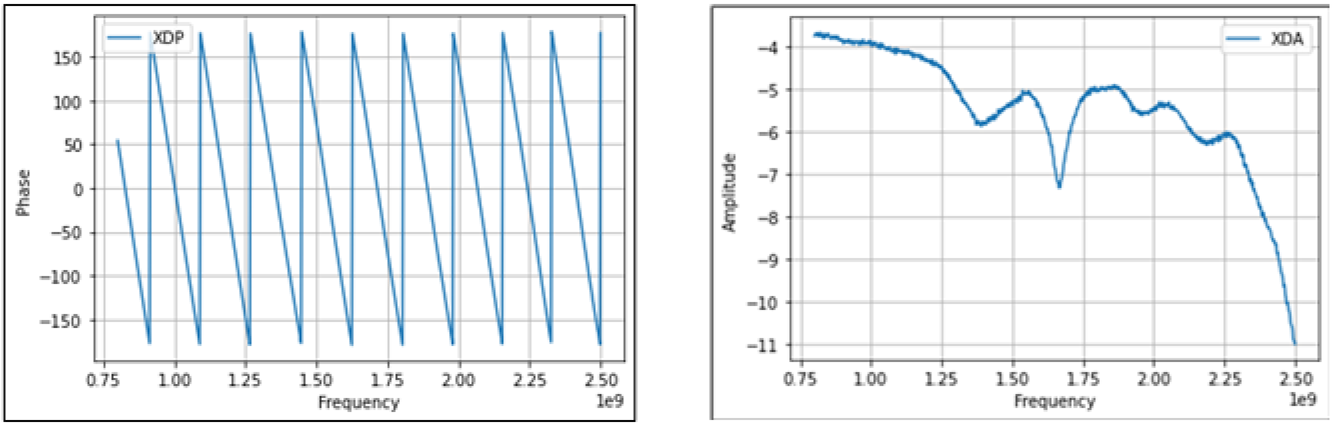



*Figure 7: Amplitude and Phase of $S_{21}$ of 'X' Input Port and 'X – Y' Output Port*

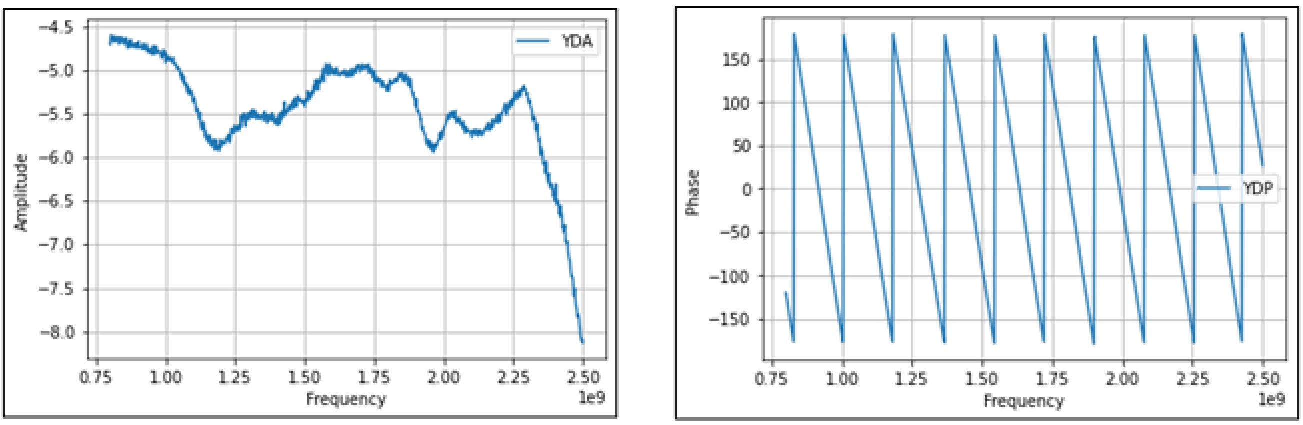



*Figure 8: Amplitude and Phase of $S_{21}$ of 'Y' Input Port and 'X – Y' Output Port*

***4. Square Wave Detector***

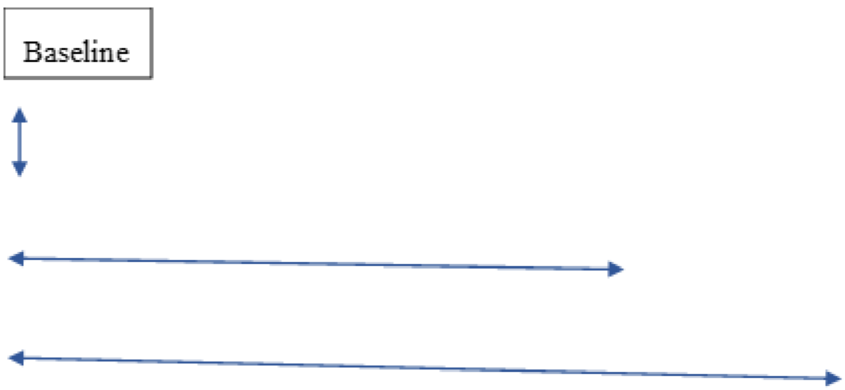
The output from Hybrid Network is then passed through a Square Wave Detector which produces an output that is proportional to the input power i.e., a voltage proportional to the square of the voltage input from both the terminals of the Hybrid network thus, yielding us the outputs $(X + Y)^2$ *and* $(X - Y)^2$.

***5. Arduino UNO***

The final output from Square Wave Detectors is connected to Arduino where the signals are sampled and visualized. The two outputs $(X + Y)^2$ *and* $(X - Y)^2$ are then subtracted resulting in 4XY which is the correlation of 2 signals. Arduino has a 10-bit analog to digital converter which is important for this process.

### 1.1.3 Construction of the Mount

To stabilize and maintain the antennas at a particular angle we constructed a mount. The mount was made with a pivot which allowed a 15 degrees elevation adjustment with respect to the zenith.

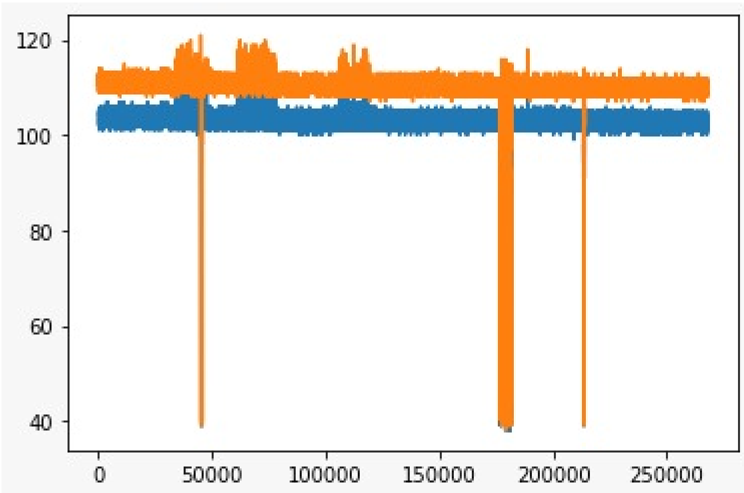


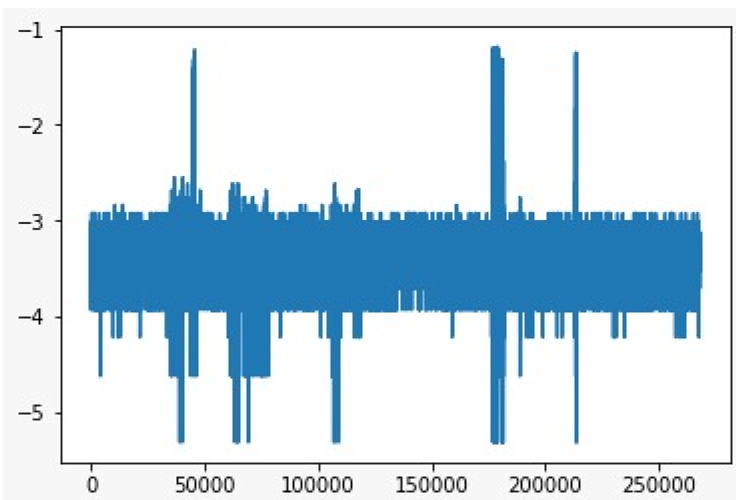

The mount base was made like a rail so that one can adjust the baseline and see the effects of change in results with increase or decrease in baseline. A pivot was made, and both the antennas were joined by a common support which was essential in maintaining a similar motion of both antennas by equal angle.
To make the measurements for the transit of the sun, it was required that we kept the setup aligned exactly parallel to the east to west axis so that during local noon or along the trajectory of the sun we get maximum flux.Antennas could only move to about 15 degrees with respect to the zenith as any angle more than that could disturb the parallel setup.

### 3.1.5 Results

The output of a dual element radio interferometer is a graph between power vs time signal which has been digitalized using arduino uno.
The power spectrum shows power as the mean squared amplitude frequency line .

**GRAPH -**




This above graph is a plot of sum and difference vs time because the signal was very minimal and the noise from the 10bit ADC of the arduino and the lack of programming delays , a lot of noise was added .
So, we didn't get expected graph output.

To mitigate these issues we can -

1) Adding two op-amps at the end of respective square law detectors.
2) While programming use the Delay() function .

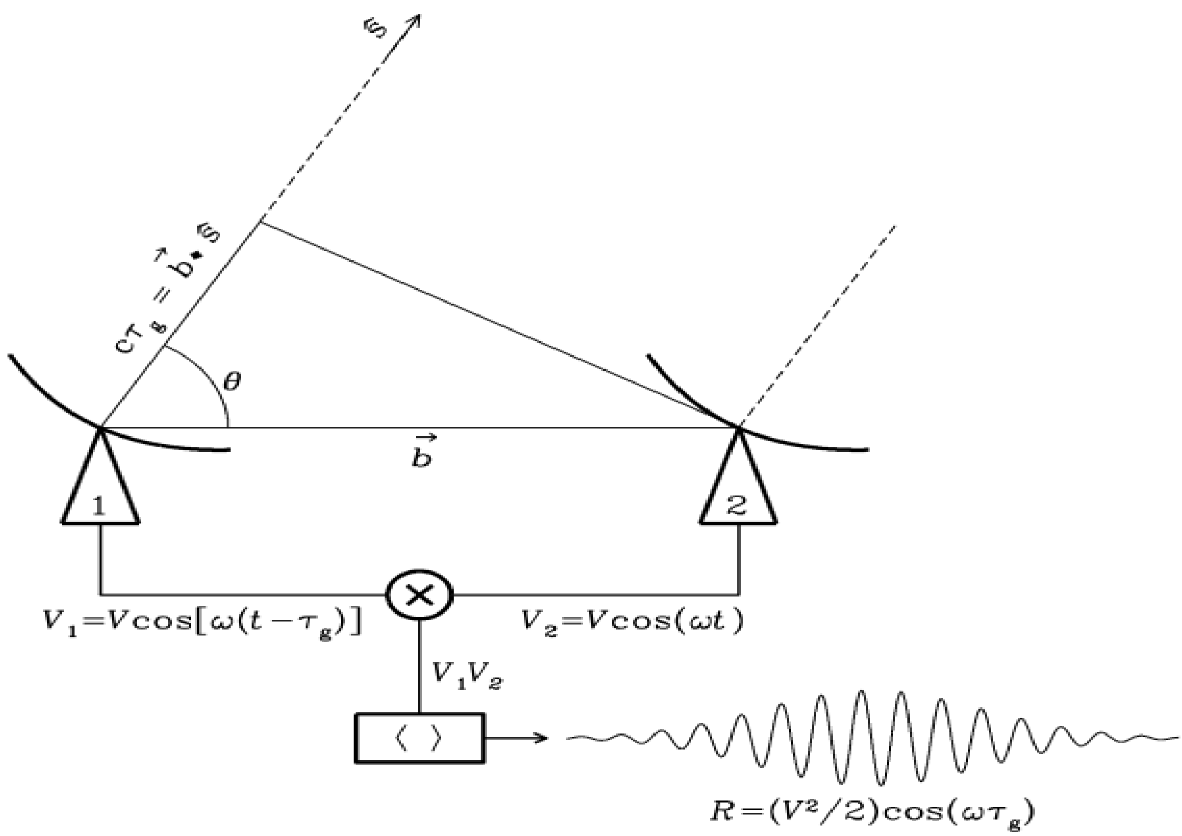
Arduino has 10 bit ADC and it takes 13 cycles to convert the data into digital form from analog form , 1 cycle takes 6.25 x 10^-8 sec .
13 clock cycles will take 8.125 x 10^-7 sec to convert and therefore frequency = 1/time period .
So, the sampling frequency is 1.23mhz.
To the following issue the delay function used should be set at least at 1 millisecond or if possible millis() function can be used which doesn't come inbuilt .

The sampling theorem tells us that the output frequency should be at least twice of the sampling frequency for accurate measurement ,
So at least 2.4 mhz .

Note - The time of observation was from 12:15 - 12:45 pm at Gauribidanur observatory.

## REFERENCE-


1. *Amy Tikkanen*. Radio Interferometer, Astronomical Instrument, Britannica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