# Implementation of FMCW Radar using GNU Radio

AMRITA VISHWA VIDYAPEETHAM | School of Engineering
Bengaluru Campus

# Team Guide :

Dr. Parul Mathur

Assistant Professor(Sr.Gr.)

# Team Members :

Bhimarasetti Karthik - BL.EN.U4ECE18021
Bhimavarapu Gautham Reddy - BL.EN.U4ECE18022
Dachepalli Manikanta - BL.EN.U4ECE18032

# Aim of the project

- Implementation of FMCW Radar
  - Generation  of Chirp Signal
  - Detecting the received signal
  - Finding the Beat frequency
    - Single Object Detection
    - Double Object Detection
  - Finding Doppler Frequency
  - Post processing analysis  in python

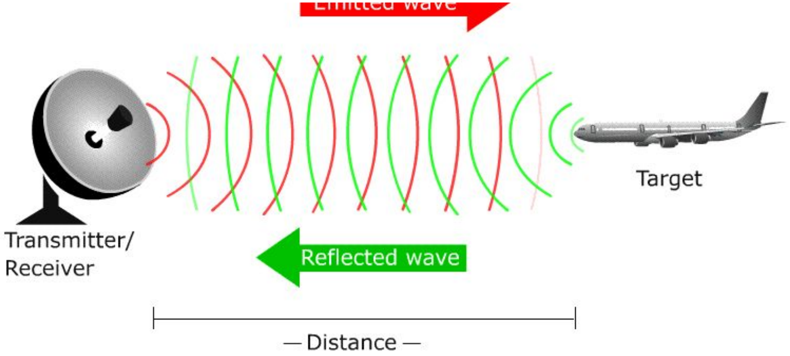
# Table of Contents

- Introduction
  - Radar
- Literature survey
- Block Diagram
- GNU radio Simulation Block Diagrams
- Results
- References

# INTRODUCTION

# RADAR

- RADAR is an acronym for Radio Detection And Ranging
- It is basically an electromagnetic system used to detect the location and distance of an object from the point where the Radar is placed.
- It works by radiating energy into space and monitoring the echo or reflected signal from the objects.
- It operates in the UHF and microwave range.




Applications:

- Military
- Aircraft rout and Air Traffic Controller
- Automobiles

Ref :- Bhatta, Niraj & Geethapriya, M. (2016). “RADAR and its Applications”, Conference: International Conference on Novel Issues and Challenges in Science & Engineering', NICSE'16At: Noorul Islam University, Kumaracoil, Thuckalay, Tamilnadu, IndiaVolume: IJCTA, 9(28), 2016, pp. 1-9

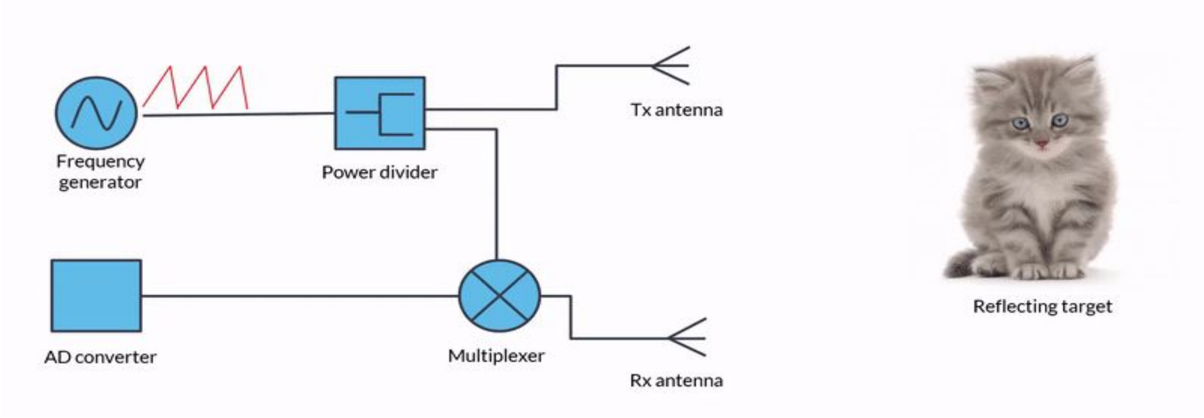
# CW RADAR(Continuous wave Radar)

- ❖ It is a Radar system which transmits and receives a fixed frequency continuous wave
- ❖ Advantages :-
  - ➢It is simple, inexpensive, easy to maintain, and fully automated
  - ➢It needs low power and is compact in size
- ❖ Drawbacks :-
  - ➢We cannot determine the range of the target using CW Radar
  - ➢When there is a number of targets there is a probability of ambiguity

Ref :- Bhatta, Niraj & Geethapriya, M. (2016). “RADAR and its Applications”, Conference: International Conference on Novel Issues and Challenges in Science & Engineering', NICSE'16At: Noorul Islam University, Kumaracoil, Thuckalay, Tamilnadu, IndiaVolume: IJCTA, 9(28), 2016, pp. 1-9

# FMCW RADAR

- FMCW Radar is known as Frequency modulated continuous wave radar
- FMCW Radar transmits a continuous carrier, which is modulated by a periodic sawtooth or triangular wave to provide range data.



# FMCW RADAR ( Advantages )

- Superior range resolution.
- Measures target range and velocity simultaneously.
- Robust data is produced.
- Lower power consumption.

*Ref :-* Sundaresan S, Anjana C, T. Zacharia and Gandhiraj R, "Real time implementation of FMCW radar for target detection using GNU radio and USRP," 2015 International Conference on Communications and Signal Processing (ICCSP), 2015, pp. 1530-1534.

# Literature Survey

- Real time implementation of FMCW radar for target detection using GNU radio and USRP (Base paper) :-

  In this paper, SDR based FMCW radar for target detection and air traffic control radar application is implemented in real time. The FMCW radar model is implemented using open source software and hardware. GNU Radio is utilized for software part of the radar and USRP (Universal Software Radio Peripheral) N210 for hardware part.

  Ref :- Sundaresan S, Anjana C, T. Zacharia and Gandhiraj R, "Real time implementation of FMCW radar for target detection using GNU radio and USRP," 2015 International Conference on Communications and Signal Processing (ICCSP), 2015, pp. 1530-1534.

- Modified FMCW system for non-contact sensing of human respiration :-

  In this paper, the modification on FMCW system was proposed for obtaining the capability in detecting the human respiration and its distance from the radar. The main aim of the paper is to develop a non-contact sensor for human respiration based on radar systems

  Ref :- Aloysius Adya Pramudita, Fiky Y. Suratman & Dharu Arseno (2020): "Modified FMCW system for non-contact sensing of human respiration", Journal of Medical Engineering & Technology,Volume 44 , May 2020

# Literature Survey

- FMCW radar implemented with GNU Radio Companion :-

  In this paper, the FMCW radar is implemented by means of the software GNU Radio Companion with a test signal.

  Ref :- Q. Zhu and Y. Wang, “FMCW radar implemented with GNU Radio Companion”, Dissertation, 2016

- Signal Expansion Method in Indoor FMCW Radar Systems for Improving Range Resolution :-

  In this paper, the range resolution is improved beyond the limited modulation bandwidth by extending the beat frequency signal in the time domain through the proposed algorithms which are verified through the MATLAB tool and actual FMCW radar.

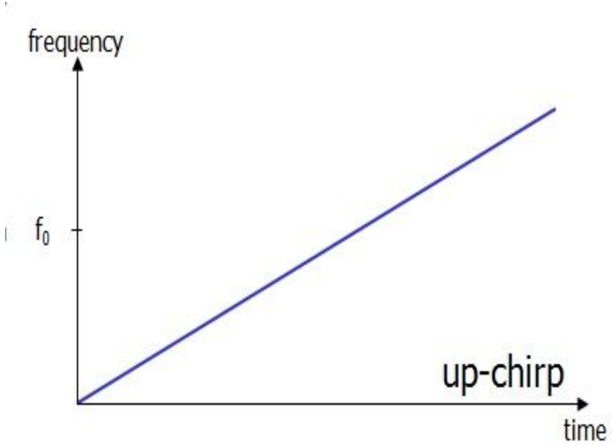
  Ref :- Baek, S.; Jung, Y.; Lee, S. “Signal Expansion Method in Indoor FMCW Radar Systems for Improving Range Resolution”. Sensors 2021, 21, 4226.

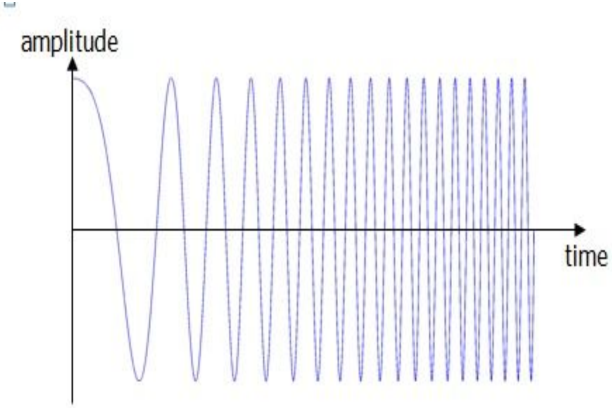
# Objectives:

- Generation of chirp signal
- Single Object Detection
- Double Object Detection
- Moving Object Detection

# Chirp Signal

- A **chirp** is a signal in which the frequency increases (*up-chirp*) with time.




Bandwidth of the chirp signal : 10MHz
Time period of the chirp signal : 50u sec
Sampling rate : 60M samples

# Beat frequency

❖ For an up-sweep FMCW signal, the beat frequency is Ft – Fr. In this expression, Ft is the transmitted signal's carrier frequency, and Fr is the received signal's carrier frequency.

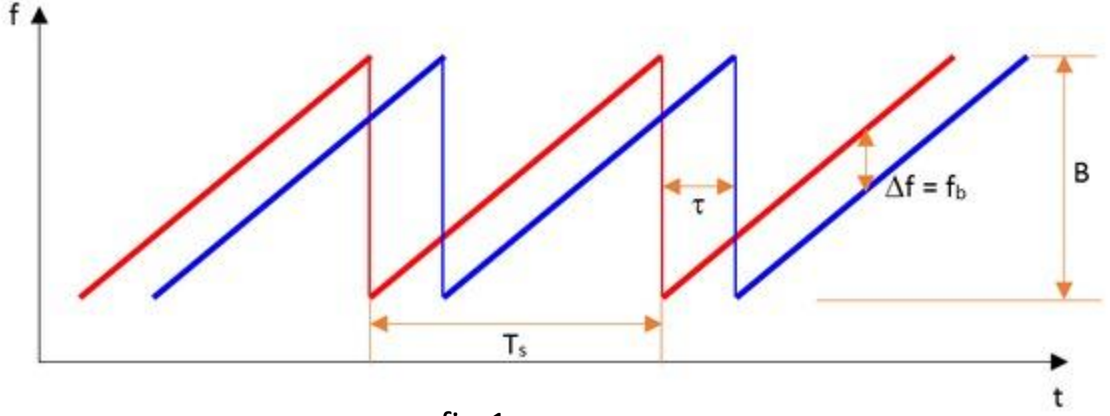



fig-1

In fig-1 Δf is the Beat frequency, **T** is the propagation delay, Ts is the sweep time

# Mathematical Interpretation

- The propagation delay is given by

$$\tau = 2R/C$$

*Where* τ= Propagation delay

*R= Range of the target*

*C= Speed of light ( 3 x 10^8 m/sec)*

- . FMCW radar range resolution is given by

$$\Delta R = C/2B$$

Where ΔR = range resolution of radar

*C= Speed of light ( 3 x 10^8 m/sec)*

*B= Bandwidth of the Chirp signal*

*Ref :-* Sundaresan S, Anjana C, T. Zacharia and Gandhiraj R, "Real time implementation of FMCW radar for target detection using GNU radio and USRP," 2015 International Conference on Communications and Signal Processing (ICCSP), 2015, pp. 1530-1534.

# Mathematical Interpretation

- The range of the target of FMCW radar is given by

$$r = C\Delta f T / 2B$$

Where r =range of the object

$\Delta f$ = Beat Frequency

T = Time period of the chirp signal

B = *Bandwidth of the Chirp signal*

*Ref :*- Sundaresan S, Anjana C, T. Zacharia and Gandhiraj R, "Real time implementation of FMCW radar for target detection using GNU radio and USRP," 2015 International Conference on Communications and Signal Processing (ICCSP), 2015, pp. 1530-1534.

# Mathematical Interpretation

- Doppler frequency of FMCW radar is given by

$$fd=(2Vrf)/C$$

Where *fd= Doppler frequency*

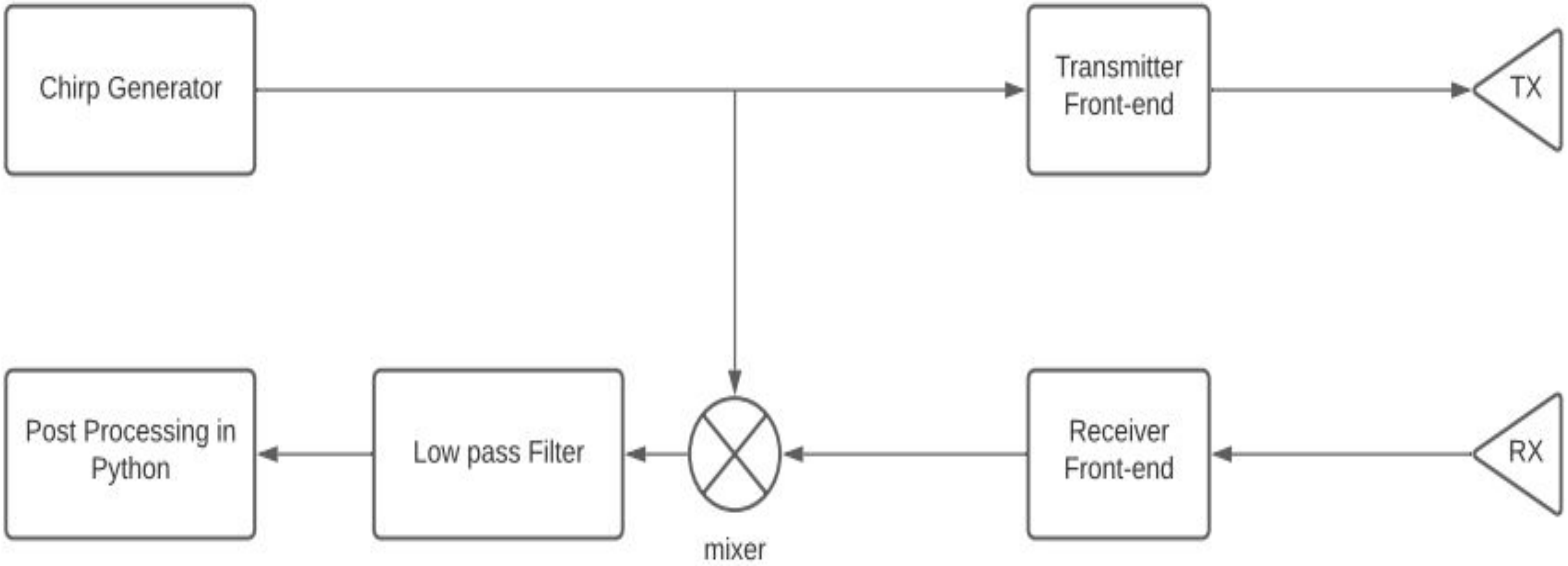
*Vr= Relative Velocity*

*f = frequency of the transmitted signal*

*Ref :-* Wolff, Dipl.-Ing. (FH) Christian. "Radar Basics". *radartutorial.eu*. Retrieved 14 April 2018.

# BLOCK DIAGRAM

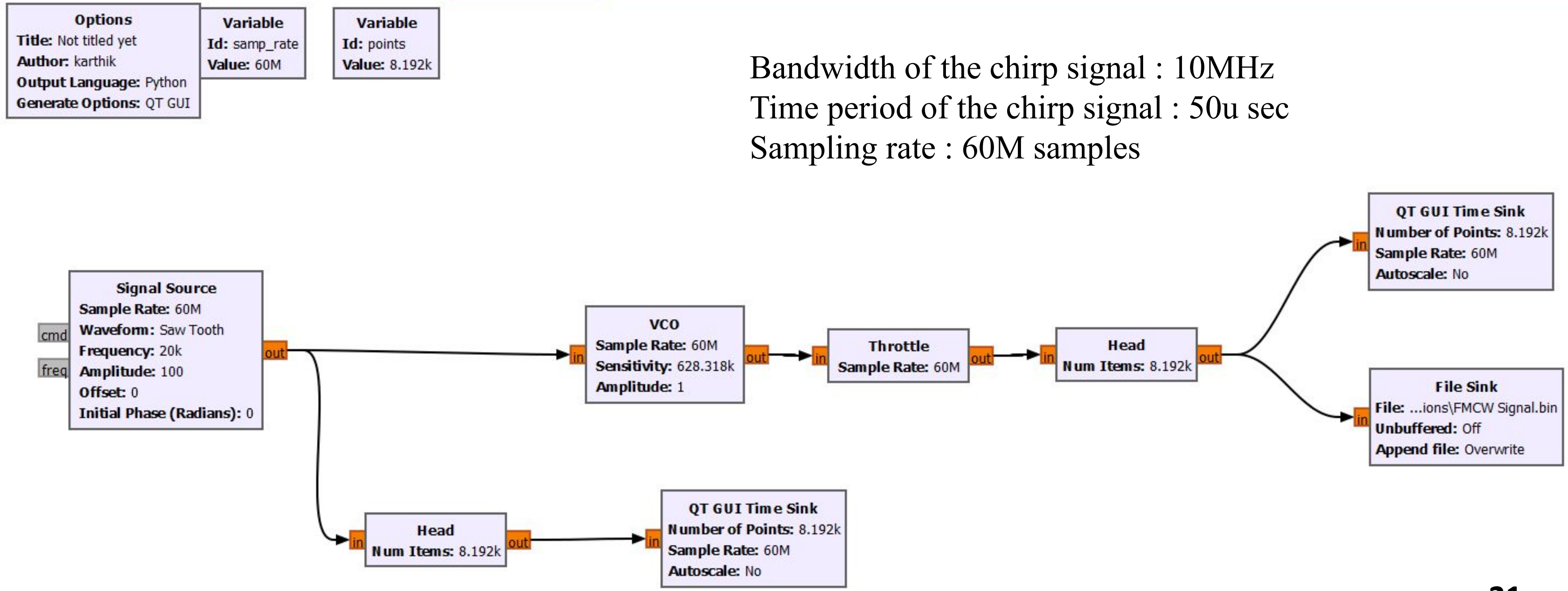
# BLOCK DIAGRAM



# GNU Radio Simulation

# Chirp Signal

## Block Diagram :-




Bandwidth of the chirp signal : 10MHz
Time period of the chirp signal : 50u sec
Sampling rate : 60M samples

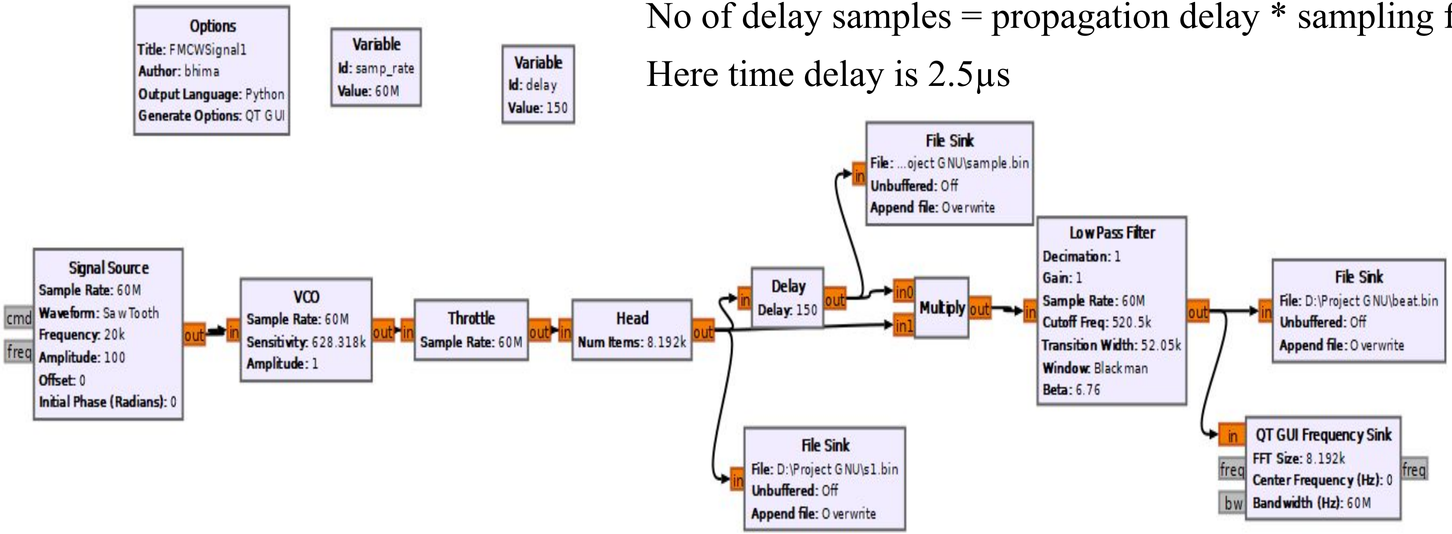
# Single object detection

## Block Diagram :-

Delay block specifies to the corresponding time delay  as follows

No of delay samples = propagation delay * sampling frequency

Here time delay is 2.5μs

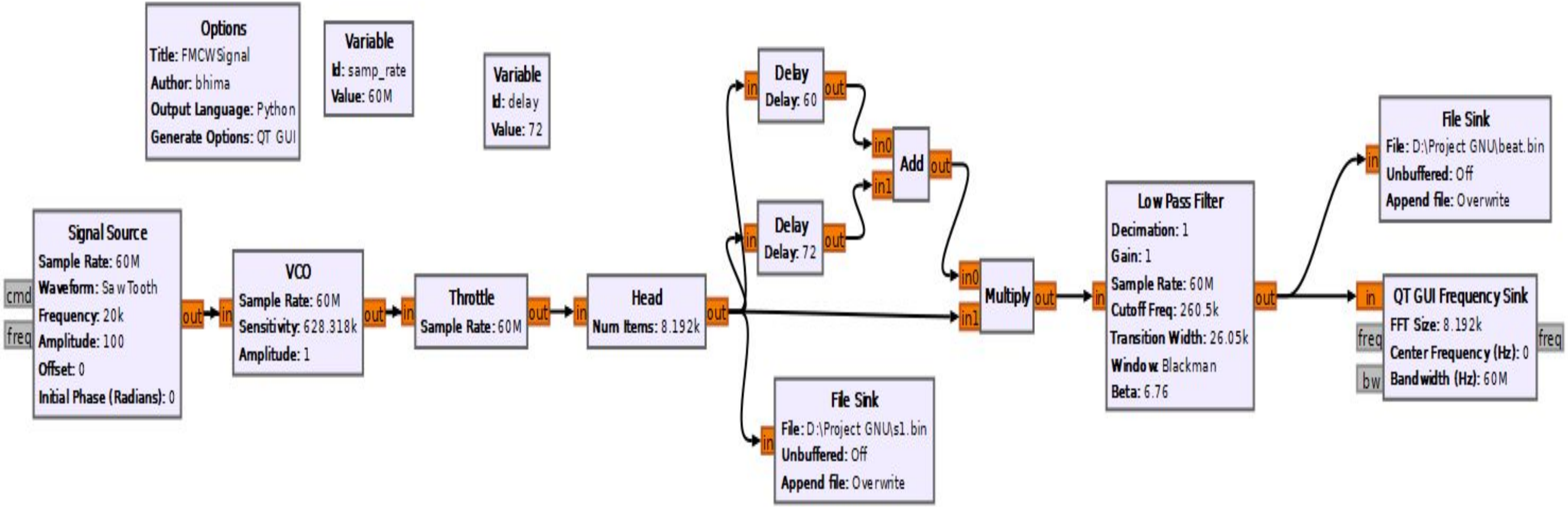


# Double Object Detection

## Block Diagram :

-

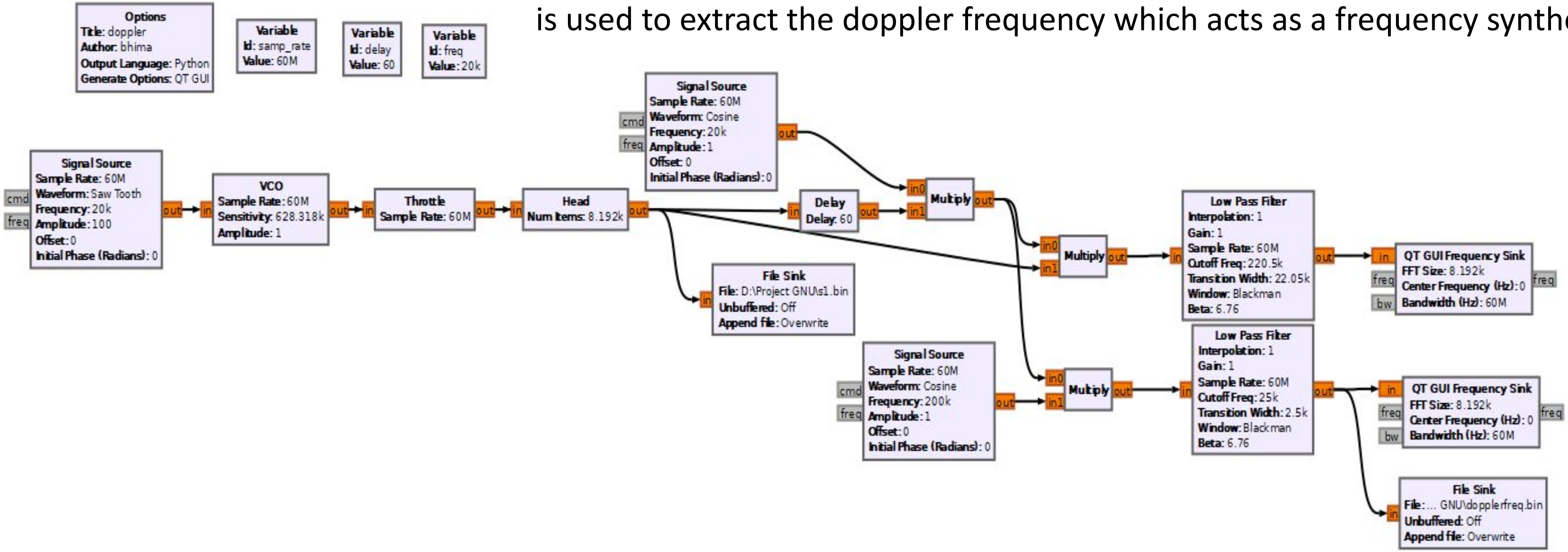
Two delays represent the presence of 2 objects and multiply block represents the mixer where the transmitted and received signals get mixed



# Moving Object Detection

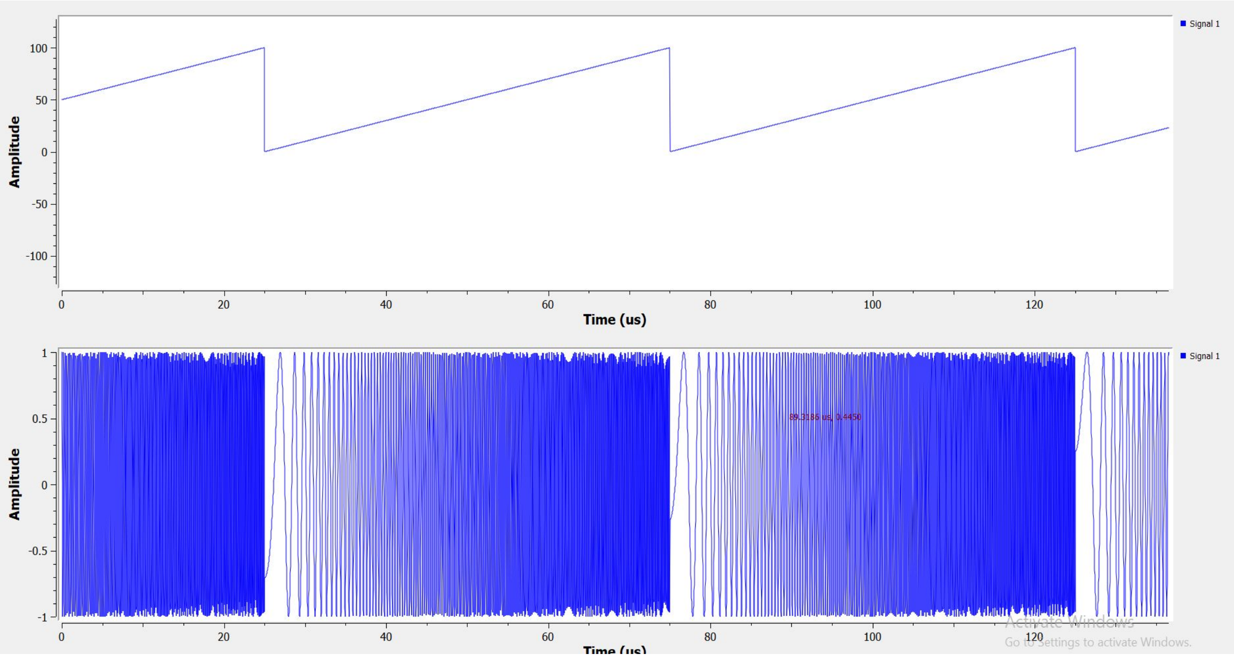
## Block Diagram:-

Here cosine wave source is used to add the Doppler Shift, other signal source is used to extract the doppler frequency which acts as a frequency synthesizer



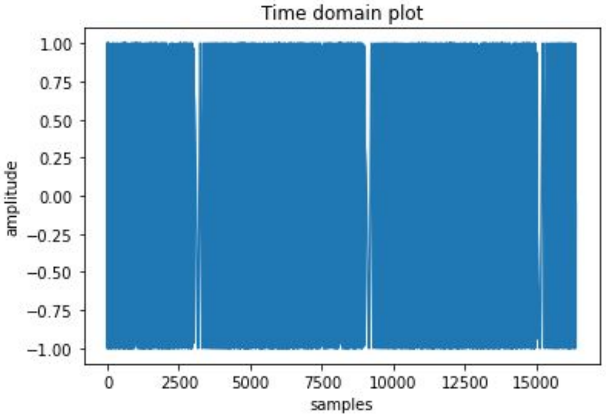
# Results

# Chirp Signal(GNU)

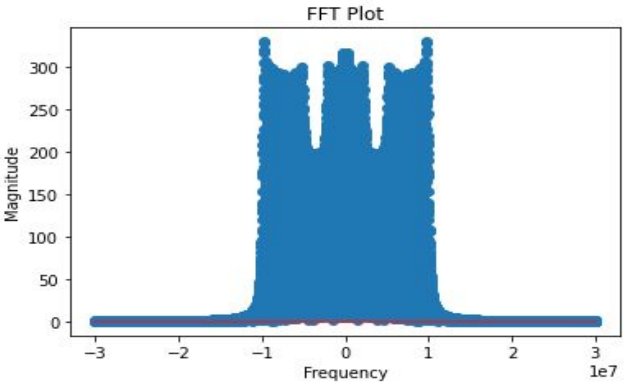



Amplitude of chirp signal : 1
Bandwidth of chirp signal : 10MHz
Time period of chirp signal : 50u sec
Sampling rate : 60M samples

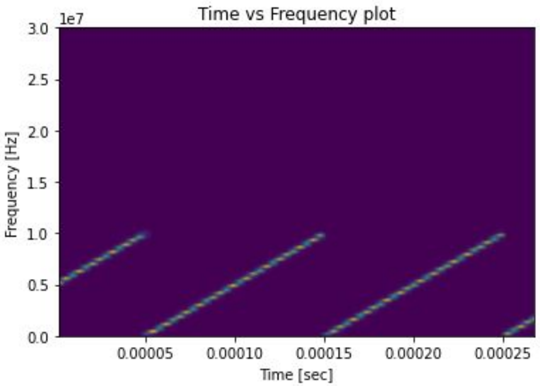
# Chirp signal(Python)




Chirp Signal

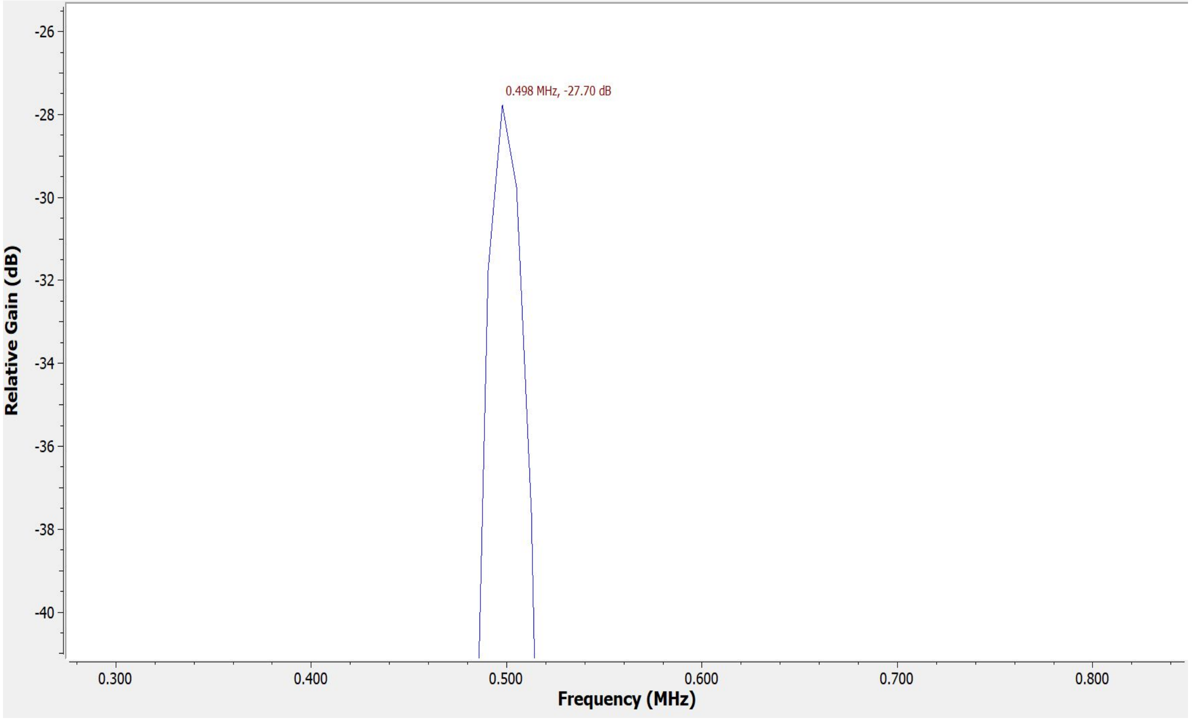



FFT of Chirp Signal



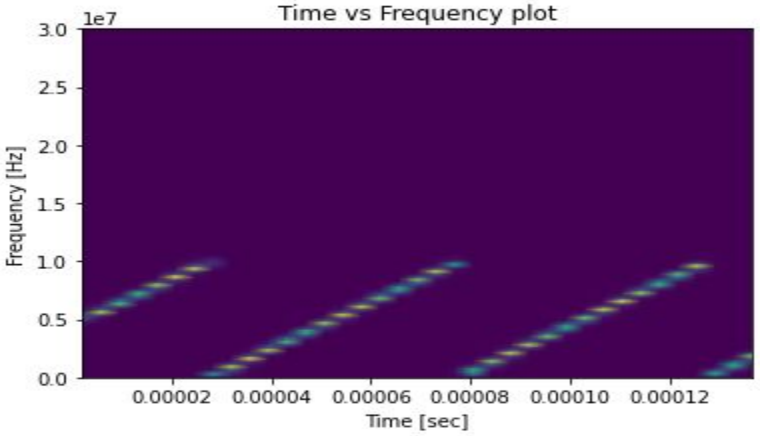

FREQ v/s TIME Plot

# Single object detection(GNU)




Freq observed at 0.498 MHz in GNU Radio with a delay block of 150 samples

# Single object detection(Python)




Received Signal “Freq vs time” plot showing a delay of 2.5μs Plotted in Python

## Python Console output:

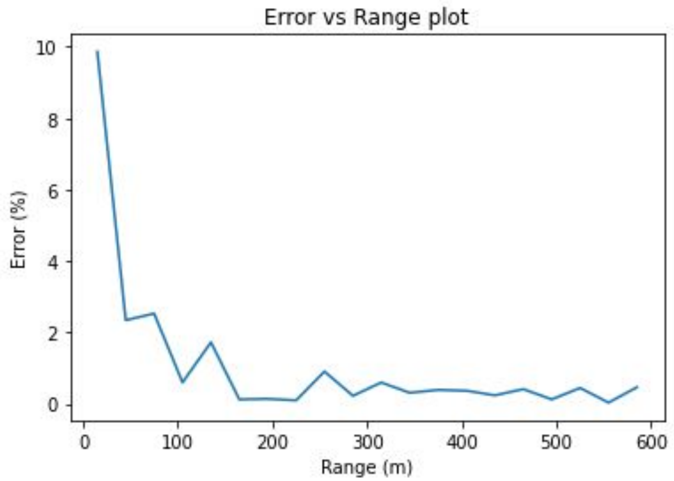
```
The object is detected at 373.53515625m distance form antenna with beat
frequency of 498046.875 Hz
```

# Result analysis

## Single Object Detection:

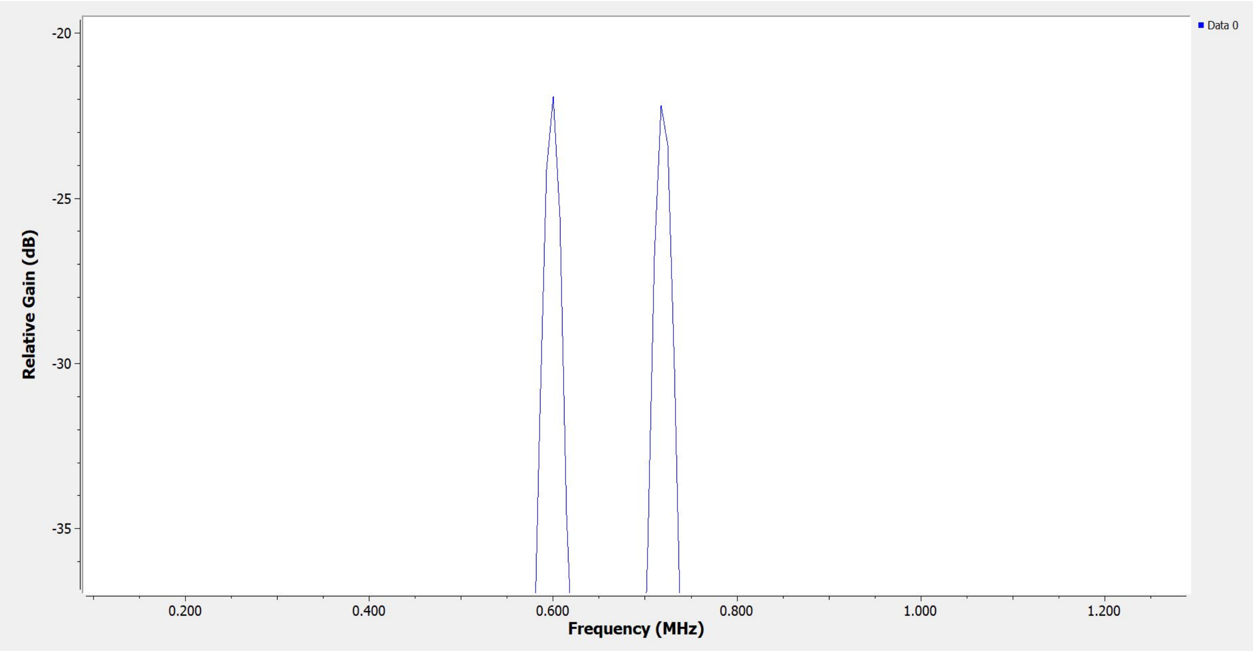
| S.No | Time Delay | Range(m) Calculated | Beat Frequency(Hz) Calculated | Range(m) Detected in Python | Beat Frequency(Hz) Detected in Python |
|---|---|---|---|---|---|
| 1. | 0.5µs | 75m | 100k Hz | 76.904m | 102.539k Hz |
| 2. | 1 µs | 150m | 200k Hz | 148.315m | 197.753k Hz |
| 3. | 1.5µs | 225m | 300k Hz | 225.219m | 300.292k Hz |
| 4. | 2 µs | 300m | 400k Hz | 296.630m | 395.507k Hz |
| 5. | 2.5µs | 375m | 500k Hz | 373.5315m | 498.046k Hz |

**Observation Table**




**Error vs Range plot**

# Double object detection (GNU)




Freq observed at 0.600 MHz and 0.717MHz in GNU Radio with delay blocks of 180 and 216 samples

# Double object detection (Python)

Python Console output:

```
The First object is detected at 450.439453125m distance form antenna with
beat frequency of 600585.9375 Hz
The Second object is detected at 538.330078125m distance form antenna with
beat frequency of 717773.4375Hz
```

# Result analysis

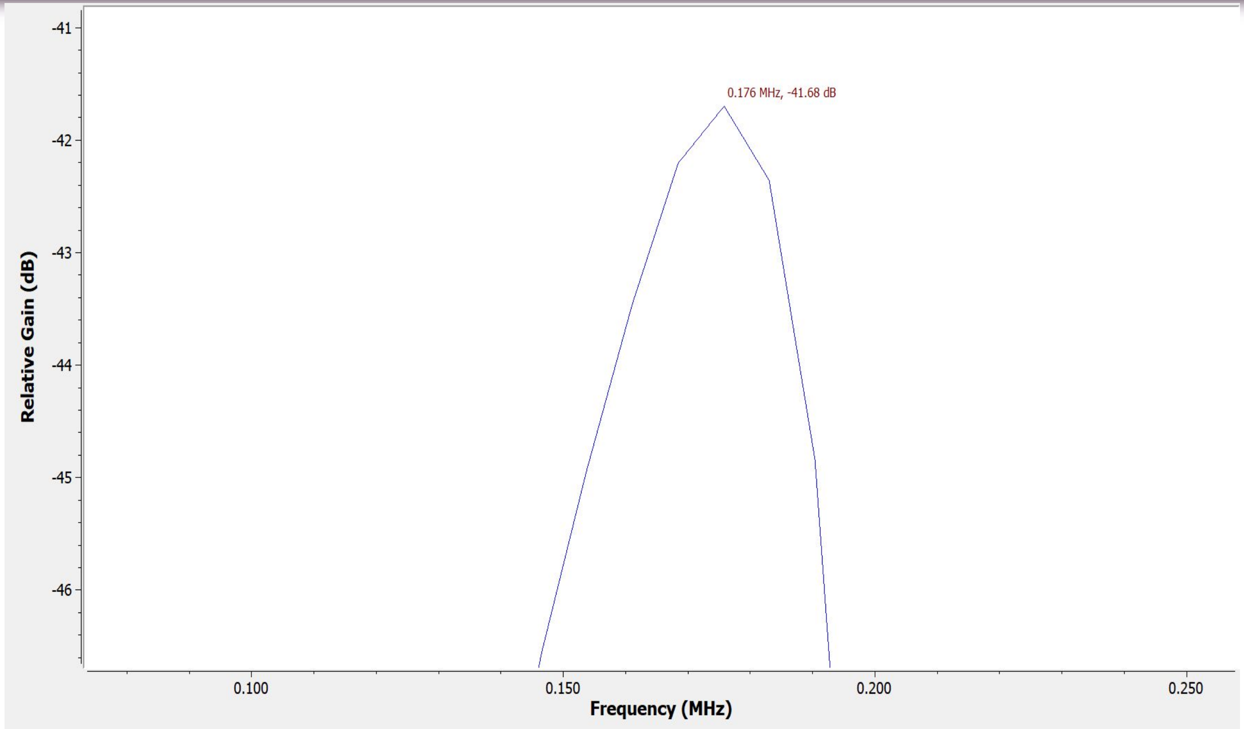
AMRITA VISHWA VIDYAPEETHAM School of Engineering Bengaluru Campus

## Analysis on Distance between two objects(Double object Detection):

| S.No | R1 | R2 | ΔR | R1’ | R2’ | ΔR’ |
|---|---|---|---|---|---|---|
| 1. | 150m | 180m | 30m | 148.315m | 181.274m | 32.959m |
| 2. | 225m | 270m | 45m | 225.219m | 269.165m | 43.946m |
| 3. | 300m | 360m | 60m | 302.124m | 362.548m | 60.424m |
| 4. | 375m | 450m | 75m | 373.535m | 450.439m | 76.904m |
| 5. | 450m | 540m | 90m | 450.439m | 538.330m | 87.891m |

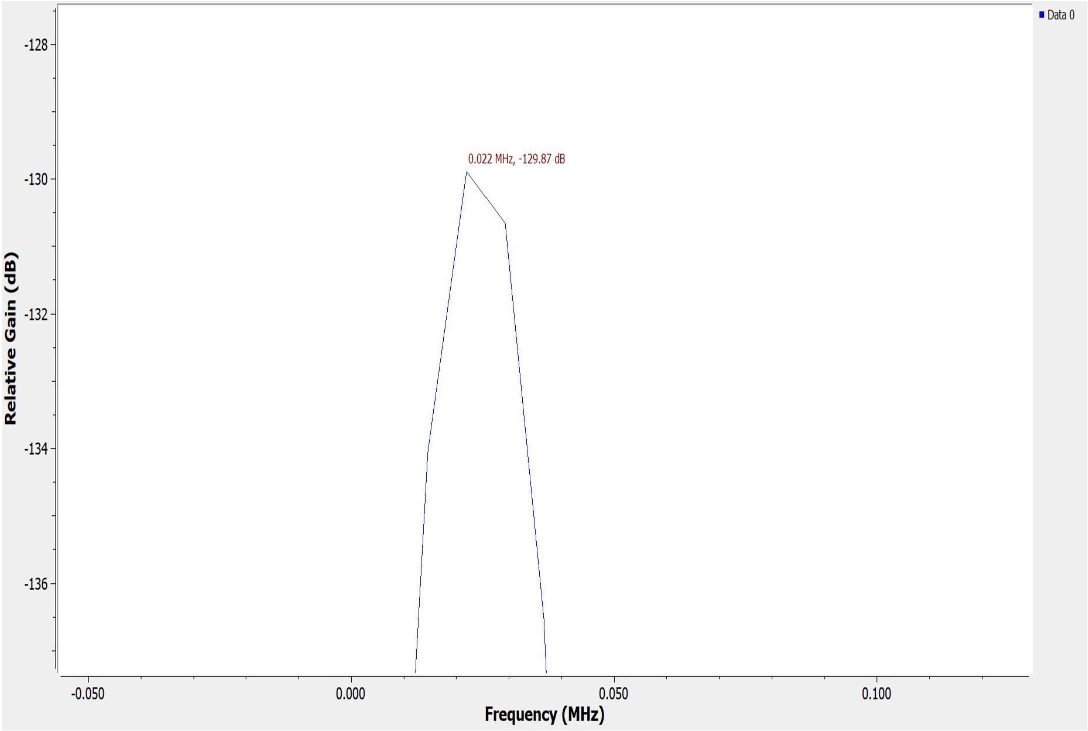
R1→1st object distance, R2→2nd object distance, ΔR→Calculated Separation between objects, R1’→1st object distance measured in python, R2→2nd object distance measured in python, ΔR→Calculated Separation between objects measured in python

# Moving object detection(GNU)




**Beat frequency after considering doppler frequency is 176KHz .The range frequency is observed to be 200k Hz.**

# Doppler Frequency




**Range Frequency for the moving object what we have taken is 200 KHz but in GNU we can’t detect doppler frequency since it is small. So we have used frequency synthesizer to detect doppler frequency and we have observed it as 22KHz as shown in figure.**

# Moving object detection(Python)

Python Console output:

```
The velocity of object is found to be 327193.4076587494m/s
```

# Future Scope

AMRITA VISHWA VIDYAPEETHAM School of Engineering Bengaluru Campus

❖ In the future we are going to work on a biomedical application in which we are going to study human respiration in which we will use a radar that can detect even small displacements and we will try to increase range resolution of radar by increasing bandwidth.

# Python Code links

**Code for the Chirp Signal Plot in Python :-**

https://colab.research.google.com/drive/1s3qoUkM2y8u0eVB85jMr514-nq9zLf3v?usp=sharing

**Code for Single Object detection in Python :-**

https://colab.research.google.com/drive/1Llkw7KI0gJZOZECCHfYPE1leYekZaDsq

**Code for double Object detection in Python :-**

https://colab.research.google.com/drive/1ItsvfKZ-I6SnnaD35cl5aE_wW1PPde-R#scrollTo=O8Dx9UenUo6F

**Code for moving Object detection in Python :-**

https://colab.research.google.com/drive/1cNpTsduzMIgg5v74a0I34kUZnxX-T8GB

# References

1.Sundaresan S, Anjana C, T. Zacharia and Gandhiraj R, "Real time implementation of FMCW radar for target detection using GNU radio and USRP," 2015 International Conference on Communications and Signal Processing (ICCSP), 2015, pp. 1530-1534.

2.Aloysius Adya Pramudita, Fiky Y. Suratman & Dharu Arseno (2020): “Modified FMCW system for non-contact sensing of human respiration”, Journal of Medical Engineering & Technology,Volume 44 , May 2020

3. Q. Zhu and Y. Wang, “FMCW radar implemented with GNU Radio Companion”, Dissertation, 2016

4. Baek, S.; Jung, Y.; Lee, S. “Signal Expansion Method in Indoor FMCW Radar Systems for Improving Range Resolution”, Sensors 2021, 21, 4226.