Lab 8 - SDR: Software Defined Radar

ECE 531 - Software Defined Radio

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1 Introduction

Lab 8 - SDR: Software Defined Radar, takes a step away from studying the signal path of digital communications and error detection / correction, and instead looks at an application of software defined radio - in radar. In particular, Lab 8 looks at continuous-wave (CW), or continuous transmission, doppler radar systems, using the PlutoSDR. While some configurations, such as the MIT coffee can radar system, require multiple physical pieces and circuits. The objective of this lab is to configure and use **just** the PlutoSDR as a CW doppler radar (instead of multiple parts), investigating variations in doppler velocity while applying fluctuations in the air at short range in front of the radar.

2 Lab Overview

2.1 Design

For this lab, two different portions of a GNU Radio Companion (GRC) flowgraph were necessary to create the CW Doppler radar: a transmitter signal, and the receiver. For the transmitter, a simple cosine signal source fed into the PlutoSDR sink was sufficient. In terms of the receiver, two AGC blocks were used to normalize the reference and received signals, respectively. These outputs were then combined and decimated via the multiply conjugate and low pass filter (LPF) blocks, in order to further focus down on the frequencies of interest for this experiment.

2.2 Implementation

The fully realized GRC flowgraph for the CW Doppler radar design described previously can be seen in Figure 1, below.

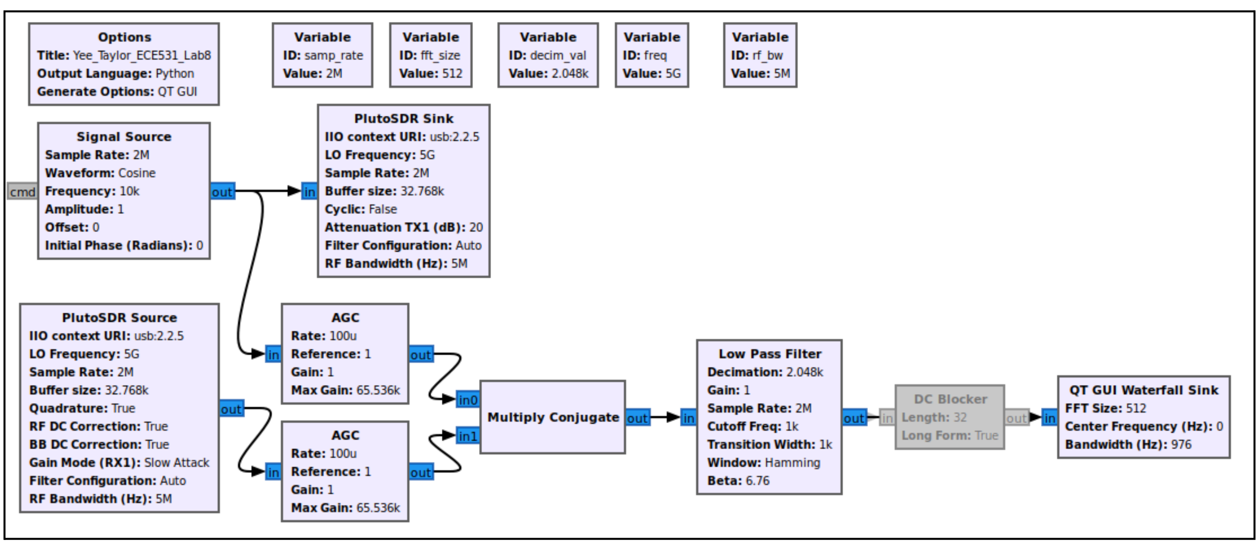

Figure 1: GRC flowgraph for CW radar with transmitter included

The DC blocker primitive block was not essential for the general implementation (hence why it is disabled in the figure), but was used as part of investigation later on in the lab.

2.3 Testing

Testing of the GRC radar flowgraph above included setting up the physical environment for the radar frequency detection. Several different objects were waved or placed in front of the PlutoSDR to capture their Doppler frequencies including a DVD, DVD case, and a variable speed fan.

First, a DVD was waved in front of the radar to elicit a quicker turnaround time of data capture to ensure the PlutoSDR was configured correctly. Once the LO frequencies and other parameters were set as desired and proven in, the DVD case and fan were also tested.

A picture of the fan setup can be seen in Figure 2, below.

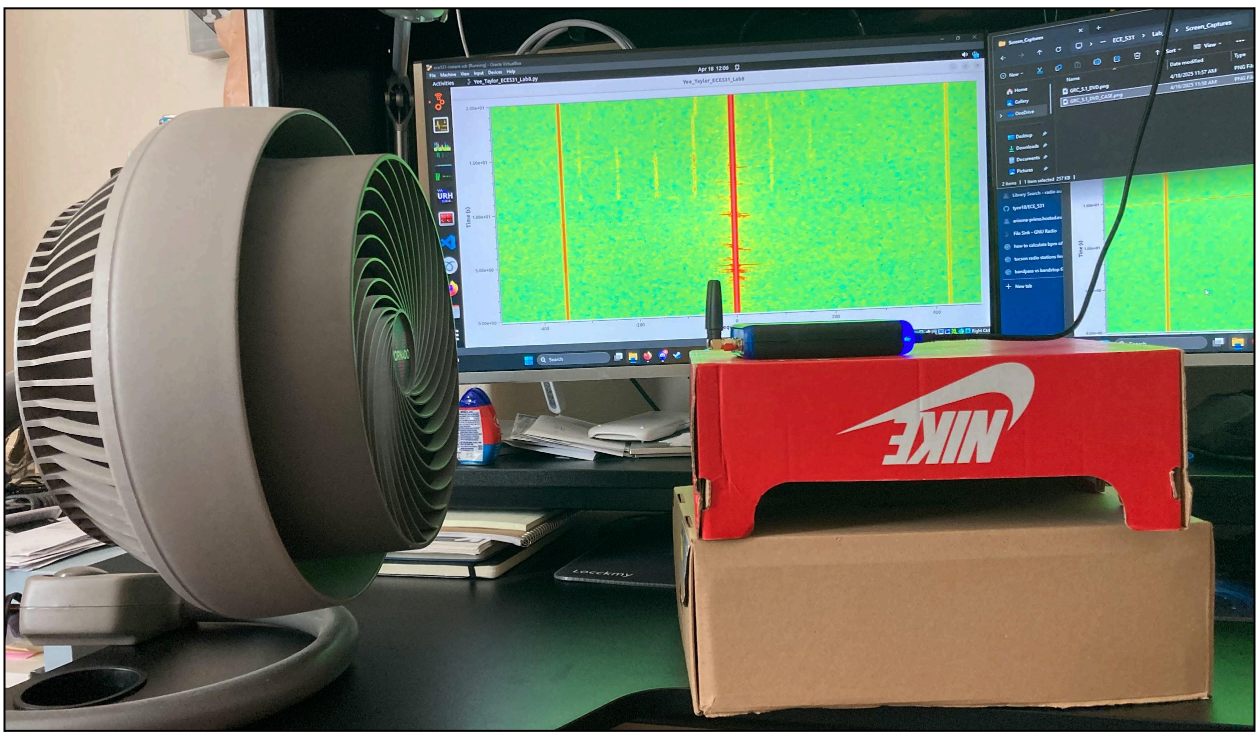

Figure 2: Desk fan and PlutoSDR radar setup

The original GRC flowgraph implementation set both the PlutoSDR source and sink LO frequencies (defined by the **freq** primitive variable block) to the 2.4 GHz ISM band, following Dr. Gallagher's implementation. However, this proved to be a very noisy frequency band that made even the highest speed setting on my fan indistinguishable. With this, I had to change the LO frequencies to operate in the 5 GHz band. I also had to prop up my PlutoSDR in order to fully capture the different fan speeds available (not pictured is a glass of water I placed behind the shoeboxes to keep them from sliding backwards at the higher fan speeds).

3 Results and Discussion

The QT waterfall plot from waving the DVD (outlined in the upper black box) and DVD case (outlined in the lower black box) in front of the PlutoSDR can be seen in Figure 3.

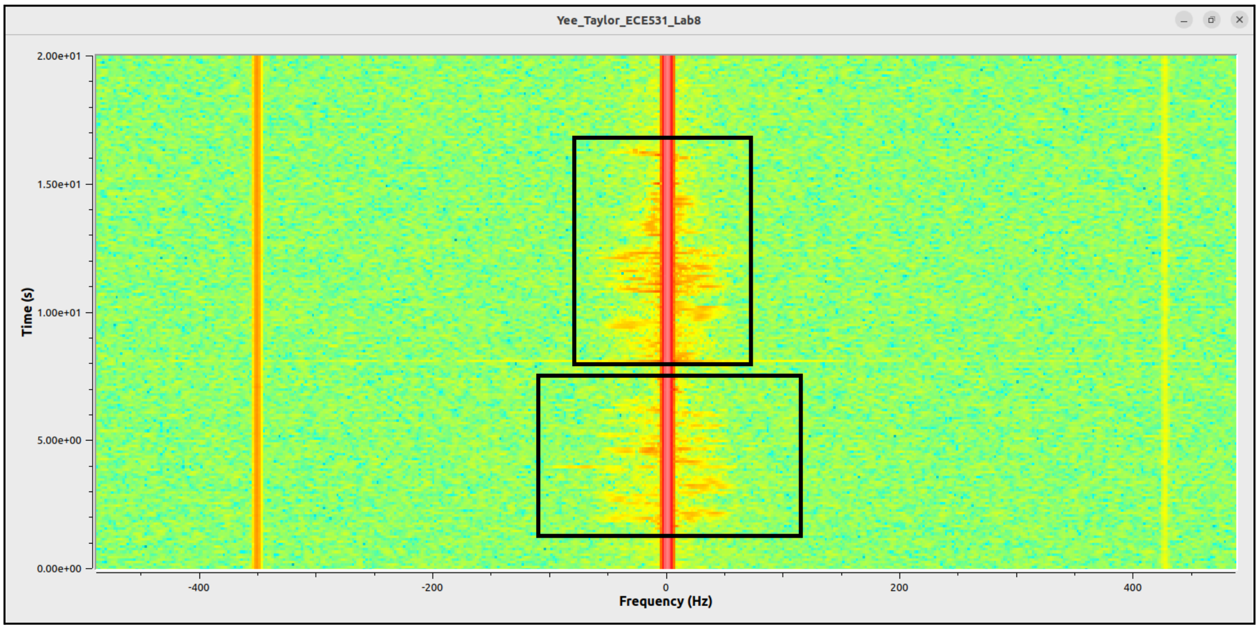

Figure 3: Doppler frequencies of waving DVD and DVD case

Here, we can see that both targets yielded roughly the same Doppler frequencies - which make sense, as these two objects are about the same size, and I made an effort to wave them at about the same speed.

The QT waterfall plot from the fan with increasing speed levels in front of the PlutoSDR can be seen in Figure 4. Black lines have been drawn to indicate when changes in the speed level occurred.

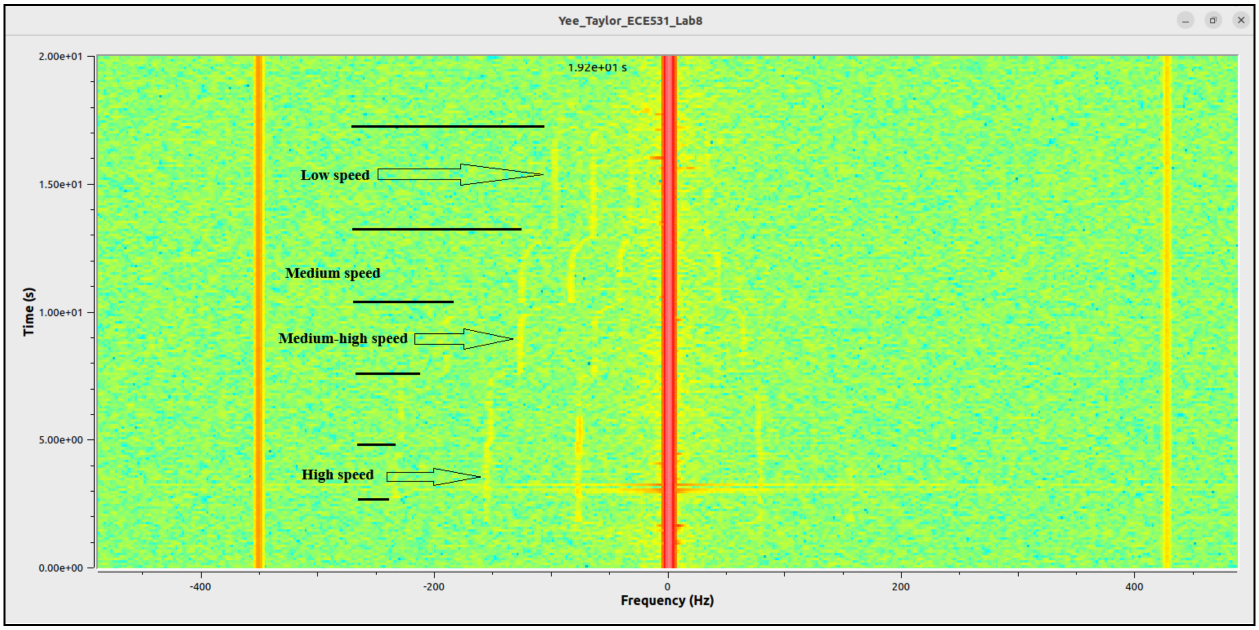

Figure 4: Doppler frequencies of fan with increasing fan speed levels

Compared to the waterfall plot of waving the DVD and DVD case in front of the PlutoSDR, the fan waterfall plot shows much more consistent Doppler frequencies. This is because the fan moved in front of the PlutoSDR at a consistent speed, only changing rotations per minute (RPMs) when I would change the speed knob. Appropriately, higher fan speeds yielded greater Doppler frequencies.

A strong return frequency at zero Hertz was noted throughout testing. There are several reasons for this. By definition, DC voltage is direct (aka unchanging in both sign or magnitude), hence its frequency component would always be at zero Hertz (unlike AC). Additionally, stationary objects (i.e., clutter) do not contribute any Doppler shift and therefore their reflective frequencies will always have a strong signal at zero Hertz. Furthermore, the implementation of the radar system above does not have any filtering or noise gates really in place to mitigate all the frequency noise coming from clutter.

The DC blocker GNU radio block was added later on to visualize removing that zero DC component. To further mitigate at least some of the DC return, the experiment could be moved to a less densely populated area (physically) - for example, if this was redone in the middle of the desert, there would be substantially less clutter for the PlutoSDR to pick up noise components from than in my house.

Especially because this lab's radar implementation is fairly rudimentary, interfering signals would affect its ability to detect targets. As I discovered when tuning the PlutoSDR's LO frequencies to the 2.4 GHz band, interfering signals would add extra noise and render the recognition of moving objects in front of the PlutoSDR nearly impossible. To improve this design's resiliency to interference, additional filtering could be added at the receiver to really hone in on the frequencies of interest. Additionally, matched filters (such as the square-root raised cosine filter from previous labs) could also be used to increase the signal-to-noise ratio (SNR). Finally, the setup itself could also be moved further away from other objects to decrease signal interference - this is why radar systems tend to be situated high up, in more unobstructed airspaces.

The CW radar as-implemented in this lab can only detect singular moving targets, and cannot detect range to the intended target. To add range-detecting capabilities, as well as the ability to detect multiple targets, the transmit signal would need to be frequency-modulated (referred to as an FM-CW radar).

The angular velocity of each object measured can be calculated as a function of its frequency, using the following equation:

$$\omega = 2\pi f$$

So, for example, in the case of Figure 2, the angular velocity of the DVD and DVD case would be approximately $\omega = 2\pi * 50\ (Hz) \cong 314.16\ rad/s$

In the case of fan speeds in Figure 4, the angular velocities of each fan speed would be approximately as follows (taking each speed's maximum Doppler frequency):

- Low speed: $\omega = 2\pi * -100\ (Hz) \cong -628.32\ rad/s$
- Medium-high speed: $\omega = 2\pi * -125\ (Hz) \cong -785.40\ rad/s$
- High speed: $\omega = 2\pi * -150\ (Hz) \cong -942.48\ rad/s$

4 Conclusions

Lab 8 was a fun application-based lab, and a good breath of fresh air after several heavy labs on the fundamentals of digital communications. Through this lab I was able to gain a rudimentary understanding of how CW (and general types of) radars work, and also scratch the surface at some of the major challenges faced when using radar for both object and range detection. It was particularly interesting to see just how sensitive radar systems can be to noise. I took my laptop and PlutoSDR (with the CW radar programmed and running) outside my front door, where I felt there would be less clutter than inside my house - and was surprised at how little difference the location made in the signal and frequency noise. This just goes to show that while a fundamental design is typically simple, to make it robust is a tall and often complex task.