IZTECH

DEPARTMENT OF ELECTRICAL
AND ELECTRONICS
ENGINEERING

EE492 PROJECT REPORT

Doppler Radar Measurements

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ABSTRACT

There are different radar types and techniques with different advantages and disadvantages for different purpose, such as pulse radar and doppler radar. However, among doppler radars, it is not clear that if 5.8GHz is better or 2.45GHz. Therefore, we tried to figure it out by building a compact, portable combined double radar system to compare them. Instead of using 4 antennas, we designed dual band Vivaldi antenna as common receiver of the system. Also, we designed the system so that we can control the power and radar activation with switches. By producing our microstrip components with external dry film and UV exposure method, measuring the power output and the gain of the antennas, then doing tests for both frequencies in different conditions, we saw that our practical results are matched with the theoretical calculations. We concluded that we cannot say that if any of them is better for all situations because according to applications we can prefer one on another.

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ABBREVIATIONS

RADAR : Radio Detection and Ranging

VSWR : Voltage Standing Wave Ratio

Wi-Fi : Wireless Fidelity

GPS : Global Positioning System

RFID : Radio-Frequency Identification

NFC : Near Field Communication

FM : Frequency Modulation

VCO : Voltage Controlled Oscillator

PLL : Phased Locked Loop

MIT : Massachusetts Institute of Technology

PC : Personal Computer

RCS : Radar Cross Section

UV : Ultraviolet

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1. INTRODUCTION
1.1. Antennas

Even though people may not be aware of it, we are surrounded by so many antennas in our lives. Just in smartphones, there are up to 13 antennas for different application areas, such as Bluetooth, Wi-Fi, GPS, RFID, NFC, and FM radio. They are not seen because they are hidden for aesthetic concerns and mounted to the motherboard of smartphones as seen in Figure 1. On the other hand, some of them are seen, such as satellite dishes for receiving direct-broadcast satellite television or Base Transceiver stations for supplying cellular networks.

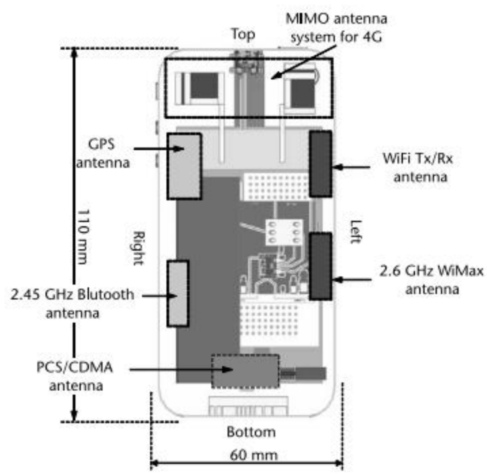


Figure 1: Inside of a smart phone [1]

Antennas are metallic structures with different shapes and sizes that converts radio electromagnetic waves into alternating current. They are being used as an interface to receive and transmit electromagnetic radiation from electric currents. They are an essential element of a wireless communication system. There are different kinds of antennas with strengths and weaknesses which are Wire Antennas, Aperture Antennas, Reflector Antennas, Lens Antennas, Printed Antennas, and Array Antennas.

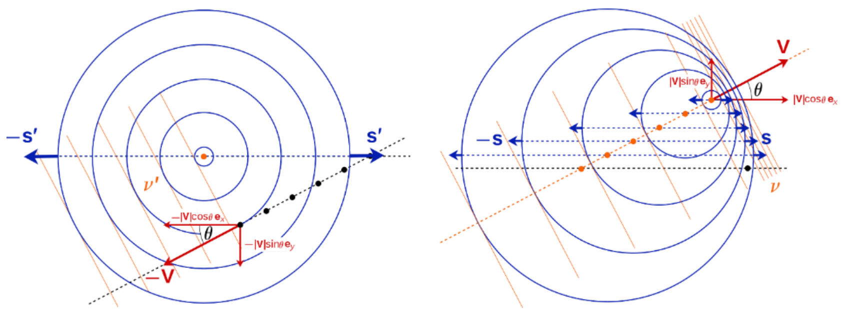
Compared to other antennas, printed antennas have interesting features for realization. They are easy to manufacture, they have low weight, and they are small. They are durable, compact, and also cheap. Printed antennas are used in medical, military, spacecraft, and many wireless applications. We can see them in radars, mobile phones, satellites, or GPS systems. Microstrip antennas are the most popular printed antenna type, they have dielectric material in the middle which separates the patch and the ground conductor.

These antennas are mostly narrowband which is good for Doppler radars. Moreover, their easy and cheap manufacturing capabilities can help us to produce and test them on the campus. For a better doppler radar application, we need to consider antenna parameters like return loss, gain, and directivity. The operating frequency of doppler radars can be divided into L, S, C, X, and K bands. Mostly used bands are S-band 2-4 GHz, and C band 4-8 GHz [2]. We wanted to use the C band for smaller antenna size and smaller power requirements.

1.2. Doppler Radars

RADARs are being used as electromagnetic sensors to determine the distance, angle, or velocity of an object. This happens while the transmitter of the radar sensors is sending electromagnetic waves and the receiver is listening to the echo coming from the object. After this electromagnetic transmission, we can obtain some information about the object [3]. There are different types of radar, such as continuous wave radar, doppler radar, pulse radar, and bistatic radar. In this project, we are concerned with doppler radar.

Doppler is an effect that happens when an object has a velocity related to the wave source, observer. When an object comes towards the observer, the signal reflecting from it is higher than when the object goes backward as seen in figure 2. Doppler radar is a type of radar that uses Doppler effect to detect the speed of a distant moving object. It uses the frequency difference between transmitted and received signals to measure the speed by the formula below, which is applicable when the speed of the object is very smaller than speed of light [4].



$$f_d = f_r - f_t \approx 2v\frac{f_t}{c} \quad (1)$$

f_d: *Doppler Frequency,*
f_r: *Shifted Frequency,*
f_t: *Original Frequency*

Figure 2: Visualization of doppler effect [5]

The frequency change is very little, so it allows narrowband applications, which eliminate false signals from the environment and other objects. With using these features, we want to design an antenna for a doppler radar implementation like in the figure 3 [7] which we use two antennas for transmitting and receiving the oscillating signal and find the difference of it as we can see the examples at various implementations [6].

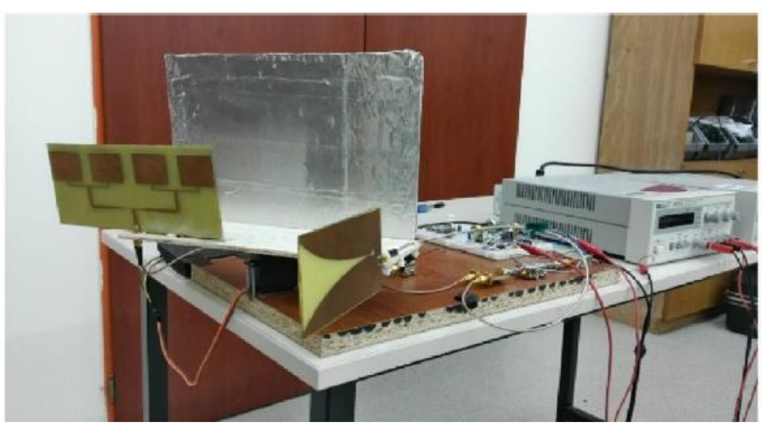


Figure 3: Example Doppler Radar Implementation [7]

1.3. Microwave Components

To build a microwave system/circuit, there are several components that make us to manipulate the electromagnetic wave. We can give examples of cavities, antennas, waveguides, circulators, filters, and splitters as passive components and amplifiers, mixers, and PLLs as active components. Simply, the difference is that we need to use excess electricity to make active components work instead of passive ones. Other than RF components, we have an audio amplifier circuit which is an operational amplifier circuit.

To briefly mention passive components in our project, there are splitters/combiners, attenuators, and antennas. The power splitter divides the incident power with the least amount of loss. Additionally, it would be a performance parameter that the branches are supposed to be isolated from each other which Wilkinson splitter does [8]. Additionally, we have 2.45GHz, 5.8GHz 4x1 array microstrip patch antennas as transmitter and Vivaldi antenna as dual-band receiver. We want transmitter antennas to have good directivity and high gain, on the other hand, the receiver has a wide radiation pattern to capture the reflected waves properly.

As active components, we have a mixer, voltage-controlled oscillator (VCO), and amplifier. To supply dedicated frequency, we use VCO, and since we want to hear the reflected wave, we need to amplify it with amplifiers. Lastly, we use a mixer to subtract transmitted frequency from reflected frequency to obtain the Doppler frequency as a result.

1.4. Performance Parameters

We see that there are microwave various components. To examine their performance, there are different parameters. We use measurement devices to test them, for example, a vector network analyzer to see S parameters, a power meter, a spectrum analyzer, and an SWR indicator. Additionally, since we simulate our devices before manufacturing, we see those parameters in simulation results. Let’s talk about those performance parameters.

When signal transmission occurs, some amount of power always returns back to the source which is called return loss [9]. It is one of the most important parameters for initial design, because it represents the ratio of the reflected power to the incident power as seen in the equation below. In other words, we detect the frequency range of the signal and how well it is matched by observing it. In some cases, VSWR is the preferred parameter to observe. It is similar to return loss but instead, it is a linear measurement.

$$Return\ Loss(dB) = 10 \log_{10} \frac{P_{out}}{P_{in}} \qquad (2)$$

For single port and multiple port devices, to see performance and characteristics, we mostly use the term Scattering Parameters. By looking at the S matrix of a device, we can see if it is lossy or lossless and reciprocal or nonreciprocal as its characteristics. On the performance side, we can observe Return Loss, Insertion Loss, Isolation, and so on. It simply gives us ratio of the ratio of voltage on port one to another as seen in the figure 4 [10]. For example, at antennas we consider S11 parameter at most because it represents us how well the antenna is matched, on the other hand for splitter, we consider S21 and S31 at most.

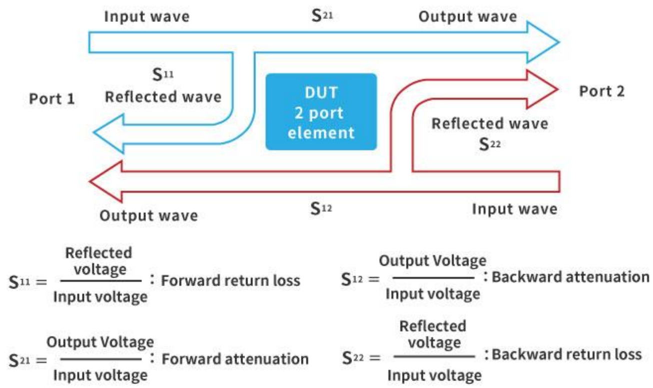


Figure 4: S-Parameters Diagram [11]

The other important parameter is radiation pattern or far-field pattern, it shows the direction of radiated power function far from the antenna. From this pattern, we can also observe the gain and directivity parameters. Especially in doppler radar radiation patter is a crucial factor.

The directivity shows the radiation direction, mainly on high gain direction. In a doppler radar application like we planned, the antenna must be focused on one direction, and this must be narrow for not radiate to other objects or receive signal from side directions. Also, the back lobe of the pattern can reflect and affect the front main lobe, so we need to decrease the side and back lobes in optimizing the directivity in our application.

Gain is the parameter of the transmitted power in terms of direction compared to isotropic antenna which is a theoretical antenna. Isotropic antenna is a perfect sphere and radiates equally to every direction which means that it has 0 dBi, no gain. Simply, when a radiated energy concentrated instead of spreading, our gain increases because we intensify the radiation on the direction as seen in the figure 5. Gain is proportional to efficiency and physical aperture area as we can see in the formula below.

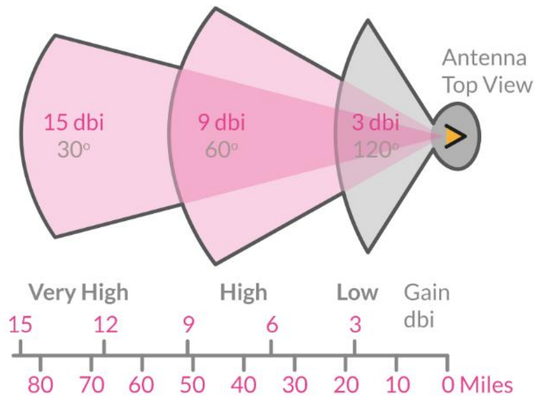


Figure 5: Directivity visualization for different angles [12]

$$G = \frac{4\pi\eta A}{\lambda^2} \tag{3}$$

G: $Gain$, η: $Efficiency$, A: $Physical\ aperture\ area$, λ: $Wavelength$

Also, from the Friss's transmission formula [13] we can denote the gain and the distance relation. As we can see in the following equation, for same power values, the gain of the receiver and transmitter antennas can directly increase the transmission distance.

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2} \tag{4}$$

P_r: $Power\ at\ the\ receiving\ antenna$ P_t: $Output\ power\ of\ transmitting\ antenna$
G_t: $Gain\ of\ the\ transmitting\ antenna$, G_r: $Gain\ of\ the\ receiving\ antenna$
λ: $wavelength$, R: $Distance\ between\ the\ antennas$

2. PROBLEM DEFINITON

2.1. Measurements with a Doppler Radar

Since we have no experience in building a doppler radar from scratch, taking measurements from it, and interpreting the results; we need to rebuild the system of 2.4GHz doppler radar and its electric circuit in the microwave laboratory. Before doing this, we are supposed to comprehend the concept of it and analytically validate the expected results by looking the parameters of the components. The MIT cantenna has many similarities with that radar, so we first need to understand the concept of them.

Next, to read the output signal coming from radar is meaningless from bare eyes on oscillator, we need to handle to capture data from a computer and with a software, we should see the results in more visual way to interpret it easily. Moreover, we are supposed to see if the radar is accurate. Therefore, we need to set up a system with known velocity. If we come across any error, we will try to figure it out by fixing the system or software.

2.2. Building 5.8GHz Doppler Radar

After building 2.4GHz doppler radar system, we need to design another system for 5.8GHz radar with new components and microstrip antenna that we designed last term. We need to check the datasheets of the components, adjust the input/output signals and build it. Since, those components are expensive and sensitive, we need to give high attention on the system because we do not have any backup.

At first, we need the check them if they work. We can use power meter to see how well the active components work, and we can see how well our antenna work in the system and on the VNA. Then, again we need to build separate audio amplifier for this new circuit.

2.3. Designing a Portable System

The MIT radar system is built on a wooden platform and all components are screwed onto this platform. Although the system is a little large with cantennas, outdoor measurements are done with it. But 2.4 GHz doppler radar needs some components to operate out of lab. Also, we wanted to design a compact radar to use both 2.4 GHz and 5.8 GHz systems. With considering our only common reference receiver horn antenna, the system will be larger than the MIT’s.

Because of these reasons, we want to design a more compact and portable radar system to make our radar comparison measurements.

The system should have:

- Its own power supply to make it portable
- Compact audio amplifier board to achieve a rigid system without break down
- Same or similar receiver antennas to make comparison sensible
- A solution to quickly change between 2.4 & 5.8 GHz frequencies within the same test environment
- A stable platform to sit on

2.4. Designing Additional Components

For working with both radar systems simultaneously, we need additional components. With our portable system design, we can decide what components we will need in order to build the system.

In the lab, we tried fabricating a microstrip antenna before, and because of inexpensive fabrication and simple design properties, our additional components can be microstrip components. In the MIT doppler radar system and 2.4 GHz radar system in the lab, one splitter component is used. So, we will need a common broadband splitter or two different splitters with different operating frequencies, and also a receiver antenna which we will decide on as the portable system.

2.5. Manufacturing

Manufacturing of microstrip components is not very easy and inexpensive. It is because, professional manufacturing is based on foreign currency and it is expensive for the budget of the project. We tried microstrip antenna fabrication with UV light method in our previous project last semester. In this manufacturing process we used a FR4 with photoresist layer provided by our lab.

However, in this semester, we are lacking those boards. Therefore, we had do find a solution for this problem to realize additional components.

3. PROPOSED SOLUTION

3.1. Measurement of a Doppler Radar

There is a 2.45GHz doppler radar [7] in the Microwave Laboratory. To get experience with doppler radars we need to rebuild them and take measurements. To build a Doppler radar we need several components as seen in Figure 6.

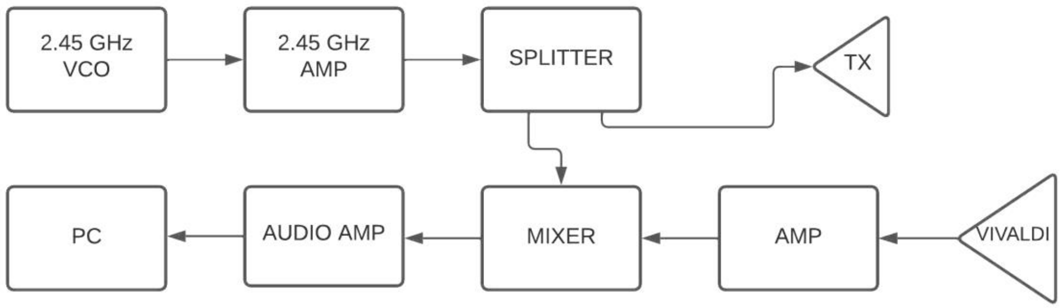


Figure 6: 2.45 GHz Doppler Radar System

At first, we need to adjust the tune voltage of the voltage-controlled oscillator to supply 2.45GHz wave to the system. Then, the signal is supposed to be amplified by an amplifier because it will go through a splitter which at lead decreases the power by 3dB at least. However, it is the theoretical least amount, so it will be more than 3dB. Also, we need to take care maximum input powers of the components, otherwise, we may damage the devices. Therefore, we can use attenuators for this purpose. The one branch of the splitter will go to a transmitter antenna as seen in Figure 6. The other one will go to a mixer, which simply does the subtraction of transmitted frequency and received frequency from the receiver antenna. We used a Vivaldi antenna as a receiver as seen in Figure 7 because it has a wide radiation pattern to capture the waves. Next, the output of the mixer will go to the audio amplifier circuit and the PC will capture the measurements by its AUX jack. We capture audio with the open-source software of Audacity.

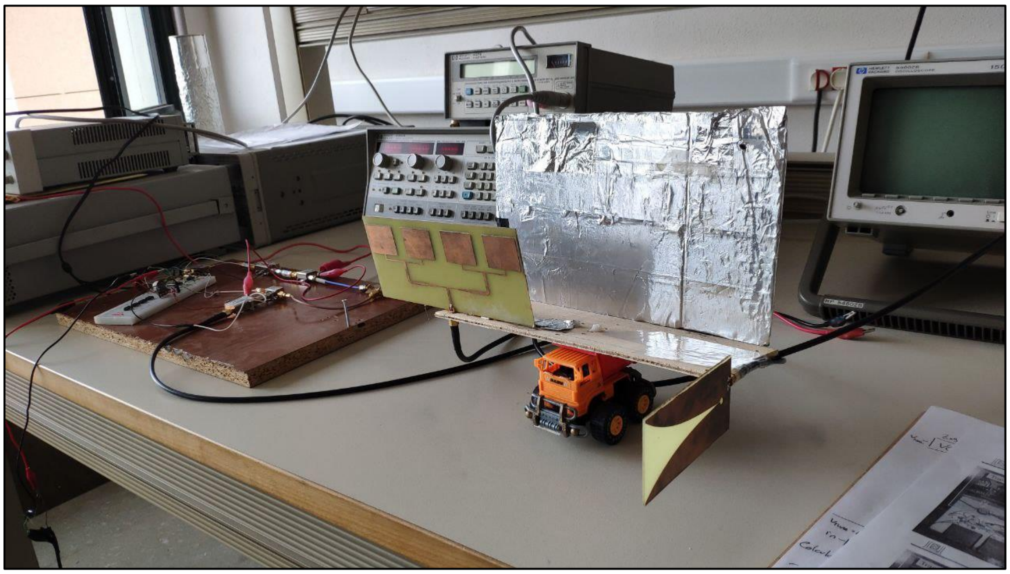


Figure 7: Realized 2.45GHz Doppler Radar System

At first, we tried to see if the radar is alive. Therefore, we connected the output of the audio amplifier to an oscillator instead of a PC. Even though cannot guess the meaning of the signal in time domain because we need to look in the frequency domain, we can deduce if it works. To check this, we covered cardboard with aluminum foil to make it more reflective and give velocity to the board. We had a problem with the audio amplifier circuit, therefore we spent time finding the error and solve it and rebuild it which seen in the figure 8. Then our impacts with the board seen like figure 9 below.

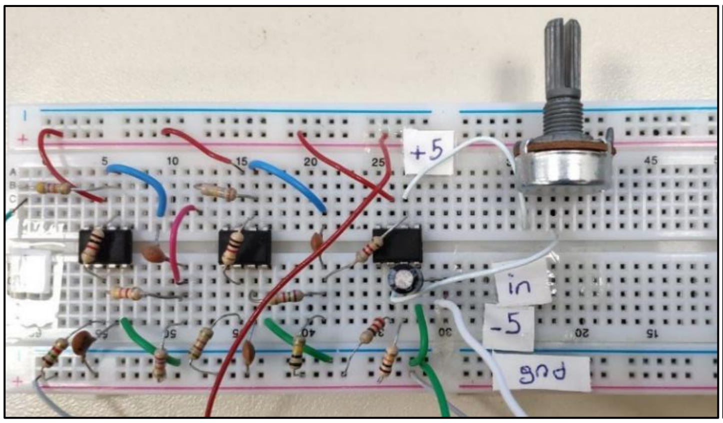


Figure 8: Rebuilt Audio Amplifier Circuit

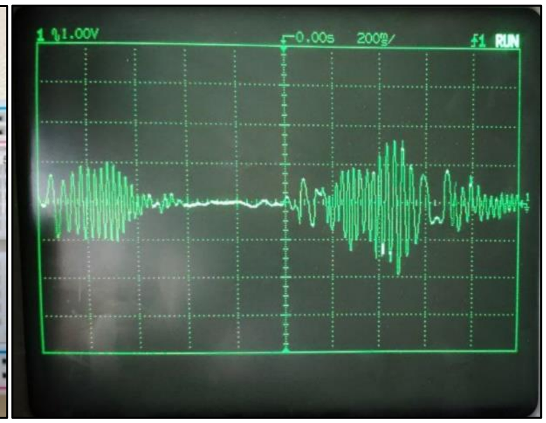


Figure 9: Detected Velocity on Oscilloscope

To take proper measurement and to see how accurate the radar is, we designed an experiment set up. We wanted to do a pendulum experiment. Hence, we connected a metal ball to a rope and knot the rope to a tripod. Since, we know the length of the rope, we calculated the maximum speed of the ball with newton physics as below:

$$mgh = \frac{1}{2}mv^2$$
$$g = 9.81\frac{m}{s^2}, h = 0.82m$$
$$v = \sqrt{2 * 9.81 * 0.82} = 4.01m/s$$

Also, we were going to take measurement with a PC, therefore we learned how to use the software and learned how it works. Then we prepared our experiment as seen in the figure 10.

Figure 10: Test Setup with Pendulum

The results of the experiment can be seen in the figure 11. We release the pendulum from the topmost point of the tripod and did not touch it for a minute. It is clearly seen that the velocity of it consistently decreases as expected and the maximum velocity is approximately 3.5m/s. This result showed us that the system works appropriately.

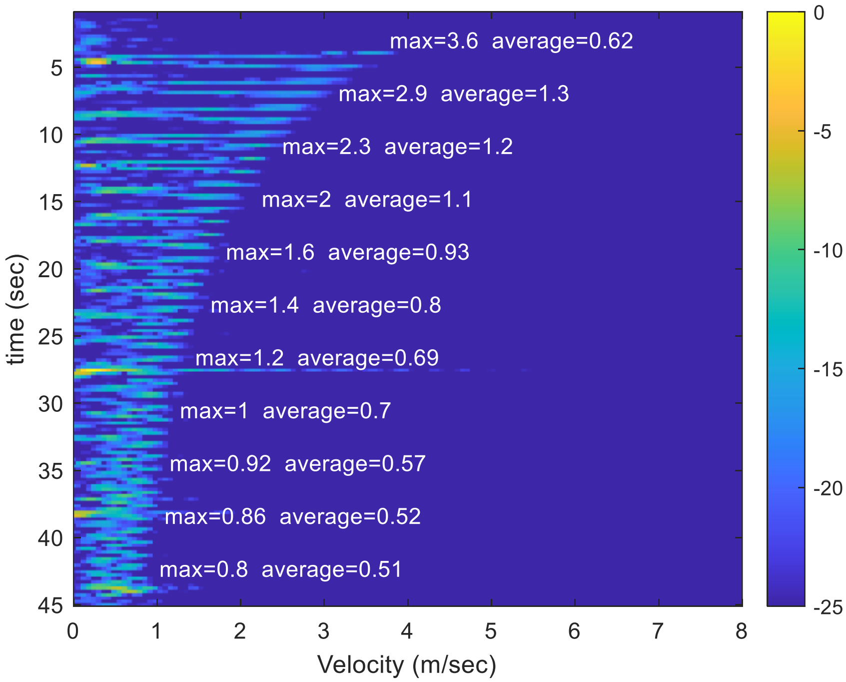


Figure 11: Pendulum Test Measurement

3.2. Building 5.8GHz Doppler Radar

In this step of our project, we were supposed to build another radar system for 5.8GHz. The active frequency range of active components of the radar before is not compatible for 5.8GHz, therefore we used different components. Even though, we know the working principle of the components because they are same with other system, we needed to get to know the antennas by checking their datasheet, input powers, tuning voltages, and output powers. With that information, we had to build the system for this radar. Hence, we did our calculations and designed the circuit we need as seen in the figure 12.

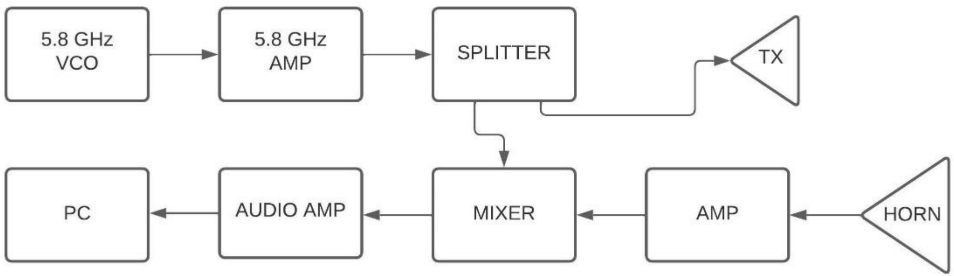


Figure 12: 5.8 GHz Doppler Radar System

Before starting to build the circuit, we consider checking if the active and passive components work. Since the vector network analyzer is operational for passive devices, we only measured our antennas and cables. On the other hand, we used power meter for our active component measurements. After the tests, we saw that one power amplifier is don't work. Fortunately, we had a wideband power amplifier at 2.4GHz Doppler Radar System that is compatible for both frequency range. Thus, we used this component to complete the second system. Furthermore, the antennas we used are also changed, we used 4x1 microstrip patch array antenna that we designed last semester as a transmitter and an industrial horn antenna as receiver which can be seen in the figure 13. We know that they both have compatible gain and frequency range for our purpose.

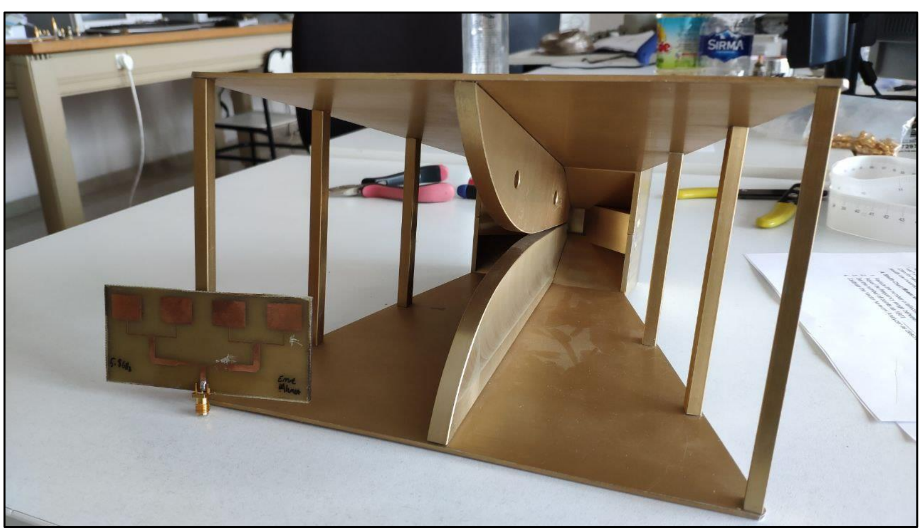


Figure 13: Antennas Used in Second System (Left 4x1 array antenna,right horn antenna)

Lastly, we adjusted the tuning voltage of voltage-controlled oscillator to supply 5.8GHz wave and took measurements from 5.8GHz doppler radar. At the end, we recorded the measurements with computer and analyzed the results. Ultimately, we saw that everything works well.

3.3. Designing a Portable System

We think combining these two systems can be possible and helps us to solve some system problems for portability, because building two of each system part will be expensive and bulky. Combining these systems can be done with different ways, we designed two main methods, one is with RF switch, and one is witch IF switch. RF switch can solve a lot of problems but its costly and we can’t realize it in our lab due to the lack of equipment. On the other hand, IF switch is inexpensive but it can only be implemented on a DC part of the system.

Then we decided to use a power combiner into the splitter outputs and combine all the receiver parts. Using combiner with one input will decrease our total power but minimize the overall system so that we use only one receiver antenna, one wideband mixer, one wideband amplifier, and one audio amplifier as can be seen on the following block diagram. In this configuration, switch can change the VCO supply voltages and the operating radar system can change directly. The proposed system can be seen on Figure 14 below.

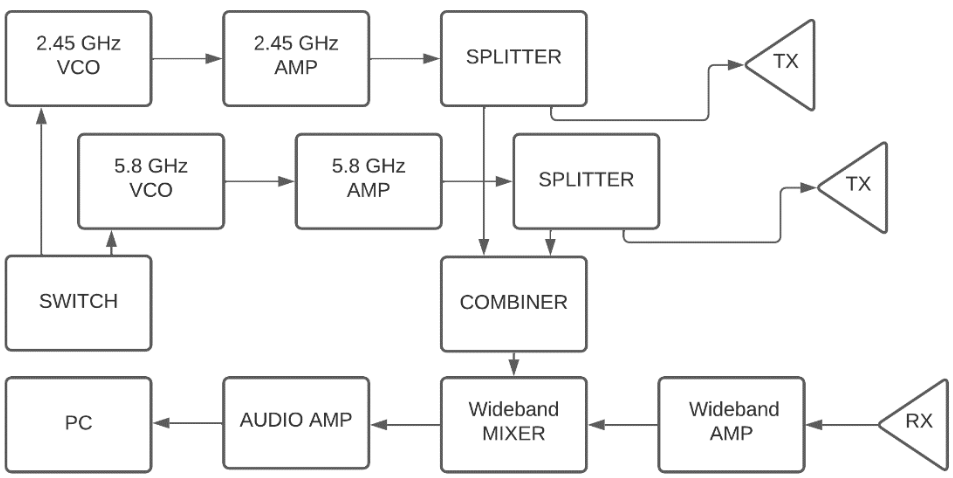


Figure 14: Combined Radar System

This system can work with the industrial horn antenna as a receiver because it operates at both 2.45 and 5.8 GHz, but as we stated earlier, for a portable design, we need a more appropriate receiver antennas instead of heavy and bulky horn antenna. As a solution, we wanted to create an ultrawideband Vivaldi antenna which will work in both radar systems as a receiver.

But there are more problems we need to solve, we use a power supply circuit for active elements, and we need to replace it with a portable source. Audio amplifier circuit uses -5V & +5V and microwave components use +5V. We can supply +5V with power bank easily, but power banks have a built-in circuit which detects low current draw and turn off. Instead of solving this problem, we will use batteries and a voltage regulation to generate +5V and -5V. Also, we need two tune voltages for voltage-controlled oscillators. We tried to combine this supply circuit with the audio amplifier circuit in a compact board. The smaller audio amplifier we made can be seen on the Figure 15.

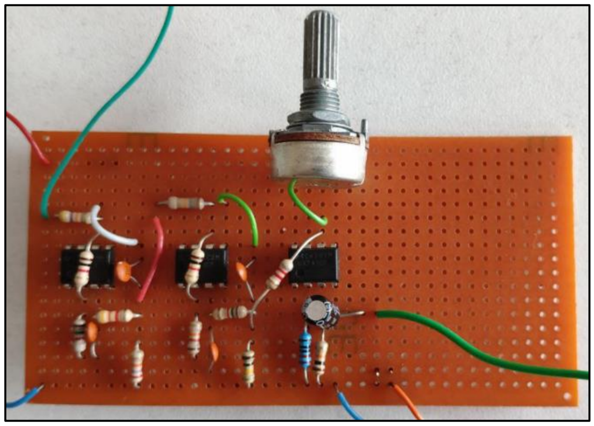


Figure 15: Audio Amplifier on Perforated Plate

Then for constant 5 volt and -5 volt power supply, we used two Zener diodes and two transistors as can be seen on Figure 16. We added a voltage division circuit for VCO tune voltages to give them 3.45 volt and 4.12 volts. After that we added two switches, one for power on, one for changing radar and combine it with batteries.

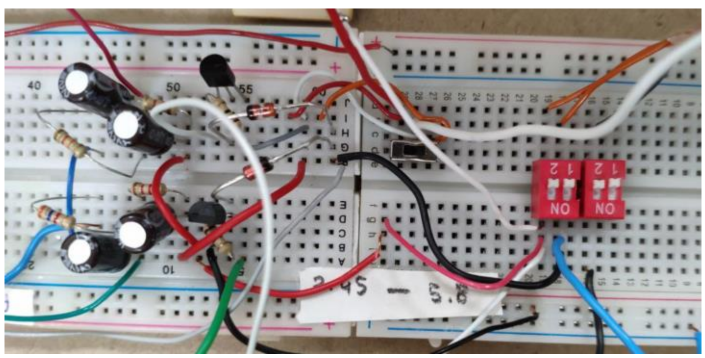


Figure 16: Power Supply & Switch Circuit

In the final portable system addition, we made a case for the system. Case has antenna and aux outputs and all antennas are on the same plane part as you can see on the following figure.

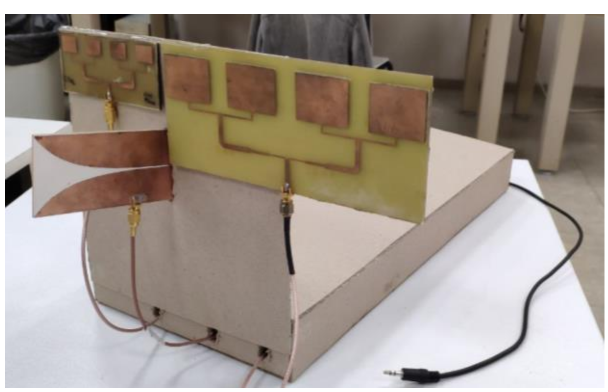


Figure 17: Completed Case

3.4. Designing Additional Components

After designing the portable system, we needed additional components for the compact Doppler radar. Firstly, we wanted to use two splitter and one combiner in our system, these components need to have minimum transmission loss and because they are between active elements, they need to have a good isolation. For these purposes we designed a Wilkinson power divider to use as a splitter. It was our first power splitter design, so we started from a simple and minimal design as can be seen in the Figure 16.

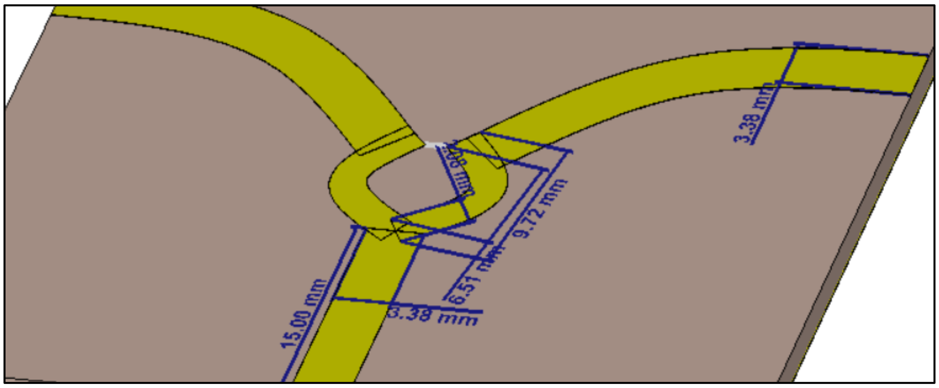


Figure 18: Wilkinson Power Divider Design; input and output microstrips has W=3.38mm(50ohm), middle arc has W=2.08mm(70ohm), L=8.12mm(lambda/4)

We combined two of splitters in one board to use it in our compact system as can be seen in the Figure 19. And changed the design so that the output ports look forward.

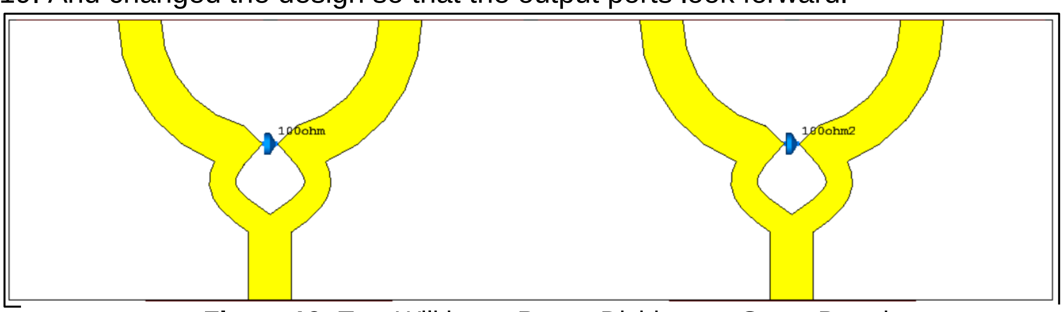


Figure 19: Two Wilkinson Power Dividers on Same Board

Secondly, we wanted to change horn antenna with a dual-band Vivaldi antenna for make our receiver antenna smaller and lighter. For this purpose, we make research on the literature and found two different basic Vivaldi designs, one with conical stub and circular cavity, and one with slot line stub and microstrip feed. We chose second design for simplicity, then we create a first design with minimum operating frequency with 2.3 GHz and maximum operating frequency with 6 GHz. We noticed resonance frequencies are shifted with slot line and microstrip line lengths, so we optimized these parameters for our doppler radar frequencies, which are 2.45 and 5.8. The final design and the parameters are given in the Figure 18 and Table 1.

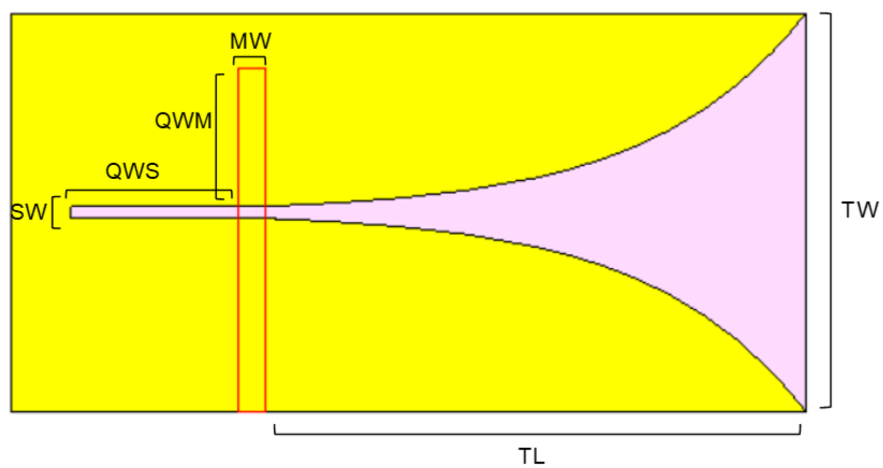


Figure 20: Designed Vivaldi Antenna

Parameter	Text	Value (mm)
Slotline Width	SW	1.5
Microstrip Width	MW	3.5
Quarterwave Slotline	QWS	21
Quarterwave Microstrip	QWM	18
Taper Length	TL	68
Taper Width	TW	50
Substrate Length	-	100
Substrate Width	-	50

Table 1: Vivaldi Design Parameters

The resulting S11 parameter is shown on the Figure 21.

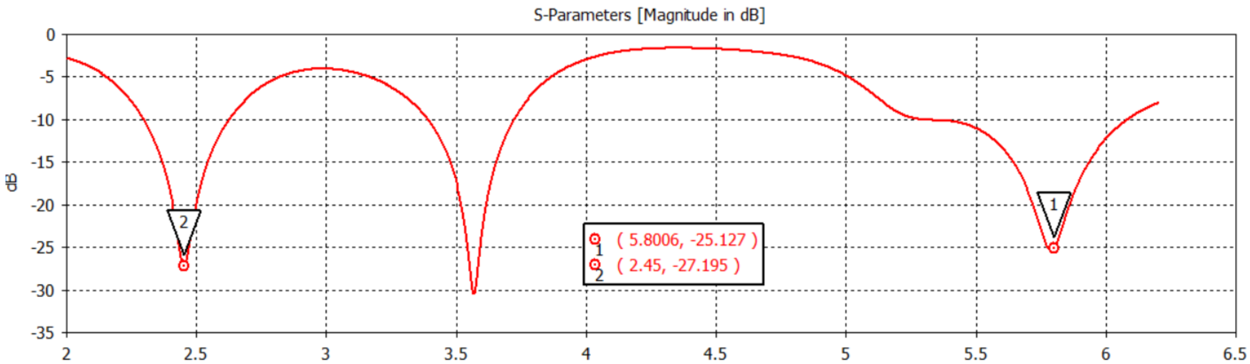


Figure 21: S11 Result of Vivaldi Antenna

3.5. Manufacturing

Since there was no preferable fabrication solution, and we found out that handmade solutions are not as erroneous as we expected, we chose to produce our antenna with UV exposure method just like last semester. However, we only have copper clads with not photoresist layer and unknown dielectric constants, additionally there was roger residuals. So, we needed to find a method to replicate photoresist layer and we wound out that there is a product called "Photoresists Dry Film", which is a film that we can apply to any board externally.

Figure 22: Photoresist Dry Film [14]

In ideal conditions, we needed lamination machine to get best possible result. However, we do not have and nowhere is willing to use their machine. On the other hand, we have a hot air gun in the laboratory, so we wanted to give a try with it as lamination. Moreover, we were lacking chemicals for the manufacturing, so we also supplied them.

- At first, a mask is supposed to be printed. So, we adjusted the area that is supposed to be etched as black and printed it on size on a transparent paper as seen in the figure 21.
- Then, we sandpapered the copper clads that we were going to use to have smoothes surface possible, and sticked photoresist dry film on it.
- We applied hot air at 100 celcius constantly for 5-10minutes to make it stick.
- We taped mask on the board and put it in an UV Exposure machine. We had Isel vacuum UV exposure device with 4 florescent tubes, 135 watt power consumption, so 5-6 minutes was appropriate for our application. This process develops photoresist layer.
- DEVELOPER: We put the board on a solution of Sodium Carbonate 4% room temperature to get rid of undevelopped photoresist areas.
- ETCHING: Since, there is no protecting layer on some areas, we can etch the copper there. To do this, we put the board on a solution of Iron (III) chloride 40% with boiling hot water.
- STRIPPING: To strip photoresist layer on the copper, we lastly apply solution of Sodium Hydroxide %5 room temperature.
- In the last step, we solder SMA connectors to the ports and test it with vector network analyzer if they work.

Figure 23: Manufacturing Steps

With this method, first, we produced a single patch resonant antenna to observe if we can guess the dielectric constant of the substrate material. This antenna in figure 24 is designed at 5.8 GHz with dielectric constant of 4.3. But VNA measurement plots a resonance at 6.05 GHz. From this result, we changed dielectric constant in the simulation and found that a dielectric constant of 3.95 gives exact resonance frequency. After this experiment result, we changed dielectric constant of our designs in simulation and optimize them with this value.

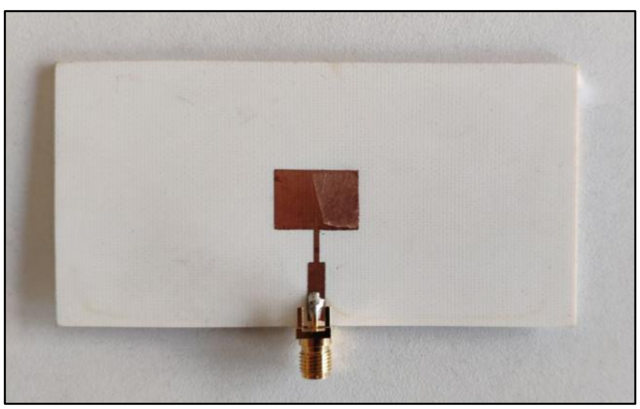


Figure 24: First Try - Single Patch Antenna

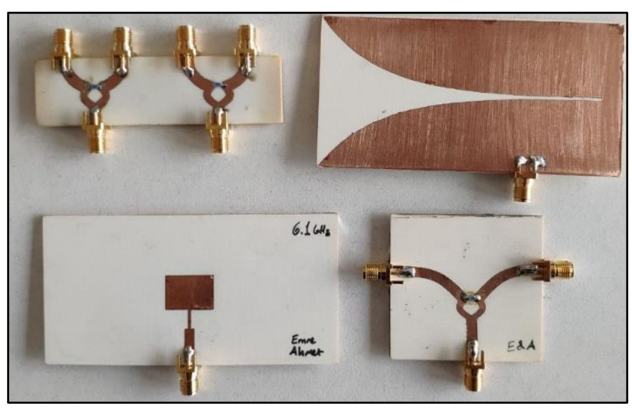


Figure 25: All components we produced

Some of them did not work as expected because of printing scaling and other resons but overall the method meets our needs, you can see all the components we manufactured in the figure 25.

4. RESULTS AND DISCUSSION

On the final, as can be seen on Figure 26, on the upper right, there are VCO, power amplifiers and splitters, on the upper left, there is combiner, mixer and broadband low noise amplifier.

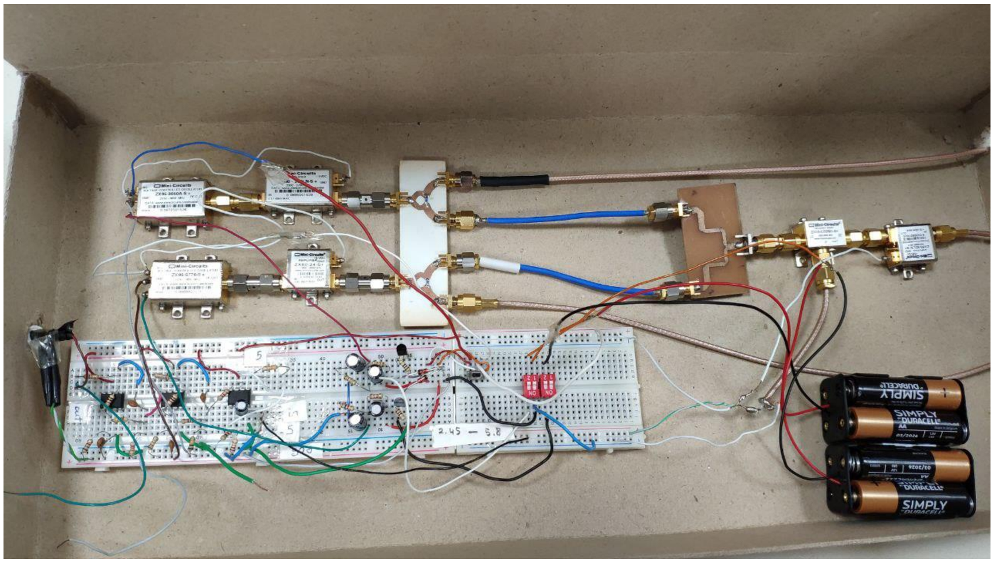


Figure 26: Inside of Final Design

When testing we generally used a reflective plate with RCS of 22 as seen in the figure 27, we swinged it and tried to observe a detection, in different situations. We also used two different configurations with known velocity to find if we get the reasonable velocity values.

Figure 27: Reflective Plate

Before testing we calculated the range of our radars with radar range equation. The final output powers and radar ranges are given in the following table.

$$\frac{P_r}{P_t} = \sigma * \frac{\lambda^2}{(4\pi R_1 R_2)^2} * \frac{G_{0t} G_{0r}}{4\pi}$$

Radar System	Amplifier Output	Tx Gain	Rx Gain	Calculated Radar Range
2.4 GHz	13dBm	7.5dBi	6.5dBi	21.49m
5.8 GHz	12dBm	8.5dBi	7.5dBi	13.24m

Table 2: Radar System Parameters (Measured) & Radar Range (Calculated)

4.1. Radar Range Test

To test range of the radars, we did an experiment by swinging the reflective plate in different range from 1 meter to 12meter. Started at 1m and continued with 2m, 4m, 6m, 8m, 10m, and 12m. The graph is simple time and velocity graph. Time is vertical and velocity is in horizontal axis. At the first swings when target is closer to the radar, we observe the signal with more power. Then it starts to decrease.

As seen in the figure 28, 2.45GHz doppler radar gives better results at further and 5.8GHz loses its power at the end of the measurement which is 12meter. This proves to theoretical calculations of radar ranges.

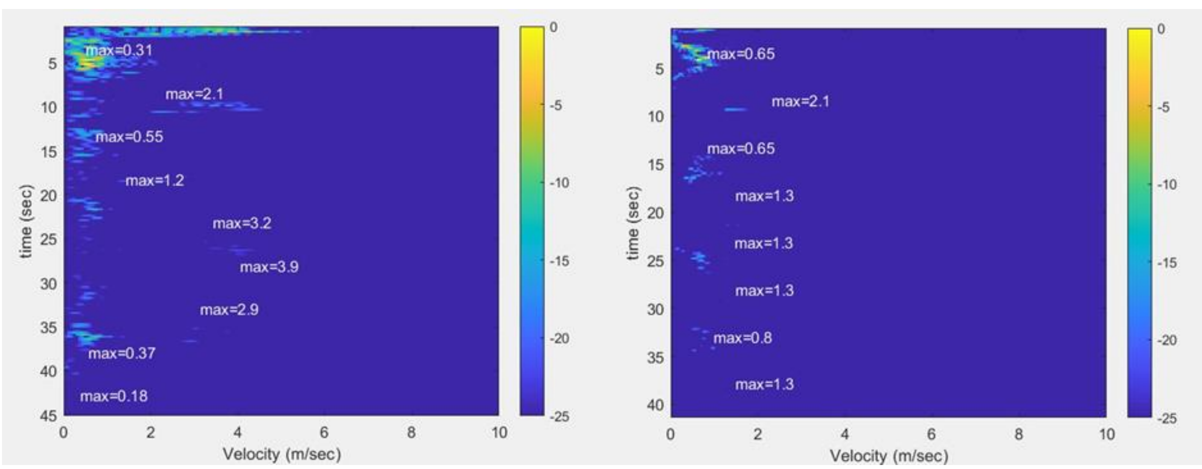


Figure 28: Using Reflective Plate at Different Distances

4.2. Pendulum Test

To see the accuracy of the radar, we did an pendulum experiment as seen in the figure 29. This is because, we can precisely calculate the speed of the pendulum by energy conservation principle just with the length of the rope. We found it as 3.9m/s at maximum velocity.

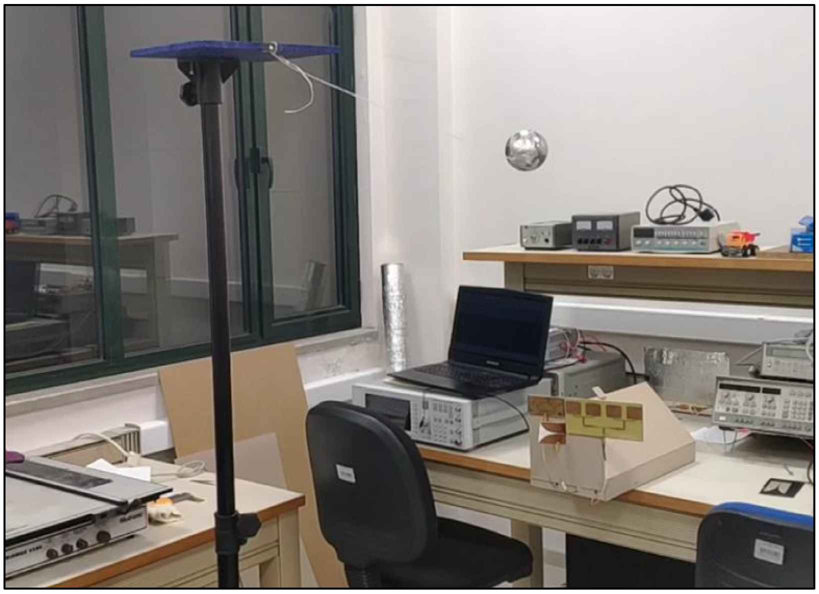


Figure 29: Pendulum Test Configuration

When we compare the result, the both radar can clearly see the pendulum swings. We dropped the ball at highest point and let it swing. So, exponential decrement was expected. Since our system can not detect negative velocity, we see forward and backward direction as same. For accuracy, they both close the 3.9m/s as seen in the figure 30. There is 10% error for 2.45 and 5% error for 5.8GHz.

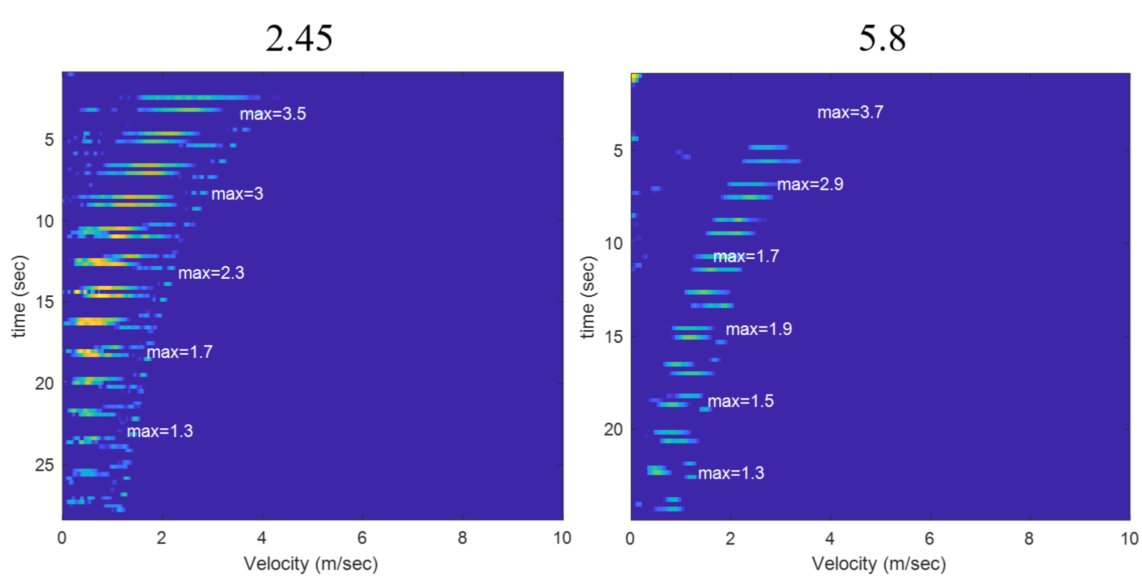


Figure 30: Pendulum Test Results

4.3. Running Test

To observe what radars detect when we run forward and backward, we did running experiment as seen in the figure 31. A target ran forward and backward with constant speed. Since we are in the range of both radars and the software take its reference according to maximum power, we expected to see similar figures.

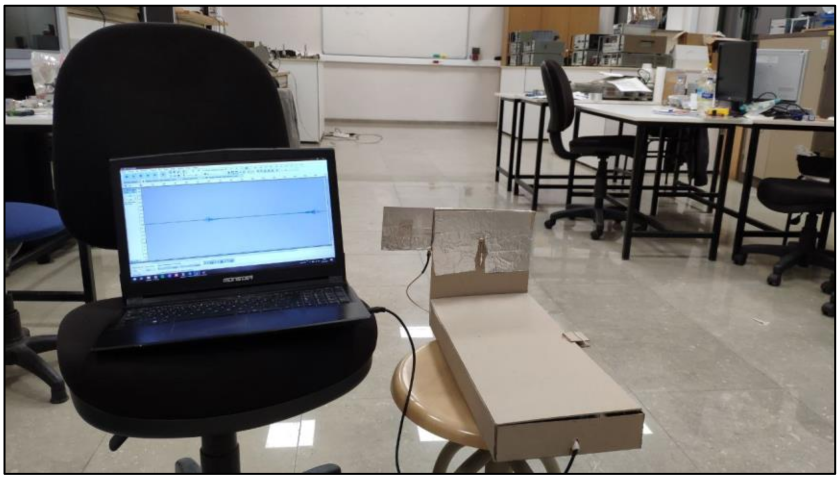


Figure 31: Running Test Configuration

As seen in the figure 32, at first target goes forward at the speed of 2.3 m/s and stops for seconds then comes back at the same speed. Both radar measurements are same as expected. Normally, radars also see the target in the middle of the time but when we adjust the software to eliminate the noise, we also lose those signals too. This is a tradeoff for doppler radar. In other words, if we want to see further, we lose accuracy.

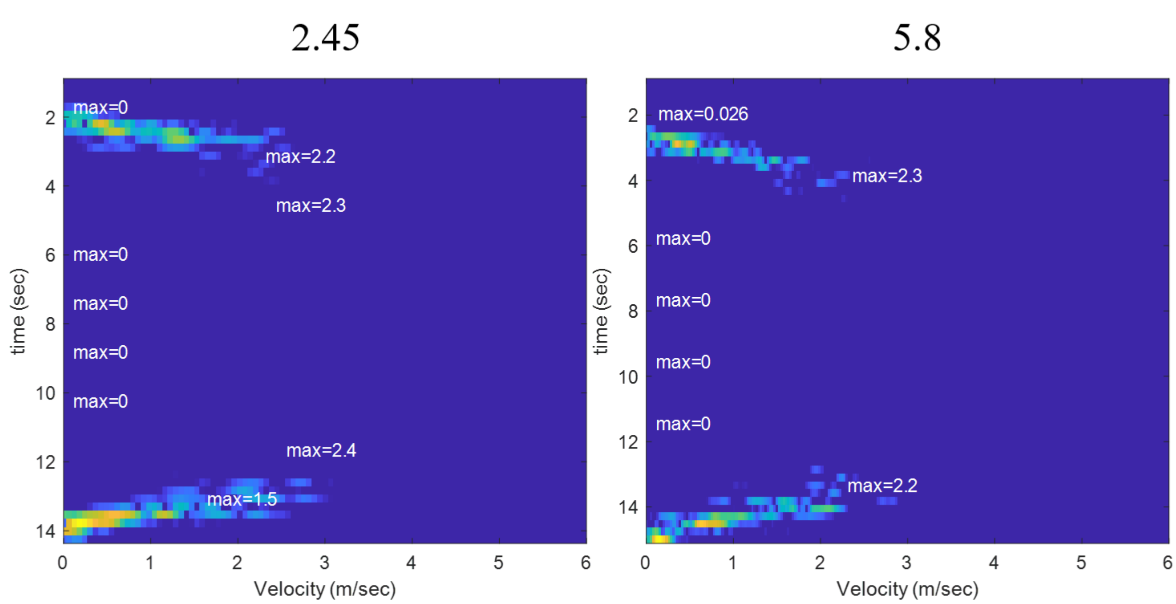


Figure 32: Running Test Results

4.4. Door Test

For the next experiments, we measured how the radar differs when there is an obstacle in front of it. We started it with a 5cm wooden door as seen in the figure 33. Similar to the radar range test, we swinged the reflective plate at definite positions to see if we get a signal back.

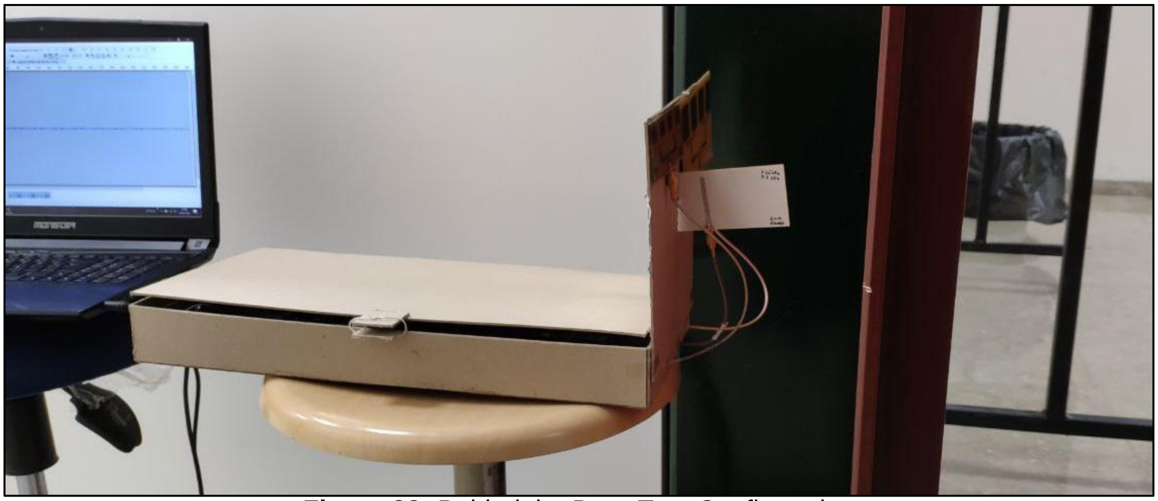


Figure 33: Behind the Door Test Configuration

We see that when there is an obstacle, received power decreases and noise starts to dominate. Therefore, to see the detection more clearly, we applied different thresholds to both of them which shows that there is a tradeoff between high power velocity accuracy and low power detection. In other words, when there is a low threshold, at powerful velocity component, we see noisy figure but when we want to make it more precise, we loose the signal with low power. We can see this phenomena in the figure 34. As seen, 2.45GHz doppler radar can detect the target 5m away behind a door.

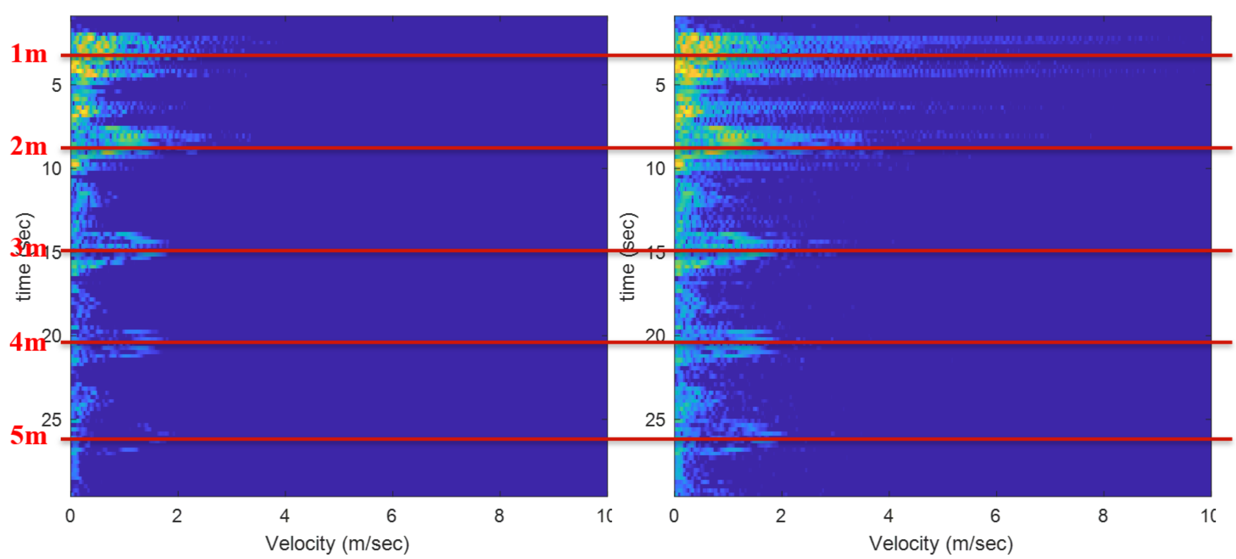


Figure 34: Handrail Test Result, -35db Threshold (left), -45dB Threshold (right)

As we see in the figure 35, 5.8GHz doppler radar cannot detect the target after 3meter. Even though we see little signals at lesser threshold, it is not significant. It was expected because higher frequencies tend to attenuate more than lower frequencies.

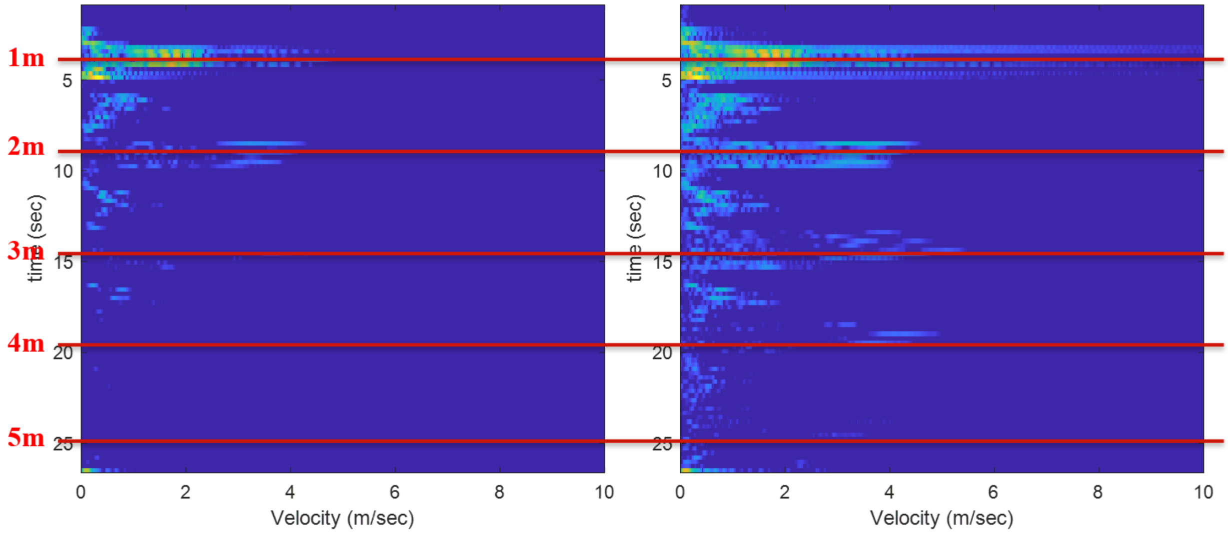


Figure 35: Handrail Test Result, -35db Threshold (left), -45dB Threshold (right)

4.5. Wall Test

To extend the experiment we followed it up with a 22cm concrete wall experiment as seen in the figure 36 with similar procedure, but we expect weaker signals this time.

Figure 36: Behind the Wall Test Configuration

Just like door experiment, power decreases when the target gets further and 2.45GHz gives better result. Since 5.8GHz has weaker signals, it has more noise as seen in the figure 37.

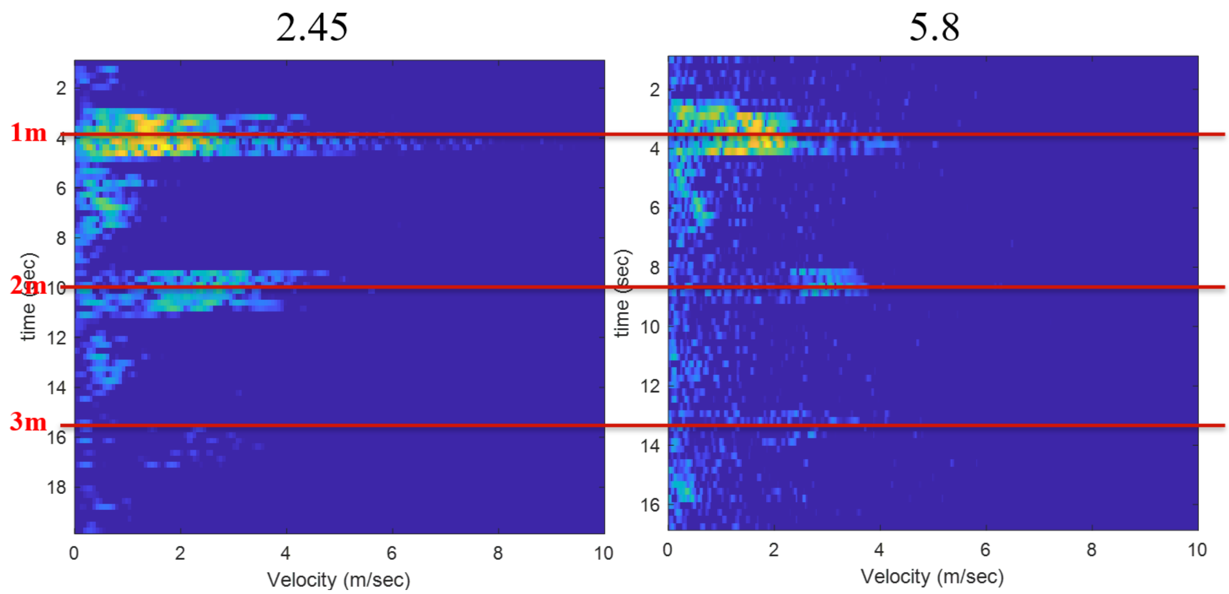


Figure 37: Behind the Wall Test Result, -30db Threshold

4.6. Pillar Test

To finalize the obstacle experiment, we did measurement behind a pillar as seen in the figure 38. We expect to see very little power because the pillar has a lot of metal rod which reflect the signals back and it is quite thicker than other obstacles.

Figure 38: Behind the Pillar Test Configuration

As seen in the figure 39, the target movement is lost. Even if we get some signal, noise clearly dominates it. So, we can say that both of them cannot detect anything behind the pillar.

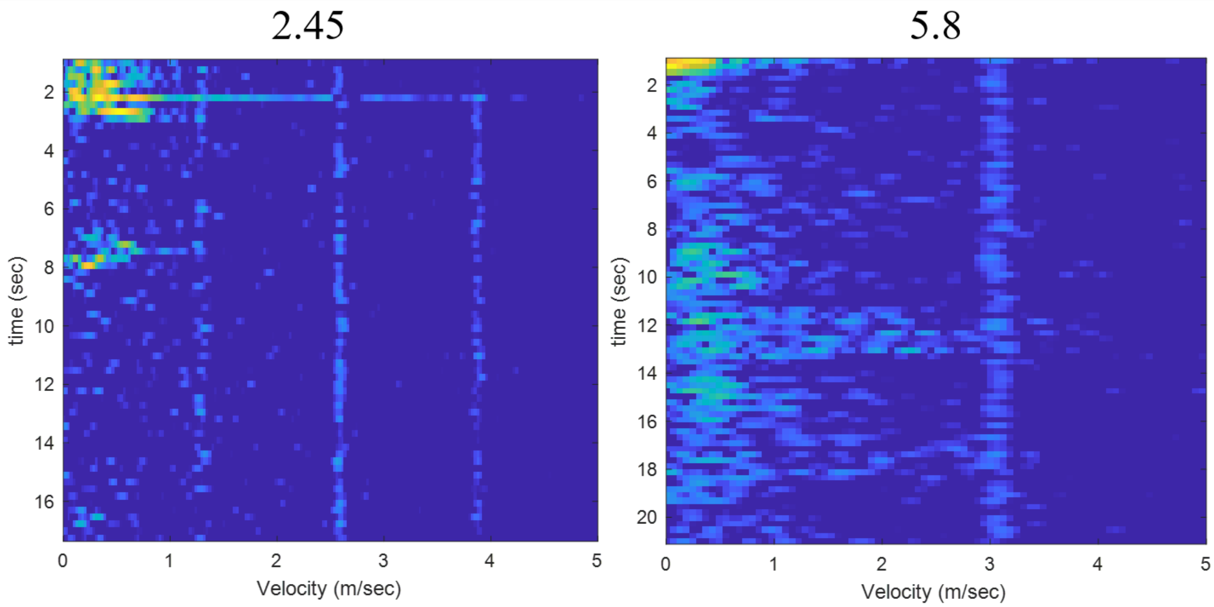


Figure 39: Behind the Pillar Test Result – -30db Threshold

4.7. Handrail Test

For the next experiment, we wanted to compare the radars when there is scattering particles in front of them. To mimic this situation, we put the device behind handrail as seen in the figure 40 and started to record. We wanted to see the characteristics of radars when there are reflective particles and objects separated in the way of target.

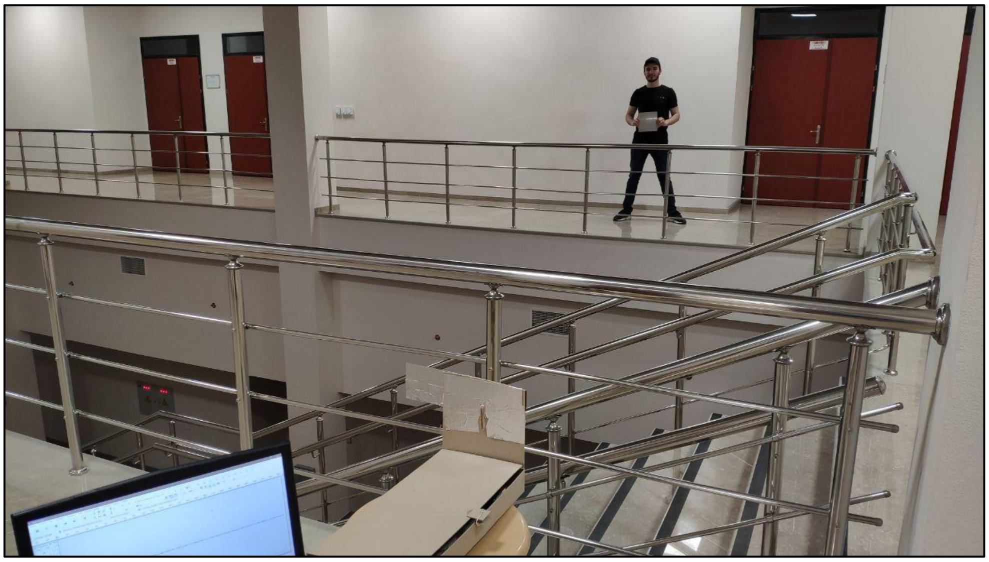


Figure 40: Handrail Test Configuration

As seen in the figure 41, there is slightly difference between the measurement, but we cannot say that if any of them better than other one. Both of them can detect the target clearly.

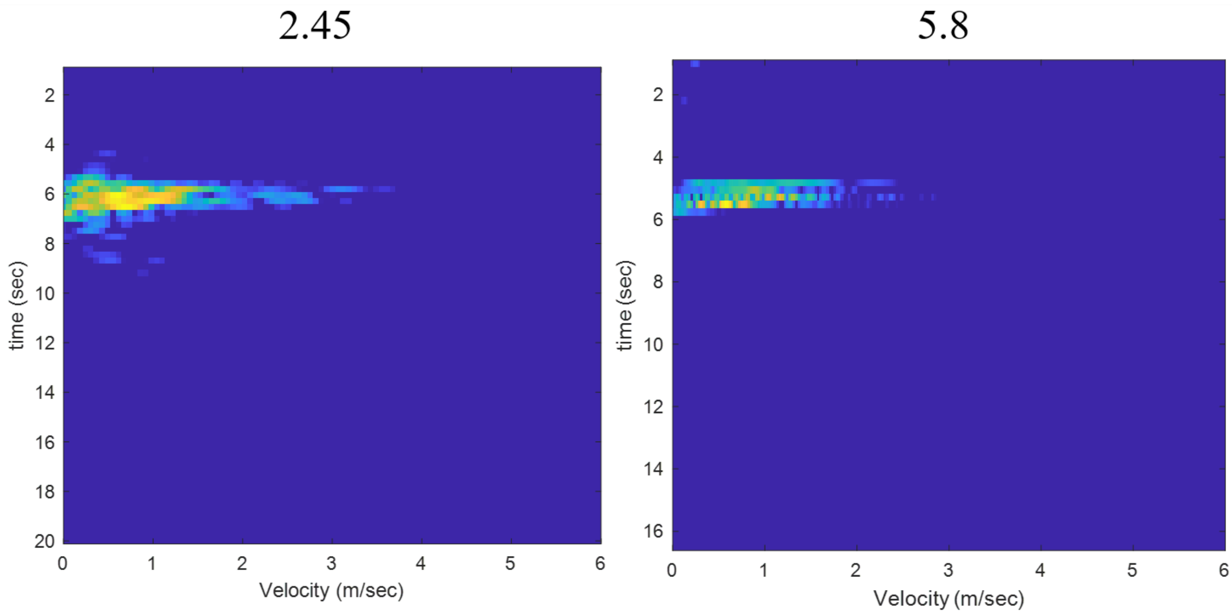


Figure 41: Handrail Test Result – 30db Threshold

4.8. Car Test

For the last experiment, we wanted to test if the radar can capture relatively high-speed target. Since car is a metal and big target, it has high RCS, approximately 100, which causes the radars to detect it more easily. For the experiment, we locate the radar as seen in the figure 42 and the car passed with speed of 18.6 m/s.

Figure 42: Car Test Configuration

As we see in the figure 43, 2.45GHz radar captured the speed clearly and accurately. There is just 3% error which comes from angle of the radar.

2.45

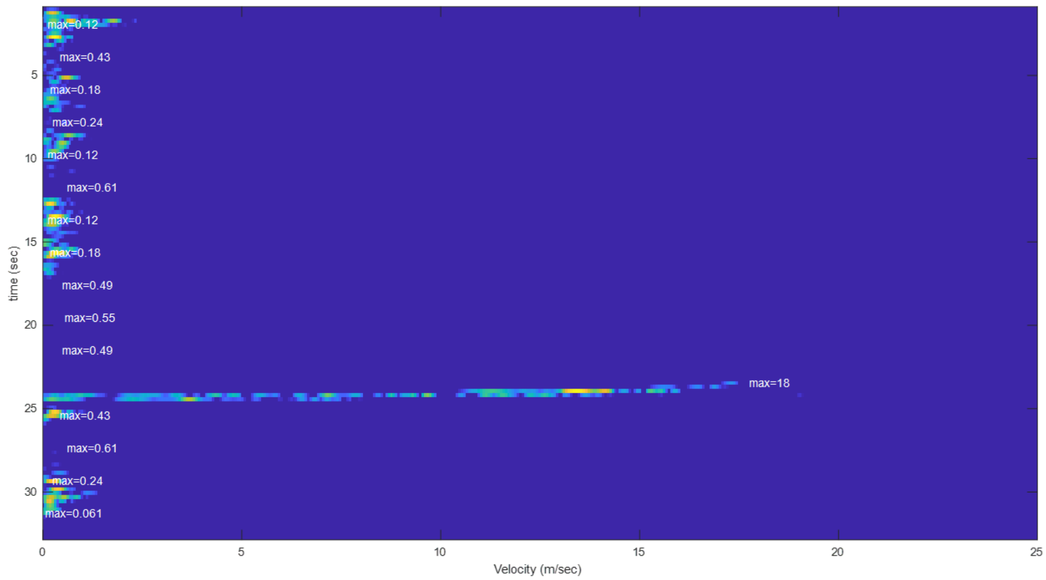


Figure 43: Car Test Result – 20dB Threshold

Again, for the 5.8GHz radar, we can clearly see the speed of the car which has slightly more error, %5, as seen in the figure 44.

5.8

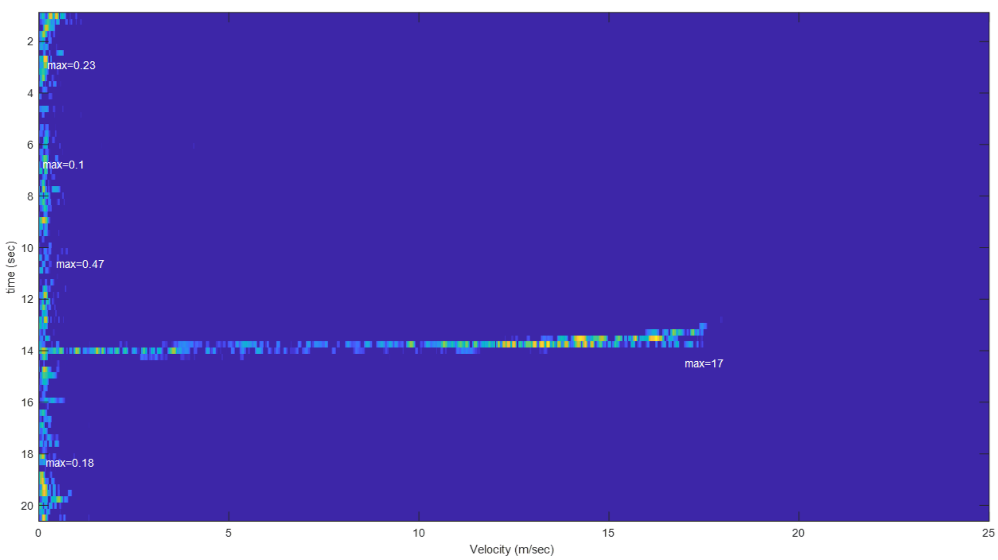


Figure 44: Car Test Result – 20 dB Threshold

4.9. Overall

Overall, we can say that 2.45GHz doppler radar performed better for range experiment and through wall experiments which were expected. On the other hand, for scattered particles and high speed high RCS velocity measurements, we cannot say that any of them is better. This is because, at the both situations we were not at the limit of the radars to see the difference.

	2.45GHz	5.8GHz
Range	✓	
Through-Wall	✓	
Scattered Particals	-	-
High Speed	-	-

Table 3: Comparison of the radars

5. CONCLUSION

In conclusion, it is expensive to order PCB from other companies, but we clearly see that with some devices and chemicals, we can produce our board precisely. Worth mentioning, manufacturing process is dangerous and tedious. Therefore, we would not recommend it if there were chance to order from professional companies.

Secondly, even though power circuits seem relatively simple, in practice, it gets complex and neglected parameters adds up to deflect expected results.

Next, surely there are differences between 2.45 and 5.8GHz doppler radars for small range usage. However, according to application we can prefer one on other. For example, 5.8GHz antenna is much smaller, so it can be preferred for size mattered applications. On the other hand, for range applications 2.45GHz can be preferred due to its higher range. However, we could not conclude a result for scattered particles and high speed car measurement experiments. They are both usable for the situations.

Although, we added a lot of features on this device. It can be improved with more stable power supply and better power amplifiers. It still has some gap to develop for better system.

Lastly, we think this that this system can help others to experiment frequency comparison applications and other doppler radar studies.

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