ECE – 449 : Target Indication Radar

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Abstract: The following paper details the construction of a continuous waver radar, proposed through the senior design project at Miami University. The purpose of this project is to implement a cost efficient and working radar. Currently, the majority of radars are only available for military use, and are too expensive for the everyday consumer. The goal was to create a radar for home security purposes that could be made both affordable and available in typical consumer markets.

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I. Introduction and Types of Radar

Radar is a device that uses electromagnetic waves to detect objects. It does so by propagating electromagnetic waves through a waveguide and into the atmosphere. It then listens for an object's backscatter or echoed signal. From the returned signal, a radar detector can calculate range, speed, acceleration, altitude and many other target parameters. Such parameters are typically used to make decisions, such as launching a missile, landing a plane or predicting the weather.

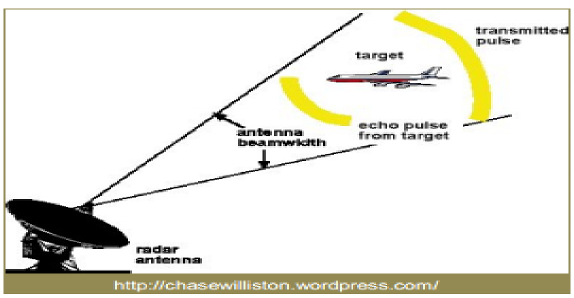

Figure 1: Basic Operation [4]

Pulsed Radar works by sending a pulsed electromagnetic wave through the atmosphere. Pulsed Radars are excellent at range finding. They are able to do so by calculating the time between transmitted and received pulses. Pulsed radars perform this functionality with the help of an oscillator and high frequency switching [1]. The oscillator is responsible for generating electromagnetic waves. It functions by oscillating between voltages at a frequency determined by the designer. Typical frequencies are in the Megahertz or above. Larger frequencies allow for smaller antennas, which is why larger frequencies are typically chosen. Oscillators are large tubes, magnetrons or klystrons. Solid state oscillators are starting to make an appearance, but have been hindered by the large power requirements of radar [1]. The switch is used to pulse the radar on and off. High frequency switching is used to shrink blind range. Blind range is the dead space between the radar and its minimal detection range. An acceptable pulse width is usually one microsecond, which corresponds to a blind range of 150 meters [2]. A target in the blind range can't be detected.

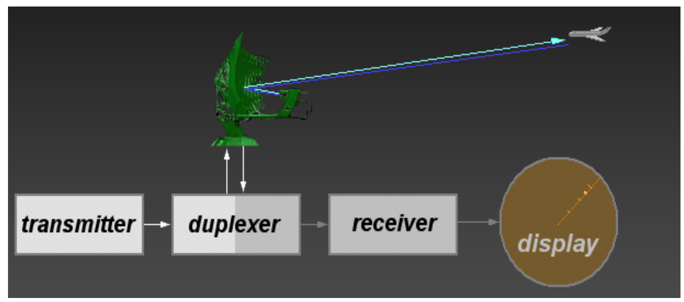

Figure 2: Pulsed Radar [2]

Continuous wave radars constantly transmit and receive. This practicality means there are usually bistatic. Bistatic radar refers to a radar that uses two antennas, one to transmit and one to receive [1]. Continuous wave radars are used in early warning systems. They work by searching the spectrum for a peak that corresponds to a difference in a transmitted received frequency. The difference in frequency is known as the Doppler shift [1]. Once found, the Doppler shift lets the radar know a target is present and allows the targets velocity or speed to be calculated. Continuous wave radars can also perform advanced features by observing the peaks move within the spectrum. Such features may includes calculating acceleration or determining if multiple targets are present.. The down fall of continuous wave radars is that they can't calculate range as easily as pulsed radar. They normally have to incorporate frequency modulation to determine range.

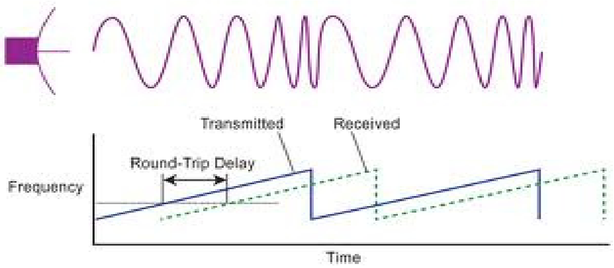

Figure 3: Continuous Wave Radar [3]

Phased array radars are radars that use hundreds of antennas, which are commonly referred to as an antenna array [1]. Phased array radars are slowly becoming the radar of choice in military applications as they have the advantage of electronically steering the radar beam. This method allows the radar to have a 40 degree steering angle in all directions [2]. The steering angle degrees is not a set number, it depends on the radar design. If the radar beam is shifted further than the specified maximum angle, there will be drops in gain and other complications. Another advantage of phased array radars is that they can track multiple targets in diverse directions. Phased array radars can function as multiple radars. Once a target is detected, some of the antennas can be set to track the target while the other antennas can function as separate radars and search for other targets [1].

Figure 4: Northrop Grumman Phased Array Radar [4]

Synthetic Aperture Radar is a method of radar imaging. It works similar to phased array radar except that the spaced antenna elements are achieved at different times [2]. It's able to create a high resolution image by time multiplexing instead of using multiple antennas [2]. It uses this method along with the entire flight path of the radar to synthetically create a large Aperture and thus a high resolution image. The phase and amplitude at each instant in time are stored and later reconstructed to create the map or image [2].

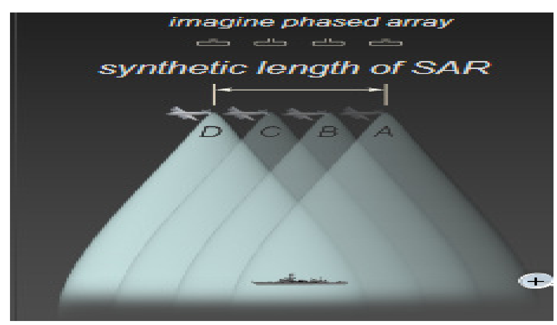

Figure 5: Synthetic Aperture Radar [2]

II. Background

The principles of radar were first discovered by German Scientist Heinrich Hertz, in the late 19th century [5]. Hertz built upon the work of James Clark Maxwell, and became the first scientist to produce and detect electromagnetic waves [5]. He later discovered electromagnetic waves could propagate through and reflect off of metallic materials. Such properties laid the foundation for the invention of radar [6].

Figure 6: Heinrich Hertz [5] [6]

The first usable radar was designed to warn ships of possible collisions during poor weather conditions [6]. The systems were designed and demonstrated by German scientist Christian Hulsmeyer, in 1904 [7]. He implemented his radar using a spark gap, dipole antenna, and a parabolic reflector [6]. The spark gap functioned as a type of oscillator that produced electromagnetic waves, which were propagated through the atmosphere using the dipole antenna. The reflector gave the radar the ability to focus its' radiated energy in a certain direction. Once the backscatter from a neighboring ship or object was detected, a bell was sounded to warn the ship's captain. He patented his device under the name of Telemobiloscope, but was not commercially successful [6]. It was during the Second World War that radar systems saw rapid advancement because of its apparent military applications. .

The 1940's were a time of war, and the reason for a newly sparked interest in using electromagnetic waves to detect enemy ships and aerial vehicles [8]. The terminology, Radio Detection and Ranging (RADAR) was give to such devices during this era. Radar is now known as the weapon that won the war and the invention that changed the world [8]. Radar made it not only possible to detect and engage enemy craft during night fall, but to serve as an early warning system to prevented enemy sneak attacks. Such devices were capable of detection up to 100 miles [8]. Smaller radars installed in aircraft could help pilots navigate and detect enemy vessels within a 2 mile radius [8].

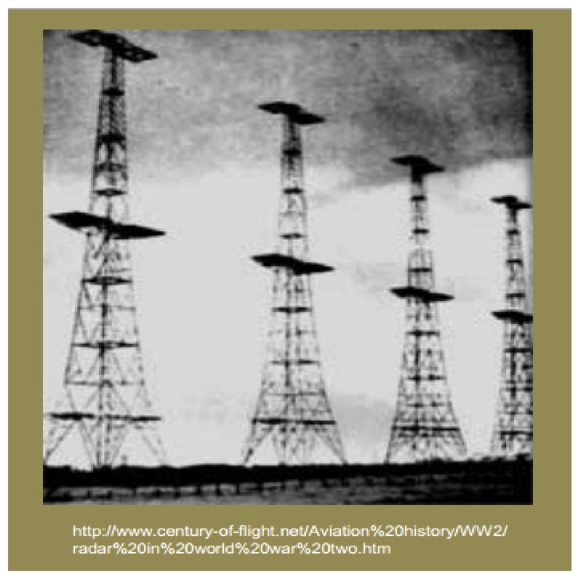

Figure 7: World War 2 Aircraft Radar [8]

Radar has now taken over the world and is used in various applications. Radar is still highly used by the military for surveillance, navigation, target detection, tracking, active homing, and imaging.Radar has reached other markets. Radar is now used to predict weather, analyze the atmosphere, map other planets and help daily drivers avoid collisions. Radar has proven itself reliable and useful. Modern technology has even reduced the size of radar enough to make it a mobile unit. Such radars can be found in law enforcement, sports and in military reconnaissance.

Figure 8: Mobile Radar [9]

III. Objectives

The objective of this project was to successfully create a working and affordable surveillance radar which implements both target detection and speed sensing capabilities. The main idea is to show the price of radar systems can be reduced significantly from those used in the military so that radar systems can reach consumer markets. Radars could then become an available and alternative option to consider in a surveillance or home security scenario.

Currently, the major forms of personal home security include proximity sensors, alarm systems and video surveillance. Each one of these options is a valid solution for home protection. Each approach has a flaw that can drastically decrease their effectiveness.

Proximity sensors offer a nice and cheap way of providing your house with an early warning system. The problem with proximity sensors is their range typically maxes out near 70 feet [10]. Many of these sensors have also become empty threats. They are being produced without alarms and solely rely on lights to scare intruders away [11].

Home alarm systems are valuable in many cases and depending on the amount of money you spend, they can be highly effective. Systems can vary in price from under $100 all the way up to over $600 [12]. They will protect all doors, windows, and other possible points of entry specified by the costumer. The major drawback of these systems is that they are only effective after an intruder has physically entered the household. Alarm systems falter because they offer no form of early warning.

Video surveillance is by far the most popular choice of high end security. Video provides the user with a recording of any intruder that enters their property line. Cameras also one-up the home alarm systems because they can be placed both within the home and outside of the home. The first negative quality of video surveillance is price. Prices on the low end are around $700 and higher end cameras may be up to $20,000 [12]. Video surveillance's second drawback is that while it does present you with a video image, this image is subject to distortion and altercation by factors, such as weather and lighting [10].

Although each of these devices has their advantage, radar may be a viable option to make up for their disadvantages. Radars can usually see in all weather conditions where a camera may fail. Radars can scan 360 degrees and have a larger detection range than proximity light sensors. Radars can send a warning before an intruder has physically entered a household. Radar could even be incorporated with these devices to create a more secure, security or surveillance network. Radar may not always be the correct way to go, but it should be an option to consider.

IV. Literature Research and State of the Art Review

To get started, much work was done in researching relative information on past projects with a similar background. Principles of Modern Radar by M.A. Richards provided the answers to many basic types of radar questions. This book also assists and walks through the step by step calculation of many important fundamental radar equations. The other piece of literature that played a large role in assisting with the hardware requirements was the *Radar Tutorial* presented by a group of MIT students who constructed their own radar. They provided a step by step process of how to physically construct their version of a continuous wave radar. With the combinations of these two specific resources, the rough skeleton of the radar system was formed. The information was used as an initial stepping stone to construct and build a machine that improved upon what their information provided to the general public.

V. Design Proposals and Analysis of Alternative Proposals

Our first proposed design was a pulsed radar capable of only determining a targets range. Unfortunately, there was difficulty in finding an affordable and implementable solution. The first problem was developing a pulsing scheme. The idea was to build a radar system that could detect targets the size of an average human, in an area the size of a typical yard. However, to create such a radar system, the switching speed needed to be in the gigahertz. If not, the blind space would be Large (150m-1us), thus making it an unreasonable product for the average Joe. Secondly, components that can handle switching or even oscillating in the gigahertz are expensive.

The second problem was data acquisition. Sampling in the gigahertz is a very costly solution. An analog to digital converter of that caliber can cost more than a $100, and a capable data acquisition board in the $1000's. The solution was to down beat to a lower frequency that could be sampled cheaply. This solution would add more complexity and make the radar more difficult to implement. It was determined a pulsed radar was out of the question.

The second proposal met the objectives and avoided the problems experienced with pulsed radar. The solution was to switch to continuous wave radar. The continuous wave radar worked by extracting only the Doppler shift, which in the case of a walking or running human being was low enough to sample cheaply. An analog to digital converter was purchased for less than $1and a processor for approximately $35. The disadvantage to this apparatus was an increase in difficulty to determine a targets range. Frequency modulation or a similar technique would need to be added to measure range accurately. However, the continuous wave radar made it easier to calculate a targets speed. Once a target is detected, its' speed can be calculated with the help of a Fast Fourier Transform algorithm.

The next step was to determine if the physical construction of a continuous wave radar would be feasible within a semester. Unfortunately, without having classes focusing on microwaves or microwave components, this became a difficult task. An MIT course that walks through the construction of a continuous wave radar was very helpful, and specified where to obtain the corresponding microwave components [13]. This left us to designing the antennas, sampling method and processing portions of the radar. From here it was decided the implementation of a continuous wave radar would be the most suitable option.

VI. Design Implementation

The design of a continuous wave radar system was based off of the MIT Cantenna design [13]. However, the Cantenna Radar was re-invented to both make it better, and to meet the needs of the project. To meet project specifications, the radar needed to be a complete and mobile system. To accomplish this goal, antennas were designed, a sampling scheme was created, and a processor was embedded to determine how to analyze data in real time.

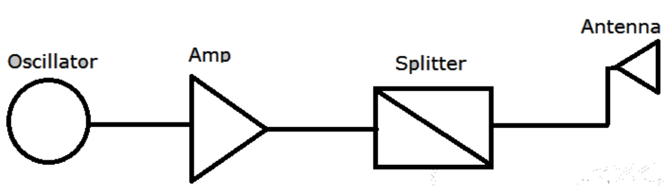

Figure 9: Transmitter [13]

The transmitter was built using a voltage controlled oscillator, low noise amplifier, splitter, and antenna. The oscillator creates a sinusoid between the frequencies of 2.3-2.5 GHz. The frequency corresponds to 0V being 2.3GHz and 5V being 2.5 GHz. In-between frequencies can be created by varying the voltage between 0V-5V. The amplifier increases the sinusoids amplitude before going to the splitter. The splitter sends half of the sinusoids power to the antenna and half to the receivers' mixer. The antenna propagates the electromagnet wave through the atmosphere to reflect off of a nearby target.

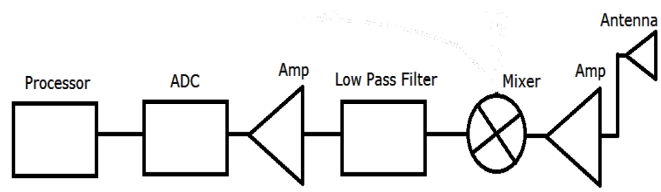

Figure 10: Receiver [13]

The receiver was built using an antenna, two amplifiers, a mixer, a low pass filter, an analog to digital converter, and a processor. The antenna receives the electromagnetic waves that reflect of off a target. The reflected waves are then amplified and sent to the mixer. The mixer multiplies the transmitted frequency with the received frequency. Multiplying the two frequencies together creates and upper and lower sideband (Fsent+Freceived & Fsent-Freceived). The lower sideband is extracted using a low pass filter and then amplified before reaching the analog to digital converter. The analog to digital converter samples the lower sideband and outputs a corresponding 12bit number. The 12bit number is sent to the processor where it's processed using an FFT algorithm.

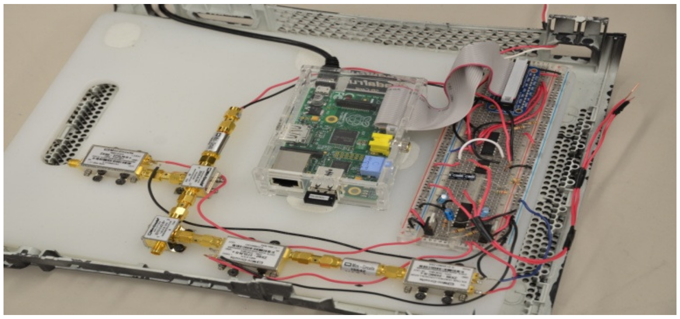

Figure 11: Fully Implemented Transceiver

The processor uses the decimation in frequency FFT algorithm to search the right half of the spectrum. If a peak is found anywhere besides 0 Hz, a target is declared by sounding an alarm. To cut down on false alarms, a threshold of two detections was used. The targets speed was then calculated using the equation $Fd = 2V/\lambda$, and displayed on an LCD screen along with the Doppler frequency. The selected processor was a Raspberry Pi. It was chosen primarily based on its low cost and processing speed.

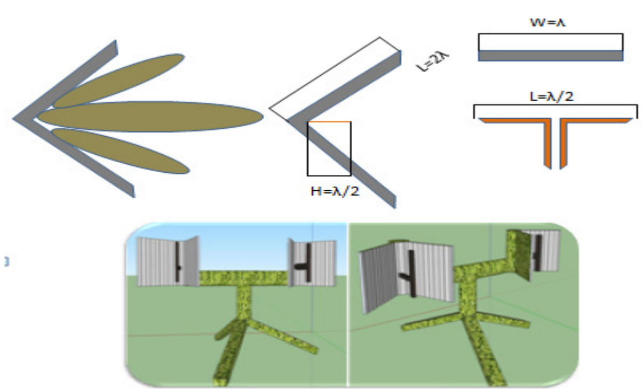

Figure 12: Corner Antenna specifications [14] [15]

Corner antennas were designed with the guidance of Antennas for All Applications by John D. Kraus [14]. They were constructed using a half wave dipole and sheets of aluminum bent at a 90 degree angle. The dipoles were created by soldering copper wire to a piece of coax that was rated up to 3GHz. Impedance matching was ignored because the reflection coefficient was found to be very small (.1). The antennas were then attached to a camera tripod using PVC piping. The entire antenna system was designed with mobility in mind.

VII. Evaluation and Analysis of Final Product

The final product was a $400 early warning and speed calculating radar system. It was easy to set-up, highly mobile, and able to detect a target the size of a human up to 80ft away. The product was successful, but it did have downfalls. Range detection was not implemented and the system functioned only if motion was present.

Range detection required the use of frequency modulation and was declared unreasonable to be implemented in a semester. However, all of the components to implement range detection were purchased, so the $400 includes the cost those components. There was also the problem of sampling at a high enough frequency to determine range. This problem occurred because of issues in the analog to digital converter. The max sampling frequency was 4 KHz, which meant the bandwidth was only 2 KHz. 4 KHz was fine for measuring the Doppler shift of a human, but range finding required higher sampling rates.

The good news is the radar was able to calculate speed and the alarm system worked well. If an intruder entered within 80ft of the radar, the alarm would sound and anyone in the area would be warned. The problem was that if an intruder stopped walking, the alarm would quit sounding. This was not a big issue because as soon as the intruder moved again the alarm would sound. The problem occurred because the radar relied on the Doppler shift to detect a targets presence. This meant motion was required to enable detection. However, this method was determined to be a better solution than threshold detection. When using threshold detection, an intruder could be easily masked by a large object. The radar was designed to be placed in a yard or small building, which meant walls, trees or other objects would create larger threshold values than a person: not to mention the threshold would have to be calibrated every time the radar was moved. These issues forced to focus on motion sensing.

VIII. Ethical, Social, Economics and Other Issues

As part of the great country known as the United States of American, every action and step taken towards advancement should always be met with the highest ethical, social and economic standard. With radar or any other form of surveillance the invasion of privacy is a large social and ethical issue that many have wrestled with over the years.

The radar system created currently acts as an early warning system that will alert a user of any disturbance in its path. However, such a system could be used for unethical purposes. For example, the radar should not act as a system used to spy on those who are not trespassers or intruders. The unethical dilemma arises when this device is manipulated for malicious purposes. By no means should the radar be used to track individuals of a specific person's interest. The radar is meant for home security purposes only.

To further portray ethical and social dilemmas of this product, the radar should not be made available to known criminals. Criminals such as drug smugglers could easily use radar to set up a perimeter to keep their unethical operations hidden. If the local authorities or the FBI were to close in, the radar may warn the smugglers in enough time to get rid of all illegal substances. This problem would of course keep criminals on the street instead of behind bars where they belong.

IX. Conclusion

Proof of concept has been provided. With modern technology and a little ingenuity, the price of radar systems can be greatly reduced from those used by the military. We have shown speed determination and an early warning system can be implemented under 400 dollars. However, in our original proposal we planned to implement range finding. We were not able to complete this task as time ran out. We also ran into analog to digital converter issues that limited our bandwidth. With a better analog to digital converter and more time, we may have been able to implement a full tracking radar that could potentially rival mobile radars used by the military.

Economic issues may arise if the radar were to strategically outsource competitors. This aspect would put competitors out of business. From a company stand point this is a good thing, but from an employee's point of view this is bad. Individuals may lose their jobs and their lively hoods as well.

Unfortunately, this is a common problem Americans are forced to deal with every day.

X. Future Work

Future work with this particular system needs to be fixing the sampling issue, increasing detection distance and implementing range finding. The addition of steering the antennas would also be helpful.

With higher sampling frequencies the radar should be able to sense objects, such as fast moving cars or airplanes. This added feature could expand the radars applications and makes it a more marketable product. An increase in detection range would also benefit this feature. The radar could sense targets at greater distances and determine speed quicker.

The added benefit of range finding would change the radar completely. The radar would be able to fully track an intruder and let the user know exactly where an intruder is on his or her property. If an intruder escapes, the escape route could even be specified. It would also make it easy for a user to know when to phone for help. For example, someone may mistakenly venture onto a costumers property, but then quickly leave. In this scenario, the customer would know where the intruder is, but would not need to phone for help, unless the intruder was approaching the house.

Antenna steering would allow a costumer to monitor their entire property. They could setup predetermined scan routs and spin the radar 360 degrees. This would allow the costumer to place the intruder on a map of their property. Instead of only knowing how far they are away from the radar, they would know what angle the intruder is within the circumference of the detection range.

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