The Applications and Advancements of Radar and Radio Technology

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1 Abstract

The study of radios and radars has allowed for easier ways of communication. Radio and radar technology is a part of our daily lives and is important in various fields. Often, people ask what the applications of radars are and radios in our modern world. Some of the most widely recognised applications in radar technology include weather monitoring, military surveillance, and air traffic control, while radio technology finds use in wireless internet, mobile communication, and navigation systems. In our research we observed and studied the use of a millimetre-wave radar sensors and the different digital modulations used in wireless communications. Through experimentation in a real-life lab environment, we tested the radar sensor with different targets including a plate in motion, tuning forks, and a metronome. Thus, allowing us to visualize the different frequencies objects can be detected at. We then performed an experiment in the lab to visualize the different digital modulations through an energy constellation and waveform diagram including BPSK , QAM, 8PSK, 16PSK, 16QAM, 32QAM, 64QAM and 256 QAM. After experimenting we concluded that the millimetre wave radar sensor is possible of detecting objects while moving and at different speeds. It was also found that the constellation diagrams that we collected in the lab from the different digital modulations compared with the theoretical ones and that maximum number of symbols is related to the energy of the constellation. The symbols must be clearly separated from each other in order to keep the demodulation errors low.

2 Introduction

In today's world, we are surrounded by advanced technology that rely on wireless communication which are included in applications such as smartphones, GPS's, airplanes, cars, and ships. With the advancement of technology radars and radios have changed the way we communicate, gather, and spread information. The question that often looms largest is: what are the applications of radars and radios? These two technologies have been around for decades and have undergone numerous advancements since.

In the 1890s Italian inventor and electrical engineer Guglielmo Marconi, known as the founder of the radio was the first to develop wireless telegraphy.[10] Marconi first demonstrated wireless communication by sending a radio signal across the Atlantic Ocean in 1901. To do this Marconi used a transmitter to create a high frequency radio wave in which was sent through an antenna in a specific direction. On the other side of the Atlantic Ocean was a receiver to pick up the signal tuned to the same frequency as the transmitter. Using morse code Marconi was successfully able to deliver the message "S".[4]

Invisible to the human eye, radio waves can be modulated to transmit music, pictures, videos, and various other information etc. Radio waves are electromagnetic waves and can be sent between frequencies as low as 17 kHz up to 300 GHz, corresponding to wavelengths of 17, 6 km to 1 mm, respectively. To transmit information, the radio waves must be modulated. Analog modulation was first used, before the creation of computers, which involves transferring low frequency signals, such as voice or low-resolution video (VHS quality). The most known analog modulations are AM (amplitude modulation) and FM (frequency modulation).

Digital modulation involved transferring digital data through radio frequency (carrier) using modulation techniques such as Frequency Shift Keying (FSK), Binary Phase-shift keying (BPSk), Phase Shift Keying (PSK) and Quadrature Amplitude Modulation (QAM). This encodes the information given by the signal into the amplitude, phase and or frequency from the transmitted signal and allows data-rates up to Gb/s using millimeter-waves.

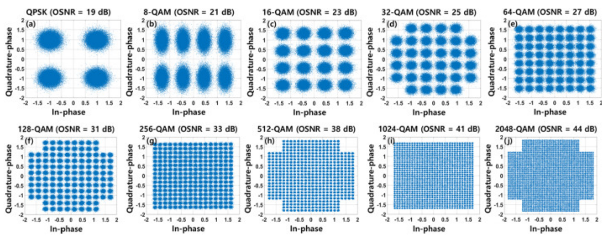

Figure 1: Image of modulations [7]

In 1904 Electrical Engineer and physicist Christian Hülsmeyer introduced the first radar system. He invented a device using radio waves that had the capability of detecting object made of metal at long distances.[10] Hülsmeyer called his invention, the Telemobiliscope and it worked by transmitting radio waves which reflected of an object in which the echo was picked up by a receiver. Hülsmeyer invention led to advancement of radar technology and is used to today in several different radar systems such as sonars and more. Radar's function using a process modulation and demodulation. [3]

In our research at the INRS (Institut National de la Recherche Scientifique) with the help of Prof. Serioja Ovidiu Tatu we conducted several experiments using radio waves. Our first experiment included testing a millimeter-wave radar sensor operating a 24 GHz. Using a digital oscilloscope, we analyzed different reflected signals from various targets such as a metallic plate in motion, tuning forks, and a metronome.

In the second experiment we studied digital modulations which included BPSK, QAM, 8PSK, 16PSK, 16QAM, 32QAM, 64QAM and 256QAM. Using a signal generator, the transmitted signal was modulated, transmitted, received, and demodulated. That demodulation is done in the test bench using an interferometer. These digital modulations are used to carry symbols containing a group of bits. All analog signals are converted into digital signals using converters and transmitted as symbols by digital modulations. A joint radar and communication system was also looked at. Crucial information can be transmitted to help in the autonomous driving. see figure 1

3 Materials and Methods

3.1 Exerpiment 1

To observe the applications of radars and how they work in a real-life environment we performed an specific procedure in a high-tech laboratory. Prior to conducting our experiment the Doppler effect was looked at in which converts an objects movement into a frequency using a specific formula 8. To conduct this experiment a millimetre wave radar with an antenna, Baseband signal generator, DC power supply, frequency counter, spectrum analyzer and oscilloscope was used. The millimetre-wave radar sensor is the main component and is what emits and receives the waves. The baseband signal generator is what used to generate the signal carried by the radar system at a specific frequency range. The DC power supply is what provides power to the entire setup. The frequency counter is what accurately measures the frequency from the electric signals. The frequency analyser is what is used to measure the strength of the RF signal at different frequencies and the oscilloscope is used as a display screen to view the oscillations and the frequency detected. Once this equipment was set up in the proper manner, we tested the radar sensor with different targets including a plate in motion, tuning forks, and a metronome to see if the radar was capable of detecting motion. See figures 234

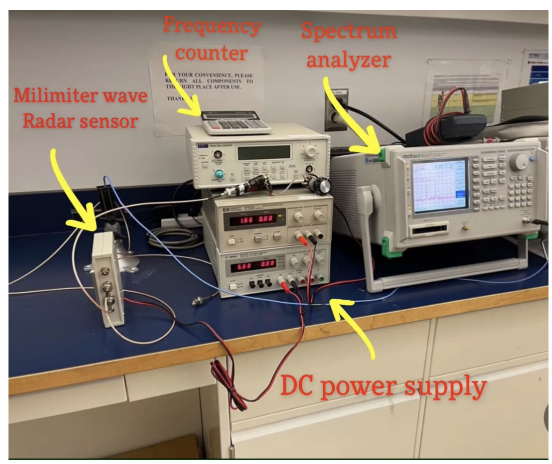

Figure 2: Right side setup

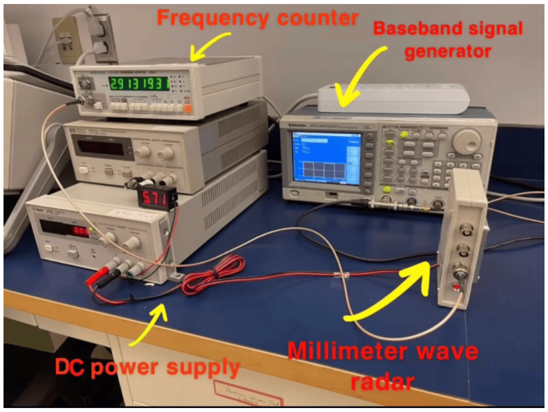

Figure 3: Left side setup

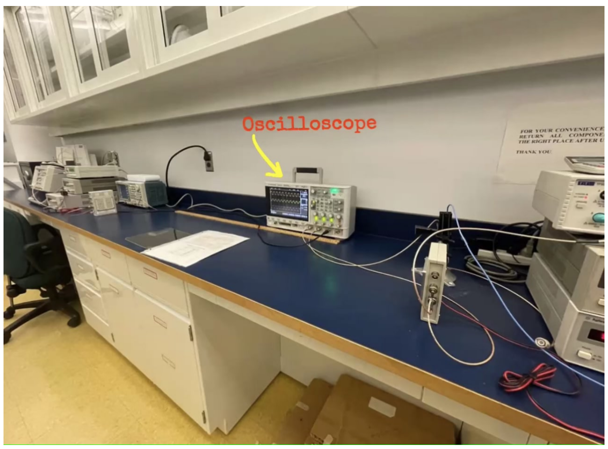

Figure 4: Oscilloscope

3.2 Experiment 2

For the second experiment we studied the different digital modulations. We used an RF signal generator, interferometer, power supply and oscilloscope. Digital modulations involve changing certain properties of a carrier wave (such as amplitude, frequency, or phase) to represent digital data. The purpose of the RF signal generator is to generate radio frequency bits which are modulated on a carrier signal and then transmitted and received onto a wireless channel. The interferometer is then used to capture the original signal from the modulated one known as (demodulation) and lastly the purpose of the oscilloscope is to observe the waveform of the generated signal to visualize the image. Once this was set up in the proper manner as seen on the test bench , we observed the different digital modulations. With this setup we were able to observe images of the energy constellation and the waveform. When the image was represented clearly on the oscilloscope for each modulation from the generated signal a screenshot was taken for each modulation and then uploaded on a USB . See figures 56

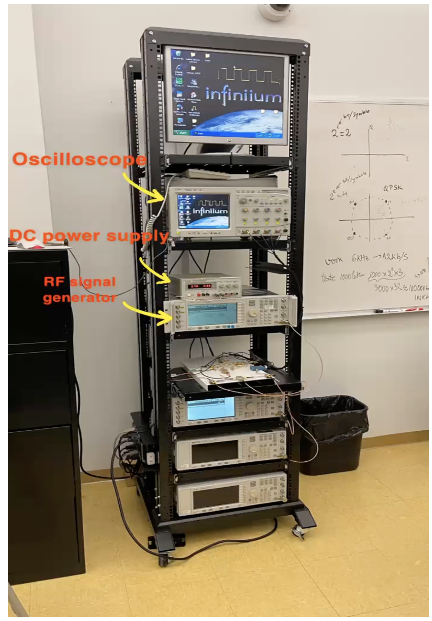

Figure 5: Test bench

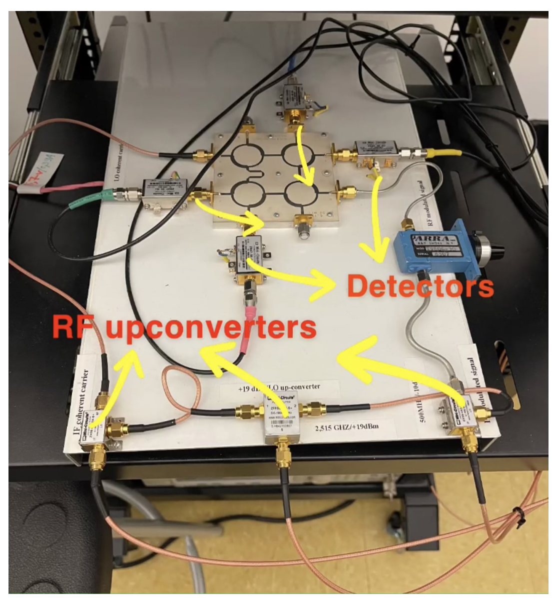

Figure 6: Interferometer

4 Results

4.1 Experiment 1

After conducting several experiments to ensure the accuracy of our results , the radar was successfully able to detect moving objects appearing within its range. If the object was placed outside the field of view of the radar or to far it wasn't capable of being detected. The oscilloscope indicated the frequency in which the movements were and also gave a clear image of the movements as a waveform. The frequency of a wave is the number of cycles or oscillations it makes in a specific amount of time. Higher frequencies were shown to have smaller wavelengths then those with lower frequencies. The tuning fork Figure **??** are designed to emit a certain frequency when hit with a specifically designed hammer. When closely looking at a struck tuning fork it emits a vibration. The shorter pronged tuning forks produce higher pitch sound and therefore a higher frequency than those with longer prongs. Once the radar detected movement from the tuning forks , metronome and plate in motion it was capable of converting it into the exact frequency.

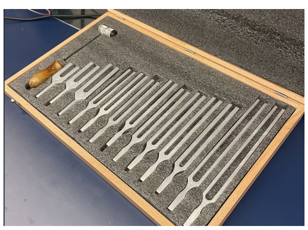

Figure 7: Tuning forks

Using the Doppler Effect and the formula 8 the radar was able to calculate the frequency from the movement and displayed it on the oscilloscope. The transmitter part of the radar is what transmits a continuous electromagnetic wave in front of an object and once it hits the object it is then bounced back to the receiver part of the radar. This information is then received by the radar and through the software , the radar automatically calculates the frequency using the equation.

Figure 8: Image of modulations

4.2 Experiment 2

After each of the different digital modulations were plotted, the energy distribution for each modulation became visible as as seen in Figure 9. The area in green is where the energy is the least and in white is where there is the most energy. Every symbol or point seen in the diagram represents a fixed amount of digital information. This symbol is made up of a group of bits and is calculated with the formula: 2^n where n is the number of bits. The smallest piece of digital data that a computer or other digital device can process and store is a bit. A bit is a binary digit, hence it can only have the values 0 or 1. Each of the different modulations have advantages and disadvantages in different situations. When looking to pick which modulation technique to use many factors can come into place such as such as data rate, noise tolerance, power consumption, and complexity [6]. The modulations with more symbols or points are capable of carrying more bits meaning that they are capable of carrying more information. For example 16QAM has 4 bits, 32QAM has 5 bits and 64 QAM has 6 bits. An example of how information gets sent with bits would be a phone text message. To send a message that involves one letter 5 bits of information are required. Meaning that to send a text message of a five-letter word for example "hello" 25 bits are required.

When comparing the digital modulations from our results to the theoretical values seen in Figure 1 our results are accurate, although there is some error. The points aren't as perfectly aligned as the theoretical ones. For example, when looking at 32QAM in our data 9 the 3 points in the bottom right are touching and not equally separated nor in line with one another.

When looking at Figure 11 it clearly shows the different waveforms for each modulation. It indicates I (in-phase) and Q (quadrature) versus time. The yellow and purple as well as the green and pink waveforms are opposite in phase meaning that their phase difference is 180 degrees. The waveforms shown are what carry the bits.

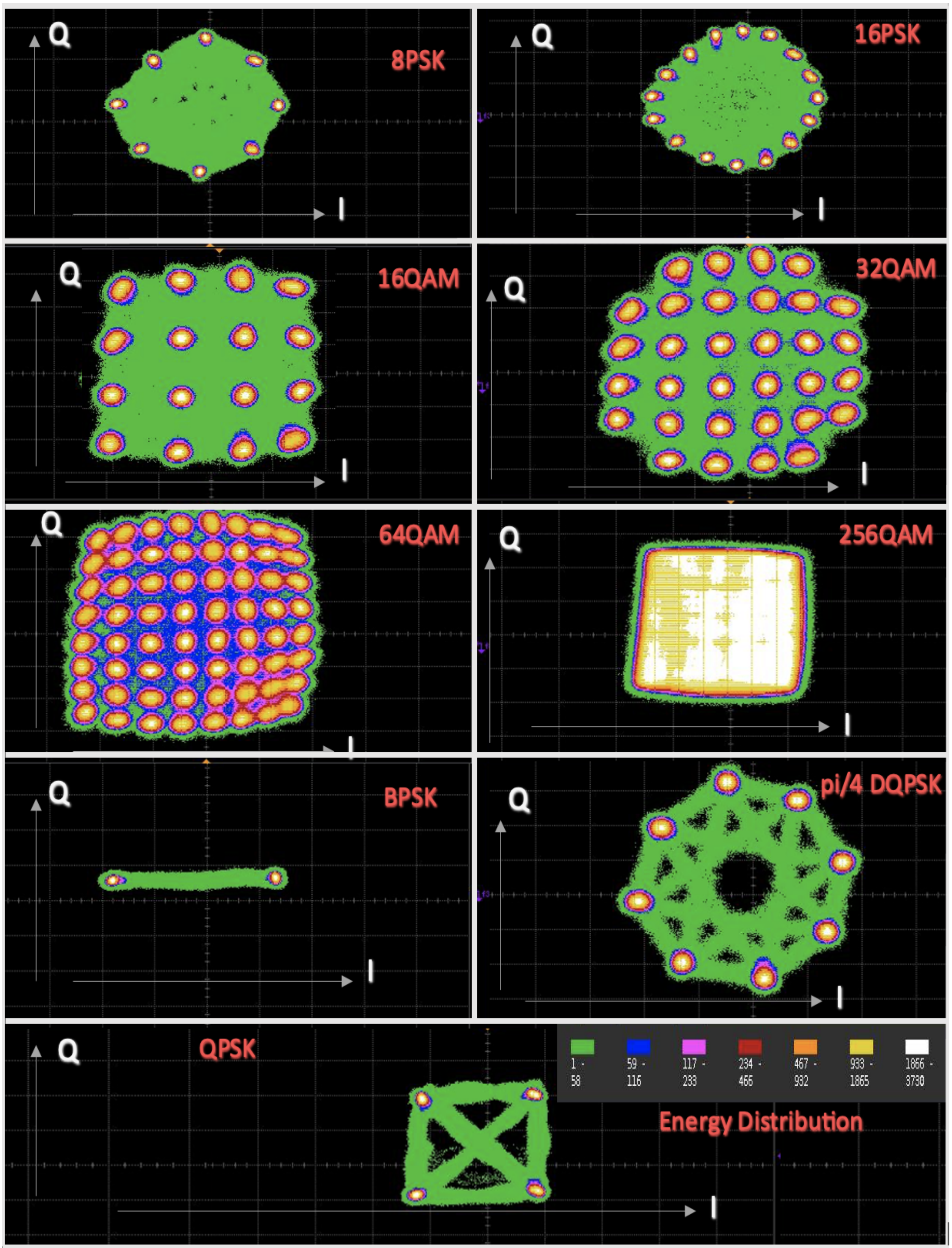

Figure 9: Energy cosntellations

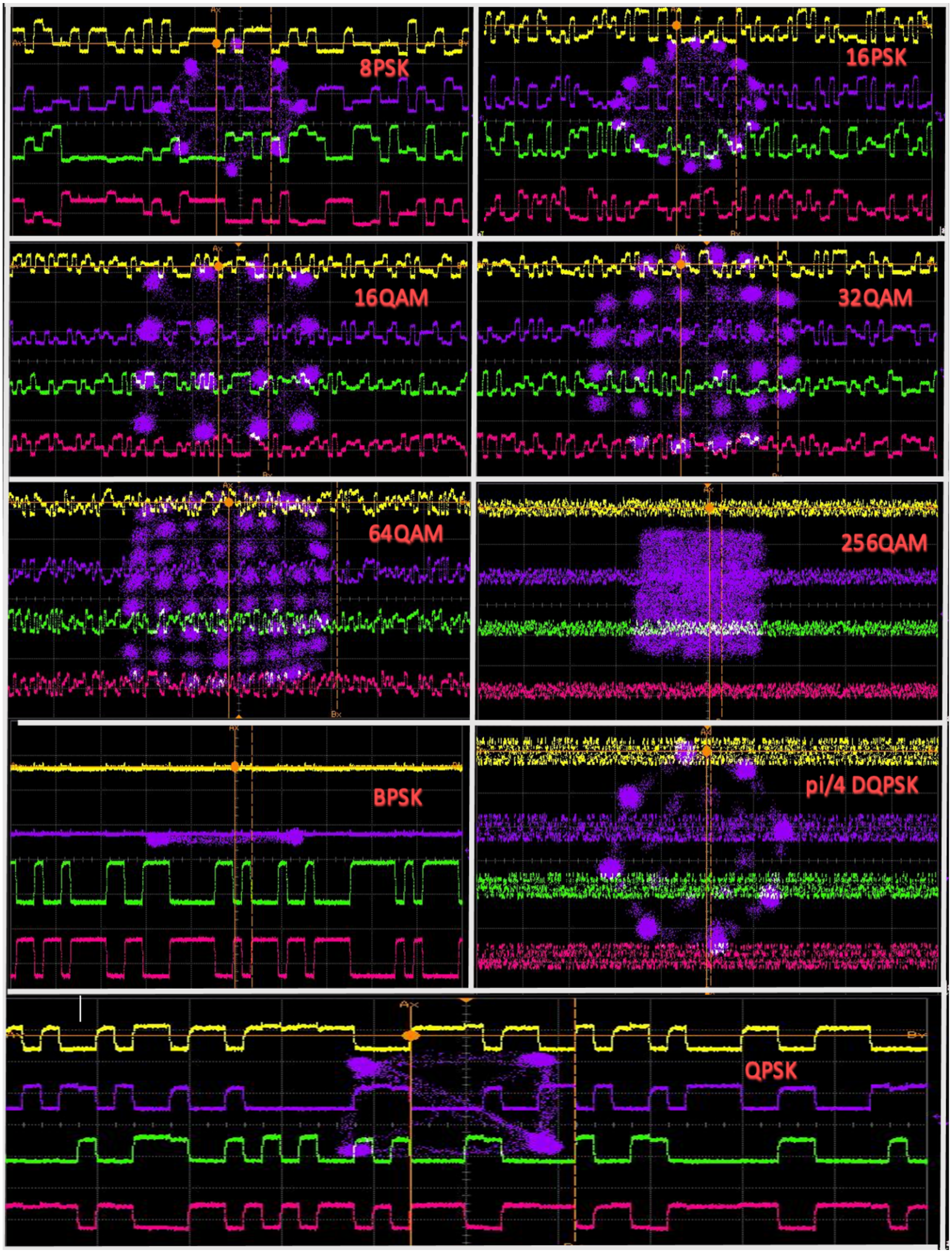

Figure 10: Waveforms

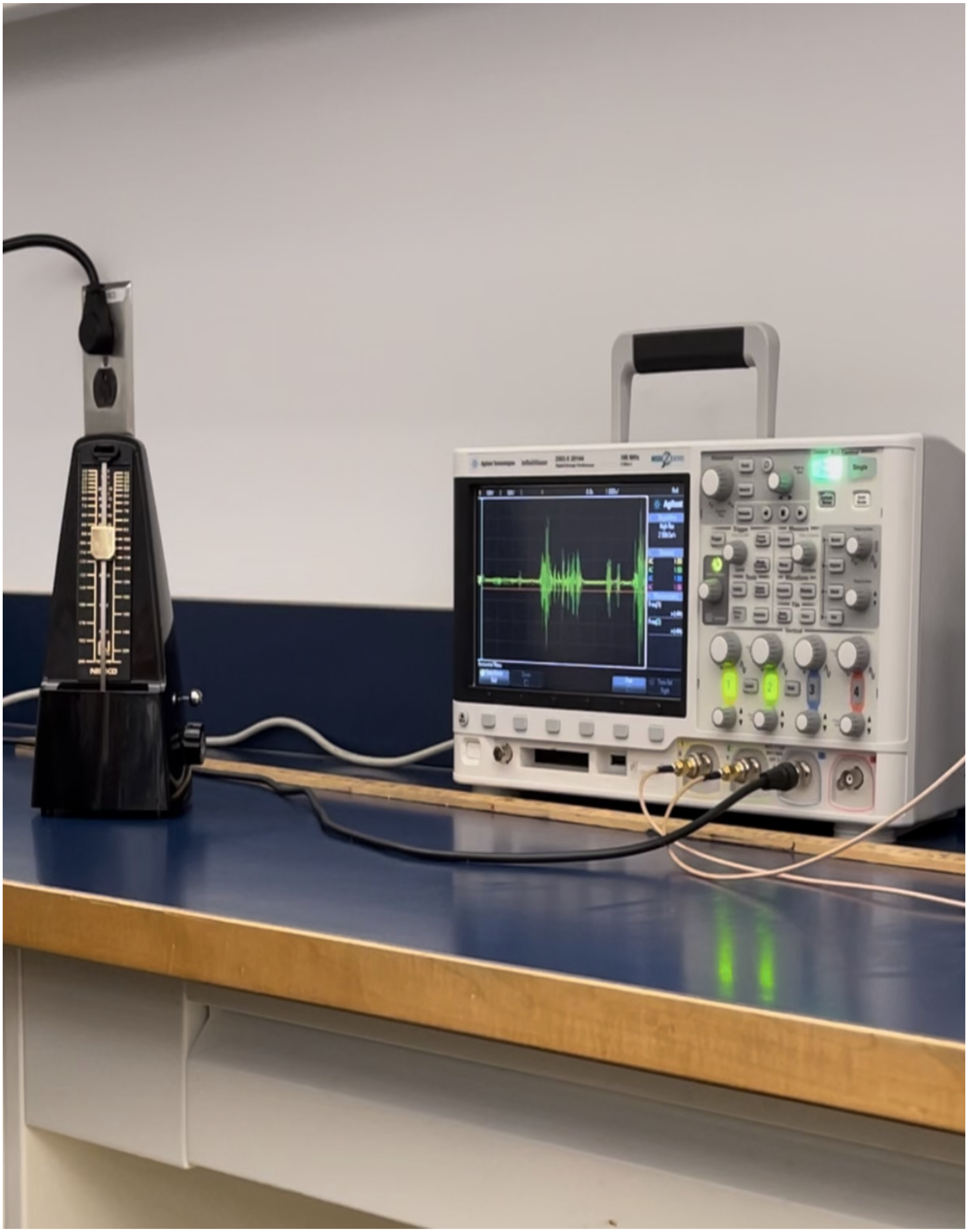

Figure 11: Oscilllloscope Reading

5 Analysis/Conclusion

5.1 Experiment 1

Radars are capable of providing several types of information of an object such as size, speed and distance. For these reasons, radars have become essential in today's world and is the the reason why they are so helpful in everyday life. Being able to detect something from large distances , something that is not yet visible to the human eye is a big advantage. For example the weather , incoming objects and more. A high frequency electromagnetic wave is directed at a target object in which disperses everywhere upon contact with the object. The radar's antenna then picks up some of the energy that is then reflected back to it.

By getting the distance and velocity measurements of an object the radar is able to calculate the speed of the object. In order to calculate the distance of the object the radar picks up the signal that was reflected and calculates the delay between the transmitting and receiving signal. The time delay is then multiplied by the speed of light (299 792 458 m/s). The velocity is then found by analyzing the frequency shift in the radar and then plugging in the frequencies and working backwards to find the velocity. The frequency of the radio wave, the size and form of the antenna, and the target's distance all affect how well an item is detected by radar[9]. Higher frequencies are easier to visualize but have a shorter range of detection and are more prone of being interfered than lower frequencies. When detecting objects the antenna is crucial as it can be the deciding factor of whether the object is able to be acquired by the radar. At larger distances bigger antennas are required in order for whats being looked at to appear clearly, such as detecting the weather

In our experiment the radar successfully detected the movement and the frequency of every object put in-front of it. The readings were accurate although sometimes the frequency reading was off by one or two hertz(Hz). This can be due to some sources of error including any exterior motion within the radars field of detection and the possible use of elder equipment.

5.2 Experiment 2

Radio technology has played an important role in communication and information dissemination for over a century. From being able to send emergency alerts to everyday personal use radios have been essential for people around the world. Radios use electromagnetic waves otherly known as radio waves in order to transmit data wirelessly. Radio waves travel through the atmosphere at the speed of light and can be received by a radio receiver using an antenna. When a radio transmitter transmits a signal an electromagnetic wave is produced with a given specific frequency and amplitude. The frequency determines the wavelength of the wave and the amplitude determines the strength of the wave. In order to transmit information through radio waves, different modulation techniques are required.

Each modulation technique is used differently. Frequency Shift Keying (FSK) is a method that involves transmitting digital information by manipulating the frequency of a carrier signal. This is done by altering the frequency of the carrier between different frequencies with each frequency representing a particular digital symbol [11]. FSK is used for high frequency radio wave transmission and is common over telephone lines and displaying caller ID [1]. Binary Phase-shift keying (BPSK) is a technique used to transmit data by manipulating the phase of a carrier wave. The carrier wave serves as a reference signal and the phase of the wave is altered in order to transmit digital data [2]. BPSK is used where the communication channel is prone to distortion or interference such as Wifi and Bluetooth connections [8]. Phase Shift Keying (PSK) is used to transmit data by altering the phase of a constant-frequency carrier wave. The phase of the carrier wave is modulated to represent different symbols or bits of digital information[12]. PSK is used for very high-speed data transmission such as wireless LAN connection [5]. Quadrature Amplitude Modulation (QAM) is used to transmit data by changing both the amplitude and phase of a carrier wave. It transmits two digital bit streams. QAM is commonly used in telephones and broadcasting due to its capability of being able to send large amounts of information [13].

After analyzing our results, we concluded that more symbols move more information and therefore more energy is required to do so. In our case, the RF generator powering the signals isn't strong enough to carry information that has over 4 bits, thus meaning maximum 16QAM. This is because there isn't enough energy being produced by the RF signal generator for the symbols to be equally spaced and in line with each other. Therefore, to move larger amounts of information an RF signal generator capable of generating more energy or an RF amplifier is required.

5.3 Conclusion

Have you ever been driving and hit a big pothole? Have you ever got into a car accident that wasn't your fault? With our research we came up with something where radars and radios can be used simultaneously in order to solve these problems. Not only will people benefit from this financially but it was ensure a safer option of autonomous driving when on the roads. In order for this to work every car will be equipped with a radar and radio. The radar will be used to detect the speed of the cars around you and any foreign objects or potholes on the road while the radio will be used to communicate with the other vehicle's. When a sudden change in speed happens from another vehicle the radio will notify the cars near to make adjustment to avoid collision.

5.4 Aknowledgements

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