AWOL: A Wireless Object Locator

Group #2

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Abstract

Since the breakout of RF engineering during World War II, high frequency systems have increasingly become relevant in our everyday lives. By utilizing this centuries old theory our team set out to solve the problem of loosing everyday items. Employing theory, simulations, and a prototype designed by our team we employed high frequency circuits, S-band frequencies, and sound to help a user locate their missing item. With our team's device an average consumer can locate an object from 5 meters away, essentially solving the issue of missing items around the house and can eventually be upgraded to a much larger scale.

Introduction

RF and microwave engineering has been a growing field since its initial boom in RADAR early warning systems during World War II. For about half a century following WWII, RF engineering played a large role in our nation's defense, from radios for the military to satellites. Its role continues to be significant today, as drone warfare, advanced early detection for enemy vehicles and missiles, and electronic warfare boom become more prevalent, affirming that microwave engineering is a prominent field within electrical engineering.

However in the early 1990's RF engineering forked down another path; that of civilian usage. DirecTV, long distance "walkie talkies", cell phones, wireless internet, and so much more have since enhanced the role of RF engineers in our everyday society. Today, Americans can not walk outside without interacting with a range of microwave devices sending electromagnetic waves through the air all around us.

As we continue down the path towards an increasingly high speed and wireless society, it is important to educate engineers with the skill set necessary to keep military and consumer technology cutting edge. The UC Davis RF senior design course takes up this gauntlet by instructing students on the practical usage of RF engineering, and then placing the burden on the students to think up and design an RF system.

As the first quarter of senior design drew to a close in December, we were tasked with the responsibility of coming up with a new RF design project for the remaining two quarters. With the option of continuing off of the RADAR from first quarter or coming up with our own unique idea, our group chose to pursue a new RF design project. Practicality, usefulness, realizability, and even novelty were all factors that we had to take into account when choosing what kind of project we wished to create. Our move away from RADAR also signified a move away from military application of RF engineering, leading us down a consumer path. This consumer application mindset should help us as we move into industry with electrical engineering degrees. After bouncing multiple ideas off of each other and the professor we finally arrived at our desired project; A Wireless Object Locator.

Description

A Wireless Object Locator, or AWOL, is a wireless system designed to locate a missing object. The system consists of two main parts, the transmitter and the receiver. The transmitter is your "fixed" device which would likely be kept in a safe and easily accessible location, such as a living room or a bedroom. The receiver utilized the Arduino Uno's microcontroller as its central command component. This microcontroller outputs a code which will be converted to the DC voltage using a resistor ladder. This DC voltage controls the voltage controlled oscillator. The microcontroller will output different specified voltages, and thus the VCO will output different frequencies corresponding to those voltages. From the VCO output, the RF signal travels through a power amplifier before being transmitted via the transmitting antenna. The transmitter is powered by a 9V battery which runs through a 5V regulator. The 5V output from this regulator is used to power all of the active components on board.

The receiver is the "mobile" unit which can be placed on any number of devices, including cell phones, wallets, and TV remotes. This device has been designed to be as compact as possible so that it can be placed onto everyday items which are commonly misplaced. Due to the need to produce a frequency for mixing, verify that the correct frequency is being received, and sound the buzzer when appropriate the receiver is more complicated than the transmitter. Like the transmitter the receiver gets power from a 9V battery, which is then converted to 5V using a voltage regulator. The receiver also requires -5V, which will be supplied with another 9V battery but with the polarity reversed and a -5V regulator.

The signal will be received through a patch antenna similar to the antenna on the transmitter. This signal will be fed into a mixer which mixes the incoming signal with the signal output from the receiver VCO. Similar to the transmitter the receiver will also have a microcontroller at its center. This microcontroller has multiple functions, however one of its functions is to control VCO in the same manner as the transmitter. After the incoming signal is mixed down with the local oscillator signal from the VCO it is passed through a baseband low pass filter and amplifier. The purpose of this filter is to ensure that only frequencies very close to the LO are being passed through the circuit. The amplifier acts to make the signal large enough utilized to determine if the buzzer should sound. Following the amplifier is a full wave rectifier with a smoothing capacitor. The rectifier turns the incoming sine wave with negative and positive values into a wave which resembles the magnitude of a sine wave. The smoothing capacitor then converts this signal into a DC signal. If the original signal had too large a frequency to pass through the low pass frequency then the output at this point would be approximately zero volts DC. Assuming the frequency was low enough to pass then it would be fed into a 3.3V regulator. This voltage regulator is designed to bring the DC signal down to a level that can be imputed to the microcontroller. Finally the signal enters the microcontroller. If the signal is 3V or higher it will be converted to a digital 1 and the microcontroller will output a square wave to the buzzer. The buzzer will sound until located by the human and reset.

Design Details

The transmitter is designed to output a single frequency between 2.35-2.7 GHz. The value of of this output frequency is determined by a voltage input into our ROS-2500-2319+ voltage-controlled oscillator. The voltage inputs into our VCO are determined by the code loaded onto the ATmega328P-PU via the Arduino Uno microcontroller. The ATmega328 chip outputs an 8-bit binary number, with 5V representing high and 0V representing low, which is then converted to a voltage output via an 8-bit resistor ladder. This resistor ladder acts as our digital to analog converter. We choose the resistors to be relatively high ohmage, 100 and 200 kilo-ohms, in order to reduce power dissipation across this large array of resistors. The voltage output from the resistor ladder is then fed to the VCO input.

On the receiver side we programed the ATmega328P-PU chip to actively search for a frequency matching the LO on the receiver. The incoming signal will be received if its frequency is operating between 2.35 and 2.7 GHz. Once received it will be passed through our mixer, the ADE-18W+. The mixer takes the incoming signal and the LO signal, and provides us with the sum, difference, and various harmonics. The difference is what is of importance to us. This mixed down signal then passes to a second order, active low pass filter and amplifier with a 3dB cutoff of 900kHz and a 40dB cutoff at 2MHz. Next the signal is sent to MB4S full-wave rectifier where it will be converted to a DC voltage. If the original signal had been low enough frequency to pass through the filter than the DC voltage would be 3V or higher. The ADC, which converts our analog signal to a compatible ATmega328P-PU format is built in to the chip itself. If the incoming signal to the ATmega328P-PU is a digital high then the arduino uno will produce a 0-5V peak square wave which will turn on the buzzer.

The antenna was designed to be a microstip patch antenna which the final design was a bow tie antenna with one side on positive and bottom side as ground. The substrate selected was Rogers R3003 with substrate thickness of 20 mil, 1.5 mil copper cladding thickness, and relative permittivity constant of 3.0. The use of Rogers R3003 was due to limited substrates selections available for sampling. With substrate determined, the -10dB S11 frequency bandwidth required was 2.35-2.6GHz with center frequency aimed at about 2.4GHz. Directivity of the antenna needed to be low for more omni-directional radiation pattern and the gain was aimed to be 2dB for an omnidirectional pattern. The size of the antenna was limited to the size of half an iPhone 4, which was about 30 mm by 40 mm. The top plane of bowtie antenna had a 50ohm microstrip feed line with attachment point at tip of the triangle. The width of 50ohm was designed for 2.4GHz. The bottom plane had the other bow tie triangle fan opposite direction to the top plane one. Ground plane side of the antenna had thicker microtrip and a rectangular shape at pcb mount connector to make the ground plane seem larger for less dielectric loss. The widths of the ground plane rectangular sections were tweaked until a desired -10dB bandwidth was achieved at the specified frequency.

Test & Measurement Results

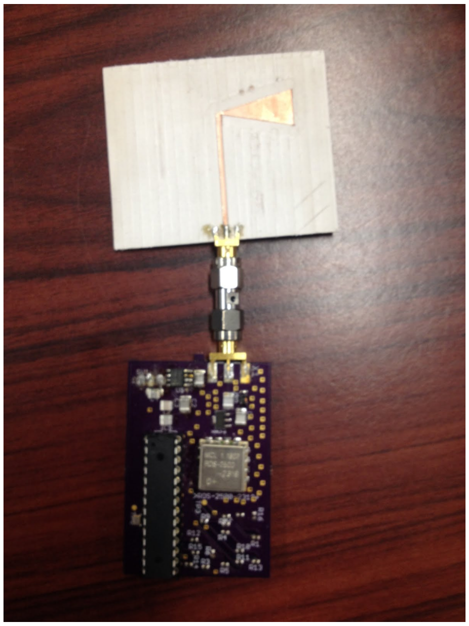

Figure 1: Transmitter

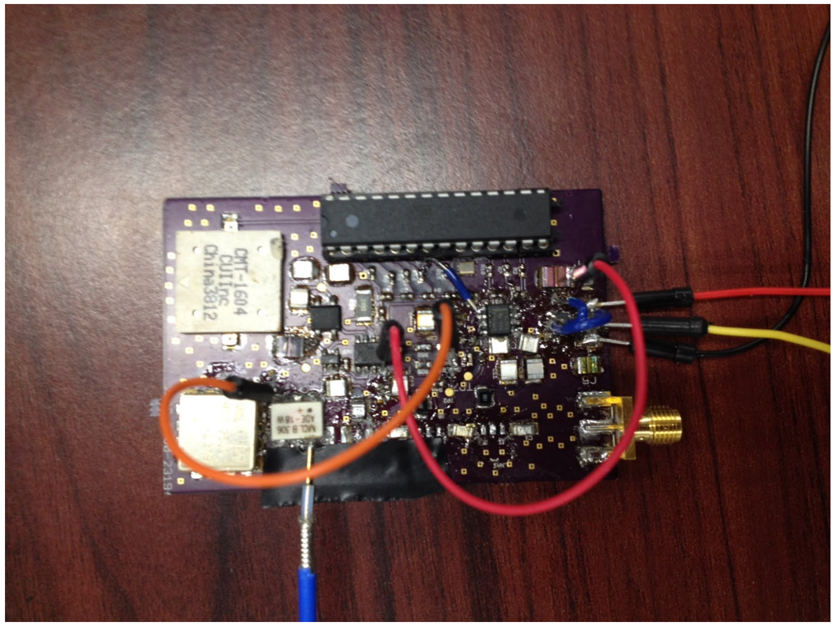

Figure2: Receiver

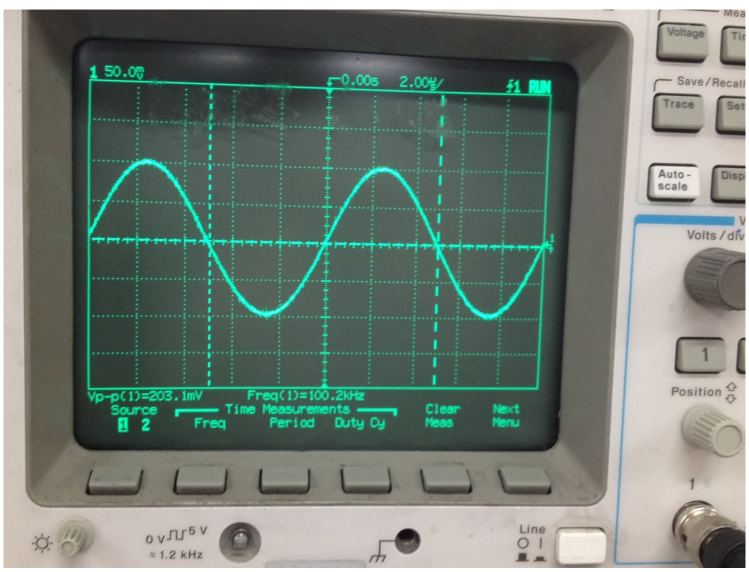

Figure 3: 100kHz wave

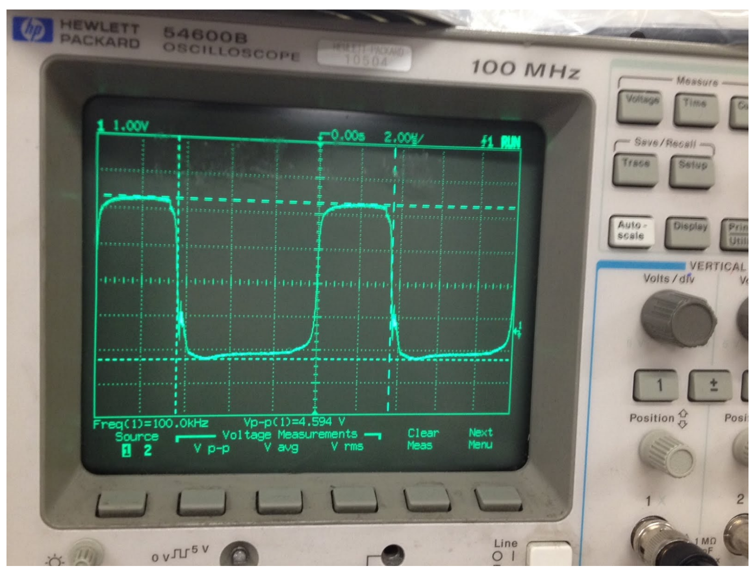

Figure 4: Amplified 100kHz wave

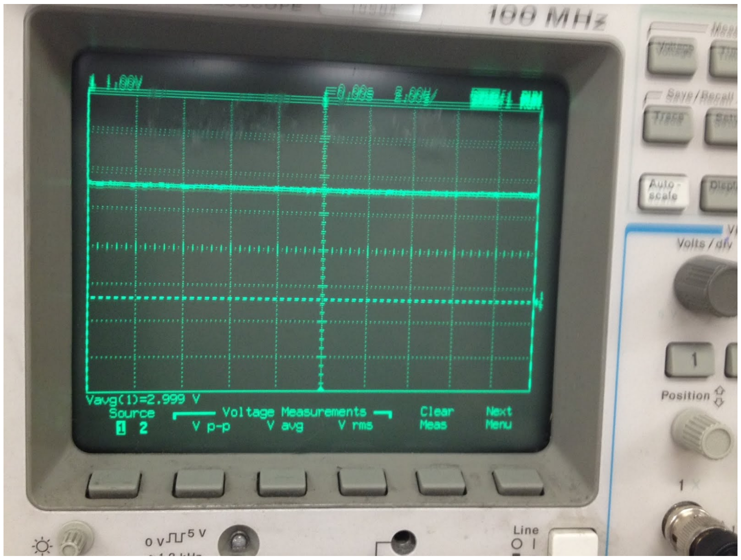

Figure 5: Rectified 100kHz signal

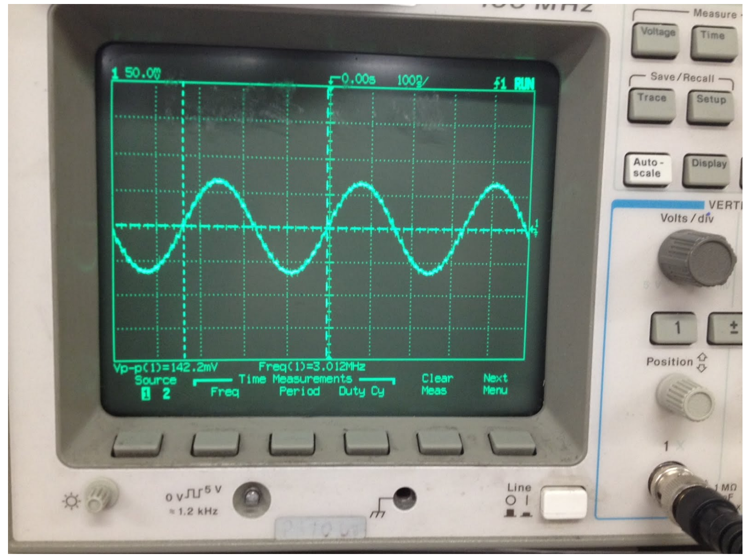

Figure 6: 3MHz wave

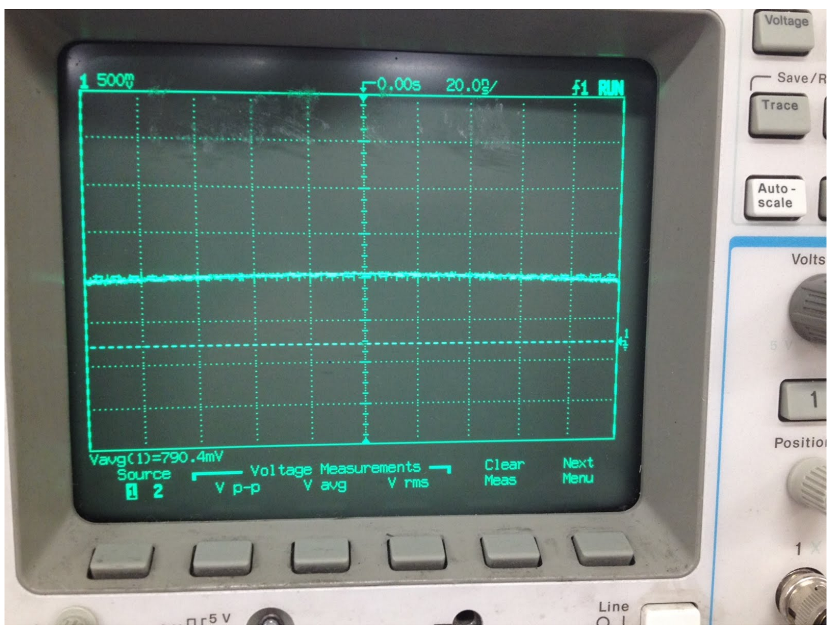

Figure 7: Rectified 3MHz wave

Our transmitter was able to transmit at the frequencies specified by our microcontroller with a deviation of .02 GHz. Our range of transmission was 5 meters.

The transmitter performance was tested as shown above. The arduino was programmed to switch between two frequencies. Another bow tie antenna was connected to spectrum analyzer to observe the switching of these frequency properly transmitted. The spectrum analyzer showed two frequencies switching which confirmed that the receiving antenna connected is receiving the correct signals from transmitter. A video link is pasted below for better visual:
https://www.youtube.com/watch?v=cfPKBjan17A&feature=youtu.be

On the receiving end we ran into more trouble in trying to get the entire system work as a whole. The mixer was having issues mixing down to a good frequency below 900 kHz. When we tested the mixer on the spectrum analyzer with two frequencies 1GHz apart we can clearly see a 1GHz impulse with good appropriate power at about 2dBm. However when the frequencies were changed to be only 500 kHz apart the power was considerably lower and unable to be distinguished above the noise floor.

This was a huge issue because this weak signal could not be amplified enough to raise above 3V to tell the arduino to tell the buzzer to sound. We were however able to determine that this was the only broken leg of the system. When we manually inputed a sine wave with a 50mV peak to peak value after the mixer we were able to make the siren sound if the frequency was below 900 kHz.   Figure 3 shows the input sinusoidal signal with a 50mV peak to peak value and a frequency of 100kHz. Then in Figure 4 you can see that after the mixer this signal is a square wave from -5 to 5V. We see a successful conversion from AC to DC in Figure 5 with a value above the necessary 3V. This signal is then fed to the Arduino which successfully puts out a square wave to turn on the buzzer. When I changed the frequency to 2MHz the system stopped working as it is supposed too. Figure 6 shows the input signal, and Figure 7shows its successful filtering after the low pass filter.

Discussion

Our transmitter was the best element of our system. Not only did it work but it worked well and was small and simple. This would allow for future expansion and possible mass production of the system. The fact that our transmitter transmitted a signal up to 5m meters was a good sign as well. This showed that our device could be used to locate items from almost anywhere in a house.

The trouble on the receiver's mixer proved to be irritating. Everything on our board seemed to be correct and we felt that the entire project should have worked. It is possible that the mixer was not receiving powerful enough inputs to keep the output above the noise floor. This would make it so that whatever came out of the mixer was essentially zero, and therefore even the amplifier could not raise it enough to trigger the activation system. After looking into this further we determined that because we are utilizing a passive mixer the LO power must be at least 7dBm (this is because the mixer is a class 7).

Because we were able to test and insure that every other component on the receiver was working properly we were able to narrow down and specifically locate the problem. The reason there as a square wave output from our baseband amplifier is because of clipping. The amplifier has a gain of 40dB, but the amplifier only runs from -5V to 5V. This limits the maximum and minimum values at the output to 5 and -5V, respectively. With another week of debugging and modifications it is likely that we could have fixed the issue and had a working system at the distance already calculated when testing the transmitter.

In the future it would probably be best to begin testing on active RF components early. These components are often difficult to debug and even understand. They can also be very “fragile” meaning a lot of time could be put into trying to debug a broken chip.

Possibility For Future Expansion

Despite the success that our team had with the design and implementation of AWOL, there is always room to improve and expand. Thinking along the line of increasing marketability to a mass audience we need to find away to allow more devices to work in the same area without interference. Our current project can only support a maximum of about 17 units without interference. This is because our system works between 2.35 GHz and 2.7 GHz, and there needs to be about 20 MHz separation between each device. In order to expand the number of users we would employ the technique of frequency shift keying (FSK). This would allow us to impersonate a digital code by by cycling through a series of frequencies on the transmitter and receiver. By using a two frequency FSK we would increase the number of users to 289 before having interference.

Another issue with our design that could be improved and expanded upon in the future is is the amplification of the incoming signal. Currently our design is not utilizing any LNAs at the signal input. By using a surface mount LNA we would be able to improve the quality of the incoming signal by raising it above the noise floor before it interacts with any noisy components. If the LNA does not give the desired amount of gain, as it likely will not, it can be cascaded with one or more power amplifiers. Power amplifiers typically have a higher gain than LNAs and therefore would be better to use after the first LNA. Because getting a signal above the noise floor is almost entirely dependent on the first component it is ok to use power amplifiers on the receiving end.

For future expansion on this project our team would like to make the receiver device even smaller. The smaller we are able to make this device, the more practical it would be. Ideally we would be able to get it down to around 2cm by 2cm or smaller. This would allow AWOL to be placed on small items that are much more easy to loose such as keychains and even pens and pencils. In order to accomplish this we might consider trying to make the transmitter network the complex circuit and the receiver as simple as possible. This would allow us to greatly reduce the receiver size. Making the receiver less complicated would likely entail shifting the verification network to the transmitter.

One issue that our team has considered since the start but been unable to solve is the large power consumption by the receiver. The receiver must always be on and searching for the frequency that will sound its buzzer to notify the user of its location. However because it is always on the batteries charge is likely to deteriorate quickly. This poses a problem because if the item the receiver is attached to goes missing and the batteries are dead then AWOL is useless. Therefore in the future it would be be smart to explore a low power alternative for when the receiver is searching for its activation signal. Then when it receives this signal it will fully power up and sound the buzzer.

The system can be modified for different applications. Besides locating small objects within household, the antennas could be swapped out for high directivity antenna to send information further. For example, on field trips for children, the transmitter can be held by the teacher and receivers could be placed in backpacks carried by each person. The transmitter could be expanded to show how many devices are connected or in range, as soon as the set amount of numbers drop, it would indicate someone is swaying away from the group. Then, the teacher could quickly react to the situation and check if any child is missing or falling behind. This is just one example of how the system can be used. Other applications could be more specific. Receivers, once made small enough, could be attached to collars of dogs or other pets. The pets could be trained to look for their owner when the receiver beeps to reduce number of pets getting lost. Another possibility could be attaching it to bikes. At a huge biking campus such as UC Davis, students or professors often forget where they locked their bikes and need to search for the bikes among hundreds of bikes. A system like this could assist the bike owner in locating their bikes quicker.

Suggestions to this Class

EEC 193 had a good setup which helped to foster the creative element of engineering by encouraging us to design our own project. However there are some things we felt could be improved about the course. First off it would be helpful to have more information sections regarding things like reading a data sheet properly, the basics of PCB design, and the basics of the microcontroller being used. These subjects could be taught second quarter. We feel that it would have been more beneficial to have weekly “lectures” like we did first quarter than to give presentations every week. However the presentations were a good learning experience and it helped to keep groups making progress and moving forward with their design. Therefore it may be worth it to have each group give one presentation midway through the quarter and at the end of the quarter. This will still force students to deal with the reality of needing to be able to present technical material in a clear and concise fashion, while allowing more time for the instructor to present new information. In order to keep groups up to date with their work they should provide a small written report every week explaining their progress. If this report had strict guidelines with clear instructions it could help to teach students how to write better written documents.

Although our group learned a lot from coming up with and designing our own project from scratch, it was incredibly difficult and at times overwhelming. To help improve the success rate of groups looking to do their own project it may be best to place stricter guidelines on what groups can take up as a project. This could help keep teams from getting in over their heads on a project and getting demoralized by the numerous difficulties and issues that come from it.

Lastly, it may be beneficial to expand the scope of the class to encourage students various emphasis to enroll. This could allow more well rounded groups of students emphasising RF, digital, communications, and analog allowing projects to go further and be more in depth. Having all these students would also help create more clear roles within a group, and prevent conflict over who does what. The final benefit of this would be a more well rounded education. Students with a RF emphasis would be forced to work hand and hand with a student who knows more about digital, therefore spreading this specific knowledge between team members.

Conclusion

With this project now complete, our team is now more prepared and capable than ever before to graduate and enter the working world. AWOL has been an incredibly educational opportunity for everyone in the group. Because this project was our own, and not based off of quarter 1, we were able to experience the full design process. The early stages of coming up with a useful and practical project at first seemed to be easy, as we had an abundance as ideas. But as we tried to transform these ideas into designs we saw numerous complexities emerge. Wading through these fundamental design issues proved to be one of the most daunting tasks of this two quarter experience.

Our team looked to employ methods of design and problem solving that were only theoretical to us, and often had never been taught. At times this left us exposed and confused when everything seemed to be behaving wrong despite us believing that the theory was correct. However we continued to research and use our numerous resources to move forward with our design towards the final goal. One of the most important things that this taught us was the fluidness of a real design project. When you start out with a design you must be open to new ideas and change. Often the first idea is never the best nor the right idea, and in order to complete a working project your plan and proposal must constantly be updated.

PCB design, component selection, data sheets, and RF components were all new issues for our team to deal with. It was a trial by fire and these new, real world unknowns were the best tools we had to being successful. Despite all of the problems that we encountered we would not have done it any differently. Pursuing our own project gave us the satisfaction that nothing else could. We struggled together every step of the way and had to learn to think and work like a team in order to move forward. There were trying times, when it seemed that all was lost, but in the end knowing that our project was 100 percent ours has showed us that we can accomplish anything we put our minds too. AWOL, whether it could be successful as a consumer project or not, has raised our engineering skills and knowledge to the next level, and sends us into industry ready to work.

Bill of Materials

ATmega328P-PU chip	2
100k ohm resistor	18
200k ohm resistor	16
ROS-2500-2319+	2
GALI-6	1
10uH inductor	1
.1uF capacitor	16
453 ohm resistor	1
620pF capacitor	1
402 ohm resistor	1
3.4k ohm resistor	1
20pF capacitor	1
249 ohm resistor	1
3.09k ohm resistor	1
39.2k ohm resistor	1
2k ohm resistor	1
16pF capacitor	2
.33uF capacitor	1
3.3uF capacitor	2
1uF capacitor	1
16MHz crystal oscillator	2
uA78L00 5V regulator	2
MIC5270 -5V regulator	1
ADE-18W+ mixer	1
AD8039 Op-Amp	1
MB4S-TP rectifier	1
LP2981 3.3V regulator	1
UA78L00 5V regulator	2
MIC5270 -5V regulator	1
CMT-1604 buzzer	1

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Thanks to Professor Leo for putting together this senior design project and giving us the opportunity to carry out an actual design project in our field of study.