RC CAR: RANGE DETECTION AND ALERT SYSTEM

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Abstract

R/C cars provide little feedback to users about its location or effective range. This causes significant frustration for R/C car operators when cars runs out of range or out of sight of sight, forcing the user to walk towards the car to regain control. We developed a range detection and alert system that allows for the user to monitor their R/C car's range while not interfering with vehicle functionality. Our implementation utilizes Bluetooth communication with a Received Signal Strength Indication (RSSI) Chip and GPS module to communicate over Bluetooth to the remaining distance and relative location of the car via an OLED display on the controller to display. We successfully integrated the RSSI chip into the Bluetooth communication to the OLED display, but the GPS Module yet to be integrated.

Contents

1. Introduction

R/C car operators struggle to understand the relative range of the vehicle. While the cars may specify the maximum range, monitoring how the range is affected by the battery depletion or interference by trees and buildings is exceptionally difficult. Therefore, the user may lose control of the R/C car. A potential solution is simply to increase the maximum range, but cars with longer ranges can cause users to lose sight of their car. These issues frustrate users, requiring them to locate the R/C car and limiting the operating range to the operator’s visual range.

To prevent the user from unknowingly driving the R/C car out of range, we have implemented a system to provide active monitoring information to the user, while still giving the user full control of the R/C car. An RF Power Detection system allows the user to monitor the remaining range of the vehicle. This allows the user to know how far the vehicle is from them, even they lose eyesight of the car, thus allowing the user to maximize the range of the car. Using GPS modules, we hoped to determine the relative location of the car.

Through both a control unit and an alert system, the system relays information between the car and the controller via Bluetooth. Based on the information sent from the control unit on the car, the alert system displays the relative location and remaining range through an OLED Display. This allows the user to monitor the location of the car even if the operator loses sight of the car.

2 Design

2.1 Block Diagram

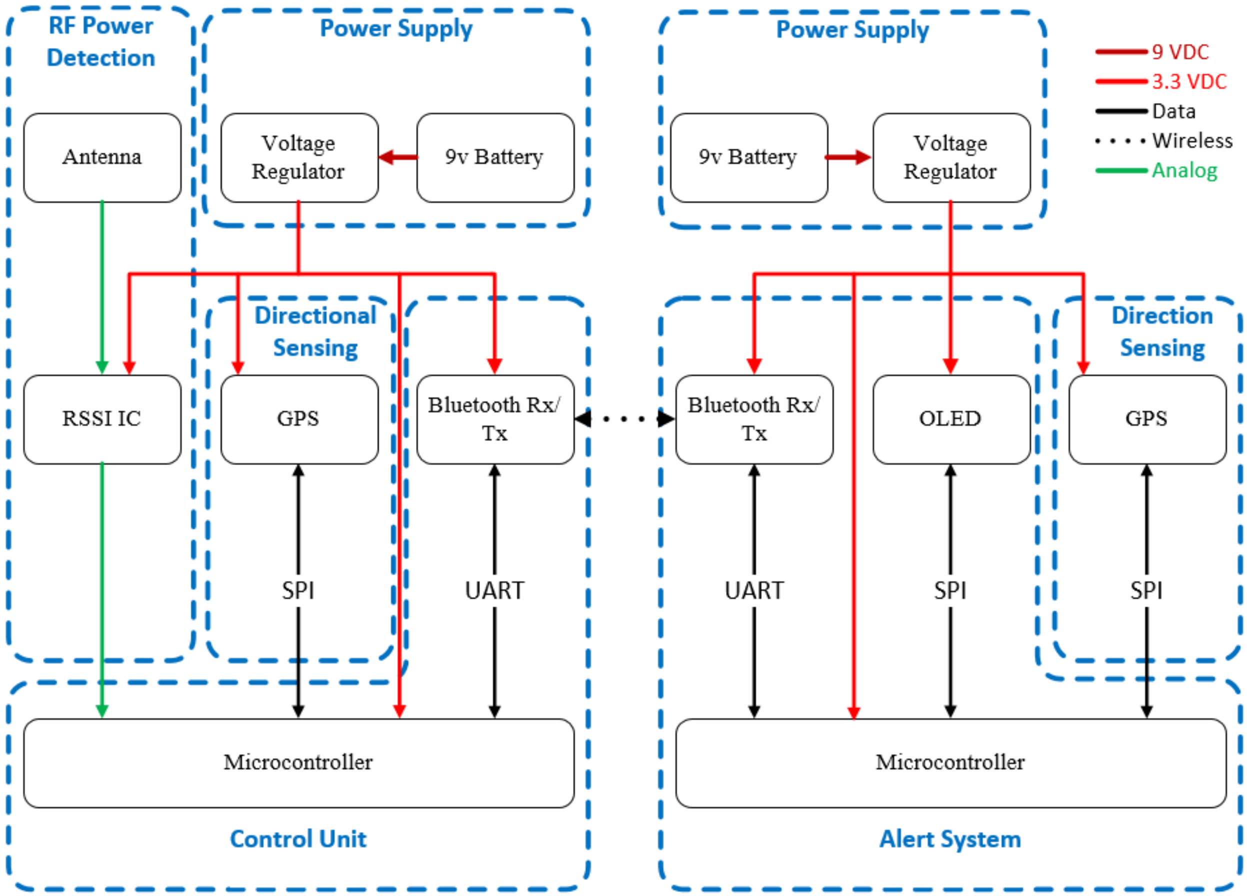

Figure 1: Detailed Block Diagram

The RC Car Alert and Detection System implemented two separate units that are comprised of 5 different modules. The unit on the car contains a power supply, RF power detection, directional sensing, and a control unit. The power supply regulates a 9.2V battery down to a 3.3V supply used by the other modules in system. An antenna receives the transmitter's signal and feeds it to the RSSI IC Chip to determine the RF power. The microcontroller in the Control Unit processes this analog signal and the directional sensing module's GPS information. The Control Unit takes the RSSI and GPS inputs and parses the information and uses Bluetooth to transmit the data to the Alert System on the controller.

The unit on the controller contains a power supply, directional sensing, and an alert system. The functionality of the power supply and directional sensing are identical to that in the unit on the car. The alert system takes in the inputs from the Bluetooth communication and the GPS module and displays the remaining range and the relative location of the car on the OLED Display.

2.2 Power Supply

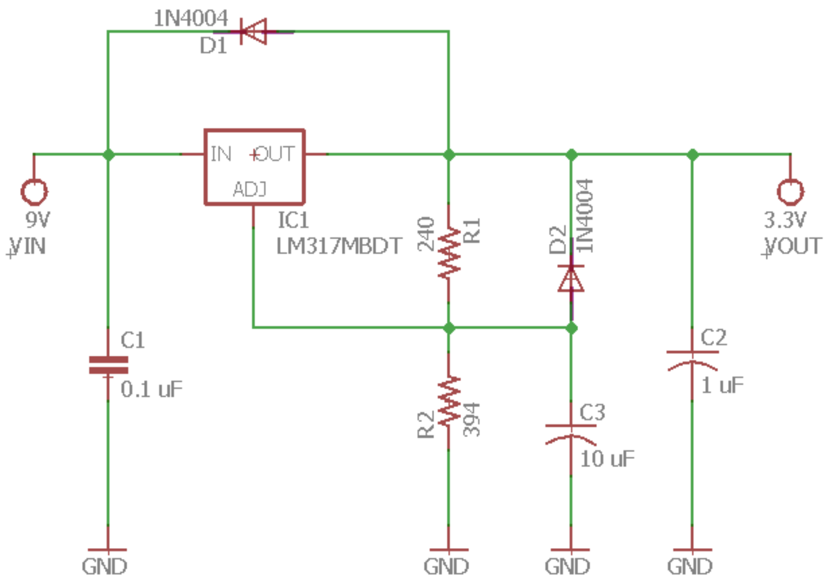

Figure 2: Voltage Regulator Circuit

Figure 2 shows the design of the voltage regulator circuit. This module takes the 9.2V battery and regulates it down to a 3.3V supply for the other modules in the circuit. During preliminary design, the chosen RSSI chip required a maximum input voltage of 3.3V. Based on the other modules, which could handle a 3.3V to 5V supplies, the RSSI chip defined the necessary input voltage for the remaining modules. While the design could have implemented a 3.3V and 5V supplies such that the other modules could have operated at a higher frequency, we decided that the 3.3V supply would be sufficient.

We utilized an LM317 TI Adjustable Regulator Chip [1] to change resistors R_1 and R_2 in the event we needed to change the output voltage. From Equation 1 and TI's recommendations for R_1 to be 240 Ω, we

$$V_{out} = 1.25\left(1 + \frac{R_2}{R_1}\right) \tag{1}$$

determined that R_2 required a resistance of 394 Ω to achieve an output of 3.3V [1], [2].

When we developed a PCB board, we did not verify the ability to get a 394Ωsurface mount resistor, therefore we used a 400 Ω resistor to achieve an expected output voltage of 3.3333V.

The diodes and capacitors in the Voltage Regulator Circuit were implemented based on recommendations from TI as a safety check for the circuit. The diodes prevent discharge through the LM317 chip and the capacitors provide stability and reduce ripple current [1].

2.3 RF Power Detection

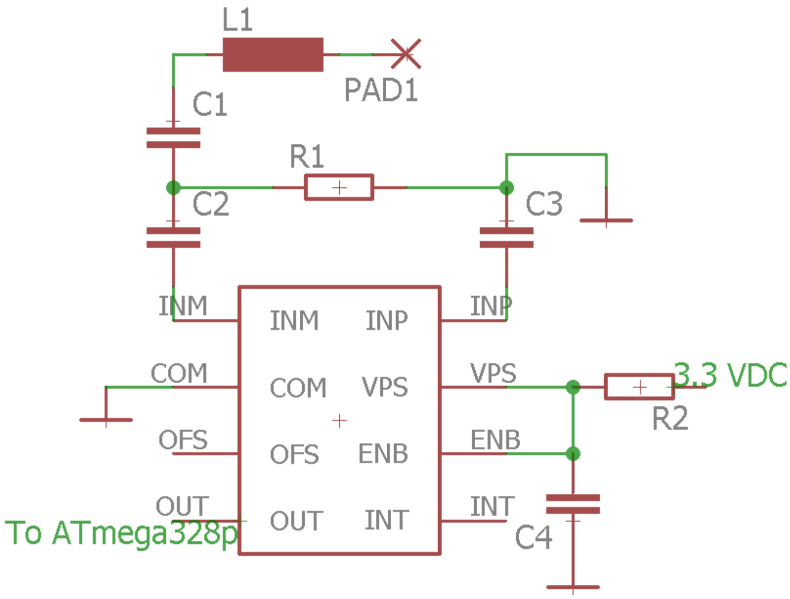

Figure 3: Final Schematic Design for the RF Power Detection Circuit

The RF Power Detection module is designed around a logarithmic amplifier. This module amplifies a logarithmic power level from the remote control to a linear voltage that can be measured by the control unit. One alternative option that could be chosen is building a custom logarithmic amplifier instead of using an off-the-shelf chip. Originally with a 2.4 GHz car, the design required a higher bandwidth logarithmic amplifier, so the cheapest and easiest option was using the off-shelf part. After switching to the 27 MHz car, the bandwidth requirement decreased, so building a custom logarithmic amplifier would have been the cheaper choice. In the end, we kept the off-the-shelf chip to keep the PCB as small as possible.

Figure 3 shows the final circuit design for the RF Power Detection module. The design should filter out all signals other than 27 MHz. The bandpass filter implemented by L_1 and C_1 in Equation 2 determines the range of values for these components. The Advanced Design System verified the functionality of the filter design. After designing the filter, two capacitors and one resistor: C_2, C_3, and R_1 remain. The two capacitors are for AC coupling the inputs of the device, and the resistor lowers the input impedance of the device from 1.1 kΩ to 50 Ω. The value of R_1 is found by using Equation 3, a simple parallel resistance formula. The most important part of the module is the AD8307, a low-cost logarithmic amplifier from Analog Devices [3]. Resistor R_2 limits the current, and capacitor C_4 decouples the device from the power supply.

$$L_1 * C_1 = \frac{1}{(2\pi f_c)^2} \tag{2}$$

$$50\Omega = \frac{1.1k\Omega * R_1}{1.1k\Omega + R_1} \tag{3}$$

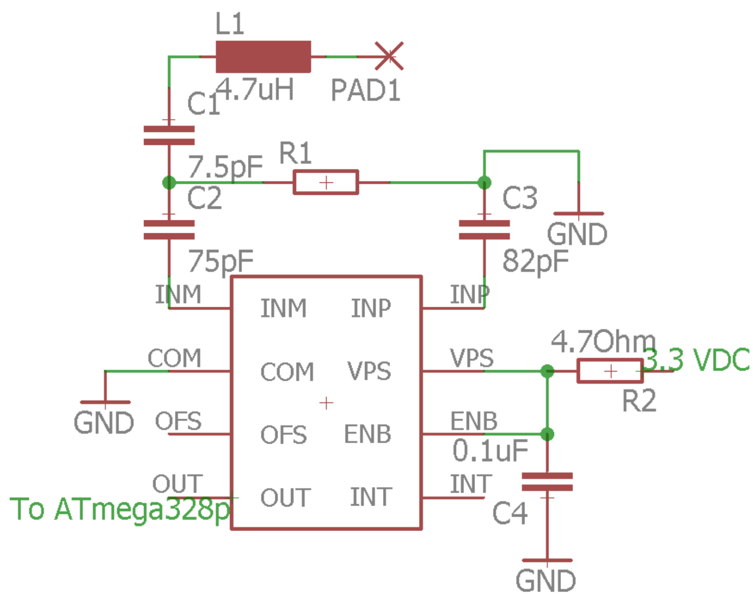

Figure 4: Finalized RF Power Detection Circuit Schematic with Capacitor and Resistor Values

Figure 4 is the circuit diagram with all component values. Using Equation 2, the value of L_1*C_1 was approximately 3.5×10^{-17} with a frequency of 27 MHz. To determine the values of L_1 and C_1 individually, an inductance in the µH range and a capacitance in the pF range are reasonable starting points. The exact values were found by choosing a capacitance of 7.5 pF and finding an inductor around 4.6 µH. These values placed the center frequency at a little over 27 MHz, but after simulation, the frequency of the RC car was found to be well within the 3 dB bandwidth. The value of R_1 is found to be around 52.3 Ω after reordering Equation 3 to Equation 4. All other values for this module are recommended by Analog Devices for a 27 MHz frequency.

$$R_1 = \frac{1.1k\Omega * 50\Omega}{1.1k\Omega - 50\Omega} \tag{4}$$

2.4 Directional Sensing

The Directional Sensing unit is responsible for providing the locational data of both the R/C car and the user. Naturally, it was chosen to implement the unit using two separate GPS chips. Both GPS modules should be able to send longitudinal and latitudinal coordinates to their respective microcontroller. The coordinates of both the car and user would be used to calculate the relative location between the two. Additionally, the GPS was required to interface with the microcontroller through either UART or SPI protocol. However, after concluding that the Bluetooth module only needed two digital pins and the RSSI chip needed an analog pin, it was decided that a GPS that can use UART should be chosen since a SPI protocol can cause clocking and synchronization problems during implementation. It was also required that the GPS can refresh its location data at a moderately quick rate in order to keep up with the moving R/C car that presumably can move a few feet per second. This data should be accurate to within at least a 3-5m radius of the true pinpoint location.

The Adafruit Ultimate GPS Breakout module, centered around the MTK3339 chipset, was chosen since its datasheet exhibited that it can meet the requirements that were established [4]. Specifically, it can interface with the MCU (Atmega328p) through simple UART, refresh the location data at 10 Hz, and provide the locational data required to calculate the relative location with accuracy within 3m. The refresh rate of 10 Hz was deemed to be quick enough to keep up with the movement with the car since it can be driven only 1-2 ft. a second.

The data output from the GPS is in the form of NMEA sentence that provide several fields of information. There are several types of NMEA sentences however GPRMC (Global Positioning Recommended Minimum Coordinates) since it provides the coordinate data needed and contain the least amount of data per sentence. This can ensure that the speed of the GPS is maximized. An example can be seen below:

```
$GPRMC,220516,A,5133.82,N,00042.24,W,173.8,231.8,130694,004.2,W*70
       1      2 3       4 5        6 7     8     9      10    11 12
```

1	220516	Time Stamp
2	A	validity - A-ok, V-invalid
3	5133.82	current Latitude
4	N	North/South
5	00042.24	current Longitude
6	W	East/West
7	173.8	Speed in knots
8	231.8	True course
9	130694	Date Stamp
10	004.2	Variation
11	W	East/West
12	*70	checksum

The NMEA sentence will be parsed so that only the longitudinal and latitudinal coordinates are sent over Bluetooth to the master MCU for processing.

2.5 Control Unit

The Control Unit takes the inputs from the RSSI Chip and GPS Module and parses the data to be sent over the Bluetooth to the Alert System. Since the control unit interfaces with three different modules, the microcontroller was the center of this design. Based on the RSSI chip, the microcontroller required Analog Inputs, so we did not need to implement an A/D converter circuit [3]. The GPS Module required SPI communication to interface with microcontroller [4]. These two main design constraints led to the decision to utilize the ATmega328P microcontroller [5].

In the original design, we initially expected to utilize the UART or SPI communication for the Bluetooth module, however we utilized 2 digital pins for the communication to the Bluetooth module. The original Bluetooth module was a SparkFun Bluetooth Mate Gold, since it features the RN-41 Class 1 Bluetooth chip [6]. The RN-41 chip had an expected communication range of 100m, which exceeds that of the R/C car [7]. Since the Bluetooth needs to communicate beyond the range of the R/C car, we decided to utilize the RN-41 Chip [8].

2.6 Alert System

The same requirements of the Control Unit drove the design of the Alert System. Since the Control Unit and the Alert System utilize the same power supply, Bluetooth Connection and the GPS Module, the differences between the two modules is the implementation of an OLED display instead of the RF Power

Detection circuit of the Control Unit. We chose the Adafruit Monochrome 1.3” 128x64 OLED Graphic Display [9]. The OLED Display needed to be able to display data as quickly as new data became available to display. Since the GPS Module had the fastest refresh rate of 10Hz, Therefore we needed an OLED with a similar or faster rate [4].

However, we also wanted to utilize I2C or SPI communication between the microcontroller and the display. The flexibility of the display’s connection to the microcontroller allowed for us to be flexible with our connections for the Bluetooth and GPS modules. Due to the GPS Module requiring the use of the SPI communication, the OLED display had to can use the I2C communication. During final integration, the OLED display connected via SPI due to the simplicity of the connection, and the lack of integration of the GPS Module.

The Bluetooth Module was identical to that of the Control Unit such that the two modules could effectively communicate between each other. During the preliminary design, we expected the modules to have the ability to Auto connect using the initialization of the devices. During testing, the devices would not Auto connect on Power up and would not connect unless a delay was utilized to ensure all portions of the module properly booted up. To prevent a continuous attempt to Auto connect, which causes the modules to not receive or transmit data, we implemented a pushbutton switch connected to the microcontroller. When the button went high, it initialized the connection code that would allow for the two modules to connect to each other. The Control Unit’s Bluetooth module was programmed to be the slave module such that the Alert System’s Bluetooth module was the master module capable of connecting to the slave module.

Once the connection was made between the two modules, the control unit passes the parsed GPS coordinates and RF Power Detection information over the connection to the Alert System. Allowing the Alert System to calculate the relative location, and to display the location and distance on the OLED display.

3. Design Verification

The following sections detail the main verifications for the system along with the failed verifications. For a detailed summary of the design requirements and verification, see Appendix A Requirement and Verification Table.

3.1 Power Supply

The top-level requirement for the power supply was to successfully regulate the 9V battery to a steady 3.3V supply to the circuit. The first verification method used was a simulation prior to the PCB board order to verify the 3.3V supply would operate at +/- 5% for input values greater than 5V. The simulation shown in Figure 5 indicates that the voltage regulator circuit produces a 3.3V supply with an input of 5V or greater.

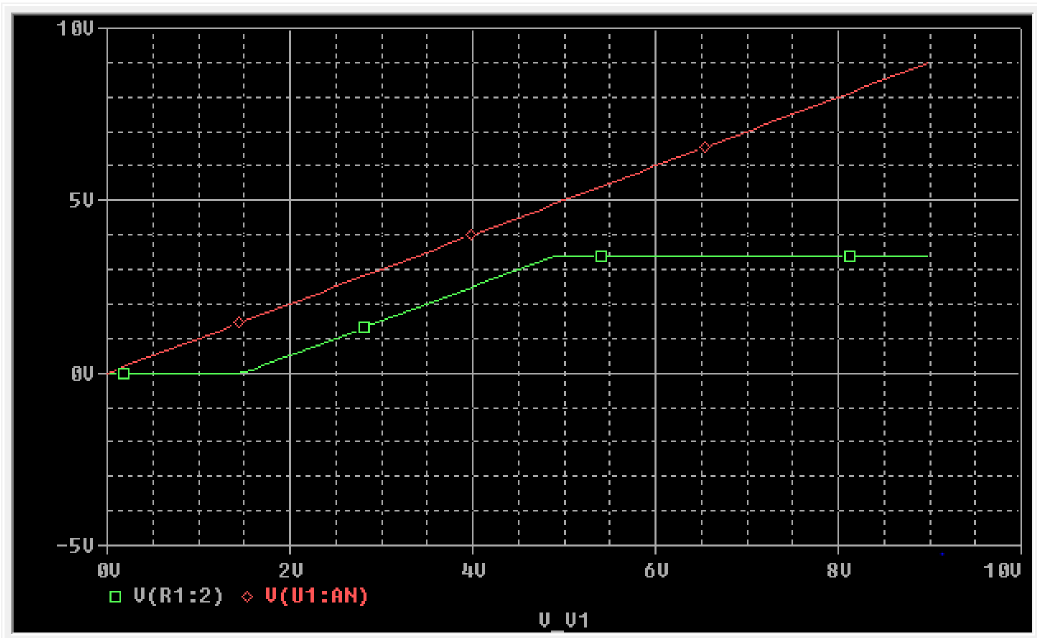

Figure 5: Voltage Regulator Simulation

The second method of verification was performed utilizing the final PCB voltage regulator circuit. A power supply was connected to the voltage input pin of the circuit board and a multimeter was used to measure the voltage on the output pin on the circuit board. The results were like that of the simulation, with the only difference being the maximum output voltage found, which was 3.282 V. The output voltage of 3.282 V was within the 3.3 +/- 5% V requirement established.

The Battery was required to provide at least 160 mA at 8.6-9.2V for the duration of 1 hour. The verification method in which a consistent 160 mA load was applied was difficult to implement and was not finished. The original implementation included a 22 Ohm resistor, however the resulting power due to the current and voltage across the resistor was beyond the rate power and the resistor overheated. At that point, we removed the battery and did not complete the verification process.

3.2 RF Power Detection

The RF Power Detection module was verified in three parts: filter measurements, input impedance measurements, and log conformance. The first two were done by using a vector network analyzer (VNA). For the filter measurements, the VNA was setup to sweep from 0.1 MHz to 100 MHz. This was done to get the bandwidth of the filter. The result was like the one shown in Figure 6. To measure the input impedance at 27 MHz, the VNA was set to sweep from 26.5 MHz to 28.5 MHz. In this frequency range, the input impedance was within the 50 Ω +/-5%, and at 27MHz, the impedance was 49.8 Ω. The last test was to verify log conformance of the AD8307. This was done with a signal generator and a multimeter. The signal generator was set to 27 MHz and swept from -56 dBm to 0 dBm. The voltage output at each power level were recorded and are shown in Figure 7.

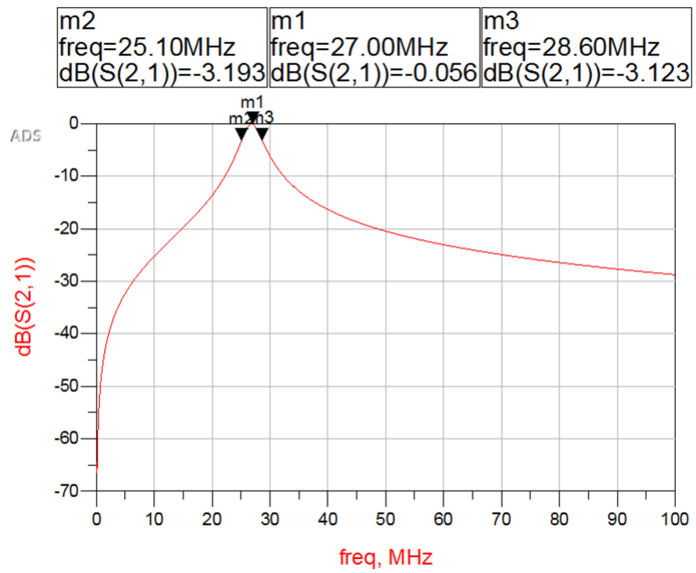

Figure 6: S-parameters for bandpass filter centered at 27 MHz

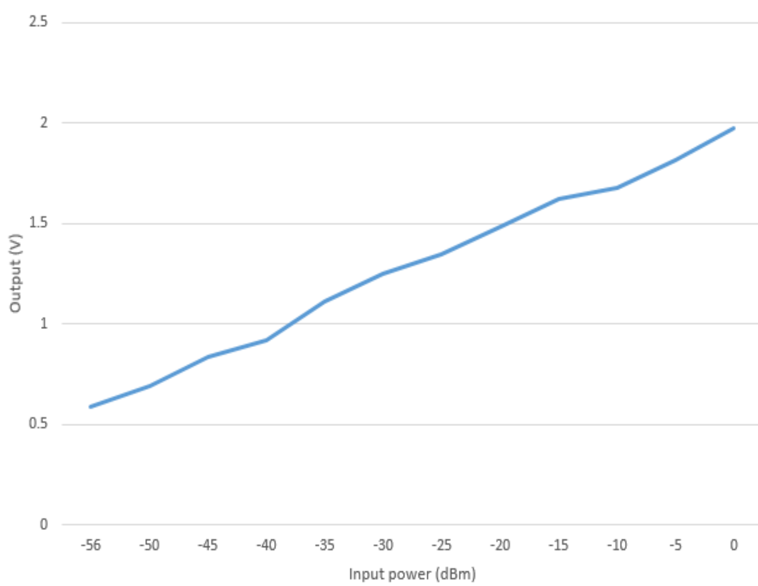

Figure 7: Log conformance of AD8307 -56 dBm to 0 dBm

3.3 Directional Sensing

To verify the GPS module, it was connected to the Tx/Rx pins of the Arduino Uno since it centers around the Atmega328p MCU, which was chosen for the Control Unit. To verify the refresh rate and data fields of the data from the GPS module, the GPS and Arduino were placed outdoors in an open space faced toward the sky to attain a satellite fix. The sentences outputted to the Serial Monitor were then analyzed. The timestamps of each sentence proved the 10 Hz refresh rate requirement by showing that there was a new updated sentence every tenth of a second. In addition, each sentence contained both the longitudinal and latitudinal coordinates as required.

Originally, the requirement for locational accuracy of the coordinates was to within a degree. However, it was realized that a degree corresponds to miles. Since the magnitude of range of the car was only a few feet the requirement was constrained to be accurate to about a thousandth of a minute which corresponds to about 6 feet.

The accuracy was tested by setting up the GPS and Arduino in a location where coordinates were known. The coordinates were found through Google maps. The coordinates from Google were then compared to what the GPS serially outputted. Unfortunately, although advertised in the datasheet, the GPS module chosen did not output locational data with accuracy within 3m. Instead the pinpoint location that the GPS module provided was about 30-50m off in every instance it was tested. This hindered calculating the relative location between user and car accurately. This was proved more difficult since the car’s range was only about 15 feet.

3.4 Control Unit

The Control Unit was verified using multiple tests that built on each other. The first test implemented was to test the Bluetooth communication range to verify it against the datasheet. To implement the test, we connected one Bluetooth module to an Arduino connected to a computer within the Senior Design Lab and one Bluetooth module to an Arduino connected to a laptop. We took the R/C car into the hallway and drove it away from the computer until the car would not operate. We then placed the laptop and Bluetooth module 10 m from the R/C car. With the two Bluetooth Modules connected, we passed short strings over the Serial Terminal from one computer to the other. This test successfully proved that the Bluetooth modules had a communication range greater than that of the R/C Car.

The next test performed was to verify that the two Bluetooth modules were capable of interfacing with external inputs. With the RF Power Detection circuit connected to the Control Unit, the values passed from the RF Power Detection were parsed and then the percentage value was passed over the Bluetooth connection to the Serial Terminal on a separate computer. By displaying the characters, it proved that the Control Unit was able to process and send information over Bluetooth the Alert System.

These two tests utilized Arduino Uno’s allowing for us to test the ATmega328P microcontrollers used in our design. Since the Arduino Uno’s use ATmega328P microcontrollers which were connected to the RF

Power Detection module and the Bluetooth modules, it provided verification that the ATmega328P was capable of interfacing with the two modules. The final Control Unit setup is shown in Figure 8. On the left side of the figure is the 9.2V battery powering the RF Power Detection which was connected as an input to the Arduino. On the right, is the Bluetooth Module with the yellow light indicating that the Control Unit is connected to the Alert System.

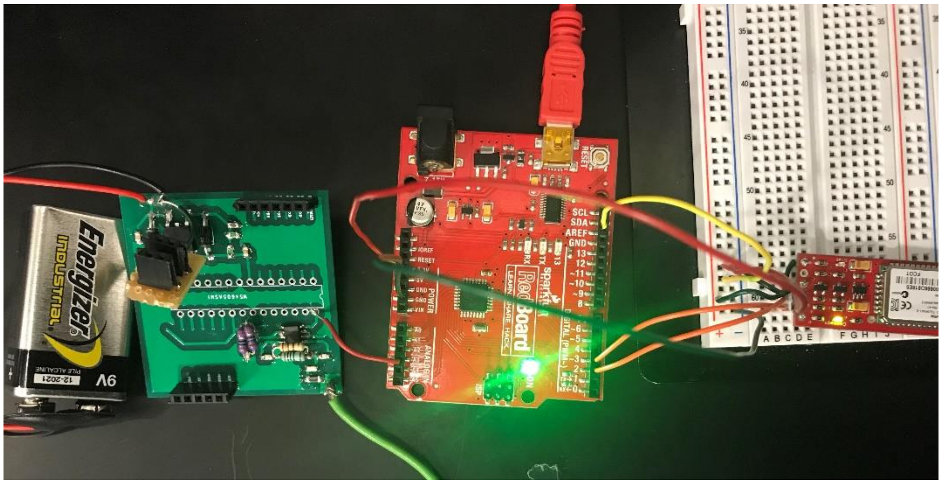

Figure 8: Final Control Unit Configuration

3.5 Alert System

Since the Alert System and the Control Unit utilize similar setups, the Control Unit's verification methods are applicable to the Alert System. To verify that the Alert System can display updated data as it arrived, we expanded on the second Control Unit verification test. To expand the test, we connected the OLED display to the Arduino and displayed the RF Power Detection percentage value on the display. During the initial test, the update rate was found to be greater than necessary and causing difficulty to read the display due to values being constantly updated. Since the constant updating made it difficult to read the OLED display, we implemented a delay with in the code such that the OLED display was easier to read and that the values displayed were the most recent.

The final Alert System test configuration is shown in Figure 9. On the left-hand side is the connection switch with the Bluetooth Module and OLED display to the right. On the OLED display, the Distance percentage shown is the value passed from the RF Power Detection input. The second line shows the character string passed between the Control Unit and the Alert System. The string starts with $ and ends with % such that the Alert System can ensure that it is displaying the proper values and not noise that may be passed before or after the RF Power Detection value.

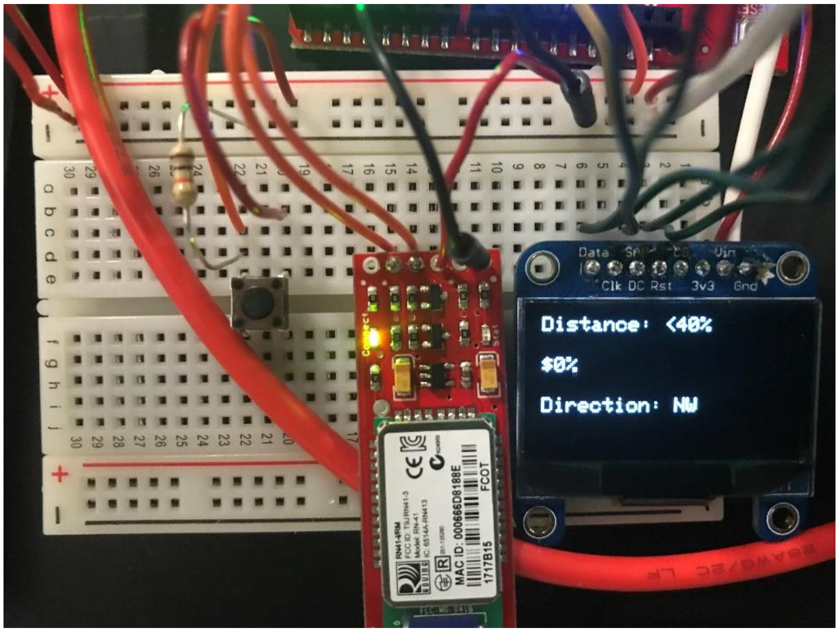

Figure 9: Final Alert System Configuration

4. Costs

Based on the Parts and Labor costs specified in the sections below, we estimate our part cost to be $200.80 and labor cost of $57,600.

4.1 Parts

Table 1 shows the detailed parts summary for the project. Nearly all the components were purchased, except for the two Ultimate GPS Breakout boards which were available for us in the Senior Design Lab. The cost of this project can be minimized by implementing the Bluetooth Mate Gold and Ultimate GPS Breakout circuits on the PCB rather than purchasing the separate modules.

Table 1: Parts Cost Table

Part	Manufacturer	Quantity	Purchase Cost ($)	Actual Cost ($)
PCB	PCBWay	2	2.00	2.00
ATmega328P-A	Atmel	2	4.16	4.16
Bluetooth Mate Gold	SparkFun	2	69.90	69.90
LM317MDCY	Texas Instruments	2	1.82	1.82
Monochrome 1.3” OLED Display	Adafruit	1	19.95	19.95
AD8307	Analog Devices	1	13.07	13.07
Ultimate GPS Breakout	Adafruit	2	79.90	0.00
Assorted resistors, capacitors, ICs	Digikey		10.00	10.00
Total			**200.80**	**120.90**

4.2 Labor

Our fixed development costs are estimated to be 40/hour, 12 hours/week over the 16-week course for three people. This results in a total of $57,600 as calculated in Equation 5.

$$3 \cdot \frac{\$40}{hr} \cdot \frac{12\ hrs}{week} \cdot 2.5 = \$57{,}600 \tag{5}$$

5. Conclusion

5.1 Accomplishments

Although we did not fully integrated the GPS Modules, we successfully integrated everything else. We successfully completed the Power Supply during the first design phase and we implemented it on both the breadboard and on the PCB.

After successfully implementing the Power Supply, we focused on getting the Bluetooth modules to connect the Control Unit and the Alert System together. Since the Bluetooth modules are essential to the final integration of the project, it was a large accomplishment when we were able to successfully complete the requirements for both units. Although the GPS did not integrate with the final design, successfully calculating the RF Power Detection values and displaying them via the Bluetooth modules without interrupting the user's experience represents a major accomplishment.

5.2 Uncertainties

At end of the demo, we had two three uncertainties with our project. The first uncertainty was due to the implementation of the RF Power Detection implementation. Since we operated in the 27 MHz range and the R/C car had a cheap transmitter, the values inputted into the microcontroller were inconsistent, causing the remaining range to be inconsistent. The antenna length and the R/C car's transmitter both contributed to this inconsistency. Had the antenna length been matched properly to the 27 MHz frequency or the R/C car's transmitter been stronger, the RF Power Detection would be more accurate.

The second uncertainty was due to the implementation of the GPS module and the use of the OLED display within memory. Since the OLED display contains a large library file, the code file was too large for the final integration. The OLED library could have been modified to have less of an impact however the we did not want to modify it right before the demonstration.

The final uncertainty was the failed verification of the accuracy that the GPS module provided. This made it difficult to calculate the relative location between the user and the car since the pinpoint location of both were off by thousandths of a minute (30-50m). This uncertainty could have been overcome if the car used had a greater range of +50m since less precision would be needed. However, this choice comes at an expensive cost. In the future, the Directional Sensing unit could have used a different GPS module where the accuracy can be verified.

5.3 Ethical considerations

Since the car has design capabilities to potentially limit or remove the user's control of the car, we must follow IEEE's #2 Code of Ethics, "to avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist" [10]. Therefore, the user of the car will be cognizant and aware that the car is taking in GPS signal and processing the relative location between the car and the user. Additionally, the user will be aware of the functions of the car, and that the car may operate at a range that the user is unable to see the car. In this event, there may be potential for conflicts if the car encounters another individual or object. As such, we will recommend that the user operates the car where visual contact can be maintained, or that another individual is able to maintain visual contact with the car and able to communicate back to the user when a safety risk is encountered.

By IEEE Code of Ethics #9, “to avoid injuring others, their property …”, we must be aware of the safety risks of operating a 9V battery on a moving R/C car [10]. While the 9V batteries are potentially hazardous on their own, the risks of a dragging battery are high due to the operation of the car. To aid in the safety of everyone around and using the R/C car, the battery will be securely mounted to the chassis of the R/C car underneath the body of the car. This will limit the ability to snag any wires running from the battery to the PCB board and limit the ability for the battery to be jarred off the car and dragged underneath. Additionally, the R/C car may be operated in areas where water is present, where there is a potential that the circuitry within the body of the car can be shorted, including the battery. These safety hazards can be addressed by ensuring that the circuitry is properly cased such that the circuitry will not be dragged underneath and water does not enter. It will have to be tested in various environmental conditions to make sure that the circuitry can withstand any terrain the user can put it through. It will also be recommended to the user to use caution when operating the vehicle and not put it through too much stress.

5.4 Future work

For the future work, we would like to implement the Directional Sensing module into the Control Unit and Alert System such that we could achieve full integration. By achieving full integration, we would be able to finalize the PCB board to include the pushbutton switch for the Bluetooth connection, and be able to build a better setup such that the implementation could be used in real-time on a R/C car.

Once the implementation was ready to be implemented on a R/C car, we would like to implement changes to be able to handle different frequencies for the R/C car’s or other R/C devices. These changes would make the RF Range Detection and Alert System to be modular and implementable on different R/C devices.

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Appendix ARequirement and Verification Table

Table X System Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
1. Battery a. The battery must be able to provide at least 160 mA at 8.6-9.2V for the duration of 1 hour.	1. Verification a. i. Using a multimeter, verify a new 9V battery supplies between 8.6-9.2V. ii. Apply a consistent 160 mA draw against the battery for 1 hour. iii. Measure the voltage output after 1 hour, ensuring the voltage is within 8.6-9.2V range.	N
2. Voltage Regulator a. The voltage regulator must provide 3.3V +/- 5% from an 8.6-9.2V source.	2. Verification a. i. Measure the voltage regulator output using a multimeter. ii. Ensure the voltage is within 3.3V +/- 5%.	Y
3. Antenna a. The antenna must be matched at 50 Ω +/- 5% at 27 MHz. b. The antenna must have a greater effective area than the car antenna. c. The antenna must be omnidirectional to within 6dB.	3. Verification a. i. Test the antenna with a network analyzer ii. Verify that the impedance is within the required range. b. i. Move the car and the antenna until the car is out of range. ii. Verify that the antenna is still detecting the signal c. Rotate the antenna through all six 90° orthogonal orientations and verify that the RSSI does not vary by more than 6dB.	Y N Y
4. RSSI Detector a. The RSSI detector must maintain accurate log conformance for 27 MHz signal b. The RSSI detector must have an input impedance around 50Ω for the 27 MHz signal	4. Verification a. i. Connect the RSSI circuit to a signal generator ii. Generate signal with 27 MHz frequency and sweep power from -56 dBm to 0 dBm. iii. Verify that the log output is accurate for all signals. b. i. Connect INHI and INLO on the chip to a network analyzer.	Y Y

		ii. Sweep over the 25-29 MHz range and verify the input impedance is around 50Ω	
5. GPS Module a. The GPS module must be able to update the location data at a rate of 10Hz to provide meaningful data.	5. Verification a. i. Connect GPS module to Arduino Uno and read NMEA sentences serially once satellite fix is attained. ii. Print sentences to Serial Monitor and analyze timestamp datafield of last 10 NMEA sentences. iii. Verify that timestamps for each sentence increments by only 0.1s.	Y	
b. The GPS module must provide NMEA sentences that include both latitudinal and longitudinal coordinates.	b. i. Connect GPS module to Arduino Uno and read NMEA sentences serially once satellite fix is attained. ii. Print sentences to Serial Monitor and analyze NMEA sentences and its data fields. iii. Verify that the data sentences include both the longitudinal and latitudinal coordinates.	Y	
c. The GPS module must provide accurate locational data within at least 0.001’.	c. i. Connect GPS module to Arduino Uno and read NMEA sentences serially once satellite fix is attained in location where coordinates are known (from Google Maps). ii. Print sentences to Serial Monitor and analyze longitudinal and latitudinal data fields. iii. Verify that the coordinates from GPS are the same as the known coordinates from Google Maps within 0.001’.	N	
6. Microcontroller a. The microcontroller must be able to handle the following peripherals to for the RSSI, GPS, and Bluetooth Modules: i. Analog Input ii. SPI	6. Verification a. Verify using the ATmega328P 32-pin TQFP Datasheet [] for the following peripherals: i. Analog Input ii. SPI iii. UART protocol	Y	

iii. UART Protocol b. The microcontroller must be able to refresh the I2C peripheral for the GPS information at a speed no less than 10Hz to maintain the GPS refresh rate.	b. Verify using the ATmega328P 32-pin TQFP Datasheet [] that the operating speed of the microcontroller is faster than 10Hz	
7. Bluetooth a. The Bluetooth Module must have a greater range than the car. b. The Bluetooth module must be able to communicate with the microcontroller over UART.	7. Verification a. i. Drive the R/C car out of range of the transmitter. ii. Measure the distance between the distance between the R/C car and the controller. iii. Add 10m to the distance to get verification distance. iv. With the Bluetooth modules connected the verification distance away from each other, send test signals from the R/C car microcontroller to the controller microcontroller. v. Indicate the receiving of the signal by lighting up an LED light attached to the controller microcontroller. b. i. Configure Bluetooth modules with microcontroller using UART connections. ii. Send test data between Bluetooth modules. iii. Verify the test data was transmitted. iv. Verify the test data was received. v. Probe transmitting terminals to verify data link. vi. Probe receiving terminals to verify data link.	Y Y
8. LED Display a. The LED display must be able to refresh display at at least the rate that new information comes to the remote controller from the Bluetooth module on the car.	8. Verification a. Verify by looking at OLED display to determine if there are frame drops.	Y