High Level Design

Group: RF Detection

Group Members: Joey Pye, André Magill, Shane Ryan, John Docalovich, Zack Bennett

Advisor: Dr. Jonathan Chisum

Table of Contents

1 Introduction

Our project will attempt to scale down the existing RadioHound sensor while also making it more power efficient and less expensive. This system is being developed for a wide range of military and commercial applications including IED detection, cellular coverage maps, and broadcasting frequency regulation. One of the most promising areas of application is to use dozens of these sensors spread out in an array across a war zone. Figure 1 below demonstrates how an array of nine sensors might be set up for RF signal detection. Each square represents a sensor. The color red represents a high power level detected in the requested frequency range, while the lighter colors represent a lower power level. Knowing the powers detected by each sensor and their locations would allow us to find the source of the signal, represented by the blue star. Moreover, this information can be sent to and stored on a cloud server and used to produce a heat map of the surrounding areas where the colors correspond to the power levels present for a certain frequency band.

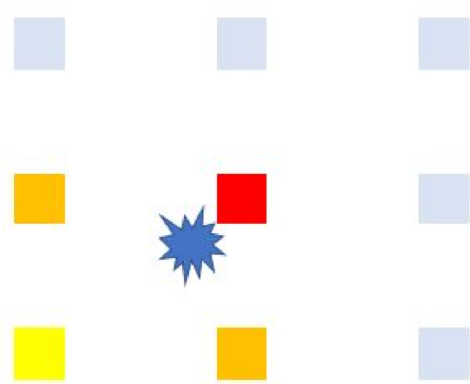

Figure 1. Diagram of an array of RadioHound sensors detecting an RF signal.

Thus, in a war zone, this technology could be used to identify the source of IED triggers or where an enemy is communicating from. It is in our best interest to produce as many of these devices as possible because the more devices in an array, the more accurate the heat map generated. Currently, the sensor is large, bulky, and costly; we will create a smaller system integrated onto a single PCB that is more cost efficient and provides a faster method of scanning than the present system. Through this, we wish to produce large numbers of these low cost devices to increase the coverage area monitored while also significantly cutting the overall price.

2 Problem Statement and Proposed Solution

The end goal of this project is to be able to wirelessly give the device a frequency range and have the device return the power levels detected in that range. This projects seeks to solve that problem at a low cost with a low power device. Specifically, the goal is to create a device that costs less than $50 each and consumes less than 3 Watts of power. We intend to accomplish this by overhauling the current device to cut down cost and power consumption.

One of the most significant changes we will be making to the current RadioHound sensor is replacing the Raspberry Pi with a CC3220SF MCU/Network Processor chip. Reasons for doing this include the fact that the CC3220SF will consume considerably less power, costs less, and simplifies the internal communication between the different components of the board. The current RadioHound sensor has the Pi relay commands to the onboard MCU and then the MCU sends commands to the various components. Our design has only the onboard MCU sending commands. The CC3220SF costs only $5 per chip while Raspberry Pi boards often cost around $65 each.

In addition, a GPS component will be added to the system using the Adafruit MTK3339 chip, priced at about $30 each. This will allow the RadioHound sensor the ability to send its location to the cloud as well as the power level data. The Adafruit GPS also provides a very accurate PPS time signal (generated from the GPS satellites' atomic clocks) so that the system is able to synchronize the timing of all of the sensors. Thus, the GPS component solves the task of figuring out when and where each piece of data is coming from during analysis. Another feature of the GPS component is that it is extremely small (16mm x 16mm x 5mm) and light (4 grams), easily fitting on a small PCB.

The power supply will most likely be a LiPo battery attached to the PCB that will be able to run for 24 hours at a 1% duty cycle. Depending on the current draw and power capabilities, we will tailor the battery choice to be the smallest, lightest, and least expensive possible while still meeting requirements. This will allow the battery to actually fit in the RadioHound housing (which it currently does not) as well as making it more efficient than the massive battery that is currently being used. We will also add a USB jack so that the massive battery could be attached if desired. A switch will be used to select the onboard LiPo or the USB jack as the power supply.

An analog circuit will be added to produce a DC voltage proportional to the detected signal's power levels that can be sampled by the microcontroller's ADC. These detector circuits are common in AM radios (used in AM demodulation) and utilize the square-law range in a diode where its output voltage varies as a result of the incident power. This detector circuit, a combination of inductors, a diode, and capacitors, will be able to integrate the incident power in the frequency bin without doing an FFT. This will speed up the data analysis process significantly since no FFT is required.

3 System Requirements

The goal price range for our RadioHound sensor will be around $50 per sensor. The power level requirements are that the system will be battery powered by a rechargeable Lithium Polymer battery with a USB option, and will run at around 3 Watts (depending on the duty cycle). The system should be able to run for up to 24 hours per charge. The user interface will be a web page where the user can input the frequency range and view the data that is stored and collected on a cloud server (both the server and the web page already exist and were created by a member of Dr. Chisum's group, we will simply be utilizing them). The RadioHound system will also house an Adafruit GPS module to track the sensor location and provide synchronized timing. All of these components will be housed in a small plastic black box that is able to be opened and secured shut for protection from the elements. The weight will not be a factor or requirement since the RadioHound boxes do not need to be held or carried while in use. For use, these boxes are stationed around various locations surrounding the target area. There will also be an analog circuit to detect the incident power levels and a WiFi antenna and network processor to receive commands and transmit data back. The system to receive, mix, and filter RF signals will be exactly the same as the current RadioHound sensor, the only change being the addition of a tuneable LPF on the output of the mixer for changing the frequency of the IF signal. Finally, there will be a microcontroller to relay commands between the various components.

4 System Block Diagram

4.1 Overall System:

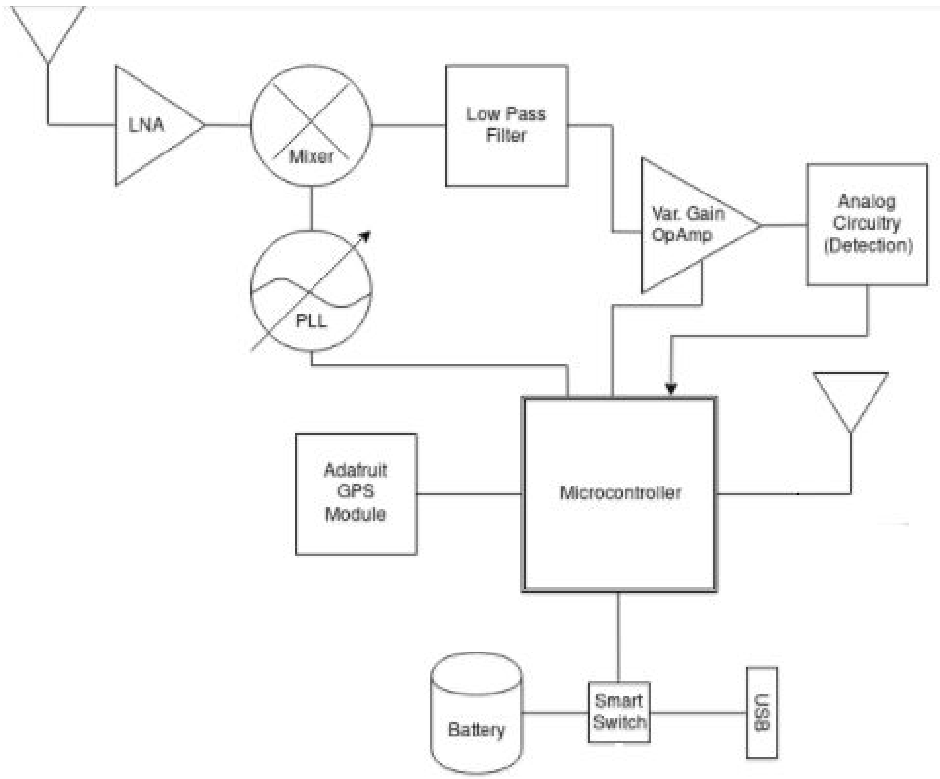

Figure 2. RadioHound System Block Diagram.

The above block diagram shows the electronic components of the circuit board. From this diagram, a couple subsystems stand out. The subsystems that seem appropriate are: the user interface, wireless communication, GPS module, filter system (including receiver and mixer), analog detection circuit, and power supply module. Those 6 subsystems will be discussed in detail in the following section.

4.2 Subsystem and Interface Requirements:

User Interface:

Fortunately, much of the user interface software has already been developed along with the RadioHound project. In terms of inputs, the user will need to be able to specify the frequency range to be scanned. On the output side, the user will need to be able to see the average power in the range in real time. We will need to calibrate our analog circuit to allow the cloud server convert the DC voltages back into power levels for displaying to the user.

Wireless Communication:

We will need to be able to wirelessly send data from each device to a server that will host the user interface. We will also need to receive the frequency range request from the cloud server. In the event that there is no WiFi and the device is turned on, the device will simply scan the entire range (700 MHz to 6 GHz) and store the contents into a cyclic memory buffer which it transmits once WiFi becomes available.

GPS Module:

The GPS module will allow us to provide a consistent clock to the microcontroller as well as accurate location of the device. Following the build criteria for the chip will allow us to integrate the GPS module into the PCB. A test of the system will be if the position is accurately recorded for the device and the devices sync to one another based on the time signature (PPS) from the GPS modules.

Filter System:

The filter subsystem is meant to describe the hardware and software that will be required to take the received RF signals from the antenna, mix them with a local oscillator signal, and filter it to convert it into a lower frequency signal that is amplified before entering the analog circuit. This system will require an LNA, mixer, PLL/VCO, low pass filter, and variable gain amplifier. The local oscillator signal is generated using the PLL/VCO with a reference signal coming from the microcontroller.

Analog Circuit:

The analog circuit will take the amplified output of the filter system and produce a DC voltage that is proportional to the power detected in the band using the square-law range of detector diodes. The analog circuit components will have to be rated for operation at high frequencies and have low parasitics.

Power Module:

We will need to select a battery that can provide the appropriate voltages and currents to run the components of the design for as long as possible. The power module will use USB power when available, but otherwise it will run off the battery.

4.3 Future Enhancement Requirements

There are many design features that future work on this project would include. For instance, we would like to be able to sweep a broader range of frequencies than our design allows. This would require more antennas and a way to change between antennae inputs for different frequencies using a mux. Another possible enhancement could be building a mobile app to interface with the devices. The CC3220SF has this ability to interact with a mobile app built in and interfacing with the devices this way would make it much more practical for use in the field. Moreover, in our current design, we are assuming that the devices have constant access to WiFi. Therefore, each device's WiFi is being configured to act as a station that will send data to the cloud server using the same WiFi access point. In the field, you would need a device to open an access point for the devices to collect data from the stations. Then you would need a way of getting data from the access point to the cloud server. Most likely, you would use some long range wireless communication possibly 3G or a mobile hotspot.

5 High Level Design Decisions

User Interface:

We decided to use the bulk of the user interface software that already exists for RadioHound. The primary interface that we would use is the heat map feature that allows the user to visually locate the RF source on a map. The only difference is that the output from our device is going to be a single DC voltage that using our calibration can be converted to a power level, so much less backend computation is needed.

Wireless Communication:

We will use standard WiFi 802.11 b/g/n in Station mode with the CC3220SF chip. In addition, the CC3220SF chip has a separate network processor with stack protocols built in to handle transmission and reception of data using WiFi. Data will be stored in a buffer before being communicated wirelessly using a 2.45 GHz antenna. We will probably use the Taiyo Yuden AH316M245001-T antenna.

GPS Module:

We plan on using the GPS Module MTK3339 chipset. This module will meet our goals of providing a consistent clock as well as location services. Its relevant features are:

a. -165 dBm sensitivity, 1 or 10 Hz updates, 66 channels
b. Ultra low power usage: 20mA current draw while tracking

c. 3.3V operation
d. PPS output on fix
e. works up to ~32 Km altitude
f. Ultra small size: only 16mm x 16mm x 5mm and 4 grams

Filter System:

This system will require a low noise amplifier, mixer, phase-locked loop/voltage controlled oscillator, low pass filter, and variable gain amplifier. Based on what has been used with RadioHound in the past, we have chosen to use the following specific components.

Part	Manufacturer	Manufacturer Part #	Price/ piece	Vendor Website
LNA	Qorvo	TQP3M9037	$1.79	http://www.qorvo.com/products/p/TQP3M9037
VGA	Hittite Microwave	HMC681ALP5	$9.90	http://www.digikey.com/product-detail/en/analog-devices-inc/HMC681ALP5ETR/1127-1865-1-ND/4756324
PLL+VCO	Hittite Microwave	HMC833LP6G	$12.57	http://www.digikey.com/product-detail/en/analog-devices-inc/HMC833LP6GE/1127-3034-ND/5360014
Mixer/Demod	Analog Devices	ADL5380	$5.28	http://www.analog.com/en/products/rf-microwave/iq-modulators-demodulators/iq-demodulators/adl5380.html#product-overview
Low-Pass Filter	Mini-Circuits	LFCN-255+	$2.99	http://www.minicircuits.com/MCLStore/ModelPriceDisplay?14720751193400.5870072024389166

Figure 3. Filter System Parts List

Analog Circuit:

The analog circuit will use the square-law range of diodes to translate input power into voltage. We are expecting input powers to the analog circuit of at most 250 mW (rough estimate), and based on our research, a Schottky detector diode will provide the necessary properties and suit our needs.

Power Module:

Switching power sources will be accomplished using an external switch on the PCB. One power source will be USB, while the other will be a LiPo battery. The default setting will be to use the LiPo but the user could plug in the massive battery and flip the switch to use it instead.

In choosing the battery, several of the components requires a voltage of 5 V while others only need 3.3 V. Since we will most likely use a LiPo battery that usually run at ~3.3 V, we will probably need a DC-DC converter circuit to step up the voltage. However, we will need to account for our device's high current draw in designing this circuit.

6 Open Questions

1. Specifications of the battery and overall power requirements
   a. What size battery will be able to power the device for up to 24 hours with a 1 % duty cycle? What will the 1 % duty cycle look like (how long will it be on and how long will it be off)?
   b. We will need to determine how much power each component requires. We think it is in our best interest to make a spreadsheet with all the component voltage and current requirements. Then, we will determine the voltages and total mAh needed from a battery to support all of the parts and can select an appropriate battery.
   c. Is there any way to reduce the current draw of the components?
2. Housing
   a. What is the smallest option for system housing that will be able to hold all of the components while shielding from the elements?
   b. How much heat will the system produce and how will the heat be dissipated?
   c. Will extreme weather (cold/hot temperatures) affect system operation? How to insulate the housing to maintain a safe temperature?
   d. Should we include the housing requirements in this project or is it beyond the scope of this version of the project?
3. Analog circuit
   a. Can we use filters to accomplish this?
   b. What components will work well at high frequencies with small parasitics?
   c. What should the circuit look like and how will we protect the ADC from getting too large of an input voltage (max input is 1.4 V)?
4. Programming the device
   a. How will we manipulate the current RadioHound code in order to work with the new CC3220SF microcontroller?
   b. Which parts of the code should we keep and which should we remove for this version of the project?
5. Adafruit GPS
   a. How much data do we need from the GPS? Just the latitude and longitude?
   b. How do we parse the serial data from the GPS to get the data we need?

6. Cost
    a. As you will see in the next section, the projected cost of each device is about $82. This is not too far from the goal, but how should we try to cut the cost more?

7 Major Component Costs

Component	Price
CC3220SF Microcontroller	$5.00
WiFi Antenna	$1.41
RF Detection Antenna	(TBD)
Adafruit GPS	$29.95
Housing	(TBD)
PLL + VCO	$12.57
LNA	$1.79
VGA	$9.90
Mixer/Demod	$5.28
Low-Pass Filter	$2.99
LiPo Battery	~$10
PCB	~$2.50
Other Expenses	(TBD)
Total	~$82

Figure 4. Component costs.

The above table specifies the cost of producing one board. In order to develop the boards, we also have purchased four CC3220SF Development Boards for $50 each.

8 Conclusions

This project aims to solve the problem of real-time, cheap frequency spectrum mapping. Our design will allow for a low cost, faster version of the current RadioHound hardware that is completely integrated onto one PCB. While still dependent on the full version being designed by Dr. Chisum’s group, our design will fit into a sensor hierarchy to allow the full version to quickly zero in on the specific frequency range that is being broadcasted on. Moreover, since this design aims to be significantly cheaper, more of these sensors can be deployed in order to provide more accurate frequency maps.

Our demonstration for this semester is to show our ability to program the PLL/VCO to output a specific frequency range of RF signals using the CC3220SF chip. Our next goal will be to begin integrating and programming the other components and putting them together onto a PCB in Eagle.