ACE-COM

Advanced Combat Emergency Communication

Professors:

Dr. Richie & Dr. Gong

Sponsors:

nScrypt

Group # 8 Members:

Calvin Wang, Christopher Marchese, Daniel Silva, and Ramy Athanassios

Table of Contents

List of Figures

List of Tables

1 Executive Summary

There are several real-world scenarios in which communication is vital, but physical proximity and ongoing events prohibit the use of a standard walkie-talkie. Would you like to communicate with someone who is out of range to speak to? Would you like to not only communicate verbally, but also be able to send information using images you have captured? Would you like to know where everyone you are talking to is located in reference to your current location? ACE-Com (Advanced Combat Emergency Communication) is a new, easy to use device that enables users to communicate with each other via a wireless system. ACE-Com uses several industry standard components, as well as some new technologies that cannot be found elsewhere on the planet, to deliver such a device. This will be achieved with the help and guidance of nScrypt.

ACE-Com will be a small device that can be strategically embedded into an outfit, such as a military uniform. This is important because the device needs to be something that will not be easily lost in a chaotic situation. Each physical ACE-Com unit will have an LCD screen to display any relevant information to the user, as well as a couple of buttons that that will allow the user to navigate through the ACE-Com user interface. The LCD will display all relevant GPS information, channel/mode information, and battery life for the user to see. The buttons will allow the user to change the operating mode, change the output volume, and view specific GPS information. The device will also have an attached headset which will contain the microphone and speaker. Since ACE-Com is a handheld system, the primary speaker used will come in the form of headphones. The microphone and speaker will be connected to the base unit by a 3.5 mm jack.

The ACE-Com system will use a standard 2.4 GHz frequency to send and receive information using several channels. ACE-Com will use three primary modes: combat, active, and standby. Combat mode will be an ideal end result in which audio will be sent over a full duplex channel. This enables users to communicate back and forth completely hands-free while the channel is open. Combat mode is the desired end goal, but will only be achieved if time allows. Active mode is a certainty, and in this mode ACE-Com will function as a typical walkie-talkie. This will be a half-duplex mode in which the user must press and hold a button in order to speak. The last mode, standby, will turn off all functionality except for the GPS. In this mode, ACE-Com will periodically send out the GPS information. This is to enable the users to always be able to find each other, even while in situations in which verbal communication is inadvisable, impossible, or simply because the battery in the ACE-Com unit is too low to power the other functions.

In addition to these modes, the user will be able to capture images using a camera attached to the ACE-Com headset. The camera will automatically store any pictures taken onto a memory card. This feature gives the user further capabilities in acquiring useful information while not needing carry an additional

external device. If time allows, the users will have to capability to send the images to other units, or keep them stored on their own units for later use.

The most important aspect about ACE-Com comes from a working partnership with nScrypt. This company builds micro dispense machine systems that are capable of printing full 3D parts. Stereo-lithography is a method in which special machinery is used to fabricate, or print, 3D prototypes. The machines nScrypt builds are very similar, except they are used to print electrical components. Once ACE-Com has been built using traditional components, a portion of the design will be transposed in order to use nScrypt 3D printed components. The large bulk of the work put into ACE-Com project will be spent in this phase. The main focus while in the world of 3D printed components will be spent on printed transceivers and antennas.

2 Project Description

Before being able to design the individual components of the ACE-Com system,

description of the ACE-
parameters were decided upon using system requirements from similar systems and the capabilities of the types of components which will be used in the ACE-Com system.

2.1 ACE-Com

professional colleague of his: Mike Newton, Director of Strategic Technology at nScrypt. After meeting with both Dr. Gong and Mr. Newton, a clear understanding of what nScrypt was looking to accomplish by sponsoring a Senior Design group was reached. 3D printed components are a very new and unique method of creating products and product parts. The long term goal would be to print out a complete product design using their products. Unfortunately, this new technology is still a while away from that accomplishment; however, a big step in
s where the ACE-
Com system comes into play. The goal for ACE-
-
transceivers and antennas. This led to the discussion of several project options that would adequately meet the needs for both Senior Design and nScrypt.

Initially, the discussion led to the idea of creating an altered version of a WIFI Hotspot that would transmit music. This would allow the user to continue listening to his music while moving freely throughout his house. The problem with this idea was that two different units would need to be created: a base unit to send out the music, similar to a router, and the handheld unit that the user could plug headphones into. This meant that no single device would truly be testing the

capabilities of the transceiver to both send and receive data. Next, the project proposal moved on to some sort of tracking system for shipping companies. This would require multiple devices that would each have a sensor used to keep track of shipments. A device on a shipping crate would interact with a separate device at the various destinations. The transceivers would communicate with each other information such as arrival time, package content, time in transit, destination, origin, etc. After much consideration, it was decided to not pursue this project for various reasons. The major reason was as follows: it would not be very easy, or even, plausible, to be able to adequately test such a product against an existing one. This is very important in order to accomplish our goal of proving the

In the end, the decision was made that a communication system comparable to a walkie-talkie would be a very good project because they are very common products. This project would allow for lots of options when it came to the comparison of the communication system using nScrypt parts against real-world existing products. With this certainty, ACE-Com was born. This project met all of the requirements for both nScrypt, as well as Senior Design. It also allowed for lots of flexibility to shape the project as needed.

2.2 Goals and Objectives

ACE-Com is intended for emergency situations, such as those often encountered by police, fire fighters, and the military. ACE-Com will efficiently cover a wide range which will be needed in combat situations. Power consumption will be a minimum; the battery will be rechargeable and long lasting. Putting in mind that the device is for military and police uses, it needs to work for a long time and in different modes (combat, standby, and active). Combat mode: it will be a full duplex, open channel where the user needs only to talk without any buttons to hold once ACE-Com is in that mode. Active: the device will work as any walkie-talkie, and the soldier has to interact with the device in order to communicate

team members. Moreover, the device has a camera that can be used to send images to Command. Briefly, the device will make a ring of communication including each individual, his team, and the commanders at some base location. Also, the device must perform all the tasks very fast and with high competence.

The outer feature will be lightweight, ergonomically designed, and built in a combat suit with the ear accessory. Thus, users will not have to carry any ungainly devices. ACE-Com is a multi-facet, portable, ergonomic, efficient, multi-channel, easy-to-use, and multi-mode way to communicate within a wide range transmission radius. Although our greatest challenges will be in making ACE-Com successful using the unique parts from nScrypt, these are equally important objectives. If ACE-Com does not meet these criteria, it is not useful. No amount

of revolutionary technology will change a useless product into something desirable.

2.3 Specifications and Operational Requirements

The ACE-Com system will fit into a small casing as shown in Figure 1 and Figure 2. The buttons will allow the user to interact with the device and change settings as needed. Credit is given on the unit itself to its designers, Group 8, as well as nScrypt for their mentorship and manufacturing of the unit.
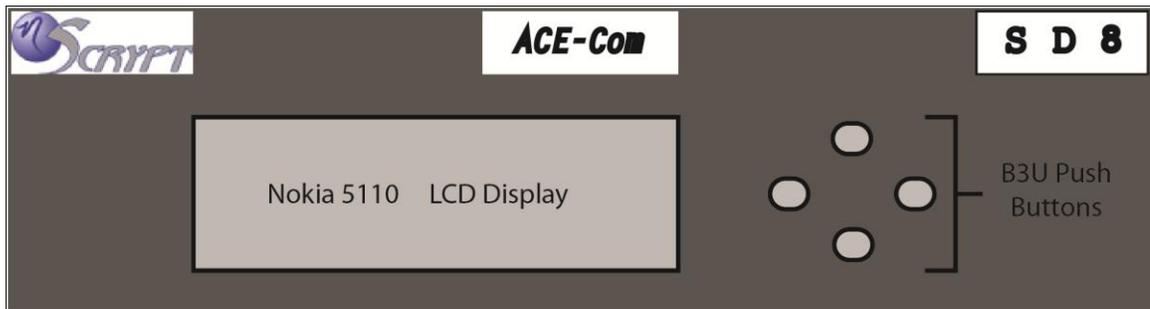
Figure 1: ACE-Com Unit Front View
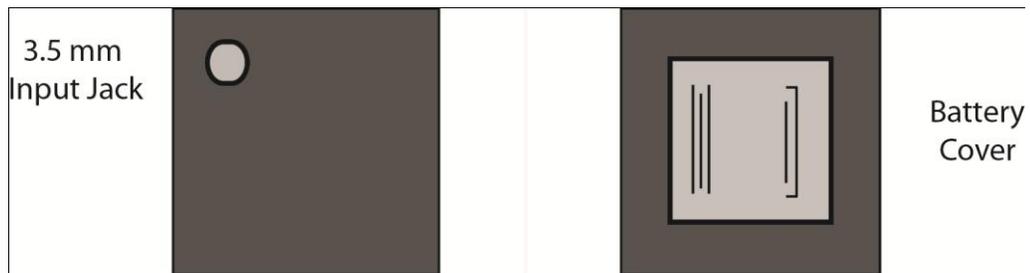
Figure 2: Left and Right Side Views Respectively

The physical unit will have a 3.5mm input jack intended for headphones on the left side and the batteries will go in on the right side. Below, in Figure 3 and Figure 4, the backside of the unit can be viewed, as well as a 3D rendering of the unit. The back view shows how the antenna will be connected to the unit.
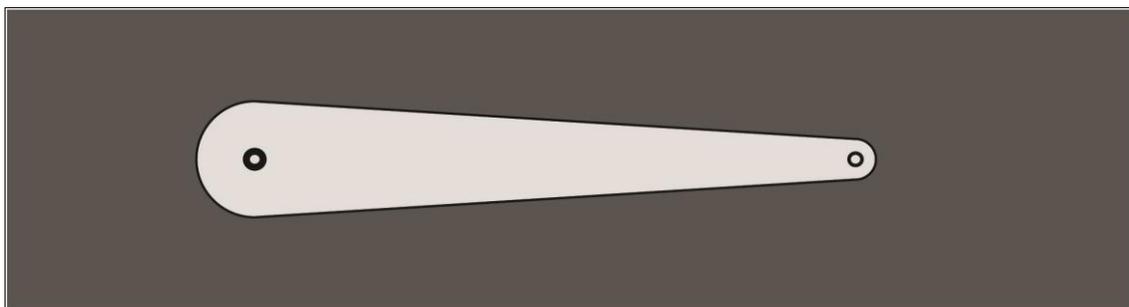
Figure 3: ACE-Com Unit Back View

Figure 4: 3D View of Prototype

Below is a list of specifications designed for the ACE-Com system.

> ACE-COM will be powered by rechargeable, lithium ion batteries (3.7-4.2 Volts, 140-220mA*h/g)
> 2.4 GHz transmitting and receiving RF channel
> ACE-COM will weigh less than 3 lbs
> ACE-COM will be integrated with GPS
> Headset accessory will weigh less than 1 lb
> A 1.3 Mega Pixel camera will be attached at eye-level to the ear accessory
> Voice transmission near .1 miles
> SD memory card slot to store captured images
> 3 interchangeable, manually switched modes: combat, standby, active
> Battery life 48 hrs, combat mode; GPS enabled, constant voice transmission
> Battery life 10 days, standby mode; GPS enable(0 0 1)4(0)-a; 0 1 144.

3.1 Existing Similar Products

ACE-Com is a new generation of the traditional handheld transceiver, otherwise known as a walkie-talkie. Walkie-
applications and implemented in numerous fashions. They can vary physically

uses from recreational use to military. ACE-Com will most closely resemble a walkie-talkie that you can find in any all-purpose store, lying somewhere near the middle of this broad spectrum. ACE-Com will also be closely related to a mmonly used in vehicles, particularly large trucks, as a means for short range communication with other vehicles.

Walkie-talkies are devices that have an extremely broad variance between products. Range, price, manufacturer, and functionality are all variables with a wide spectrum. Motorola, Midland, Garmin, Kenwood, and Uniden are all common manufacturers for these products. In Table 1 below, you can see some values for these walkie-
averages of values that we have noted in our research.

	Starting At	Ending At
Price	$10.95	$374.99
Range	55 ft	36 miles
Channel Number	1	22

Table 1: Walkie-Talkie Characteristic Values

Walkie-talkies can have additional features such as a GPS capability, weather radio, voice scrambler, waterproof casing, altimeter, and weather alert tones.

3.2 Technologies used in ACE-Com
3.2.1 GPS

It was a dilemma to find a suitable GPS receiver that would fit the ACE-Com n the market. However, we needed a cheap, accurate, and power saving GPS receiver. Research led to many GPS receivers, three of which were researched further for use with the ACE-Com system. The first was Holux UB- 93 receiver; it took more in depth research to find that the Holux   -Com system for many reasons, which will be mentioned later. Then we found the Copernicus II GPS receiver, but we found a lot of drawbacks, from our perspective, that would be unacceptable for us. Finally, we agreed that the most suitable one was EM 408.

Holux UB- 93:

Its dimensions are 17* 22.4* 3mm, and it has up to -159 dBm sensitivity. Also, it has 32 channels of satellites besides supporting NMEA0183 V 3.01 data protocol. Operating frequency is 1575.42 MHz with accuracy 3M 2D-RMS

(without aid) and velocity: 0.1m/s (without ait). as for acquisition time, reacquisition is <1 sec, hot start 1 s (average), warm start 33 s (average), and cold start 36 s (average). Baud rate ranges from 4800 to 115200 bps adjustable (default 4800); in addition, it has an operation current: acquisition: 60 mA at 3.3V, operation current- tracking＜45mA at 3.3V. Input power ranges from 3V to 5V.

Copernicus II:

Copernicus II GPS receiver is the latest product of Trimble; Copernicus II is a 12-channel GPS receiver in a 19 mm* 19 mm* 2.54 mm. It has a lot of features: -160dBm tracking sensitivity, 120 mW typical continuous tracking, supports SBAS (WAAS, EGNOS), Active or passive antennas; protocols (NMEA, TSIP, and TAIP), 2G dynamics. Also, its specifications are: acquisition -130 dBm, 50% _ reacquisition: 2s, hot start 3s, hot start without battery backup: 8s, warm start: 35s, cold start: 38s; interface characteristics; connections: 28 surface-mount edge, it has two serial ports. Its prime power is 2.7 V DC to 3.3V DC, and its power consumption is 40 mA (120 mW) at 3 V. Copernicus II can be used for portable devices like cell phones, cameras, etc.

EM 408:

It is a high performance GPS chipset with dimensions: 36.4 mm* 35.4mm*8.3mm. It supports NMEA 0183 and SiRF binary protocol and has 20 channel all-in-view tracking. Operating frequency is 1575.42 MHz and with sensitivity -159 dBm. Accuracy position is 10 meters, 2D RMS 5 meters, 2D RMS, WAAS enabled. Its velocity is 0.1m/s, and synchronous time to GPS time is 1us; as for acquisition time, reacquisition is 0.1 sec (average), hot start 1 s (average), warm start 38 s (average), and cold start 42 s (average). It needs a main power input 3.3V DC input, and its power consumption is 75mA (continuous mode). Baud rate ranges from 4800 to 57600 bps adjustable.

Comparing and contrasting:

Holux UB-93 looked good in the beginning for many reason: it was cheap, very sensitive, and low power consumption chip. Nevertheless, its datasheet was too ambiguous about some things; 1_ power consumption: it was only mentioned (low power consumption without giving a specific number) 2_ sensitivity: datasheet mentioned -159 dBm while on Holux website the specs part (up to -159 dBm), and in another place was better than -159 dBm 3_ Reacquisition<1 sec. The main facet for rejecting Holux was the company had no branch at the USA, so if I wanted to order, I would have to contact the vendor in China. Also, there are a minimum number of chips to be able to order.

project. First, it had no built in antenna, so we needed to purchase with it an

our transceiver has only two antennas for the voice communication. Also, all the external antennas were wired which would cause hassles on the PCB. Moreover,

Copernicus II needed its own board to be able to connect with the outside antenna which would cost us with its external antenna more than EM- 408.
-
408.

Finally, EM-408 had suitable features; it had 20 channels, and sensitivity -159 dBm which was less than that of Copernicus II, yet it was still acceptable to us.

project. Also, the EM-408 has an internal antenna, and this is an important factor because wiring another antenna could be burdensome due to the fact that the RF signals could cause noise that will interrupt each other. It should be noted; that the EM-408 is a very economical option too this is because the antenna already comes with it. Thus, the extra cost of an omni-direction PCB antenna costs around $20.00. Moreover, the EM-408 is a standalone component this is a good feature because it will not have to be mounted onto the main PCB. This is clearly a bonus because when working with RF the layout of the PCB is extremely important. Furthermore, the EM-408 has a vendor in the United States and the Holux component only had vendors in China, and shipping and availability is a big obstacle if the component is not in stock. It should be noted, that the Holux also is only available if the user will buy more than 50 units minimum. Then production and shipping of overseas products can take months and months. Additionally, the EM-408 has the most online material and the datasheet, application notes, design notes, and tutorials are the most in depth and well written. Thus, it will be a lot simpler to implement this device rather than the other two. And, the accuracy of the EM-408 is accurate within 5 meters. Also, the EM-408 uses the NMEA 0183 protocol this is an industry standard for GPS components, and that is a good feature because it will be easier to work with than other protocols. Also, the EM-408 utilizes two different power modes: trickle-down and active this is good for the project because power savings is a high priority. Overall, the EM-408 is a clear choice not only is it more economical, but it is easier to use as well, and the performance is much better than other GPS units.

3.2.2 RF Communications

Radio Frequency (RF) Communication is a wireless communication. This project will focus on the RF communication linked to the two way radios or what is called
-   two technologies
of RF communication.

Conventional radio systems:

In which each group of users has one discrete frequency to communicate with. Through this frequency any user in the group can either transmit or receive on first come first serve base. Communications can be occurred with and without a repeater; if they are without a repeater, they will be simplex communications which cover very small range. A big advantage of this system of communication is that it gives the opportunity for users with different brand devices to

communicate given that they all using the same single frequency. Also, its issues.

Trunked radio systems:

In which 20 or more groups are allocated to a certain radio channel, and the system computer assigns a user of the users group a certain frequency to use when push-to-talk button is pressed, so a single conversation occurs over several channels, to remove the need for manual channel changers. Also, this system has repeaters, so it covers very wide range and not limited to specific areas; this system is considered a complex system. The advantage of this system is the higher secure communication than that of the conventional, yet it suffers from all the RF drawbacks, and it increases the complexity of infrastructure.

This project will be kind of hybrid between the conventional and the trunked; it will have a single frequency to use, yet a repeater will be used to get wide range of communication.

Types of equipment used:

Portable radios: are small, light, handheld wireless devices; also, they have microphones, speakers, rechargeable power supply, and antenna. They can communicate with other portable devices or base station radios. Usually, they are low power consumers.

Base station radio: contain transmitters and receivers. The radios are powered by external electrical systems, and the antennas are located far from the base by tens or hundreds of feet. Due to the usage of external electrical sources, the bases have powerful transmitters and highly sensitive receivers.

Repeaters: have both receivers and transmitters; repeaters are used to improve the quality of communication coverage. The receiver of the repeater is tuned to the frequency used by the portable or base station transmitter for incoming signals, and the transmitter of the repeater is tuned to the frequency of the portable or base station receiver. The repeater rebroadcasts back the signal to the network with higher power.

Accessories for the portable devices:

Most accessories are for the portable devices to allow more flexible usage. For instance, extra batteries are used to extend the operating time. Also, making the device to be attached to the suit to give the user high degree of freedom, and keep his hands free for performing his task efficiently; moreover, packaging with a water resistant package will allow working in extremely wet situations. In addition, microphones have many varieties; wired microphone with the noise

bone microphones which worn behind the ears, or throat microphones.

Battery eliminators: are very useful accessories used to allow the radio device to work using external electrical system other than its battery like the vehicle electrical system which will prolong the life of the battery before needing to be charged.

Vehicular adapters: allows the device to work as a mobile radio. When the portable device is placed into a vehicular adapter, it will use the electrical system of the vehicle and will be connected to the car antenna, and power amplifier might be added to amplify the signal. While the device is in the vehicular adapter, its battery will be recharging.

Analog wireless technology:

When analog is mentioned that means electronic transmission fulfilled by summation of signals of varying frequencies and amplitudes to be used as carriers for a certain frequency of varying electromagnetic current represents the message, analog is used for many decades now. Analog represents any fluctuating, or varying signals. Analog is usually represented by sine waves, and it uses FM, AM, DSB, SSB, or VSB modulation techniques. Because of existence in market for a long time, engineers worked on every facet of the analog technology to improve its performance. Advantages of Analog technology are high quality equipment, reduced costs, use natural voices (which is favored by many users), many compatible accessories/products, use bandwidth efficiently, very well known/ understood by public, and ability to communicate with weak and noisy signals; on the other hand, the disadvantage is: it allows only one conversation at any time on each channel, needs hardware receivers/transmitters to suit certain transmission, upgrading with features not technology, and no software applications available.

Half- Duplex and Full Duplex:

Two way communications are possible, but the   -talkies have this feature; nobody will be able to talk and hear simultaneously. There are two frequencies one for transmitting and one for receiving. In this project, the main objective is to have a half duplex system with CC2500 due to the limitation of the technology provided to us by the sponsors yet secondary objective is to have a full duplex system with CC2510 through convincing the sponsors to provide a printed transceiver with the capability of full duplex communication since full duplex saves time and full capacity channel use for both directions.

Noise and Interference:

Any communication system will be affected by the surrounding which will cause noises, and engineers have to solve the problem of the surrounding interference. Noise is any signal that will affect or distort the original signal causing degradation in the quality of communication. There are different types of noise or interference.

1. Noises caused by nature:

   considered in the design and calculations to make sure that the input power for the signal is high enough to compensate the losses due to the natural noise.

2. Artificial noises: the surrounding is full of equipment that radiates waves that can impact the quality of the RF signal like microwaves, power lines,
   er is
   higher or equal to the power of the original main signal. Also, if this range of frequency used is not unique for this system, and there are other devices that operate on the same signal or close ones this will lead to high destructive interference.

3. Intentional interference: sometimes it is intentional to cause interference or distortion to the signal to prevent communication. It happens through jamming or interference.

The first two types of interference can be overcome by increasing the signal to noise ratio of the signal sent by the walkie-talkie through increasing the input power; power amplifiers in the circuit of the before the antenna can boost up the power, yet the third part must be handled through encryption techniques.

Antennas:

Antenna is the part responsible for transferring the signal from electrical to electromagnetic waves so as to be able to travel in air, so antennas play vital roles in wireless communications. Most antennas are based conceptually on the idea of resonance which explains why antennas have operating frequencies and narrow bands. For successful communication, some aspects must be considered. 1. Input impedance: the input impedance has to be the same along the whole antenna circuit of the transmitter till the stage of transferring signals to electromagnetic waves. 2. Polarization: it is the shape or orientation made by the signal in air; there are many shapes for the signals depend on the type of
to keep
the shape of the waves coming from transmitter antenna the same as the shape of the signals received by the receiver antenna, one orientation for the whole communication line. The orientations must match each other to fulfill maximum power. Some specifications have to be considered in picking the antenna especially for this project because it is a two stage project regular whip antenna then 3 D printed antenna. Therefore, the first antenna must be chosen carefully since it will be replaced by a printed one.

Frequency and size: the sizes of antennas vary according to the antenna usage, so microwave antenna is different than the one used in cell phones. Therefore, for each range of frequencies, it has to be certain types of antennas with certain shapes.

Directivity: antennas radiate the signal equally in all direction like the omni-directional. Some other antennas radiate in a specific direction more than the rest

180 degree and narrower to 60 degree or below. RF antennas are directive ones with some differences depending on the design and the materials used in the antennas.

Applications: there are either base stations or point to point applications. Base station from its concept it needs to be a multiple access point, so its antennas have to be omni-directional or wide range directive ones as for point to point applications only use directive antennas.

The project antennas will be of the category of antennas for low power applications; two technologies will be used non embedded and embedded antennas. The very popular non embedded antenna for walkie-talkie application will be the whip antenna. It is a quarter wave length; also, it has to be grounded (connected to circuit trace and batteries). Whip antenna radiates in any direction except straight up if it is mounted vertically. To calculate the length of the antenna that is needed. In this project, the frequency will be 2.4 GHz; therefore the wavelength will be 12.5 cm. ANT-24G-WHJ-SMA antenna is chosen to be used in the project. ANT-24G-WHJ-SMA antenna has operating frequency 2.4-2.5 GHz; it is omni-directional, 90 degree joint with SMA fixing. The figure below shows the VSWR of the antenna and the operating frequencies.

It should be noted, that overall the whip antennas are typically the most economical out of all the common designs of antennas that are easily acquirable. Additionally, whip antennas are commonly used in portable RF communication devices, like walkie talkies. Also, whip antennas typically use SMA connectors which is an industry standard for RF communications. Another motivating factor to test out this type of antenna stemmed from the conversations with lead RF design engineer at Ansys, respectively. In which, he explained that whip antennas are always a decent reference to monopole antenna designs; this is the printed part that the system will utilize. Thus, one of the major goals to accomplish is to prove that the printed component can work better or just as well as the traditionally made components. This will be a breakthrough in technology because printed components are typically less than half the cost of traditional components.
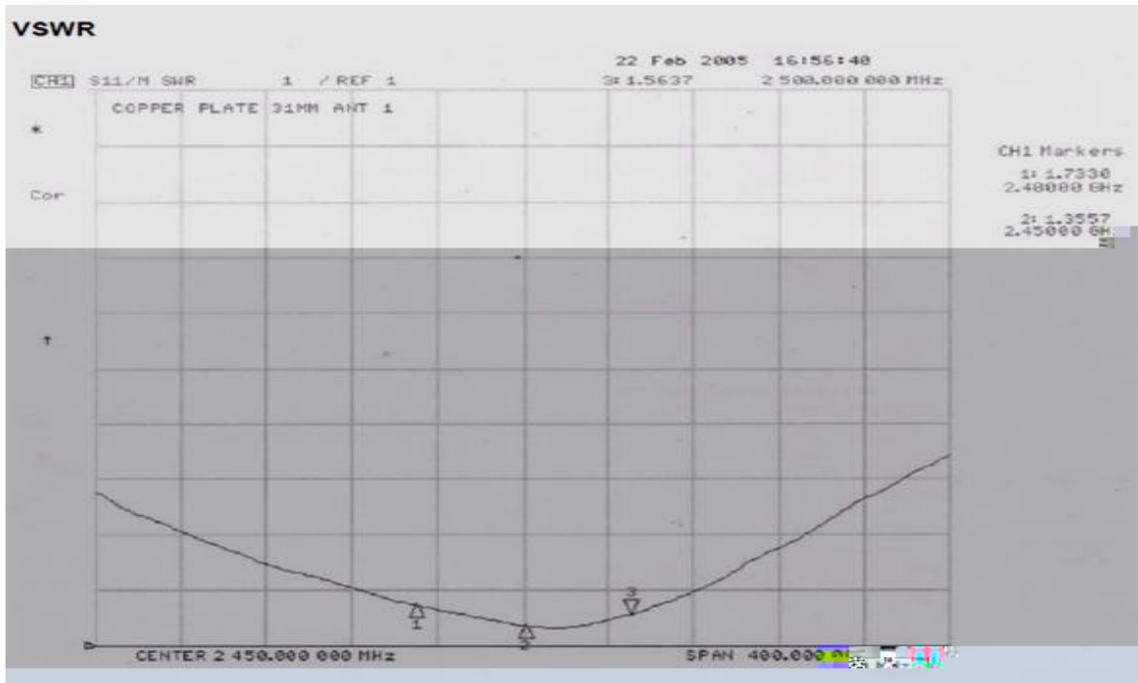
Figure 5: VSWR Graph Printed from the Datasheet by Permission from RF Solution

To connect the antenna two the PCB, we need SMA terminator female 50 ohm. The other half of the project, we will use a new technology of the embedded 3 D transceivers, so the antennas will be printed, and this technology will be provided by nScrypt. It will be a kind of prototype project for testing the new technology to later on widen the range of frequencies and the ranges of coverage.

The specs of the printed antenna are: Its main operational frequency is 2.4 GHz; its secondary is 5.165 GHz, and the antenna gain at2.4 GHz is 1 dBi. The antenna is dual band antenna; the antenna can be made to work at multiple frequencies of the two arms and the gap between varying the length of the two arms and the area of the gap enclosed by them will vary the tuning frequencies. Longer antenna arm is the main frequency while the short arm helps in tuning and in providing the second frequency. The figure below shows the antenna simulation in the frequency domain.
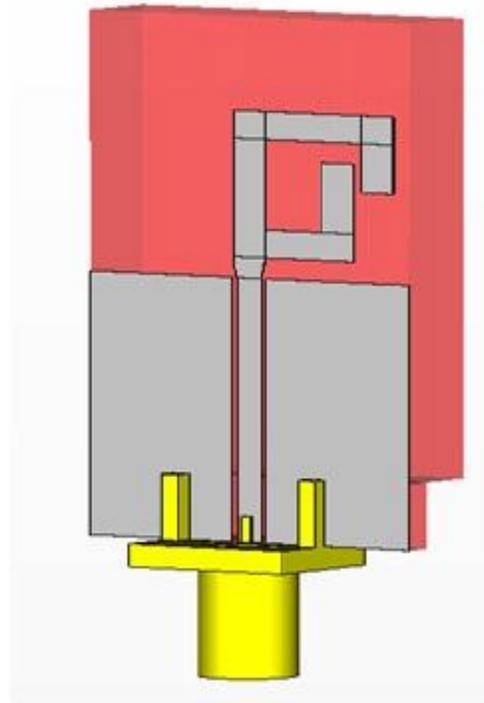
Figure 6: 3D Printed Antenna Current Design (shown with permission from nScrypt)
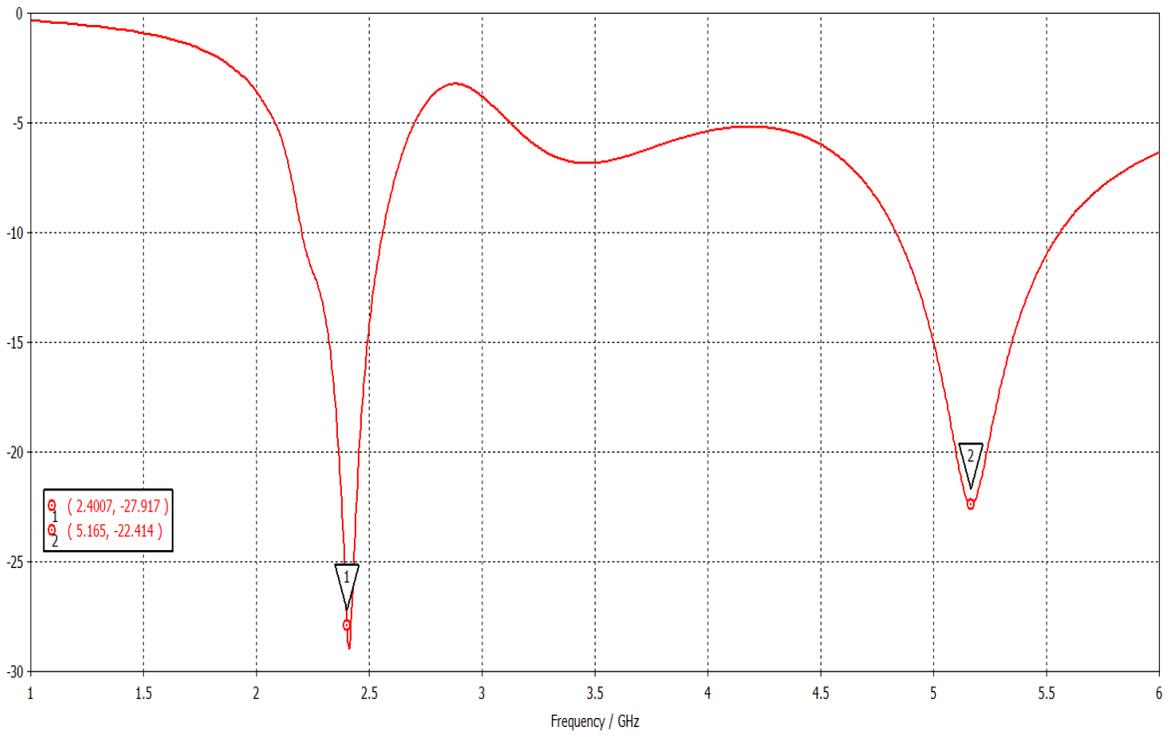
Figure 7: S-Parameter Frequency Domain Response Simulation (shown with permission from nScrypt)

14

The figure shows the two operating frequencies of the antenna.
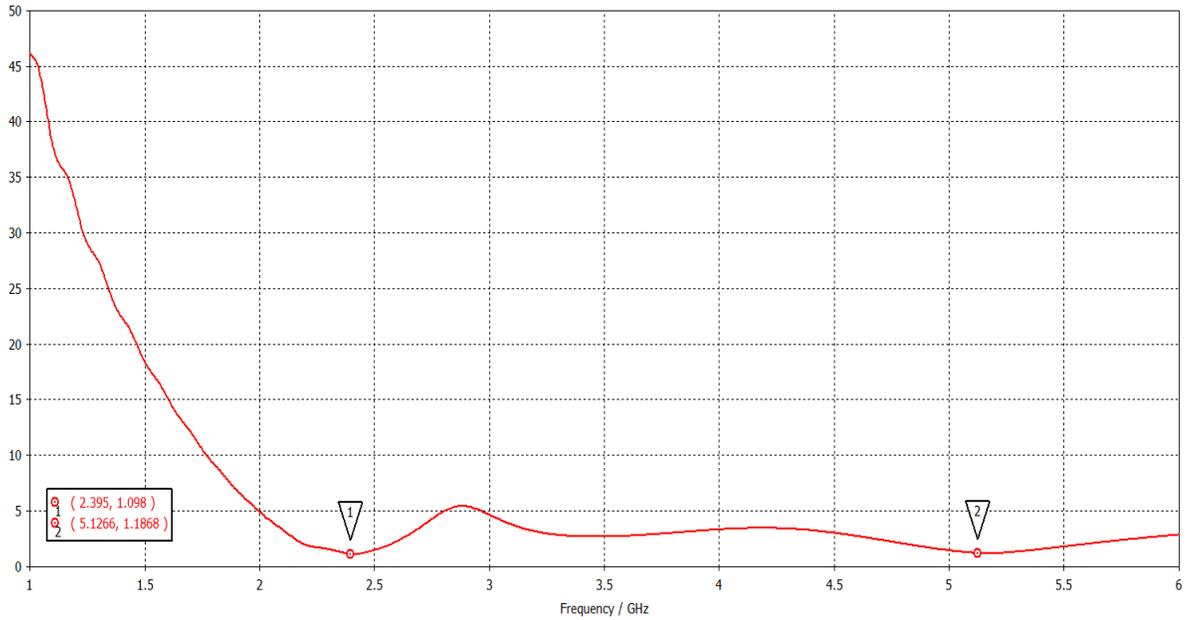
Figure 8: Voltage Standing Wave Ratio (shown with permission from nScrypt)

The figure below shows the smith chart of the antenna.
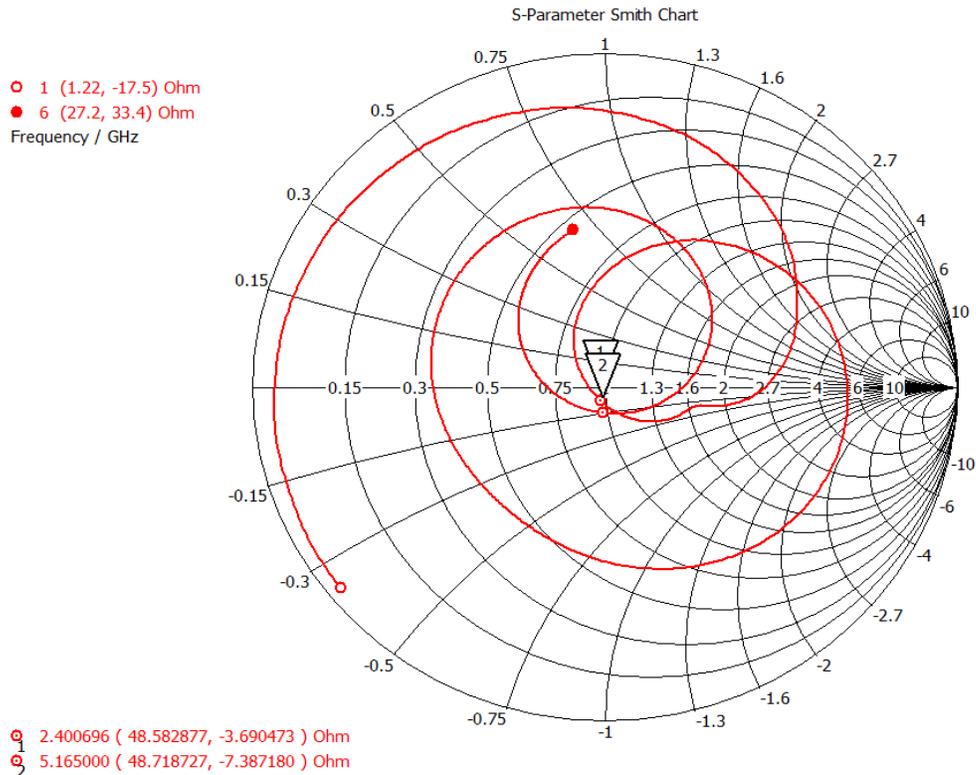
Figure 9: S-Parameter Smith Chart (shown with permission from nScrypt)

The smith chart above shows that at points 1 and 2 we have minimum reflection coefficient for the antenna interface connection which means less power reflected so less power dissipation from the antenna. The impedance approximately equals 1.

In the beginning of the project, we thought about having full duplex walkie-talkies with a GPS tracking system. When we studied in depth the technologies we are

do the full duplex as the transceiver we will get from them is only designed for half duplex applications. Therefore, we had to forsaken the idea of the full duplex. This is because the microcontroller that the ACE-Com system will utilize, the CC2500, cannot support full-duplex. Moreover, it should be noted that the sponsor of the project, ACE-Com, is NScrypt and this company designed a very unique packaging and antenna for the transceiver at hand. Also, as engineers design must be made to tailor what the sponsor has provided or it could cause conflict and be burdensome. Additionally, the CC2500 is an analog component. Thus, the project is forced to be an analog design. Also, the transceiver we have pushes us to use analog technology; it is an analog transceiver. However, the GPS part has to be digital, so we need to work half digital and half analog. Moreover, in the beginning of our project, we thought about a coverage range of 10-20 miles, yet we got information about the transceiver we have to use for the project that its range is below one mile only. Therefore, we had to lower our range to less than a mile but think about alternatives like using repeaters to widen the range.

3.2.3 Power Gauge

Due to time constraints, a power gauge was not implemented in the final ACE-Com prototype. If it were to be implemented in a future version, the following paragraphs describe how it would be handled.

The BQ27010 will be the battery capacity monitoring integrated circuit that will utilize for the project, ACE-COM. Several factors weighed into the decision; the project required a device that is easily integrated with the MSP430, which is economical, and space-saving. The BQ27010 is also known as the BQJunior, and comes with bonus features which also are beneficial towards the project. BQJunior is specifically targeted for portable devices because it is a stand-alone, single-cell Li-Ion monitor. This feature fits well for this project. Thus, ACE-com will not have to over budget by sampling a multi-cell monitor.

The motivation to install a battery monitor is driven by the fact that the target audience is a portable application mainly; thus, users will surely desire a battery monitor to know when to charge the device. Moreover, many of the components have a low-power operation which is important for the specific project. In essence, many times since the device will run on such low power it will be difficult to know when the device will require charge without a monitor. And the monitor offers down to 2% accuracy on charge capacity, which is very accurate;

this is one of the benefits working with a single-cell monitor rather than a multi-cell monitor.

The plan is to connect the battery monitor to a microcontroller, specifically MSP430, and to relay the information to the LCD display. ACE-com will program on the display to show percentage of battery remaining, and time left on battery with current usage (which will vary). This is an important feature to the project specifically because ACE-COM will have many different modes; which will demand a different amount of power.

MSP430	CONNECT	bq27010 (EVM)
P1.0	← →	HDQ (J1-3)
VCC	← →	PACK+ (J1-1)
VSS	← →	PACK– (J2-1)

[1] A 10kΩ pull-up resistor must be installed between PACK+ (J1-1) and HDQ (J1-3)

Table 2: Interconnections between MSP430 and BQ27010 & explains the requirement of a pull-up resistor.

Above in Table 2 is the suggested connections from Ti.com; this is also another reason the bq27010 was chosen; the compatibility and troubleshooting is undeniably the best. Also, in the same manual teaching us how to use the BQ27010 properly (http://www.ti.com.cn/cn/lit/an/slva413a/slva413a.pdf), and which MSP430 model specifically, MSP430F168, will work optimally with this specific battery monitor. It should be noted, that ACE-com will use the HDQ connection rather than the I^2Q connection (master-slave) to avoid complications. Since, the HDQ interface will be using single-wire communications it will be more simple to implement, and also because I^2Q is more commonly used for a multi-cell monitor.

Since HDQ interface is the chosen method of communication, it should be noted that the HDQ pin is an open-drain device, and a pull-up resistor is required (typically, around 100k value), but of course it should be calculated for the exact value required. Also, it should be said that since all the communication is going through only one-   -answer/answer-call rather than simultaneous communications. Also, the HDQ pin transmits 8-bits at a time; so, longer information (16 bits) can be transmitted, for example:

    1. Read high byte (H0).

    2. Read low byte (L0).

    3. Read high byte (H1).

4. If H1=H0, then valid result is H0, L0.

5. Otherwise, read low byte (L1) and valid result is H1, L1.

Typically, though ACE-com will be working with 8-bit communication and will not have to worry too much about 16-bit communication, but it is possible even in HDQ interface mode.

There are many different methods to measure battery capacity, but the BQ27010 uses the coulomb counting method. Also, the BQ27010 has on-chip auto-calibration for all internal voltage offsets so the charge measurement will be very accurate. However, external voltage offsets will have to be measured and calculated then programmed into the EEPROM to compensate. Also, on board the BQ27010 measures temperature and discharge rate; which seems like an excessive feature, but without these extra measurements the battery gauge would not be as precise. The auto-calibration is also a nice bonus feature. Typically, the auto-calibration starts it take about 5.12 seconds to measure capacity, voltage, and temperature and update information; which is stored in RAM onboard the BQ27010.

The BQ27010 requires 3.3V/< 90µA to be actively measuring, auto-calibrating, updating, sending & receiving information. This is actually quite a high demand for power, but the BQ27010 has five different modes which make saving power very easy because the five different modes are enabled automatically. The power modes of the BQ27010: Active, sleep, ship, hibernate, and data retention.
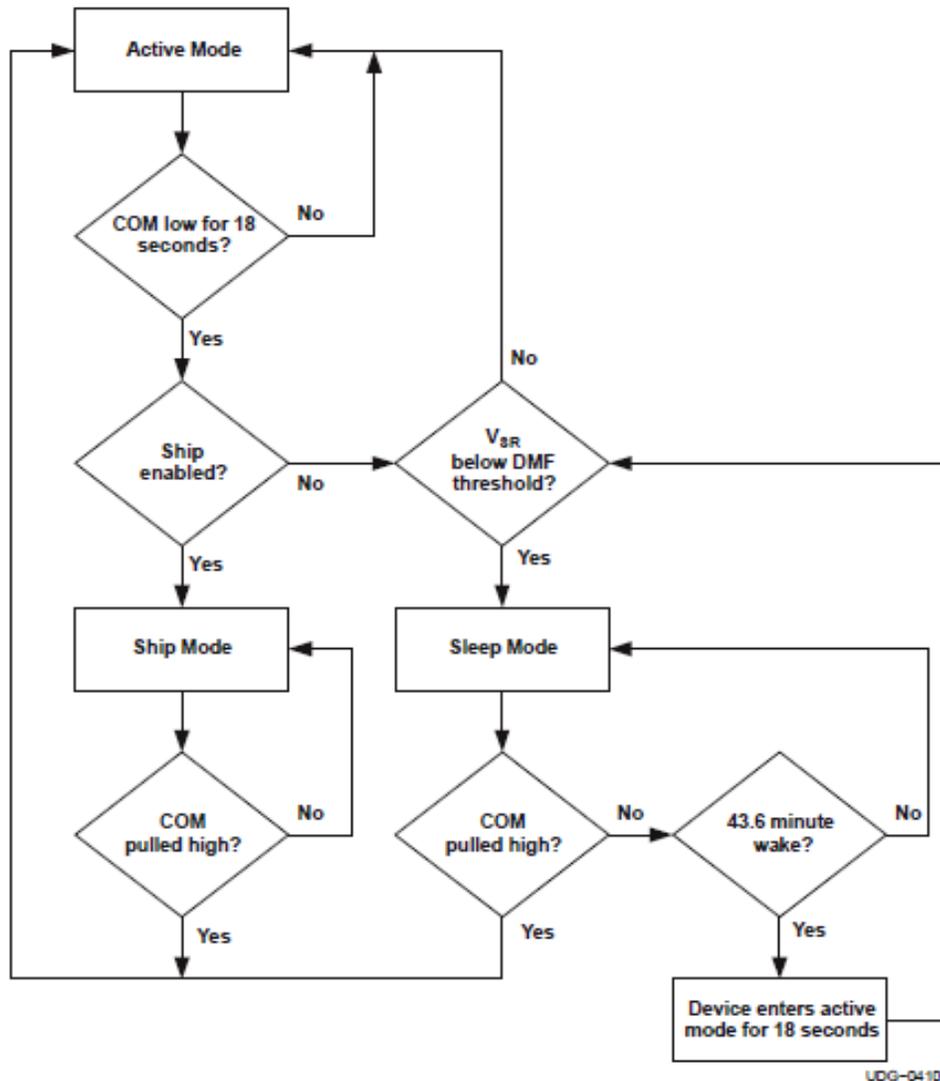
Figure 10: Power Modes of the BQ27010, and the internal decisions the IC makes to transition.

Above is a flowchart of the power modes. In active mode, this device has the highest power consumption. Processes such as measuring capacity, storing memory in on board RAM are performed. It is possible to keep BQ27010 in active mode forever bypassing the other modes. This is possible due to putting a pull-up resistor from V_{CC} to keep HDQ or CLK and DTA at logic 1 for the entire time. It should be noted, that this pull-up resistor needs to be calculated with precision.

However, the project will not be utilizing active mode locked because it is desired to conserve power on a portable device. Thus, ACE-Com will utilize the other automatically activated power modes. In sleep mode, which is activated by having the HDQ or CLK, and/or DTA pulled logic 0 for at least 18 seconds and the charge or discharge active is below the DMF threshold. Also, in sleep mode

any sort of capacity gauging is ceased, but battery self-discharge based on temperature measurements is still maintained. The BQ27010 wakes every 43.6 minutes to update temperature readings. Then it will check if HDQ, CLK, and DTA line and if they are still logic 0 and discharge is still below DMF threshold and if they stay for 18 seconds it will go back to sleep. This is really important for the project because all these process are automated and do not need to be programmed and save the end user a lot of power while still monitoring and managing the battery.

Ship mode is typically reserved for the manufacturer to enable right after production. During ship mode, all functionality is disabled; this is not going to be used and it should not really be utilized once the device has been put into active mode, but it is important for the BQ27010 because it will preserve the IC.

Hibernate mode happens when V_{CC} goes below $V_{(POR)}$ basically when the power source for the BQ27010 is running out of power. During hibernate mode; all information stored on RAM is retained. Obviously, this is very important because if a device lost all its memory when it was powering down it would require a re-initialization and re-programming of many functions. Clearly, these power modes are a very important feature to the project seeing as one of the major motivating factors is to make a low-power communication device.

The BQ27010 has very good tech specs for the purpose as well; it is very weather resistant with a $-20^{O}C$ - $+70^{O}C$ range, uses less than 2.5µA while in sleep mode, less than 1.5µA in hibernate. Also, when deciding the BQ27010 price was a large factor as well; considering, that the device will cost $1.25 for 1000+ units, and of course assuming that the project is a success and demand is high, and remembering   the ambitions, goal retail price of $180.00; considering all these factors the price is acceptable for the project.

It should be considered that the power usage for the BQ27010. ACE-Com would
is only for 2-4 cells of Li-
Ion batteries. Thus, if ACE-Com does adopt the BQ3055 the power budget will go up. So, ACE-Com will be able to use more demanding components. This can be good because ACE-Com can increase the gain of the antenna by accruing a better antenna, possibly by adding a high-gain antenna to the GPS, and overall use better performing components. The BQ3055 is $3.75 this is three times the cost of the original choice, and of course this must be considered when put into production e
relate to end-retail price and end-production cost.

Overall, the BQ3055 works similarly to the BQ27010, but since it is a multi-cell power gauge it will require a $I^{2}C$ interface rather than HDQ. However, the BQ3055 used the SMbus interface which is derived from the $I^{2}C$ interface. This means the device, the BQ3055, can transmit and receive data at the same time. Another difference between the two devices is the BQ27010 can only measure batteries at a max of 7V and the BQ3055 can measure at a max of 25V batteries. Also, since the BQ3055 is a higher performance chip typically the power

requirements are higher, and in this case they are a little bit higher with operating voltage requirements of 3.8-5.0V.

Firstly, the BQ3055 has two different low-drop out regulators (LDO) so there will be no need to wire a external regulator to the product. Similarly to the BQJunior the BQ3055 also has auto calibration which enables when the SMBus stays low for a minimum of 5 seconds. The BQ3055 requires two ADC pins for measurements: the first pin for current measurements and the second for individual cell and battery voltage and temperature measurements.

Perhaps the most important feature are the safety features included on board the BQ3055. Overcharge protection is an important feature because when charging the device current will normally continue to flow to the batteries. However, the Bq3055 will not allow that. Also, over temperature, overcurrent discharge, and short circuit discharge/charge conditions are all safety features that are included on board the BQ3055.

3.2.4 Battery Charger

Due to time constraints, a battery charger was not implemented in the final ACE-Com prototype. If it were to be implemented in a future version, the following paragraphs describe how it would be handled.

The BQ24158 is a switch mode charge management device for single-cell Li-Ion battery packs. The main use for this is to combine the BQ24185 with the BQ27010 because the BQ24185 will be able to charge whatever battery pack is being monitored by the BQ27010. This specific IC charges in three stages: conditioning, constant current and constant voltage. The BQ24185 is USB friendly and the charge parameters are programmed through I^2C interface. This is a helpful feature because when the ACE-Com system is ready to be charged then it will just be connected to a computer with USB ports, and a C program will be written and stored in the MSP430. In essence, when the IC is connected to a PC without any connection to the microcontroller it will still charge, but the values of the registers will be default.

Typically chargers can have either linear charger or switch pump charger; the BQ24185 utilizes the switch pump. Typically, the switch charger is more efficient and will work with a wider range of input voltages. However, typically switch chargers are usually more expensive and take up more space. The BQ24185 has three operational modes: charge, boost, and high impedance. During charge mode, the IC charges single-cell Li-Ion battery packs. During boost mode, the IC boosts the totally battery voltage to the value V_{BUS} for powering attached OTG devices. During impedance mode, the IC stops charging and boosting this is similar to standby mode for similar devices; low amounts of current are used during this mode.

Built into the BQ24185 there is battery protection, like, output over voltage protection and battery short protection. Also it should be noted, that even if there

is no I^2 -

During this mode, the charger will charge the battery without any programming language, but it will use the default values of each register.

3.2.5 Voltage Regulators

For the overall design ACE-Com will be using many voltage regulators, boost and step-down, these are required for the design because there will be many different components that all require different operating voltages. Specifically, ACE-Com will be using the LP5951, TPS 73018, TPS60151, and LM2622. First, the LP5951 will be used to regulate voltage going to the external audio filter. This is because the LP5951 has input voltage range from 1.8-5.5V and the output voltage is 1.3-3.7V, and since the input voltage (from the batteries) will be XX V the external audio filter connected to the microphone can operate on 3.3V it works out nicely. Second, ACE-Com will use the TPS73018 this is available in two different ICs one is a fixed version with internal voltage divider, and one is an adjustable version with a feedback pin where the voltage divider will be connected externally. ACE-Com will be utilizing the variable version which will output voltages between 1.8-3.3V from an input voltage in the range -0.3   6.0V. This is very fitting for the microcontroller and transceiver because they both can operate on 3.3V easily. Moreover, ACE-Com will adopt the TPS73018 because it has high PSRR so the battery will generate less noise when going to the transceiver. Third, ACE-Com will utilize the TPS60151 to regulate the voltage going to the GPS chip. This is because the GPS requires 5.0V for its typical usage in its most active mode, and the TPS60151 has a fixed output voltage of 5.0V with an input range from 2.7-5.5V. Lastly, ACE-Com will utilize the LM2622 for the display this is a switch regulator which is different from the other regulators (which are all linear inductor-less). ACE-Com will require a switching regulator over a linear for the last one because it was found with a low total input voltage of XX V from the batteries that the required voltage to power the display was difficult to come up with (the display requires 6-9V). Overall, the linear, inductor-less regulators was chosen because these regulators in general save a lot of space on the PCB and low noise. These are really important factors when working with an RF communication system. However, it should be noted that the LM2622 is more efficient than the linear regulators, and that is expected.

Specifically, the regulator for the external audio filter fits well for ACE-COM because of the low quiescent current (IQ), output voltage range, price, size, and junction temperature range. And that reasoning also goes towards the other linear, inductor-less regulators. Typically, linear regulators are much smaller on the PCB and cost less than switching regulators because linear regulator technology was developed earlier and is simpler. Also, it should be noted that with a low IQ the device will be virtually draining little to no current while the project is in sleep mode. The price of the three linear regulators average is $0.22 which is a low price for a regulator. However, a switch regulator was required to utilize the display. Since, the display has a higher demand for voltage. It should be noted that switch regulators typically require an inductor which will take up a lot of space on the board. This is a huge factor to consider because layout of the PCB and magnetic field from the inductor should not interrupt or create any extraneous noise factor.

3.2.6 Camera

The first realization from researching how the ACE-Com system will handle imaging was that an image files can be very large. This means that transmission of the image could be time consuming and could possibly interfere with communications and/or GPS data, which might be more time sensitive than the image. Therefore, it was decided to integrate a memory storage device onto which image files can be stored until the user specifies that it is an appropriate time to transmit the image. This will allow the user to capture an image and then retreat to a safer location to transmit the image.

Due to time constraints, a camera was not implemented in the final ACE-Com prototype. If it were to be implemented in a future version, the following paragraphs describe how it would be handled.

When determining which image sensor to use, there were several factors to take into consideration. The ACE-Com system needs a compact sensor which would interface easily with the MSP430. This means an image sensor with UART interface would be ideal. Another factor which came into play was output format. In order to keep the ACE-Com system simple, the image sensor chosen should be able to output the image data as a digital file ready to be viewed by the receiving end of the system. Therefore, the device should utilize a widely used

memory storage device, which would be able to hold several Gigabytes of
e
image sensor will only be turned on when a picture needs to be taken and will then turn go into a low-power state. Finally, and perhaps most importantly, the imaging device needs to be cost effective.

Due to the above factors, the ACE-Com system uses the LinkSprite LS-Y021 camera. This image sensor uses TTL interface which will output a JPEG file. This will make it very easy for the user to view the images since the JPEG file format is supported by many common software packages. Furthermore, the TTL int
footprint of only 32mm^2, this sensor would be easy to incorporate onto a compact design. With the LS-Y201, the user can also vary the compression ratio and image size. This gives the user the option to take an image which will be very detailed, quickly transmittable, or a balance of both. For power, the LS-Y201 runs off of 3.3V power and consumes 80-100mA; however, since the camera will only be used temporarily and infrequently, its power consumption is not expected to have a great impact on the ACE-

Due to the LS-
relatively low cost, this device would be a nearly ideal addition to the ACE-Com system. Furthermore, aside from the interface with the memory storage device, this image sensor requires little exterior circuitry and processing, making integration with the rest of the system simple and less prone to failure.

3.2.7 Memory

Since the ACE-Com system will have the ability to capture images, there will need to be some sort of memory storage device. These storage devices have become very common and come in a wide variety of packages and sizes. The ACE-Com system will need a small device which will be able to store several images and can interface with the MSP430 microprocessor. In order to pull the pictures off of the memory device, the user may need to mate the memory card with a laptop or desktop computer. Therefore, the device chosen should also be commonly used.

A perfect device for this would be an SD card. These non-volatile memory cards can be easily plugged into most commercial laptop or desktop computers with little to no installation required. Furthermore, these devices come in a very broad range of capacities; all the way up to 32 GB in some cases. For the-ACE Com system, however, such large sizes will rarely be used. In order to reduce cost to the consumer, the ACE-Com system includes a 2 GB memory card. This size will accommodate more than enough images. Should the user require a larger memory card, a larger one may be switched out.

Since the camera outputs JPEG files, no conversion will be necessary between the camera and SD card. Upon receiving the signal to capture an image, the camera will write the JPEG file directly to the SD card at an address specified by the microcontroller. Here, the image can either be stored to be examined once

user decide to transmit the image, the SD card will send the file directly to the transceiver to be transmitted over to the home base.

Even the largest SD card package is smaller than 35 mm^2. Since smaller packages are typically more expensive, it has been decided that the largest would be the best choice for the ACE-Com system. This will help keep the cost to a minimum.

3.2.8 Encryption

Due to time constraints, encryption was not implemented in the final ACE-Com prototype. If it were to be implemented in a future version, the following paragraphs describe how it would be handled.

It is a very important issue in wireless communication because nowadays anyone can purchase one of several radio receivers that make him capable of virtual monitoring the wirel
essential to offer a secure mean of wireless communications. Encryption can be done to both conventional and trunked RF radios. Encryption can be done by equipping the system with the suitable encryption electronics, or some devices may need encryption modules for safe communications. Voice and data can be

encrypted through inversion, rolling code, or by digital encryption. Therefore, we need to check all kinds of encryption and choose the one that suits our project and our budget.

Voice inversion:

Frequency domain scrambling: is taking the signal and turning it inside out usually this happens around pre- known frequencies. There are three types of voice inversion: base- band inversion, variable- band inversion, and split band inversion. Base band inversion: inverts the voice signal around one frequency that never changes, so it is so easy to break because running the inverted signal through another inverter that operates with the same frequency will be able to break the encryption. Variable- band inversion: inverts the voice signal around constantly changeable frequency; breaking the encryption is possible but not as easy as base band inversion. Inversion can be detected by the explode noise of the modem at the starting of transmission, and the frequent clicking sounds as the inverting frequency changes. Split- band inversion: splits the voice signal into two with two different frequencies and inverts them separately; also, some systems provide better security by randomly changing the frequencies. Rolling

away from the voices applications.

Voice Encryption: is a stronger for voice security than any form of voice inversion. There are two types of encryption, hardware based encryption systems, and software based encryption systems.

Hardware based encryption systems: they are voice encryption techniques that use hardware (circuits) to encrypt voice signals; they are very useful since no computer programming is needed. They are more efficient, secure, easier, and harder to break, yet they are very expensive and hard to get.

Software based Encryption systems: they are software modules their main disadvantage is soft voice encryption, but most programs use good crypto and free. However, hardware encryption proved to be the most powerful encryption for many reasons. First speed: One of the major benefits to encrypting data using hardware based encryption is speed. When encrypting data using software encryption, an application running on the device which actually does the encryption. This means data has to be processed through the running software first before being stored on the device. This is typically a slow process much slower than copying files straight to the device and not using software encryption. We actually have to run software to initiate this. Hardware encryption actually encrypts data using a special chip inside the device. Since a physical chip is what encrypts the data and not a piece of software, the result is drastically faster encryption times as well as zero strain on our micro processor resources. Second ease of usage: Software encryption applications require encryption of our data using the software itself. We usually have to designate a spot on our flash drive just for encrypted data, which can often be a complex and confusing task to set up. Encrypting data with hardware encryption is much easier. Since the

hardware on the device does the encrypting. [24] Its a circuit will be added to the whole design and connect it to the microcontroller. Voice encryption provides secure communication and prevents outsiders from monitoring the conversations. Nevertheless, it requires cryptographic key management; also, encryption is very expensive. In order to get effective encryption, analog signals must be converted to digital signals as the encryption techniques in digital are many.

Frequency hopping:

In this system, the transmitter frequency changes so rapidly that it is difficult for anyone not authorized to listen in or to jam the signal. The receiver is synchronized so that it hops from frequency to frequency in a predetermined pattern in unison with the transmitter. Frequency hopping scatters the intelligence over several hundred discrete frequencies. A radio operator listening to one of these frequencies may he
perhaps capture all of these little bursts; however, the task of picking these bursts out of the other natural and man-made bits of noise would be daunting, requiring a team of experts several hours just to reassemble a short conversation. Jamming one channel would have minimal impact on the hopping communicator. To effectively jam a frequency-hopping radio, most or all of the frequencies that the hopping communicator uses would have to be jammed, thus preventing the use of those frequencies by the adversary as well. [28]

However, all the previous ways of encryption techniques are so expensive and over the budget; there are also lots of challenges in technology and to get the components (security clearance).

Digital Encryption:
There are many types of digital software encryption;
- DES (Data Encryption Standard)
- AES (Advanced Encryption Standard)
- FEAL (Fast Data Encryption Algorithm)
- IDEA (International Data Encryption Algorithm)
- Safer (Secure and Fast Encryption Routine)
-
 We in our project will work with DES although it is old compared to others.

Challenges:

The used transceiver is an analog transceiver, so the first try to encrypt was to find a suitable analog way of encryption; there is no reliable analog encryption and in the same time within the budget. For instance, the analog voice scramble is easy to break, and in the same time is its circuit is expensive too. Another dilemma was that half of the project was digital (the GPS part) and half was analog (the transceiver part). Therefore, it was decided to end this dilemma by converting everything to digital. Moreover, it was tried to get a digital encrypting

circuit to do encryption for both voice and data   after long time of searching the web; it was found it is hard to get that kind of chip for two reasons: 1. Security reasons   they need the buyer to belong to a company or have a sort of security clearance. 2. The cheapest chip price is 150 dollars per chip so software encryption was the suitable choice although it has drawbacks   it is not strong enough comparable of the hardware encryption. Nevertheless, no software application is compatible with any analog based technology; therefore, everything must be converted into digital signals and then apply the software encryption. The figure below shows the encryption steps.
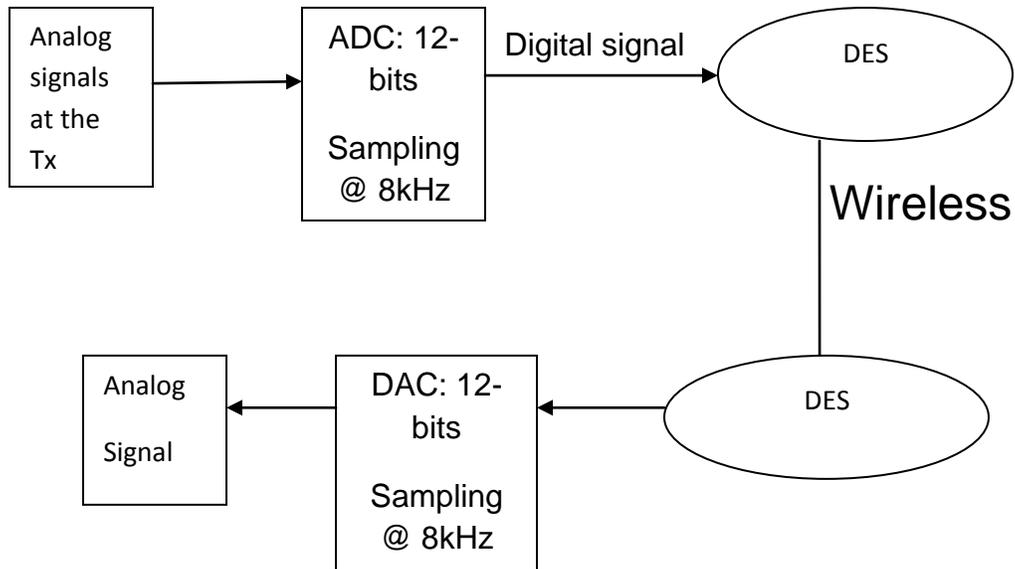
Figure 11: Encryption process of the voice and GPS data

The internet is full of encryption software programs for all type of encryption, yet the program has to be suitable to the project and compatible to the components used. A decision was made to use DES (Data encryption standard) which has been used for long time, and it uses symmetric key. DES algorithm was implemented in MSP430 which is the microcontroller used in this project. Moreover, it is for free and easy to download the whole compressed file from Texas Instrument web page. Although it is old, it is within the budget and there is a version compatible with the microcontroller that explains why DES is preferred over

3.2.9 Display

ACE com will adopt the LCD display, Nokia 3310, for the display. This was not an easy decision, but in the end it was decided to go for easy-to-use, economical(about $10), and overall a good fit for the specific objectives and requirements for ACE-COM. Specifically, the Nokia 3310 is an acceptable requirement (6-9V) and uses the PCD8544 microcontroller, which is quite easy to

use. Also, the reason this specific LCD display was chosen is because it is very small/discreet, but also easy to read because of well-lit backlight.

When choosing between a graphical display and a character display it was quite easy to choose that ACE-COM requires a graphical display. This is mainly because ACE-COM will show battery status, open channels to communicate, and signal strength. Clearly, these desired features would be much more difficult to implement on an ASCII character display. Also, since there are many libraries for graphical LCD displays such as the Nokia 3310; the programming of characters will just as easy versus a character display.

Another factor that was weighed into the decision was price of the display. While sampling, buying 1-10 units, the price of each unit will be $10 before shipping. Assuming that the project is successful and demand is high this display will only cost $4 before shipping and if 1000+ units are bought. Comparing this to similar LCD displays in size and tech specs on crystalfontz.com the average cost of those are ~$30 when buying low numbers and around ~11$ when buying 1000+ units. Thus production would cost about three times as much if the crystalfontz display was chosen instead of the Nokia. The LCD display is not the main part of the device and that a more economical choice is a better fit.

Because of the choice of MSP430 as the main microcontroller there are only 48 useable pins on the MSP430.Of course noting that the main choice of the microcontroller was to not over budget memory and capabilities, and of course not to under budget either. Which, is why using this microcontroller fits that exact purpose. Thus, a device that capabilities of 4-bit mode was a requirement this is one the main reasons the Nokia display was chosen. Although it may seem obsolete to use 4-bit mode it actually is okay for this specific project because the microcontroller requires it, and the Nokia 3310 comes with the PCD8544 on board microcontroller. The PCD8544 easily connects to the MSP430 and this chip runs at 3.3V which is compatible with the MSP430 as well. Thus, the power requirements are the same which works well.

The technical specs, like temperature range, humidity range, power consumption, and overall size was a deciding point. ACE-COM needs rugged, durable components like the Nokia 3310. For example the -20° C to +70°C temperature resistance is perfect for the target environments of ACE-COM. Along the same lines, a 0-90% humidity range is exactly what ACE-COM requires because of the possible terrain that users will be located. Because ACE-COM is going to be used in very rugged terrain and sometimes hostile environment; low power consumption is a must because there may not be many chances to recharge batteries. Thus, the 6-9 V required to use the display is optimal for ACE-COM. Also, the Nokia 3310 is a small size LCD screen. This is great for the project because it should be discreet. Considering the end user; possibly military/law enforcement.

Considering the end user and target environment in which ACE-COM maybe used; it was realized that the LCD monitor would have to come with a backlight

while illuminated would not be strenuous on the eyes, readable in broad day light, and of course readable in night hours. On the actual display the percentage of battery remaining, different RF channels available for communication, time, date, and current temperature will all be displayed clearly.
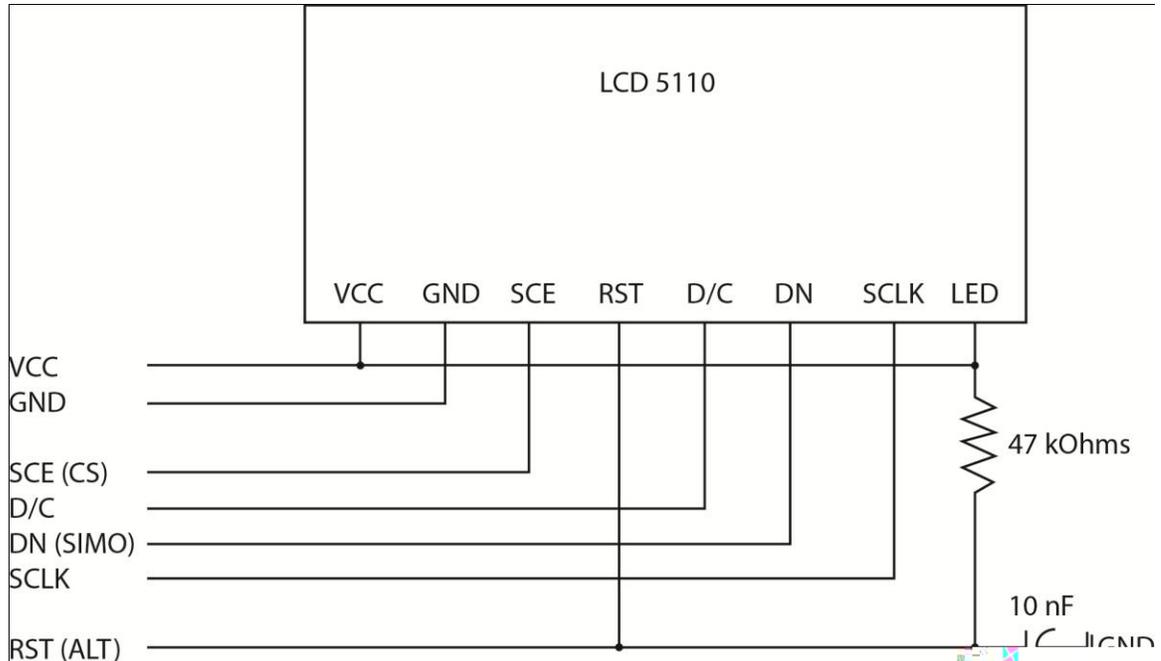
Figure 12: LCD Pin Assignments

Overall, the parameters for an LCD display were quite specific and also pended on a lot of other components. So, the search for the perfect fit was difficult, but the Nokia 3310 is a great choice to bolster and highlight the capabilities of ACE-COM.

However, if time and budget allows ACE-com would like to adopt a much more advanced display: CFA735-TFK-KR. The reason behind this much more advanced display is because the capabilities are many times better than the Nokia LCD chosen. Of course price should be considered, the CFA735-TFK-KR is priced at $73.00 more than seven times the price of the original choice.

First, the CFA735-TFK-KR is easily connected by using the UART pin on the MSP430, but also it can be connected by a USB port. This is also could be an option because simply adding a USB port (TUSB3410) to the MSP430 would allow the CFA735-TFK-KR to be connected by USB. It should be noted, that programming the CFA735-TFK-KR is quite simple as well because the microprocessor on board the CFA735-TFK-KR is the STM32F103. This specific microprocessor is a 32-bit ARM processor that can be programmed in C language. Also, the CFA735-TFK-KR accepts a TLL serial connection which is the adopted method if this display is chosen.
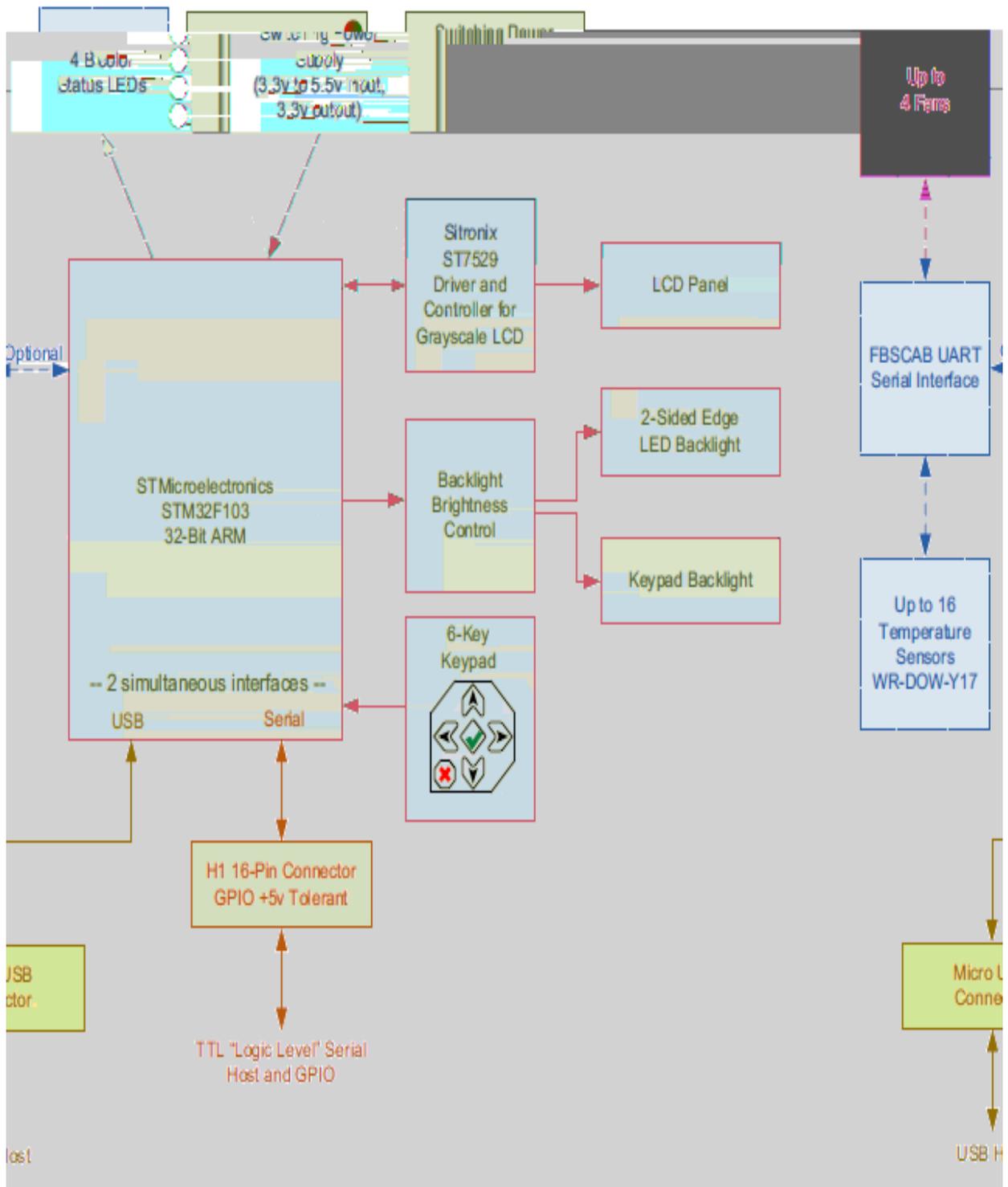
Figure 13: Alternate Display Connection Flowchart. (This was taken from the datasheet: CFA735-xxx-KR datasheet at crystalfontz.com)

It is easy to see the amount of features provided on board, and there is almost no comparison when comparing to the Nokia display. Also, if this display is chosen there is already an on board switching regulator for the power supply which will eliminate the requirement of one of the voltage regulators. Also, considering the voltage required for this specific display (5.5V) it is less than the Nokia display as well. Not only is the voltage demand lower, but the backlight can also be dimmed. Considering the backlight is large power drains this will save even more power. Also, considering there is a 6-Key Keypad this will cut the requirement to install external components to control the display since this display already has a programmable keypad. Another feature which is appealing to designers would be the large viewing angle on this LCD compared to the Nokia. The viewing angle is $+45^O$ to -45°.

3.2.7 Balun

A balun is a conversion device used to change an electrical signal from a balanced signal to an unbalanced signal, and vice versa. This means that the signal changes from a ground differential to a single-ended signal, which also means that the signal will be 180 degrees out of phase. Baluns are used for numerous purposes, but they are all used to make sure systems are compatible with each other. ACE-Com needed a balun in order to convert the signal in between the transceiver and the antenna.

Baluns are used extensively in modern communications real-world applications. Some examples of these applications are radars, security cameras, telephone networks, satellites, VGA/DVI sources, and wireless network routers. Baluns also change the impedance level between high and low signals: high impedance for the unbalanced line and low impedance for the balanced line. This makes baluns

As recommended by nScrypt, ACE-Com used the Anaren 0404 BD2425N50ATI. This balun is designed specifically to work with the Texas Instruments CC2500 transceiver and will therefore work well with ACE-Com.

3.3 Strategic Components
3.3.1 Microcontroller

The microcontroller acted as the brain of the ACE-Com system and handled all of the data crunching. Since it was such an important component, there were many aspects to take into consideration when selecting one for our system. To make troubleshooting easier, the ACE-Com system utilized a microcontroller which has a large support base from other engineers. Furthermore, the ACE-Com system needed a microcontroller which consumed low power. These two factors pointed to The MSP430 line from Texas Instruments.

The MSP430 line of microcontrollers came in a broad variety. These different components cover a range of 0.5 to 256 KB of flash memory and 128B to 2KB of RAM. This was more than enough flash memory to store the ACE-
software load. The main memory size concern was the size of RAM. Since the GPS data came in strings of ASCII characters, they took up a considerable amount of RAM. Furthermore, the ACE-Com system needed a fair amount of data space to act as a buffer for image files   if there was extra time to implement the camera feature   when being transferred from camera to SD card or from SD card to transceiver. With 2KB of data, 1KB can be used to act as a buffer and the other MSP430 handled the GPS, power management, display, and all other data used for program execution (counters, internal computations, etc.)

The next step was to verify that the microcontroller has sufficient I/O ports. Since the ACE-Com system needed the transceiver to be operating simultaneously with other components, the two microcontrollers needed a minimum of 2 UART ports. For user interface, there were a total of three devices: GPS, LCD, and transceiver. Furthermore, the MSP430 line comes equipped with Analog-to-Digital Converters. This made conversion of the audio signals from analog to digital very straight-forward. Some MSP430 microcontrollers are equipped with a Digital-to-Analog Converter, which allowed the ACE-Com system to decode a digital audio signal into analog to be sent through the headset to the user.

Now that the requirements have been outlined, a particular model of MSP430 can be selected. This leads to the MSP430F168. This device has 48KB of flash memory and 2KB of RAM. With 6 8-bit I/O ports, it has a total of 48 pins to use for I/O, which covers the requirements of the ACE-Com system and leaves room to grow. Furthermore, this MSP430 is equipped with the DAC mentioned above. These features make this model of the MSP430 ideal for the ACE-Com system in terms   of   system   requirements.

After finding a component that sufficed the ACE-
environmental requirements of the system need to be considered. With an operating temperature range of -   -
all temperatures the ACE-Com system can expect to see. Furthermore, the low-
-Com

power. Since the microcontroller encased, humidity and submergibility requirements met by the case. With these operating requirements, it can be assured that the MSP403F168 was a good fit for the ACE-Com system.

In the ACE-Com system a camera, display, power management module, battery charger, SD card, and GPS receiver connected to the microcontroller and due to the limited number of UART ports on the microcontroller, all of the above

microcontroller. However, in order to use only two ports, there has to be a switch that allowed communication to the correct feature. For this, a 16-bit FET bus switch SN74CBT16244 was chosen. The ACE-Com system needed one switch.

The switch SN74CBT16244 has four 4-bit inputs, four select lines, and four 4-bit outputs. The way it works is if Select1 is high, Out1 is GND, but if Select1 is low, Out1 is equal to In1 same thing for Select2, Select3, and Select4. , so the SPI pins on the microcontroller UART1 is connected to the four In1 pins and the the Select1. Then, the 4 Out1 pins connected to the SD module.

The supply voltage range for the FET bus switch, VCC is from -0.5 to 7V; Input voltage range, V is also the same as VCC, and Continuous channel current is 128 mA in addition to Input clamp current, IIK (VI/O < 0) is-50 mA.
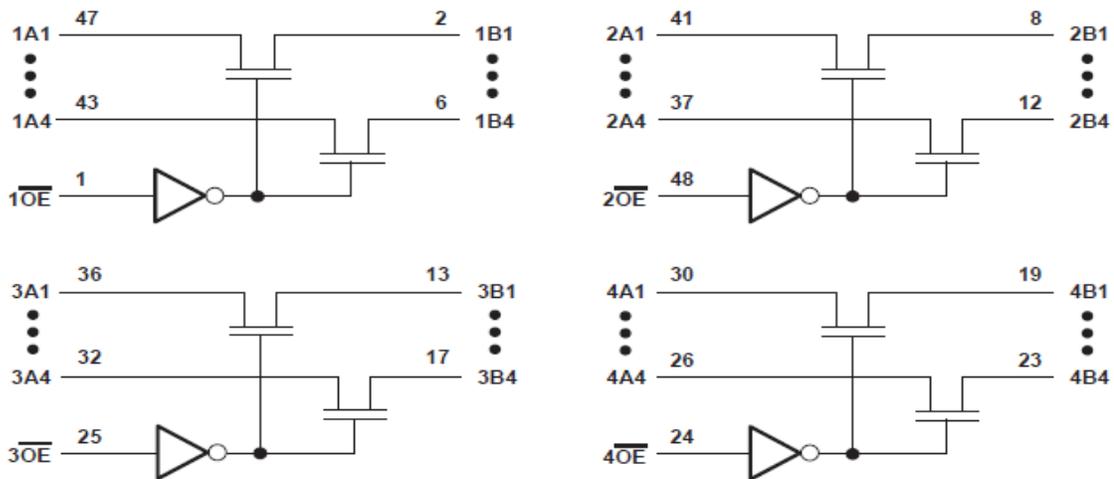
Figure 14: Logic Diagram of 16-bit FET Bus Switch with pending permission from Texas Instruments

In the beginning of the project, only one microcontroller would be expected to handle and manage the communication between the GPS, LCD, and the transceiver, yet so as to simplify the code and fasten the processing, two MSP430 microcontrollers were used: one was for the transceiver data, and the other was for the GPS and LCD displaying. These two MSP430s were communicating to each other through the 16 bit fit bus.

3.3.2 Transceiver

The CC2500 is a low-power, low-cost, and industry standard transceiver. The intended frequency band is 2400-2483.5 MHz. Also, the CC2500 pairs well with all MSP430 models because their power requirements are very similar. Typically, the transceiver and a few other elements are controlled by the microcontroller,

and that will be for the project as well. The CC2500 is a great choice for the project because of the many features that come on board or automated such as: configurable baseband modem, and this modem has many different modulation formats and has a data rate up to 500 kBaud, also, the cc2500 supports extensive hardware for packet handling, data buffering, burst transmission, clear channel assessment, link quality indication, and wake-on-radio. Also, the CC2500 can be operated with an SPI interface.
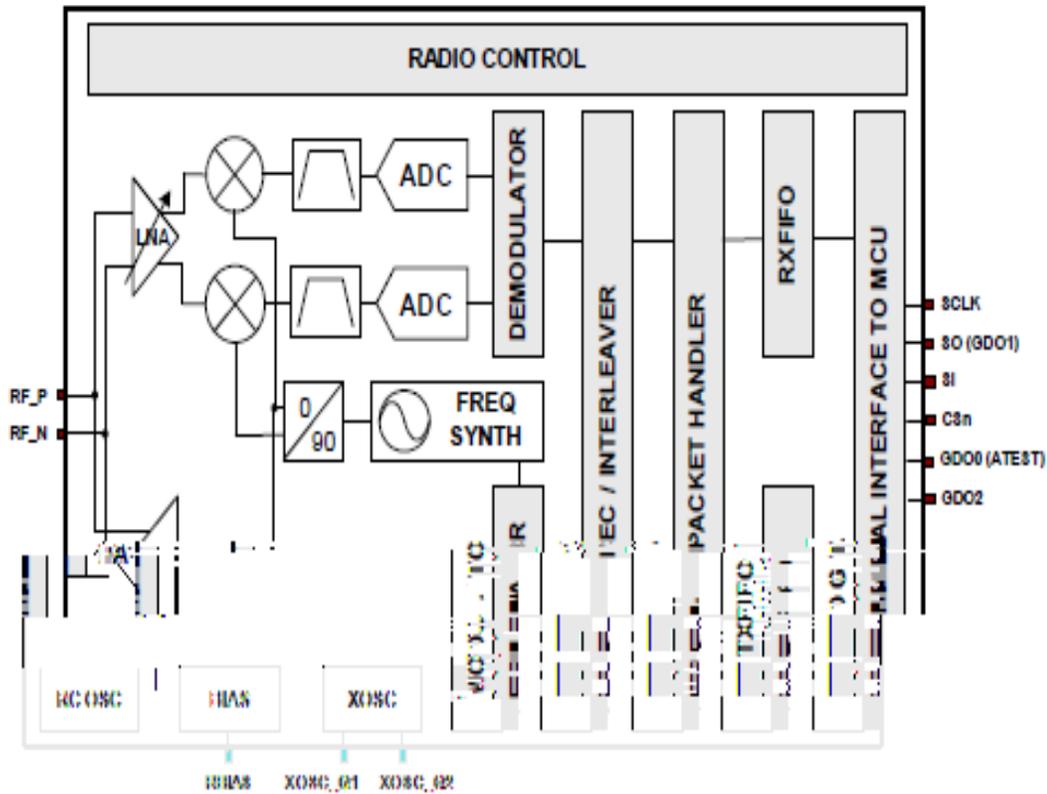
Figure 15: Internal hardware features included in the CC2500, and a basic flow of how the IC functions

Some key RF features of the CC2500 include: very high sensitivity, low current consumption, programmable output power, amazing receiver selectivity and blocking performance. Moreover, analog features include: OOK,2-FSK, GFSK, &MSK support; suitable for frequency hopping and multi-channel(90 us settling time), automatic frequency compensation, integrated temperature sensors. Also, digital features include: support for packet systems (on-chip support for word detection, address check, flexible packet length, and automated CRC handling), efficient SPI interface, digital RSSI output, programmable channel filter BW, programmable carrier sense, programmable preamble quality indicator, support for automated clear channel assessment, support for per-package link quality indication, and optional whitening and de-whitening of data. Low power features include: 400 nA sleep mode current usage, fast start up time from sleep, wake on

polling, separate 64 byte Rx and Tx data FIFOs. All these features are available in one of the most popular transceivers at a small price of $1.49. This price is unbeatable with these features. Other transceivers such as the TRF2443 are also low-powered, and have similar features from TI. The TRF2443 costs $24.00; more than 16 times in cost. When comparing the TRF2443 with the CC2500, the features are similar and of course, for such a high-price the TRF2443 has better specifications. However, specifically for the project price is a very important issue because of the aggressive retail price of $180.00 would not be possible if ACE-com elected for the most advanced specs in every component, and it just so happens that the TRF2443 is too expensive. Of course, if price was not a motivating factor ACE-Com would adopt the TRF2443 because the performance is very nice, and would also make a nice fit for an upgraded version of the project. However, if ACE-COM were to adopt the TRF2443 in a more advanced model it could cause problems because not only is it over budget economically, but also over budget technically. Since, the TRF2443 requires more pin outs there is no possible way ACE-Com utilized the MSP430F2274 efficiently, and ACE-Com forced to use a more powerful microcontroller such as the: mp123. And also considering that the mp123 also costs more money, demands more power, and in general the technical specs are better; the entire system would have to be redesigned, and since ACE-com is sponsored it probably is not feasible since their products are designed to utilize the CC2500 as well.
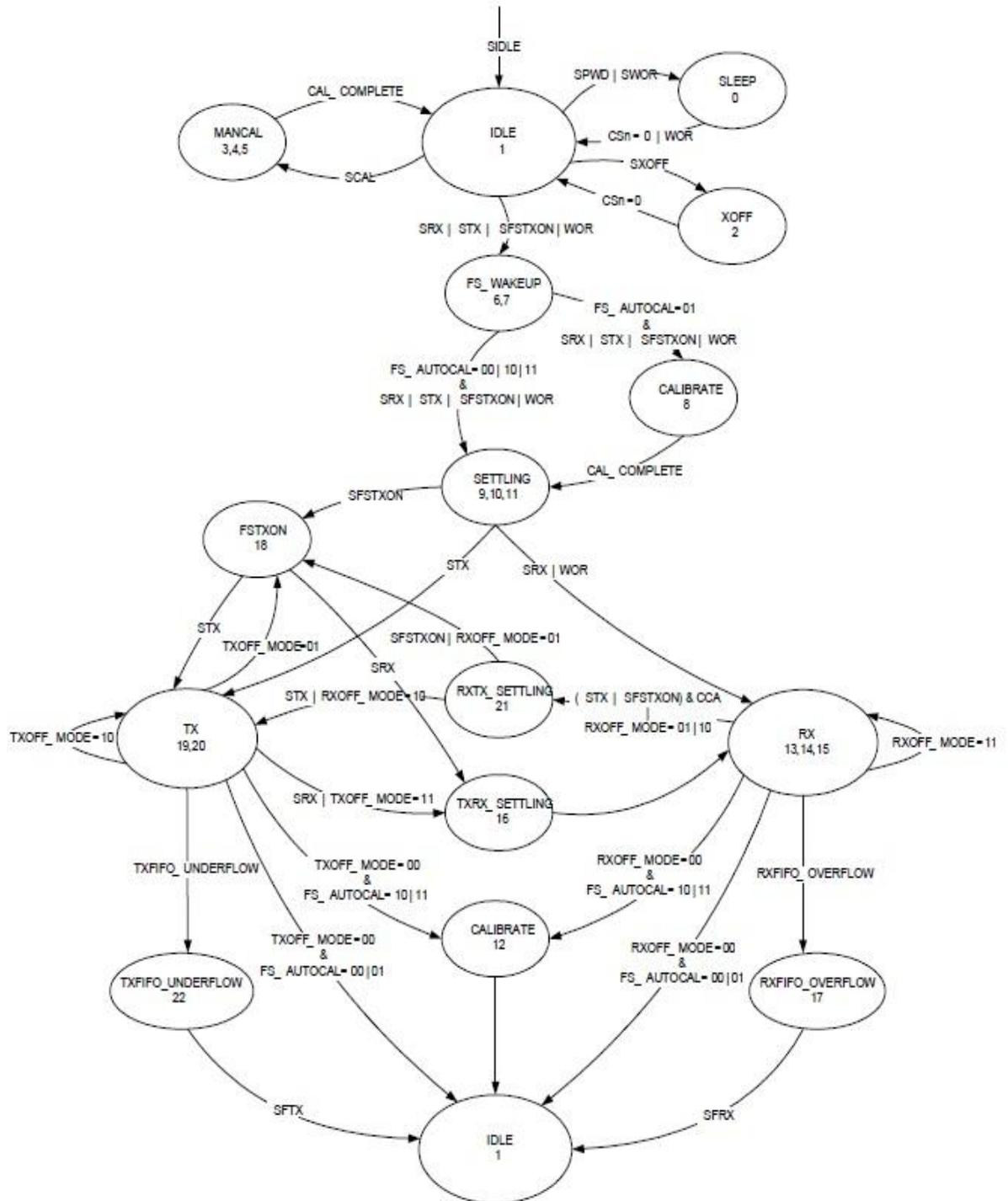
Figure 16: State-diagram of the power states and the transition conditions of the CC2500. (Taken from CC2500 datasheet)

I
in-depth at the TRF2443 i
well in a mobile communications aspect. First off, the TRF is an intermediate

frequency (IF) product which works well because when the device is decoding and processing data the transmitting/receiving of data should not be interrupted due to frequency. Moreover, when amplifying an IF the potential of amplified noise is gone because the data will first pass through filters and then integrates a quadrature modulator (IQ) producing a linear frequency and then the data will be processed; obviously, this procedure is a nice upgrade which helps also from sending false positives to the transmission line. Also, it should be noted that the transmitting and receiving of data occur on different frequencies this is also important to note due to the fact that the device is capable of full-duplex communication, unlike the CC2500. It should be noted, that one of the main target products that TI produced this specific transceiver for is broadband communication in mobile devices such as mobile computers. Thus, it is without question that the performance should be quite a bit more efficient than the CC2500; in which, TI produced that specific transceiver specifically for budget low-radius communications, respectively.

Aside from the filtering build in through hardware, The TRF2443 has more than 40 dB of gain range programmable through the SPI in 1 dB steps. Thus, this will enable ability to add external IF filters to weed out even more unwanted signals. And then if the device is receiving too slowly due to massive amounts of filtering. Bypassing is made easily because bypassing can be enabled via direct connect to SPI. Internally, the LNA is programmable from 0dB to -19dB and the LNA is followed by analog-controlled VGAs which are bypass-able. However, bypassing will not filter and buff data which is all internally hardwired.

Transmitting data chain starts with an IQ modulator then a variable attenuator and finally amplification. Firstly, the IQ modulator converts the in-phase data and the quadrature signals to the specific transmitting IF. Then the attenuator provides 5.5 dB of attenuation in 11 steps; then the output amplifier increases 6 dB in 5 steps. Overall there should be 35.5 dB of output power control.

Overall the TRF2443 has over 80 pins. Most of the time, users will not use all 80 pins. However, typical usage and to utilize all the internal functions of the more-modern transceiver will require many more pins than the CC2500. Thus, the MSP430F168 will be unable to accommodate the TRF2443 efficiently.

The culmination of both the TRF2443 and the CC2500 would be the CC2510. The CC2510 is a low-cost 2.4GHz, low-power, full-duplex transceiver. The CC2510 is system-on-chip and comes with the 8051 microcontroller; specifically, it has up to 32 kB of in-system programmable flash memory and 4 kB of RAM. This transceiver can be connected to a PC either through a high data rate (12Mbps) USB interface. The price of the CC2510 is around $3.00 average from all suppliers on TI.com. This is about twice the cost of the CC2500.

Key features of the CC2010 include: optimized 8051, two data pointers, in-circuit interactive debugging which is supported by the IAR embedded workbench, non-volatile flash memory which is in-system programmable by simple two-wire interface, high flash endurance (1000 write/erase cycles), 8-512 byte packet

support through USB controller, industry standard I^{2}S interface for transfer of digital audio data, full duplex, configurable baud rate, 128-bit AES support in hardware coprocessor, DMA controller, programmable watch dog timer, two programmable USARTs either for SPI or UART interface, 21 general-purpose digital I/O pins, random number generator, four different power modes, programmable channel bandwidth filter, 2-FSK support, and optional automatic whitening/de-whitening of data. It should be noted, that there is a possibility of four different channels when using the CC2510. Considering the center frequency is set to 2406MHz then the channels will have 250 kHz separation. Thus, the channels are 0, 13, 26, and 39 correspond to the frequencies of 2406, 2409.250, 2412.500, and 2415.750 MHz, respectively.

The CC2510 is configured to perform micro-law compression and expansion. Using micro-law compressing the ADC samples are compressed from 11 to 8 bits. This will reduce the total number of bytes in each packet and the amount of data transmitted. Of course the SNR must be acknowledged when a compression/expansion is used, and of course the SNR will be worse than if no compression was performed. The compression and expansion can be disabled through software.

Parameter	µ-law Enabled	µ-law Disabled
ADC Samples per Packet	54	60
Packet Length (bytes)	61	92
RF Data Rate (kbps)	250	300
Period between Packets (msec)	7.5	6.75

Table 3: The following table shows the specs between disabling and enabling micro law

Seeing the results of compression enabled versus disabled- it would seem that disabling would be worth it considering the SNR would be better overall. However, also it must be considered that most of the resources on the TI website and application notes are tailored towards enabling the compression that is what ACE-Com would adopt.

Overall, the CC2510 is a better choice as a transceiver. If there is time to implement this transceiver ACE-com will adopt this over the CC2500 because the cost is not too much more, and the possibilities are more promising, like, full-duplex mainly.

3.3.3 Battery

Battery is an important part in the project because it is the part that will provide all the components with energy to perform their tasks. The project needs batteries that will last for a long time, rechargeable, and with no memory effect (need to be completely discharged before being recharged). There are many battery types in

market, but the most efficient one for our project is the Lithium- ion battery. It has many advantages that are favored to be in the battery used in the project.

Advantages	Disadvantages
1. It keeps its charge; a Lithium-ion battery pack loses only about 5% of its charge monthly. 2. It has no memory effect. 3. Lithium- ion batteries can be charged and discharged hundred times they handle the miss use of the chargeable batteries. However, it has also many drawbacks which must be considered too.	1. This battery type degrades as soon as it leaves the factory, so its life time is from two to three years from the manufacture date. 2. It is so sensitive toward high temperatures; heat increases the rate of degradation. 3. Fully discharge destroys the battery. 4. They are expensive batteries. 5. If the battery pack fails although it is rare, it will burst into flames. 6. It has a very complex design with a circuit to monitor temperature and over heat. 7. It needs a specific charger with a charge rate monitor.

Table 4: Li-Ion Advantages and Disadvantages

The battery from inside:

It has an outer metal case with pressure- sensitive vent hole. If the battery temperature increases to a dangerous level which will cause explosion due to over pressure, this vent will release the extra pressure, yet if the battery reaches this point, and it will be ruined. This metal case holds a long spiral comprising three thin sheets pressed together: A Positive electrode - A Negative electrode A separator, inside the case these sheets are submerged in an organic solvent that acts as the electrolyte. Ether is one common solvent. The separator is a very thin sheet of micro-perforated plastic. As the name implies, it separates the positive and negative electrodes while allowing ions to pass through. [26] The positive electrode is made of Lithium cobalt oxide; the negative electrode is made of carbon. When the battery charges, ions of lithium move through the electrolyte from the positive electrode to the negative electrode and attach to the carbon. When the battery discharges, Lithium ions move back to the Lithium cobalt oxide.

Lithium- ion battery:

kinds of batteries, yet the right one had to be chosen for the project. It needed a light, small, rechargeable, and slow to discharge. To choose from among those batteries, compare and contrast between them were the only resort.

Lead Acid batteries:

Lead Acid batteries are the workhorse batteries of industry. They are incredibly cheap, rechargeable, and easily available. Lead acid batteries are used in machinery, UPS's (uninterruptable power supply), robotics, and other systems where a lot of power is needed and weight is not as important. Lead acid batteries come in 2V cells that mean we can have a battery with an even number of volts. The most common voltages are 2V, 6V, 12V and 24V. Pros: cheap, powerful, easily rechargeable, high power output capability, Cons: very heavy, batteries tend to be very large bricks because power density is very low, Prices: A 12V lead acid battery with 7Ah of charge should run approximately about $20, and Power Density: 7 Wh/kg.

Alkaline:

Alkaline batteries are the highly common in market, most useable in servicing projects. They have higher power density than NiCads and NiMH. Nevertheless, they are non-rechargeable. Cells are 1.5V, and found in different sizes from coin cells to AAAA to D cell.6V lantern batteries are very large alkalines made of a couple large cells, have massive capacity and capability and easy to clip/solder onto their tabs. 9V batteries are a combination of of 6 very small 1.5V batteries; they are size of coin cells. Th   ility and very expensive. If the project needs
Prices: AA size battery costs approximately about $1 and has up to 3000 mAh of charge capacity Power density: 100 Wh/kg, Pros: easy to find, well known, safe, long shelf life, Cons: Non-rechargeable, low-capability

Ni-Cad batteries (Nickel Cadmium):

They are the oldest rechargeable batteries in the market. They are available in certain sizes like AA and C. They are rarely to be used nowadays since NiMH batteries have much higher power density and cheaper, so they are still used in many cordless phones, solar lights and RC cars; they discharge slower than NiMHs. Battery cells are 1.2V, often bundled in "packs" of 3 to make 3.6V. **Pros:** Inexpensive, rugged, come in "standard" sizes, easy to recharge, **Cons:** Lower power density, memory effect, contains toxic metal, **Prices:** AA size battery costs around $1 and has up to 1000mAh of charge capacity, and **Power Density:** 60 Wh/kg.

Ni-MH batteries (Nickel Metal Hydride):

They are very well known rechargeable batteries; they also come in 'standard' sizes. These are used in many projects as a replacement for Alkaline batteries. The battery cel voltage is 1.25V per cell, that's less than the 1.5V of alkalines and more than the 1.2V of NiCads. They like to be charged at about 0.1C but can be discharged at 0.2C- Pros: Good alternative to Alkalines in many cases, high power density, "standard" size, better capability than alkalines, pretty easy to recharge but not as rugged. Cons: More expensive than Ni-Cads, short life time,

doesn't like to be used in high-drain projects, and self-discharges quickly. Prices**:** AA size battery costs around $2 and has up to 2500mAh of charge capacity, and Power Density: 100 Wh/kg.

Li-Ion (Lithium-Ion) and Li-poly (Lithium-Polymer):

These are the newest technology rechargeable batteries and are most commonly used in electronics. They are very light in weight, tolerate high discharge rates, and have very high power density. However, they are very delicate and require special circuitry to keep them from exploding. Most li-ion batteries are provided by protection circuitry that keeps the battery operating safely. Li Ion cells are around 3.6V so 3.6V and 7.2V are the most common battery voltages. They can easily provide up to 1C of current, some can go up to 10C Pros**:** Ultra-light, high power, high capability, and high cell voltage. Cons**:** Expensive, delicate, can explode if misused-Prices: replacement "cell phone" batteries cost around $10 and have ~750mAh charge capacity. Power Density: 126 Wh/kg for lithium ion, 185 Wh/kg for lithium polymer

Lithium batteries & Coin cells:

Most of the lithium batteries are in the form of coin/button cell; Lithium cells are used (3V) but Alkaline, zinc air, and manganese are also used (1.5V). They are very small and very light; fit small, low-power devices. They're also fairly safe, have a long shelf life and fairly inexpensive per unit. However, they are not rechargeable and have high internal resistance, so they can't provide high continuous current: 0.005C is about as high as they can go before the capacity is seriously degraded, but they can provide higher current with pulsing. One of the most popular coin cells in use right now is the CR2032 which is 20mm diameter x 3.2mm thick, provides 220mAh at 3V. Lithium coin cells can get as large as the CR2477 (24mm x 8mm) with a capacity of 1000mAh for $3.50. The only other thicker than a AA battery and a bit shorter too. Pros: Light, high-density, small, inexpensive, high cell voltage, easy to stack for higher voltages, long shelf-life Cons: Non-reusable, low current draw capability, needs a special holder Prices: CR2032 are around $0.35 (220mAh) CR123's are $1.50 (1300Ah), and Power density**:** 270Wh/kg. Finally, after comparing and contrasting, the Lithium- ion batteries were chosen if time would permit although of all the drawbacks. Lithium-ion batteries were the most suitable ones for the project.

Unfortunately due to time constrain, the lithium ion battery idea had to be forsaken and AAA batteries were used.

4 System Design

After selecting the appropriate parts for each component, the method in which each part interconnected with the rest of the ACE-Com System. The sections listed below outline these details. These details include schematic and block diagrams created and taken from datasheets, Application Notes, and other online resources pertaining to the selected components.

4.1 Previous Design Architectures

As a whole, walkie-talkies are fairly simple devices that do not need many components to function at a basic level. The level of functionality from model to model varies greatly, and obviously the intricacies of the designs do as well. In order to complete its most basic functions as a walkie-talkie, it must contain the following major components: a microcontroller, speaker, microphone, transceiver, and an antenna. Figure 17 below shows a flowchart for this simple design architecture.
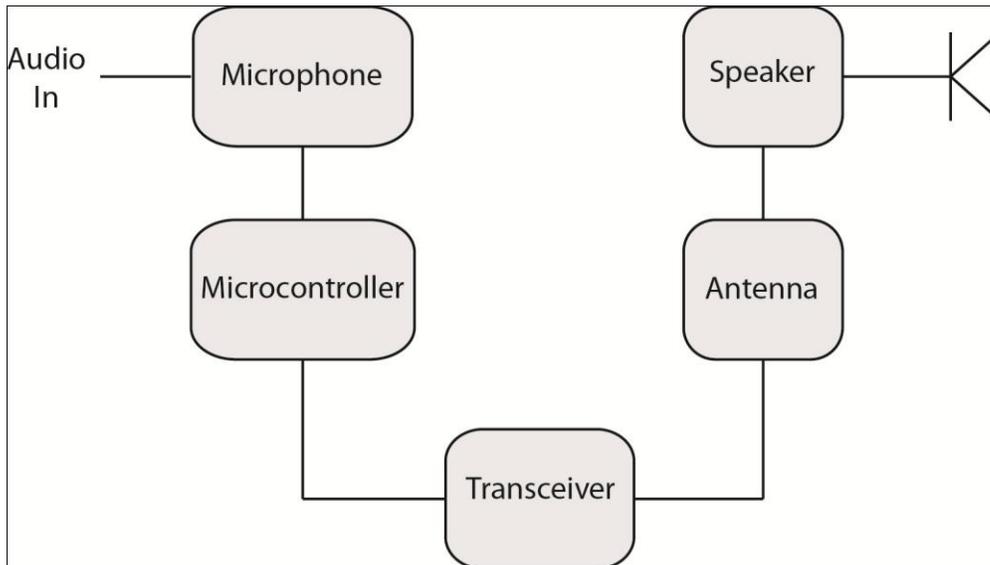
Figure 17: Basic Walkie-Talkie Design Architecture

All five of these main components can vary in and of themselves, not to mention all of the other components that can be added for additional features. The choice of microphone is significant because it can determine whether or not the audio going into the microcontroller is analog or digital. This can also be determined inside the microcontroller itself. Determining what to use to process the data will affect what you can do with it. A really expensive microcontroller with lots of processing power and memory may be able to save snippets of audio for later use, while a cheap microcontroller would be nothing more than an airport terminal directing the data which direction to go next. The quality of the signal will be affected by all five of these major components. Transceiver and antenna designs will mainly affect the range of the signal, the frequency it runs at, and

direction   that   the   signal   will   be   broadcast   in.

4.2 GPS

As stated in section 3.2.1, the EM-408 GPS microchip was chosen for the ACE-Com design. Below in Figure 18, a PIN assignment can be seen for this component.
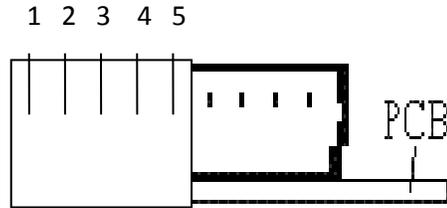
Figure 18: Male (left) and Female (right) GPS PINs printed with permission from globalsat

These PIN assignments have the following designated functions.

PIN Assignment	PIN Description
1: Enable/ Disable (NC)	
2: GND	GND provides the ground for the engine board. Connect all grounds. Enable**/**Disable**:** On/Off
3: GPS- RX	This is the main receive channel for receiving software commands to the engine board from SiRF demo software or from user written software.
4: GPS- TX	This is the main transmits channel for outputting navigation and software or user written software. Output TTL level 0V ~ 2.85V
5: VIN	This is the main DC supply for a 3.3V DC input power module board.

Table 5: EM-408 PIN Assignments and Descriptions
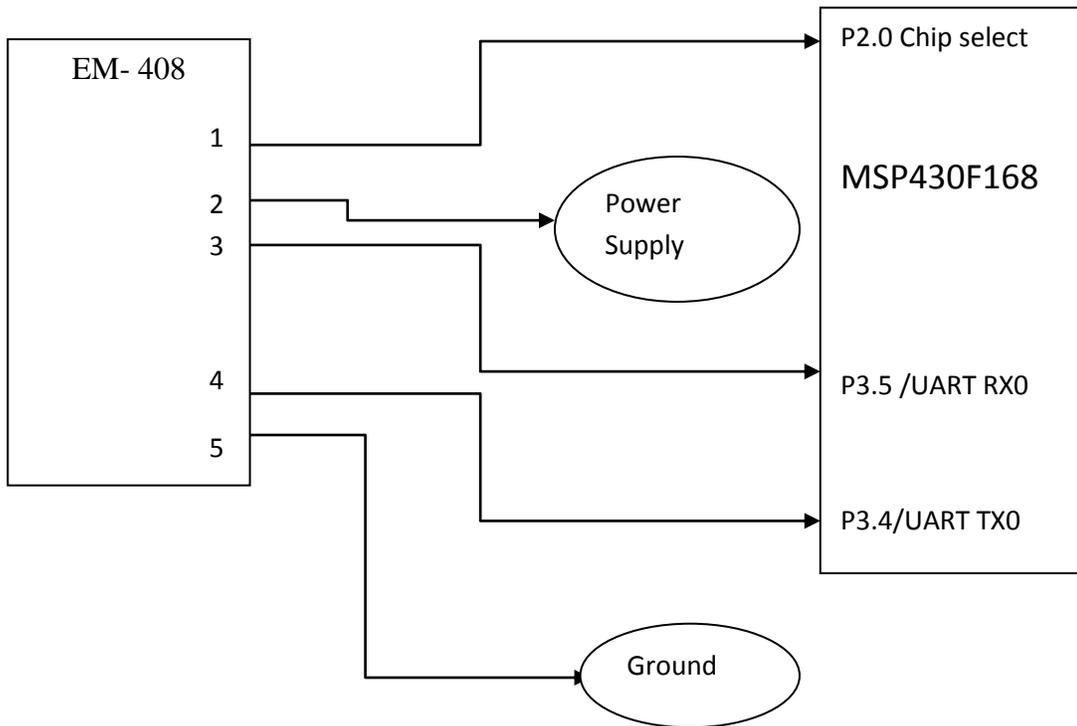
Figure 19: GPS to Microcontroller Interconnection

The GPS comes packed as the figure below with the dimensions shown only the interface with the outside world is through the five pins.
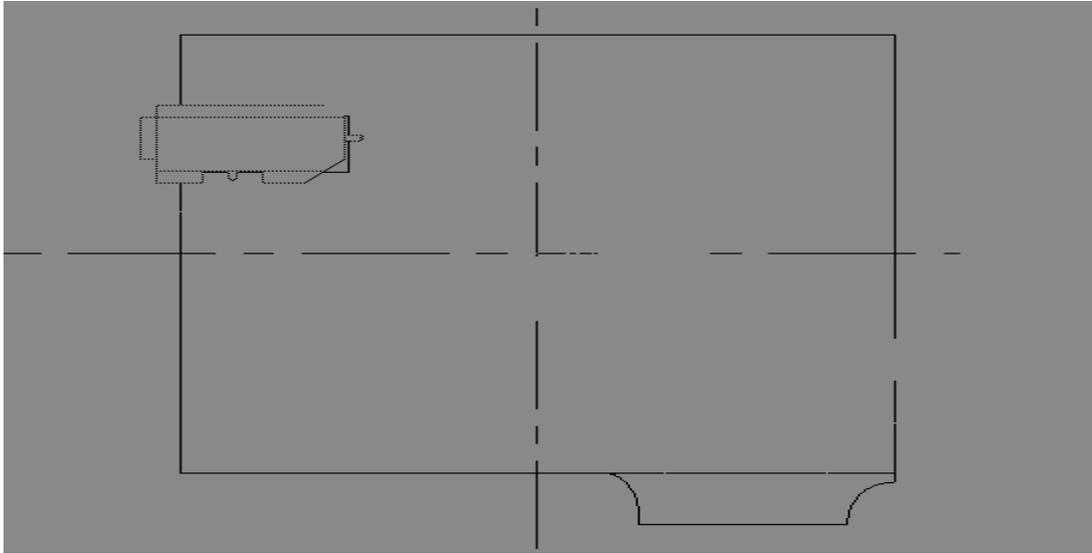
Figure 20: Dimensions of the Outside and Inside Packaging (Printed with Permission from globalsat.com)

Recommended P.C.Board Layout
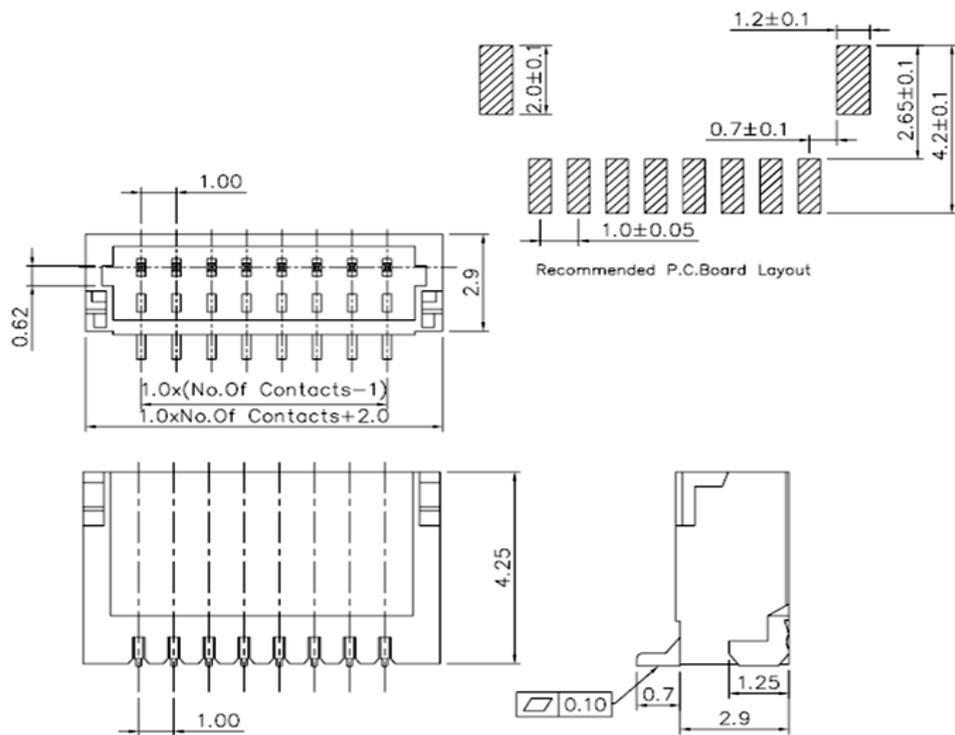
Figure 21: Footprints of the GPS Pins (printed from EM-408 datasheet by Permission from globalsat.com)

EM 408- SMD connector is used to connect the chip to the board.

1. Software Command:

NMEA protocol is used as an output for the GPS chip, and as an example for the output:

$GPGGA,161229.487,3723.2475,N,12158.3416,W,1,07,1.0,9.0,M,0000*18

In the table below, the each part of the code of the GPS output is explained:

Name	Example	Units	Description
Message ID	$GPGGA		GLL protocol header
UTC Time	161229.487		hhmmss.sss
Latitude	3723.2475		ddmm.mmmm
N/S Indicator	N		N=north or S=south
Longitude	12158.3416		dddmm.mmmm
E/W Indicator	W		E=east or W=west
Position Fix Indicator	1		P.F.I table
Satellites Used	07		Range 0 to 12
HDOP	1.0		Horizontal Dilution of Precision
MSL Altitude	9.0	Meters	
Units	M	Meters	
Geoid Separation		Meters	
Units	M	Meters	
Age of Diff. Corr.		Seconds	Null fields when DGPS is not used
Diff. Ref. Station ID	0000		
Checksum	*18		
<CR><LF>			End of message termination

Table 6: Interpretation of GGA Sentence

Value	Description
0	Fix not available or invalid
1	GPS SPS Mode, fix valid
2	Differential GPS, SPS Mode , fix valid
3	GPS PPS Mode, fix valid

Table 7: Position Fix Indicator (P.F.I)

Position fix indicator in the GPS has four values in this chip. First, if the value is 0, it means that the GPS is not able to calculate a correct value for the position. Second, if the value is 1, it means that the position is calculated correctly, and it has a valid value which also fixed value. Third, if the value is 2, the calculations come from a differential calculation between a fixed point as datum and another point with respect to the first one. Finally, if the value is 3, the GPS is on PPS mode which is the mode that allows 8 meter circular error probability within 100ns; this capability needs a permission to be used as it is only for military.

4.3 Microcontrollers

The MSP430F2274 comes in a 38-pin PM RTD package, and the MSP430G2553. Table 8 shows the Pin- Outs for the pins used by the ACE-Com system.

Pins for MSP430F2274:

Pin Number	Pin Name	Connection/ Description
1	TEST/SBWTCK	Pin 8 JTAG
2	DVCC	VCC
4	DV_{SS}	Pin 9 JTAG/GND
5	XOUT/P2.7	GDO2 in CC2500
6	XIN/P2.6	GDO0 in CC2500
7	RST/NMI/SBWTDIO	Pin 6 JTAG
8	P2.0/ACLK/A0/OA0I0	Input Audio Filter
11	P3.0/UCB0STE	The inverter to CS in CC2500
12	P3.1/UCB0SIMO/UCA0CLK/A5	SI in CC2500
13	P3.2/UCB0SIMO/UCB0SCL	SO/GDO1 in CC2500
14	P3.3/UCB0CLK/UCA0STE	SCLK in CC2500
25	P3.4/UCA0TXD/UCA0SIMO	Pin 47/1A1 fit bus
26	P3.5	Pin 46/1A2 fit bus
33	P1.2/TA1	The output audio filter
34	P1.3/TA2	The push switch
35	P1.4/SMCLK/TCK	Pin 7 JTAG
36	P1.5/TA0/TMS	Pin 5 JTAG
37	P1.6/ TA1/ TDI/TCLK	Pin 3 JTAG
38	P1.7/TA2/TDO/TDI	Pin 10 JTAG

Table 8: Microcontroller Pin Out. The connections listed for UART and Chip Select Signals will be connected to their components via the FET bus switch.

From the table above, the connections can be broken up into six groups: power, user interfaces, chip selects, UART1 interface, and programming. The power pins will be connected to the power supply and will serve as the input for all the

power to the microcontroller. During operation, this will be 3V. The next group is the user interface pins, which will be connected to the P1 port of the microcontroller. When depressed, these signals will be sent high, telling the microcontroller to perform a particular subroutine. The mode select pins will be connected to a single-pole, triple-throw switch, with +3VDC on the other side of the switch. This will ensure that only one mode can be selected at a time. The next group of I/O is the chip select group. These signals are all on the P2 port of the microcontroller. Each external device requires a control signal, which indicates to the component that the microcontroller is communicating to them.

.

The next group is the UART0 interface. These pins will be the interface between the microcontroller and the GPS module, Display, SD, and Battery Charger with the SD and Display on the SPI interfaces, the GPS on the TTL interface and the Battery Charger on the I^2C interface. Since only one of the components using SPI could ever be used at one time, they can all both the pins. This port will also be used when transmitting data to and from the SD card. The next set of I/O is the UART1 interface. This interfaced transceiver to the microcontroller. The majority of the time, this port will be used for the transceiver. The last group of I/O is the programming interface. These will be connected to the JTAG connector and will be used in programming and testing of the ACE-Com system.

Pins for MSP430G2553

Pin Number	Pin Name	Connection/ Description
1	DVCC	Pin 1 LCD/ VCC
2	P1.0	Pin 3 LCD
3	P1.1	Pin 2/13 fit bus
4	P1.2	Pin 3/14 fit bus
6	P1.4	Pin 5 LCD
7	P1.5	Pin6 LCD
8	P2.0	Pin 48 fit bus
9	P2.1	Pin 25 fit bus
14	P1.6	Pin 7 LCD
15	P1.7	Pin 4 LCD
20	DVSS	GND

Table 8': Microcontroller Pin Out. The connections listed for UART and Chip Select Signals will be connected to their components via the FET bus switch.

The table above shows the connection pins between the MSP430G2553, fit bus, and the LCD.

Again, in order to have several components connected to just one UART port, there will need to be a method to control which component receives the signals at which time. To do this, a 16-Bit FET Bus Switch is connected between each microcontroller and the GPS. The mechanical Data for the 16 bit Bus switch

SN74CBT16244 datasheet from Texas instrument is shown in Figures 22 and 23.
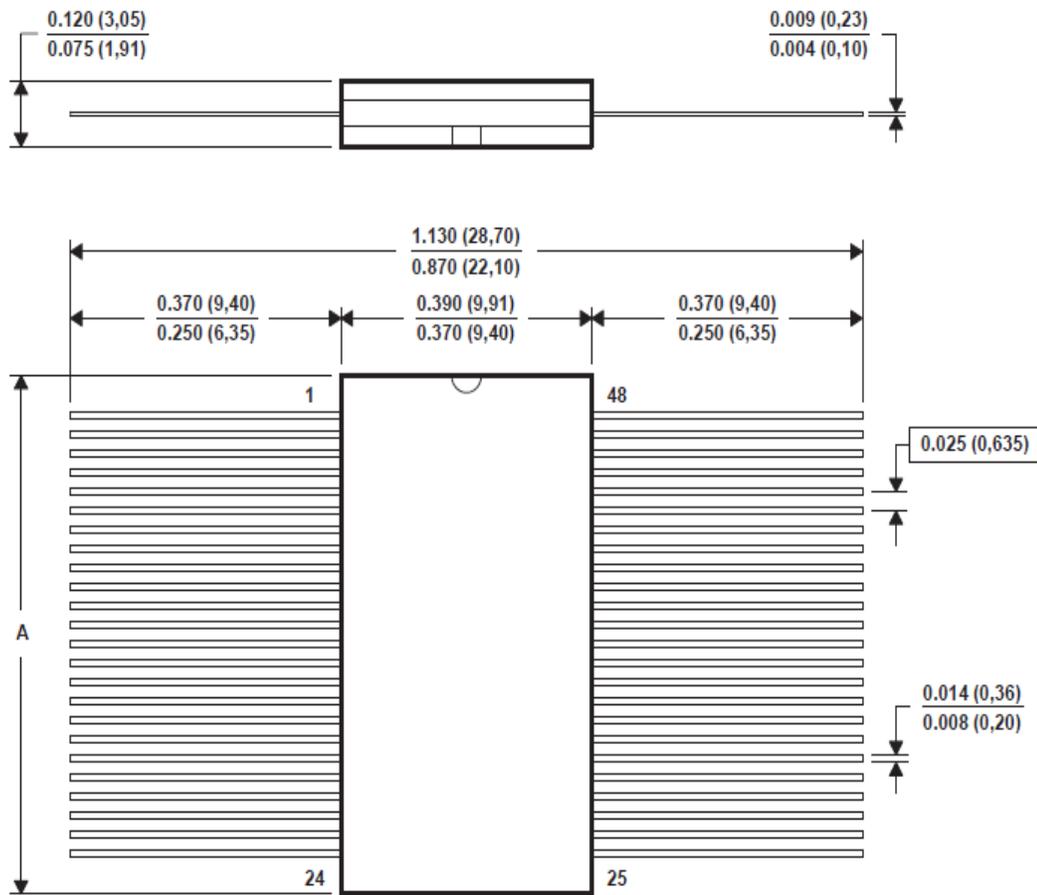
Figure 22: 16-bit FET Bus Switch Package Dimensions
(Permissions from Texas Instruments Pending)

The footprint of the chip and the distance between any two successive pins are shown below.
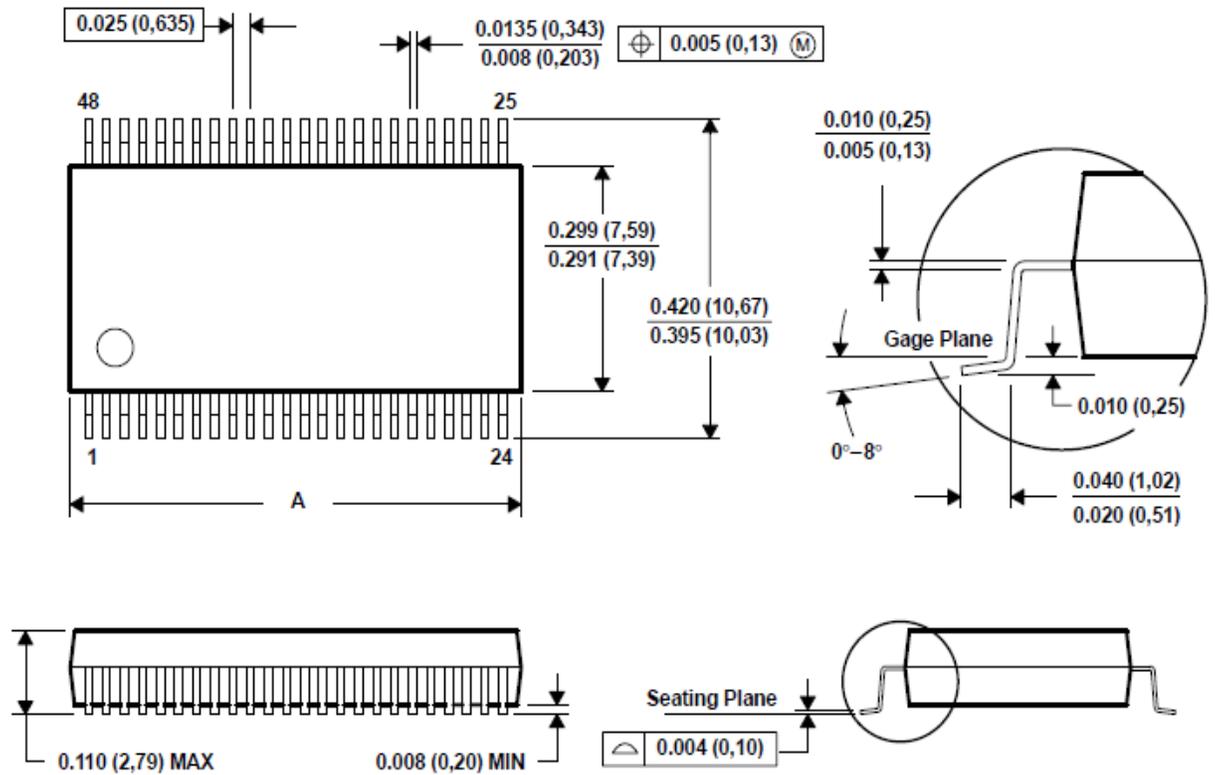
Figure 23: Footprint for 16-bit FET Bus Switch (Permissions from Texas Instruments Pending)

4.4 Microcontroller Software

As with many other systems, the majority of the data processing happens in the microcontroller. That being the case, the ACE-
software load is one of the most critical components. This software load controls everything from when each component is utilized to crunching the GPS data and telling the camera where to store the image file on the SD card. A C code written using the Code Composer Studio Software to create the microcontroller software load.

The software will contain several functions to perform each action. The first of these functions will be the ACE-Com-
function will begin execution as soon as the system is powered on. Its purpose is to determine which mode is selected. Once the mode has been identified, the software will jump to a subroutine pertaining to the selected operation mode. Once the microcontroller sees a mode change, it will return to the Mode Select function and the cycle continues. Figure 24 describes this cycle.
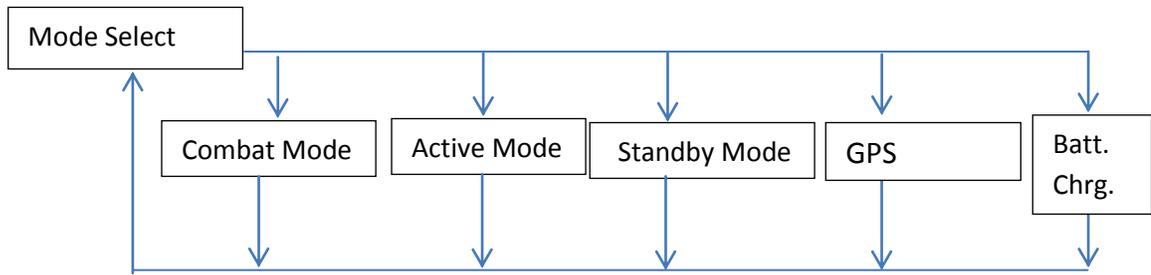
Figure 24: Mode Select Subroutine Flowchart

The diagram above shows the recommended software flowchart for future design.

The Combat Mode subroutine will first tell the transceiver to start sending and receiving audio. This will allow the user to speak when the PTT button is depressed and hear the other users. After the communication line is established, the subroutine will repeatedly check for one of four events to occur. The first possible event is for the user to activate the camera. This will cause the program to jump to another subroutine, which will handle all of the functions pertaining to the camera. The second possible event will be to collect GPS data from the GPS receiver. This will be triggered by a counter which will cause this event every minute and will, therefore, jump the program to the GPS subroutine. The next event the ACE-Com system software will check for is a change in the User 2 GPS data. To do this, the microcontroller will compare the latitude and longitude coordinates from the last incoming transmission to the GPS data already in memory. If the GPS data has changed, the program will jump to the Collect & Analyze GPS subroutine. The final event that may occur is a mode switch. When this happens, the system will return to the Mode Select subroutine, which will determine which mode has been selected. Figure 25 shows the flowchart for the Combat Mode.
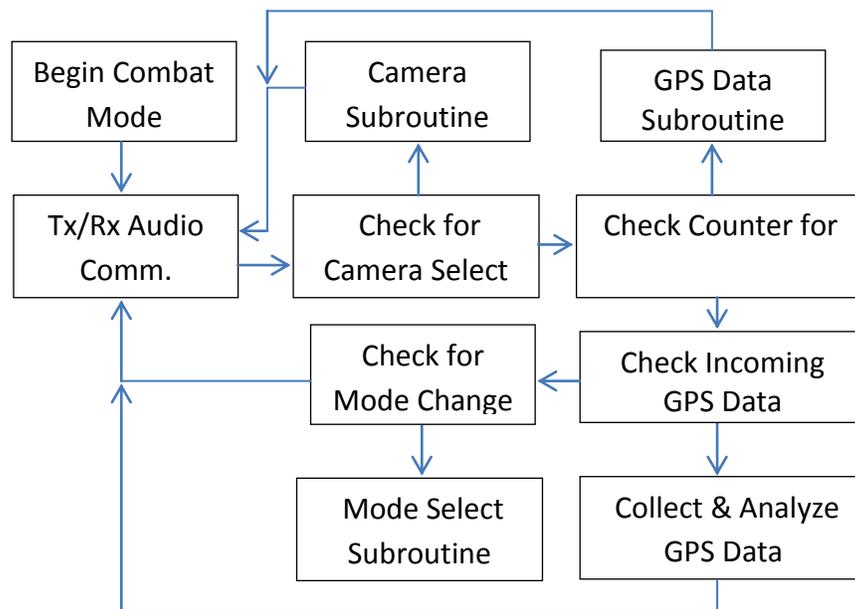
Figure 25: Combat Mode Subroutine Flowchart

The next mode possible is the Active Mode. Again, the first step of this subroutine is to initiate the transceiver to start transmitting and receiving the audio signals. From here, this subroutine will function similar to the Combat Mode subroutine except that there will be no camera usage (so this check can be eliminated) and the microcontroller will not be collecting or analyzing GPS data from other users (so this check will also be eliminated). The only events left are to check the counter for GPS data acquisition and transmission. Again, after performing these two checks, the program will revert back to check the status of the Mode Select and repeat the cycle. Figure 26 shows the flow chart for this subroutine.
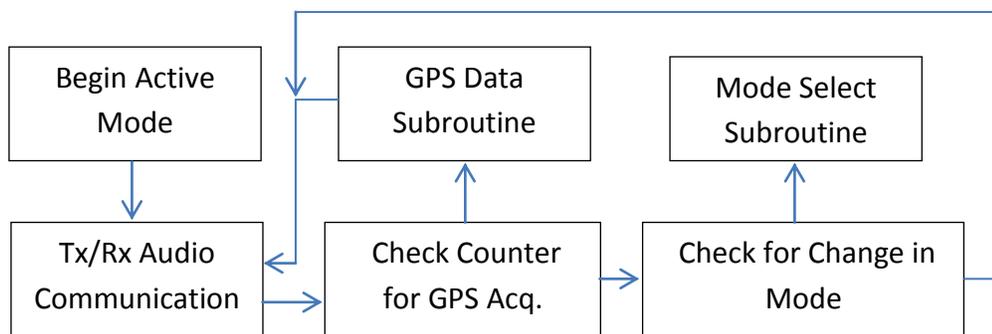
Figure 26: Active Mode subroutine Flowchart

The next subroutine is the Standby Mode subroutine and is this simplest mode. This mode only utilizes the GPS data transmission capabilities. Since this is the

54

case, the step in which the transceiver is initiated and the check for whether or not the PTT button is depressed. Now the only tasks left are to check the counter (which has now been set to 5 minutes), and check to see if the mode has changed. Figure 27 shows this flowchart.
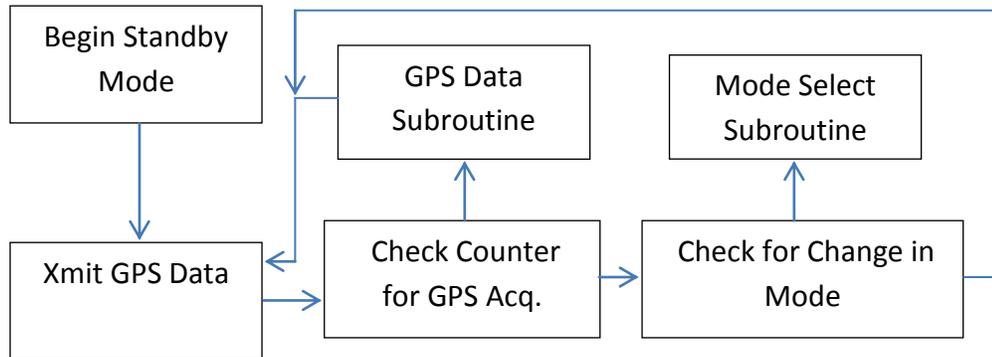
Figure 27: Standby Mode Subroutine Flowchart

This would happen if there is no constrain in time. The next subroutine is the Battery Charge subroutine. This subroutine will be triggered when power is applied to the battery charge port. During this subroutine, the microcontroller will initialize communications through the transceiver and then communicate to the Battery Charger module until the battery is fully charged. When the battery is fully charged, the display will be updated with a message indicating to the user that the battery is fully charged. At any point during this subroutine, if power is removed from the charger, the software will return to the Mode Select subroutine. During this subroutine, the UART0 port will be strictly used to operate the Battery Charger, therefore, no other components will be able to function during this mode. Figure 28 shows the flowchart for this subroutine.
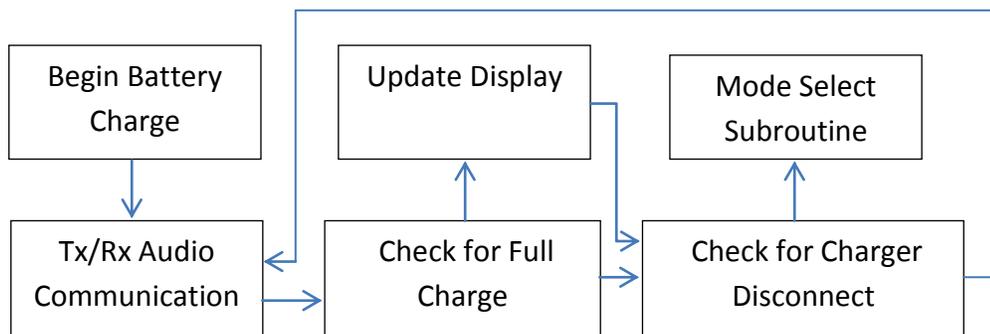
Figure 28: Battery Charge Subroutine

The next subroutine is the Camera subroutine which would be used if the camera future was implemented. This subroutine will first send a control signal to wake up the camera. After receiving a signal from the camera that it has been activated, the software will wait an additional 2-3 seconds to ensure the camera

has been fully powered up. Next the program will check for inputs from the user. Upon receiving the capture command, the microcontroller will send a signal to the camera to capture the image. The camera will then send the data to the SD card to be stored. The other possibility for this subroutine is to receive an input to leave Camera Mode. This will return the system to the Combat Mode subroutine. Figure 28 shows the flowchart for this subroutine.
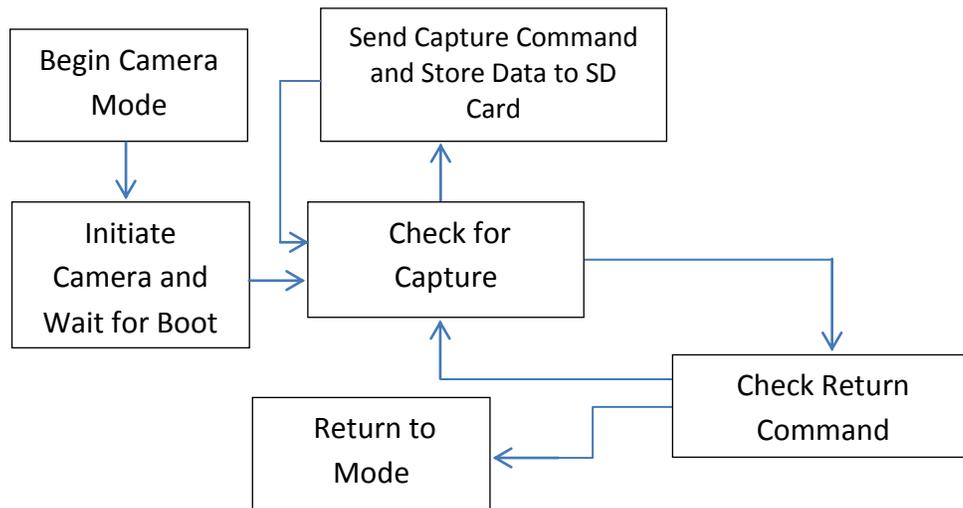
Figure 29: Camera Subroutine Flowchart

The next subroutine is the GPS Data Acquisition subroutine. This subroutine takes in the GPS data and analyze it. To do this, the software first sends a signal to power up the GPS unit. Next, it will send a statement to the GPS unit to tell it to capture a particular NMEA string. This string is stored onto the microcontroller RAM. Once in RAM, the microcontroller needs to convert the ASCII characters to digital numbers which it can crunch. The three values the microcontroller extracts from the NMEA sentence are the Altitude, Latitude, and Longitude. This information is then transmitted via the transceiver to the other units. After

position. If so, the subroutine calculates the relative position and store, it in memory for the next display update. Next, the software jumps to the Update Display subroutine, then back to this GPS Data Acquisition subroutine, and finally, back to the Mode subroutine the subroutine callout came from. Figure 29

shows   the   flowchart   for   this   subroutine.
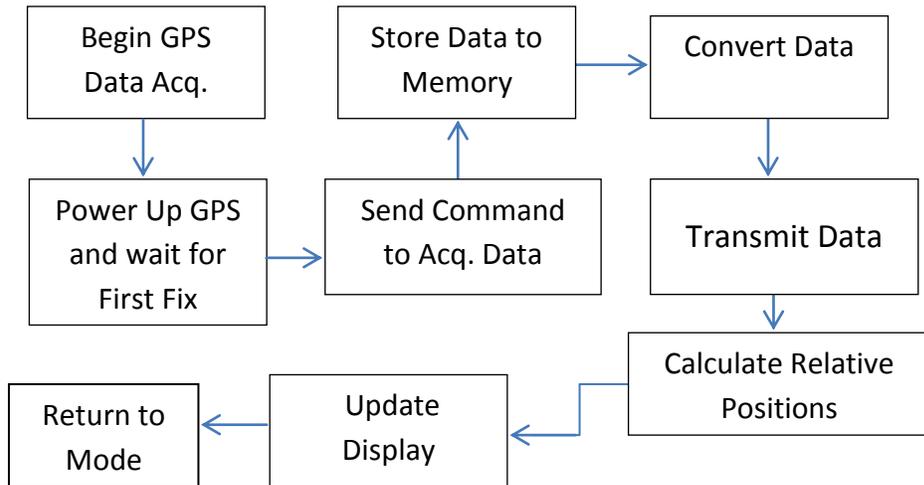
Figure 30: GPS Data Acquisition Subroutine Flowchart

The next subroutine is the subroutine used to collect GPS data about the other users. Collecting this data allows the system to calculate the distance between each user. The first step in this subroutine is to simply collect the data and store it to memory. This data comes from the first 36 bits from the transceiver. Since the data has already been converted into a useable form, there is no further processing required. As soon as the data is acquired, the software checks it against what is currently in memory to see if it has changed. If it has changed, the relative positions are calculated and the display is updated. Once the display is updated or if the GPS data has not changed, the software jumps back to the subroutine for the mode in which it
flowchart.
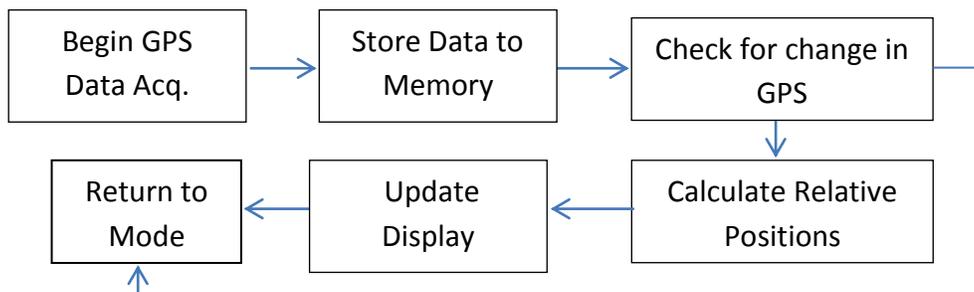
Figure 31: GPS Calculation Subroutine Flowchart

system calculates distance between users. As was stated above, the NMEA

longitude, and altitude. Using these three pieces of information, the ACE-Com system can calculate the distance between points. If the world is thought of as a very large sphere, this positional data becomes the equivalent of spherical coordinates. Furthermore, since the world is so large, it can be looked at as essentially flat, so the arc distance between the two points is equivalent to the distance a person travels between them. To find this arc distance, the ACE-Com system first finds the average between the two points. This altitude is used as the radius when calculating the arc distance. Next, the ACE-Com system finds the distance between the two points in the North-South direction. To do this, the microcontroller finds the difference between the two latitude positions and the indicators which signify North or South. By converting this distance into radians

has the distance between the two points in the North-South direction. The North and South indicators will help in determining in which direction each user is. This same method is used when calculating the distance between points in the East-West direction, only this time, and the system uses the longitudinal positions. With these two distances the display can show the distance between points in two methods. The first would be to simply display these distances (i.e. 4m N, 3m E). The other would be to convert these rectangular distances into polar

theorem on the two calculated distances. The angle between them will be the equivalent of the arctan of the East-West distance divided by the North-South distance. Again, the North, South, East, and West indicators are used to specify the   direction   of   the   angle.

To ensure the messages and data transmitted by the ACE-Com system is only seen by the parties the messages are intended for; the microcontroller software has an internal encryption/decryption subroutine. All data to be transmitted first runs through this encryption software prior to being sent to the transceiver.

In the future expansion, in order to be able to contain both GPS and audio data in one packet, the ACE-Com system will use its own custom protocol. Each data packet will follow the following format:

Latitude	N/S	Longitude	E/W	Altitude	Audio
14	1	14	1	6	12

The first 14 bits will be the latitudinal coordinates. Since the ACE-Com system is going to perform calculations with this number, it will need to use an unsigned binary number to represent the latitudinal coordinate. In order to have the high resolution necessary to accurately measure distance, the ACE-Com system will need to convert the input coordinates from degrees and minutes into millionths of radians. This coordinate resolution was chosen in the millionths of radians

because this corresponds with a resolution in the order of ten-thousandths of a degree, which is a much higher accuracy than the accuracy of the GPS receiver. When this value is calculated, it will be a 32-bit number, however, due to the limited range of the ACE-Com system, it can be assumed that the majority of the MSB of the two points to compare will be identical. Therefore, the ACE-Com system can eliminate the leftmost 18 bits to save data, leaving a 14-bit latitude coordinate. These 14 bits still provide for a maximum calculable distance of over 100 km, which is much larger than the ACE-Com-
latitude coordinate, there will be 1 bit, which indicates whether it is a North or South coordinate. A value of 0 would indicate a South coordinate and a value of 1 will indicate a North coordinate. The next 15 bits represent the longitudinal coordinate and follow the same format as the latitudinal with an East/West indicator value of 0 representing a West coordinate and a value of 1 representing an East coordinate. The next six bits will represent the altitude in meters. The

ADC. This a 48-bit packet which will be transmitted and received. Once received and decrypted, the microcontroller will take the first 52-bits and store them to the appropriate memory locations for analysis. The other 12-bits will be sent to the microcontroller DAC to be converted back into audio.

The final aspect to decide on when designing how the microcontroller will work was to decide on the clock and data rates for the peripheral devices. The main driving forces for this parameter were how much data the ACE-Com system will have to analyze and power consumption. Since higher clock rates consume more power, the ACE-Com system was designed to have the lowest clock rate possible. This clock rate needs to be fast enough to transmit the 48-bit data packet at a rate of 8kHz yet still needs to be able to handle the UART devices with minimum error rate. The first step in calculating this ideal value with minimum UART error and high enough to handle the 384kbps (48 bits * 8kHz) rate required to transmit all audio data is to decide on the baud rate for the UART controlled peripherals. To keep error rate down, a low baud rate would be preferred, therefore, all UART controlled peripherals will run at 9600 bps. The User Manual for the MSP430Fxxx family indicates that at a clock rate of 1Mhz and a baud rate of 9600 bps, the maximum error rate is ±2%, which is very low. To verify that this clock rate would be appropriate for the SPI interfaces as well, this clock rate and our baud rate (384000 bps) are entered into the following equation:

$$\text{Baud rate} = \frac{BRCLK}{UxBR}$$

However, UxBR must be an integer. To allow this equation to be true with an integer value for UxBR, we will adjust the SPI baud rate to 500kbps. Using these settings, the ACE-
rates required by all peripheral systems.

4.5 Audio

When choosing the microphone/speaker assembly for ACE-Com, the important factors to take into consideration are mainly based around user preference. preferences vary so drastically, the microphone/speaker assembly was chosen to be interchangeable with the wide variety of devices presently on the market. With the 3.5mm connector is so readily available in -Com uses to connect the microphone/speaker assembly. This does not only allow the user to utilize a broad spectrum of wired headsets, but also allow for the use of various wireless er similar technologies. However, should such wireless devices be utilized, it is recommended that the user ensures that the device does not occupy the 2.4 GHz frequency range. This may interfere with ACE-receive information between units. Furthermore, the user should ensure that the chosen device has at least two channels of operation. This allows the user to utilize both microphone and speaker simultaneously.

When selecting a headset, the user should bear in mind certain factors. First and foremost, personal comfort is vital when making a decision. The headset chosen should not distract or interfere with the user during operation. The user may be wearing the headset for several hours at a time and in very high stress situations. A poorly chosen headset poses the possibility of distracting the user during an instance in which a fraction of a second could be the difference between life and death. The speaker portion of the headset is also critical to choosing the appropriate headset. Since the ACE-Com system is utilized in situations in which it is necessary for the user to be aware of his/her surroundings as well as being able to effectively communicate, it is recommended to choose a headset which only contains a speaker for one ear as opposed to both. This allows the user to distinguish sounds coming from their immediate surroundings and sounds coming though the headset. Furthermore, it is recommended that the chosen headset incorporates some degree of noise cancelling technology. This is further

coming through the ACE-Com system. ACE-Com utilizes internal speech filters to help isolate the human speech range, but any further action taken by the user to improve the sound quality only increases ACE- Though it is highly recommended that user investigates the consumer market for personal preference and comfort, ACE-Com comes equipped with the Panasonic KX-TCA60 headset. This device offers all of the necessary elements required for full functionality of the ACE-Com system. With only one speaker, the Panasonic KX-TCA60 headset would allow the user to leave the left ear able to hear sounds s headset also comes equipped with an ear cushion to provide extra comfort and some noise cancellation. Another factor taken into account when selecting this headset was cost. Since it is recommended that the user investigate their own headset,

supplying a lower end headset allows the ACE-Com system to be available at lower cost.

The headset chosen will send/receive an audio signal via the 3.5mm jack in the ACE-

travel to the audio filters and amplifiers. After passing through the filters and amplifiers, the analog signal will go to pin P6.6 of the microcontroller. This pin is the input to the 12-bit ADC. This will sample the audio signal at a rate of 8kHz. This frequency will be more than enough to provide a clear voice signal, but will still be small enough to not overburden the microcontroller or transceiver. The audio signal coming in from the transceiver will come in the form of a 12-bit digital signal. After being decrypted, this signal will travel to the DAC on the microcontroller. This will output the analog audio signal onto pin P6.7, which will be connected to the audio filter/amplifier. After passing through the audio filter/amplifier, the signal will pass to the output of the 3.5mm jack and on to the speaker.

4.5.1 Audio Filters and Amplifiers

In order to help keep the audio signal clean, speech filters have been applied to both the input and output of the Speaker/Microphone assembly. Applying filters on both inputs and outputs will help ensure that the ACE-Com system not only sends a clean signal, but will also give the user a clear and audible signal, regardless of input noise.

These speech filters are comprised of an active, first order high pass filter and an active, first order low pass filter in cascade. Together, these create a bandpass filter between 300Hz and 3kHz (the frequency range of the human voice.) The schematic used to build this circuit can be found in Figure 32.
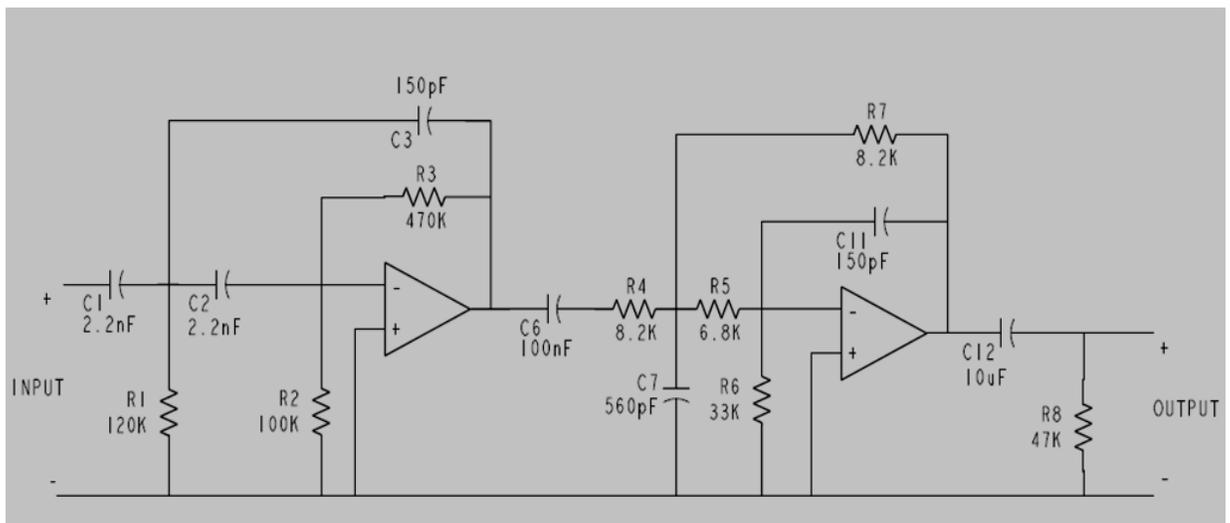
Figure 32: Audio Speech Filter Schematic

The op-amps selected for this task were TL072AI. These have very low output noise, which will help keep the audio signals clean enough to interpret on both
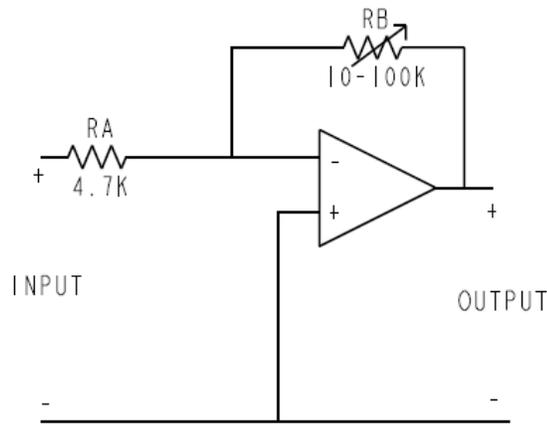
Figure 34: Speaker Audio Amplifier Schematic

4.6 Imaging

Due to time constraints, the camera was not implemented into the ACE Com system.

If the camera were implemented, the LinkSprite LS-Y201 would interface with the rest of the ACE-Com system using only four pins. These are the Power, GND, Tx and Rx pins. The Power and GND pins will bring in 3.3VDC power to the camera. This power will come from the power supply. The two communication pins, Tx

FET bus switch. When the Chip Select: Camera signal is low, the Tx and Rx signals from the microcontroller would be passed to the camera.

contain a subroutine to handle the camera. When this subroutine is selected, the first thing it would do is set the Chip Select: Camera signal to low, enabling

successfully been

image size. To do this, the microcontroller would send the following instruction indicating image size to the camera:

56 00 31 05 04 01 00 19 XX

Where XX is determined by the optimum picture size. After receiving this command, the camera will output the following signal indicating it has received the command:

76 00 31 00 00

Next the microcontroller will set the compression ratio. To do this, it will send the following command to the camera:

56 0 31 05 01 01 12 04 XX

Again, XX indicates the compression ratio. Upon receiving this command, the camera will reply with the following:

76 00 31 00 00 XX

Now that the camera parameters have been set, the system must reset the camera by sending the following command:

56 00 26 00

Upon resetting, the camera will return the following:

76 00 26 00

Now that the camera has been initialized, it is ready to capture images and will indicate to the user to do so via the display. From here, the software will look for
-button, which would also have
to be added to the system. Upon receiving this signal, the microcontroller will send the following message to the camera, instructing it to capture the image:

56 00 36 01 00

After receiving this command, the camera would capture the image and return the following:

76 00 36 00 00

the SD card, which would also have to be added to the system. To save the image, the microcontroller will send the following instruction to the camera, instructing the camera to send the image data:

56 00 32 0C 00 0A 00 00 00 00 00 00 00 00 00 0A

After receiving this command, the camera will start sending the image file to the microcontroller in 8 Byte chunks. The microcontroller will save this data to RAM
If
the particular chunk does not contain this command, the microcontroller will save the chunk to the SD card and move onto the next chunk of data. Once it does

which will instruct the camera to take another picture. This routine will continue until the user depresses

subroutine.

Prior to leaving the camera subroutine, the microcontroller will send a signal to the camera to instruct it to go to a low power mode. Below is the signal to be sent by the microcontroller:

56 00 3E 03 00 01 01

Upon receiving this command, the camera will go into power saving mode and will return the following:

76 00 3E 00 00

If, at any point during execution of the camera subroutine, the camera does not return the appropriate response, the display should show an error message. From here, the camera should restart the subroutine and try again. If the error repeats, the user would be recommended to depress the Camera Mode button to jump out of the camera subroutine.

4.7 Display

Designing the pin out and network around the display was much more simple than other components. This is because many times the microcontroller in the display will have a passive network already, and the designer will not have to implement their own. Also, it should be noted that the layout was an important factor as well. The Few passive components used were ceramic because this would reduce ESR and the LCD does not like extra noise from other sources. Also, considering the ultra-low current usage of this specific Nokia display that created a lot less noise than other high usage displays.
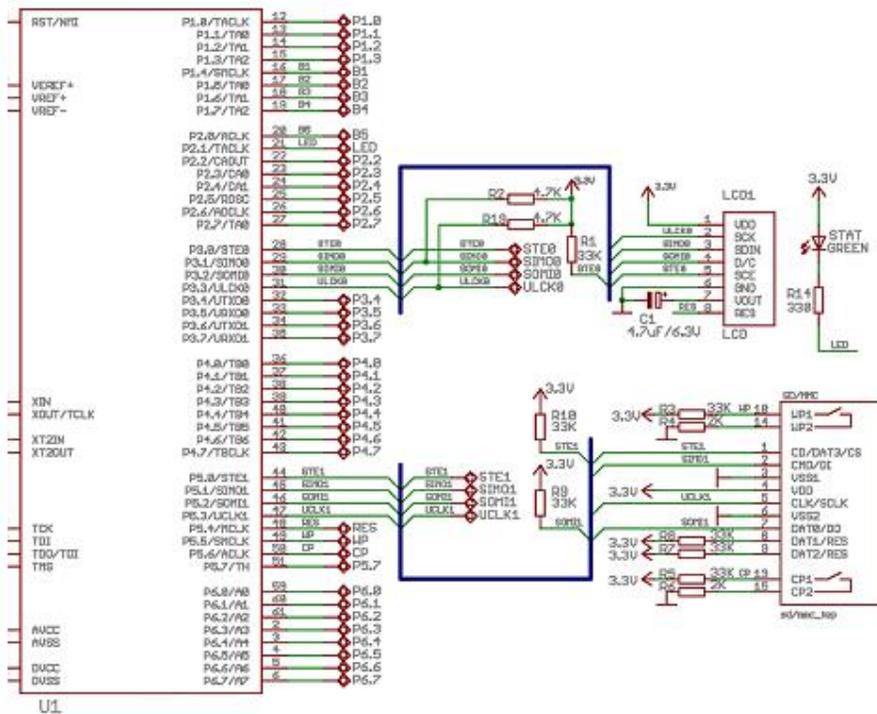
Figure 35: Schematic of the MSP430 pinout to the LCD display, Nokia 5110.

4.8 Encryption

Due to time constraints, the Encryption/Decryption software was not implemented. If it were implemented, this would be entered into the F2274

sends the data to/from the transceiver. The following describes the software as it would have been implemented had time permitted.

The DES algorithm- as written in the TI datasheet- contains 16 rounds of operations, so the data and the key are mixed together. The file DES.s43 contains only the routines that must be called from the same program. The main program must also declare the RAM variables and its addresses. There are two

generates a set of 16 sub keys; each sub key is stored in the variables SUBK_1,

variable PLAINTEXT   the result is stored in variable TABLE_OUT. The variable

be   encrypted   or   decrypted   as   follow:

bytes) must be loaded with the data that will be encrypted or decrypted; the
ion to perform as mentioned above.

However, the software, that would be used, works on data only, so the voice
must be transferred into data. The figure below shows the sequence of
operations needed to apply on the voice to convert it to data.

```
┌──────────┐      ┌──────────┐      ┌──────────┐      ┌──────────┐
│ Analog   │      │ ADC:     │      │ SWR      │      │ 48-Bit   │
│ voice    │ ───► │          │ ───► │ Combine  │ ───► │ Digital  │
│ received │      │ 8-bits   │      │ with GPS │      │ data     │
│          │      │ @8kHz    │      │          │      │ packet   │
│          │      │          │      │          │      │ ready to │
│          │      │          │      │          │      │ be       │
│          │      │          │      │          │      │ encrypted│
└──────────┘      └──────────┘      └──────────┘      └──────────┘
```
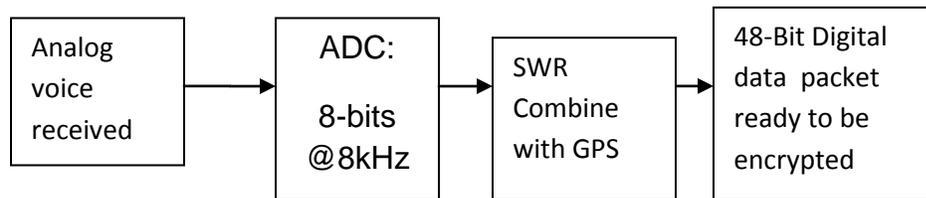
Figure 36: Block Diagram for Digitalizing Analog Signal

There is no another way to encrypt voice and GPS data in the same time without
having them both either analog or digital.   The figure below is the inverse
operations.

```
┌──────────┐    ┌──────────┐    ┌──────────┐    ┌──────────┐
│ Digital  │    │ SWR      │    │ PWM:     │    │ Analog   │
│ data     │ ─► │ separates│ ─► │ 32kHz    │ ─► │ voice    │ ─► 🔊
│ decrypt  │    │ with GPS │    │          │    │          │
└──────────┘    └──────────┘    └──────────┘    └──────────┘
```
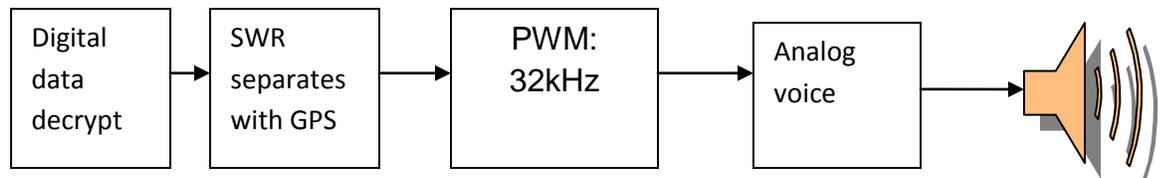
Figure 37: Block Diagram for Converting Signal to Analog

4.9 Motherboard

One of the most unique features of the ACE-Com system is its utilization of new printed circuit technologies. Ideally, the entire ACE-Com system would be printed in one process with an SLA machine printing all structural components and component interconnections while a Pick-and-Place machine places the components in the correct locations at the correct times. This fast, streamlined process would be capable of producing an extremely consistent product while driving down production costs. However, these technologies are far from being mature enough for such an endeavor and only certain portions of the ACE-Com system were attempted to be mounted on these printed substrates. In particular, these components were the antenna and transceiver. These parts were chosen due to the existence of preliminary designs by nScrypt. In order to ensure the

components should
comparison allowed for an accurate comparison of traditional parts to the printed components and see if the printing process causes any unexpected reactions to
difficulty of completing these printed components, no printed components were used on the final design. In the future, these printed components should only be implemented if they behave in a similar fashion   to   traditional   components.

Again, time constraints prohibited us from being able to accomplish an appropriate test board. However, in future builds of the ACE Com system, in order to ensure an accurate comparison is made, there are several aspects of
and foremost, traditional components would need to be able to be interchanged with printed components and vice-versa. When swapping traditional components to printed, care should also be taken to ensure that the traditional component is completely removed from the rest of the circuit. This would guarantee that the traditional component does not interfere with the performance of the printed components. To do this, the motherboard should be designed such that each portion of the system is interconnected using header pins or a similar method. When using a traditional component, shorting jumpers would be attached such that the component in question is connected to the rest of the system. When using the printed component, the shorting jumper would be removed and the printed component would be connected to the rest of the system. These jumper terminals would also be used as test points during testing of each component. To further isolate each component from the rest of the system, each component should have its own power and ground planes. These should be interconnected using two sets of header pins. This will ensure a sufficiently robust connection to allow enough power to be supplied to each component without burning up the header pins and minimizing   unwanted   impedance.

To help keep each subsystem isolated and easy to identify, all circuitry associated with each subsystem should be located within proximity of each other and should not cross into areas for another subsystem. Using a silk screen, each system should also be outlined with dotted lines and labels to further aid in

identification of each subsystem. In doing this, it would be clear which component belongs to which subsystem and would aid in troubleshooting.

During testing, it may be found that further filtration is necessary to maintain a clean and clear audio signal. In order to support this expansion, a breadboard should be placed on the motherboard. With this, band-reject or notch filters can be installed to remove unwanted frequencies. Furthermore, the breadboard would allow for additional components needed for the system to operate properly.

In order to ensure a proper comparison, the component layout and spacing is consistent between traditional and printed parts. Since the configuration of the CC2500 transceiver has already been designed by nScrypt, the traditionally

cost at a minimum, all components were laid out on the top of the motherboard and the motherboard does not have any internal layers with traces or power planes.

After the traditionally printed motherboard was tested to verify proper functionality, it would be used as the baseline when designing the printed components. However, due to time constraints, the printed components could not be completed. During completion, as stated above, each printed layout should match the traditional layout as much as possible. Each subsystem should be printed and tested. Any printed components verified to have similar functionality as the traditional component could be integrated into the final design.

The motherboard has six I/O ports. The first is the battery connector. This will simply mate to the AAA battery pack and is the entry point for all power during use of the ACE-Com system. Next is the GPS port. This five pin connector mates to the GPS receiver and is the point where GPS data enters the system. After the GPS port, there are the two 3.5mm female connector which are where the sound signals enter and exit the system. The display port is be where the display screen is mated to the system. Through this connector, the display receives the necessary data to keep the user informed. And finally, there is the JTAG connector. This was be used to program the F2274 microprocessor with the necessary software load to perform the audio and transceiver functions of the ACE-Com system.

In addition to the I/O ports listed above, the motherboard also contains terminals for the various user inputs. These include the power switch, the Display backlight button, the Push to Talk (PTT) button, and the volume control for the headset. In future builds, there may also be a mode select switch and the camera buttons (Capture/Transmit Image and Camera mode select). These are the interface for the user to operate the ACE-Com system. If implemented, Tte motherboard will also have the port for the SD card to allow the images to be stored. This slot

should be located near the edge of the board so that the SD card can be easily removed via an opening in the ACE-

Since the nScrypt components were so difficult to print correctly, it was decided that no components would ultimately be printed and everything was be built traditionally.

Pros: Using surface mount	Cons: Using surface mount
1. Surface mount components are less expensive 2. Surface mount components take up less space on the PCB 3. Physically larger components are easier to hand assemble 4. Fewer unwanted extraneous RF signals 5. Better vibration performance 6. Lower resistivity and lower inductance 7. Potential for double sided boards	1. Cannot use bread board 2. Manual handling is difficult for repair 3. Difficult for prototyping
Pros: Using through hole	Cons: Using through hole
1. Much easier to install while using 3D printing 2. Easily adjustable compared to surface mount 3. Prototyping friendly 4. Can use bread board 5. Strong mechanical bonds 6. Good for bulky and large systems 7. Beginner friendly	1. More expensive 2. Higher impedance due to leads 3. Limited routing area 4. Takes up both sides of board 5. Drilling holes creates costs more

Table 9: Pros and Cons of Surface Mount Technology & Through-hole Technology

This is another aspect to consider when designing the motherboard in general. Specifically, which type of component to use: Through-hole or Surface Mount. Due to the lack of many components in Through-Hole packages, ACE-Com utilizes all surface-mount technology. This is important because components will have a variable factor. When ACE-Com is ready to be produced and sold to retail markets by that time ACE-Com will maintain the surface mount technology. Not only will that save money during production, but it should also perform more optimally.

Also, it should be noted that a general rule of thumb is to work with ceramic

passive components. This is because ceramic typically have the lowest ESR (equivalent series resistance), and this is beneficial for the ACE-Com system because when working with many ICs and other components like an antenna it is important to have as close values as the calculated. Thus, the resulting design will be easier to verify. This is because the components work differently than in software, like MultiSim or LTSpice. Moreover, ceramic capacitors also age slower than other materials. This is beneficial for the project because overtime the components may not have to be replaced.

4.10 Memory

Due to time constraints, the SD card was not implemented into the final ACE-Com design. The memory card on the ACE-Com system is mainly intended to be used as a buffer where image files can be stored until they are ready to be transmitted to the base unit. Since the camera was not an included feature, this SD card is not necessary.

the ACE-   signal will be set to low, which enables use of the SD card. From here, the SD card will wait until the microcontroller receives data from the camera. When this happens, the data will then be saved to the SD card.

Since transmission of the image data could take a long time, the images will be stored on the SD card until the user has gotten to a safe location where they can transmit the images without the risk of missing mission critical information coming in from other users. When the user is confident that they can transmit the

Camera Mode, this button will cause the ACE-Com system to jump into the

from the user. Then, the software will begin reading data from the SD card and will forward it to the transceiver to be sent to the base unit. However, before being sent to the transceiver, the data should first be run through the encryption routine to encrypt the data. When in transmission mode, the software will send images one image at a time. To identify the end of an image, the software will

data   is   transmitted   to   and   from   the   SD   card.
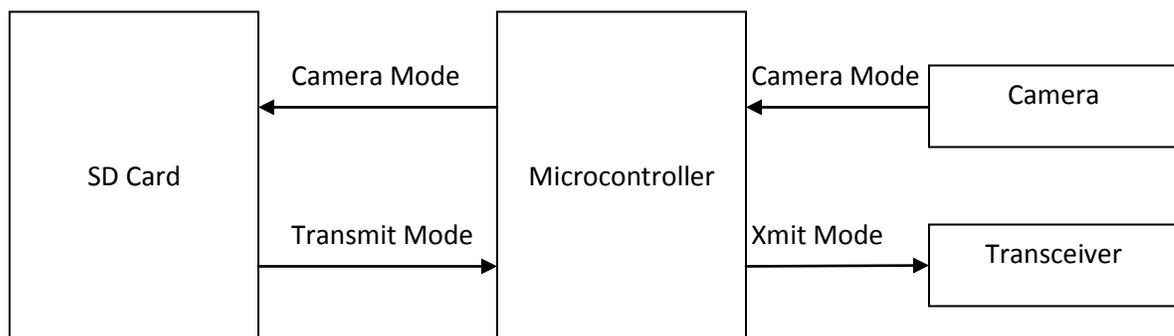
Figure 38: Block Diagram for Sending/Transmitting Data to/from the SD Card

4.11 Battery Management

Again, due to time constraints, AAA batteries were used to power the system. However, it is recommended that future units use Li-Ion batteries due to their rechargeable nature. Should a Li-Ion battery be used, there should also need to be a BQ27010 power management circuit implemented as described below.

To utilize the BQ27010, layout on the PCB is a key factor. To be efficient, the de-coupling capacitor from VCC to VSS and the filter capacitors from SRP and SRN to VSS should be placed as closely as possible to the bqJUNIOR, with short trace runs to both signal and VSS pins. All low-current VSS connections should be isolated from the high-current discharge path from the battery and should tie into the high-current trace at a point directly next to the sense resistor. This should be a trace connection to the edge or inside of the sense resistor connection; so that no part of the VSS interconnections carry any extra load current and no portion of the high-current PCB trace is included in the effective sense resistor (i.e. Kelvin connection).

Since HDQ interface is the chosen method of communication, it should be noted that filtering the HDQ line is a requirement. Due to the fact, that the HDQ engines may detect interferences such as: noise in as short of intervals of 5n seconds. Clearly, a sensitive command line is necessary since all communications are going through the HDQ line. However, a false transmission can waste a lot of power, and create unnecessary false positives. Thus, a simple remedy of a band stop filter is an easy fix.

Also, stated in the research section it is possible for the BQ27010 in HDQ interface to read/write both 8 and 16 bit words which is a plus. Clearly, this specific device works more efficiently if all words to be written or read are 8-bit words. However, the project is not being made in an intrinsic world, and of course ACE-Com must prepare to read and write 16-bit words, and to remedy the BQ27010 so that it will have little to no problems.
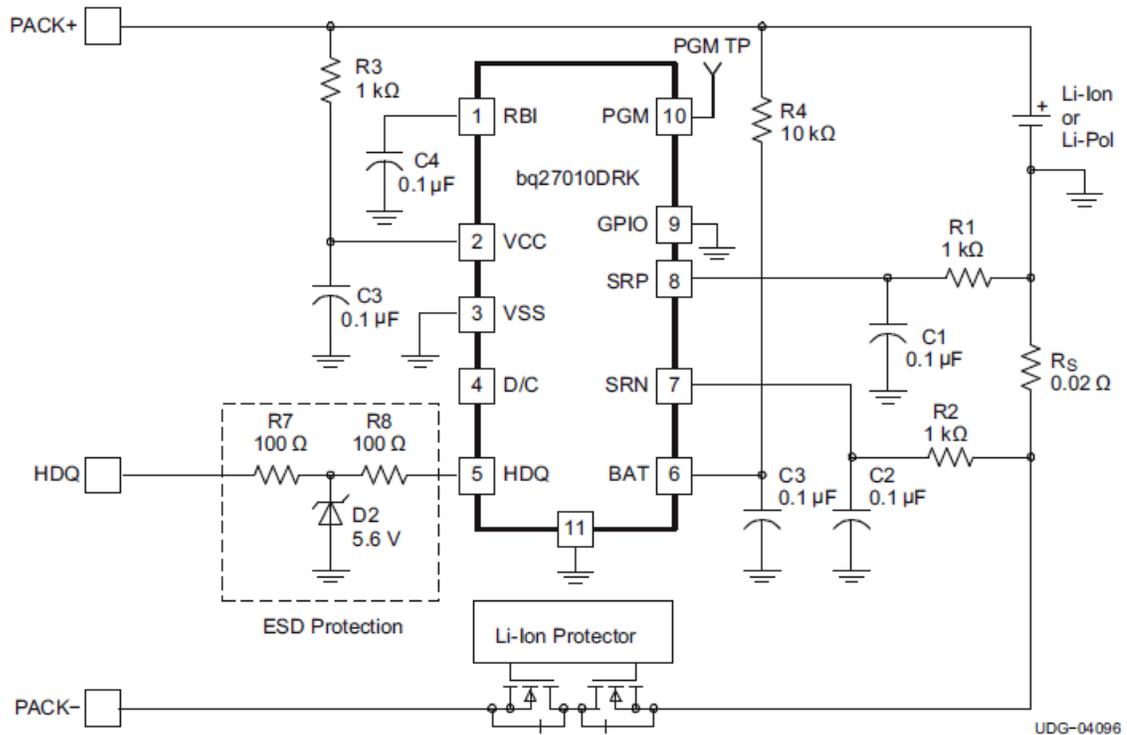
Figure 39: Passive network design for BQ27010

Considering the BQ27010 will be connected to a main microcontroller, in the case of the MSP430F168, to note the obvious the microcontroller in any case will have interrupts. In essence, ACE-Com must not allow interrupts during critical HDQ communications because it those interrupts could break the words of communication up. Thus, this is easy to remedy the entire system must disable interrupts on the MSP430F168 during low time between communication, and enable interrupts during long breaks of communication; obviously, this will be written   in   a   loop.

That is one consideration of interrupts; there is another solution if you are unable to cease interrupts of the main microcontroller, then every time there would be an interrupt you must program a break in the communication and then resume communication after the interrupt. Clearly, this method is much more difficult and requires   a   large   amount   of   probability   calculations.

However, communications using the HDQ interface can best be utilized by using a UART (Universal asynchronous receiver/transmitter) ACE-Com would be using the UART pin on board the MSP430G2553. Clearly, a UART is the most universal method because main microcontroller interrupts do not affect the timing of the HDQ communication with the slave. Of course since the UART, is essentially a buffer state the communication between the master and slave will be slower overall, but there is almost no need to program any extra code besides initialization.

Specifically, it would be desired to set the UART baud rate to 57,600 with no parity and 2 stop bits. This yields a data word with 11 bits total (start bit, 8 data bits, and 2 stop bits). At a baud rate of 57,600 (17.3 us per bit), this is a total communication time of 190.9 s and meets the required HDQ bit timing of 190 s minimum. If data of 0xFE is sent to the UART, the transmitted data is low for 34.6 s and then high for the remaining bit time and is interpreted by the HDQ slave as a one. If data of 0xC0 is sent to the UART, the transmitted data is low for 121.5 us and then high for the remaining bit time and is interpreted by the HDQ slave as a zero. When data is sent to the host from the HDQ slave, the received data could be interpreted as either 0xFE or 0xFC if a logic 1 is sent, or either 0xF0, 0xE0, 0xC0, 0x80, or 0x00 if a logic 0 is sent. A simple test of the received data determines the received data bit. If the received data is greater than 0xF8, the data bit should be interpreted as a logic 1 and if less than or equal to 0xF8, the data bit should be interpreted as a logic 0. This analysis assumes the UART samples the received data approximately half-way through each of the 17.3-us UART bit times and that capacitive loading on the HDQ line may delay the rise time of the data a few microseconds. Note that the TX and RX of the UART must be tied together because HDQ is a single-wire interface. In case the TX output is not an open-drain output, it needs to be converted to an open-drain output as shown in Figure 5. Note also that any data sent out to the HDQ slave is also received by the UART. So, if 8 bits of address are sent and then 8 bits of data from the HDQ slave are received from that address, the UART inputs 16 bytes of data into the UART data buffer. The host needs to skip the first 8 bytes which contain the command word sent to the HDQ slave and use the second 8 bytes of data.

Consider the second choice of the BQ3055: ACE-Com would use a SMbus (slave-master bus) interface. For this specific interface the BQ3055 will require a serial clock and serial data line (on the MSP430). These lines must be kept low by using pull-up resistors.
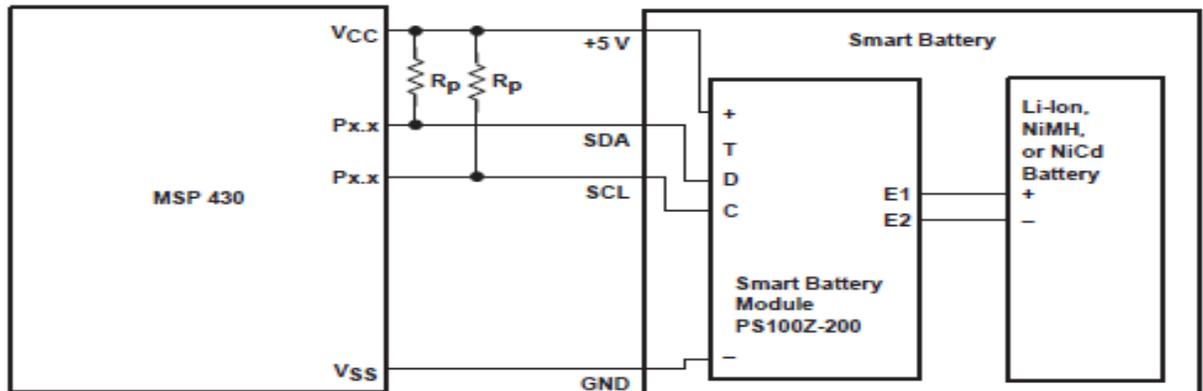
Figure 40: Interconnection for BQ3055

Above is typically how ACE-Com will be connected to the chip, the BQ3055, to the MSP430. Instead of the smart battery module replace that with the BQ3055.

4.12 Battery Charger

Again, due to time constraints, AAA batteries were used to power the system. However, it is recommended that future units use Li-Ion batteries due to their rechargeable nature. Should a Li-Ion battery be used, there should also need to be a battery charging circuit implemented as described below.

When designing the passive network around the charger an important factor is power topology. For this design and the purpose of ACE-Com a system load after sensing resistor topology will be used. For this design the AC adapter is disconnected and the battery pack powers the main system with low power dissipation. This topology encourages dynamic power management because the total charge current and the system current can be programmed to a desired value. Then when the system current increased the charge current will drop by that amount; thus there will be no over current or over heating issues another bur
topology as well. If the system demands high current the battery charging will never terminate; thus the total lifespan of the battery will be reduced. Also, if the totally current is fixed the system may always require some current to charge the battery. Thus, the full-charge time may take a longer time than normal. Thus, fixing a total amount of current is a tricky process and must be calculated with precision. In rare cases, if
has stopped charging. Then after the IR drop across the battery impedance may cause the battery voltage to drop below the refresh amount and a new charge cycle will start, and when a new charge cycle starts it could take a long time to charge   again.

V_{BUS} = 5 V, I_{CHARGE} = 1250 mA, VBAT = 3.5 V to 4.44 V (Adjustable).
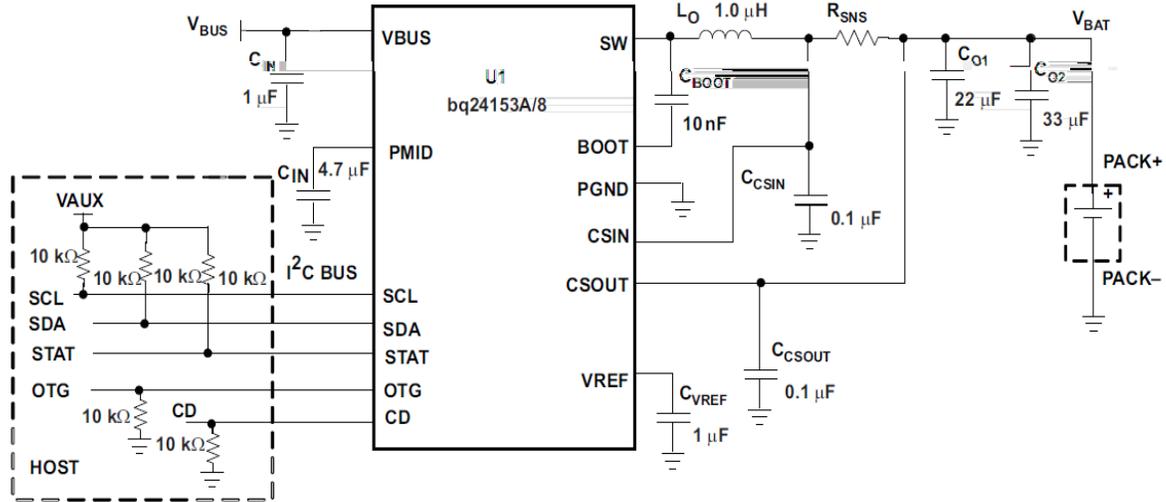
Figure 41: Passive Network and ESD Protection for BQ24153

To obtain optimal performance special attention is required to the PCB layout. The power input capacitors should be placed as close as possible to the pin. The output inductor should be placed close to the IC and the output capacitor from the SW pin through the LC filter and back to the PGND pin. To prevent high frequency oscillation the sense resistor should be adjacent to the junction of the inductor and output capacitor. It is important to place decoupling capacitors close to the IC pins and close to the PGND; route all small control signals away from the high power current paths.

Grounding plate should be directly connected to all return paths of all components through vias. Star-ground design typically is used to keep circuit block currents isolated this will reduce total noise coupling and ground bounce issues. The high current paths should be sized correctly; very short and very wide.

4.13 Voltage Regulation

When placing the passive components around the voltage regulators it was important to calculate and choose components considering their topology and materials that they are made out of. Specifically, the capacitors in the circuits were ceramic capacitors which typically have lowest ESR (series resistance). Clearly, lower resistivity in capacitors are more optimal because then the capacitor can act as a capacitor rather than a resistor. Moreover, exterior capacitors typically reduce ripple, lower noise, and improve stability. Also, exterior capacitors were placed as close as possible to the voltage regulators to reduce resistivity in the junction. It should be noted that capacitors values will decrease over time due to aging, and selecting ceramic capacitors was the best choice because they are quite resilient. More specifically, the input and output capacitors which are connected to the regulators to stabilize the internal control

loop of the system. Overall, aside from making leads as small as possible exterior passive component choice maybe were the most important decision when   using   voltage   regulators.

Layout was also an important factor when working with voltage regulators specifically grounding plate is an important factor. Usually when working with RF communication create very large ground plates to reduce inductance. In the case of voltage regulators, the ground plate of the input and output were separated to reduce the chance of surge/feedback. Also, it should be noted that space was also considered as well, and because with many large grounding plates users could expect to have a multi-level PCB. However, with space considerations designs   was   tailored   around   space   requirements   as   well.

Power dissipation and junction temperature is another design factor that ACE-Com had to work around. Typically, and in for this project power dissipation was desired to be as low as possible. Considering the junction will be under the typical maximum junction temperature of +125° C; then users will be able to

$$P_D = (V_{IN} - V_{OUT}) \times I_{OUT}$$

As the designers of ACE-Com, the system did not need toadopt a cooling method to keep the junction under the max temperature allowed. The PCB was enough to reduce the heat in a simple method by using the copper area on the PCB   to   transfer   some   of   the   heat   from   the   device.

Also, when dealing with voltage regulators, the designer also considered how to enable the device. In this specific case, the LP5951 is enable high. Thus, a signal source must be connected to the enable pin which can swing above and below the   turn   on   and   turn   off   voltage   thresholds   (0.4V/0.9V).
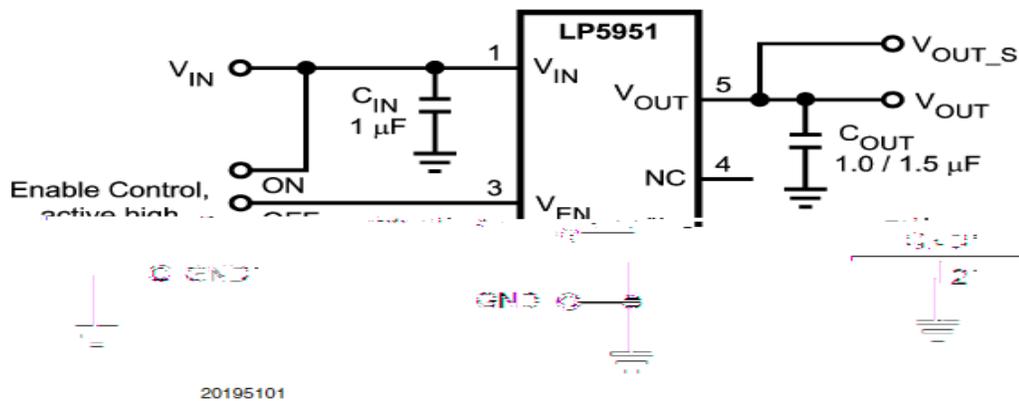
Figure 42: The following shows the low dropout regulator, LP5951, with passive network design for typical usage.

Specifically, for the LM5951 output and input capacitors were chosen, and according to application note, AN1486, the application note for the LP5951 if desired output voltage after regulation is below 2.8V use 1.0 µF for C_{IN} and use 1.0 µF for C_{OUT}, and if the desired output voltage is above or equivalent to 2.8V use 1.0 µF for C_{IN} and use 1.5 µF for C_{OUT}.

Also, it should be noted that for the LP5951 during normal operations the input voltage is higher than the output, but configurations can be made to make the output higher than the input. In the LP5951, an inherent parasitic body diode is reverse biased, but the diode is forward biased then the output will be higher than the input. Also, if the desired output is higher than the input the output the current in the diode must be limited to 50 mA. However, for currents above the limit an internal Schottky diode should be connected from V_{OUT} to V_{IN}. This was not necessary for ACE Com.

OUTPUT VOLTAGE PROGRAMMING GUIDE

OUTPUT VOLTAGE	R_1	R_2	C_1
1.22V	short	open	0pF
2.5V	31.6kΩ	30.1kΩ	22pF
3.3V	51kΩ	30.1kΩ	15pF
3.6V	59kΩ	30.1kΩ	15pF
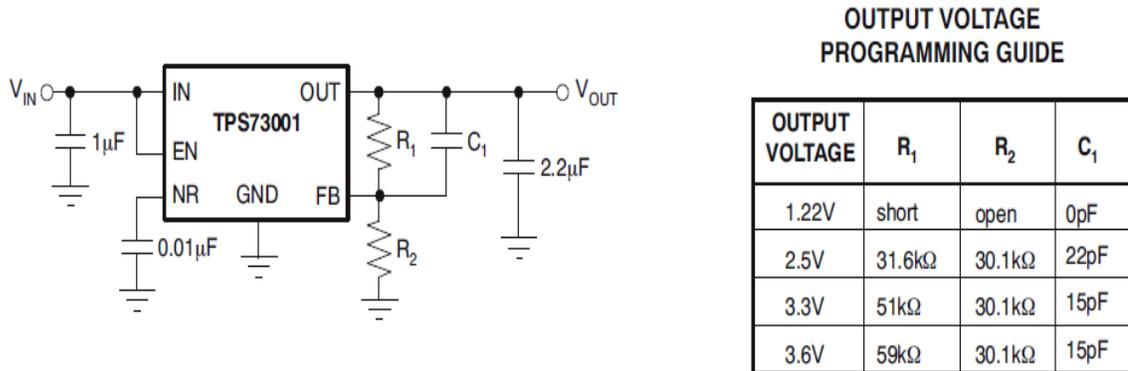
Figure 43: Passive Network Design for TPS73001.

Specifically, for the TPS73001 which also requires input and output capacitors. The values of the design are given in the table above. Also, it should be noted that this schematic is the variable version of this voltage regulator. Specifically, for this design there is a bypass capacitor connected to the NR pin. This is an optional bypass capacitor, but ACE-Com adopted this option because this specific bypass capacitor creates a low-pass filter internally, and the LPF will reduce voltage reference noise and this overall reduces noise. The value of the bypass capacitor was made very small because if there is any leakage current it will create an IR drop across the internal resistor which in turn will create an output error. As stated earlier ceramic capacitors were be the best choice; thus ACE-Com will adopted ceramic capacitors for this regulator as well.
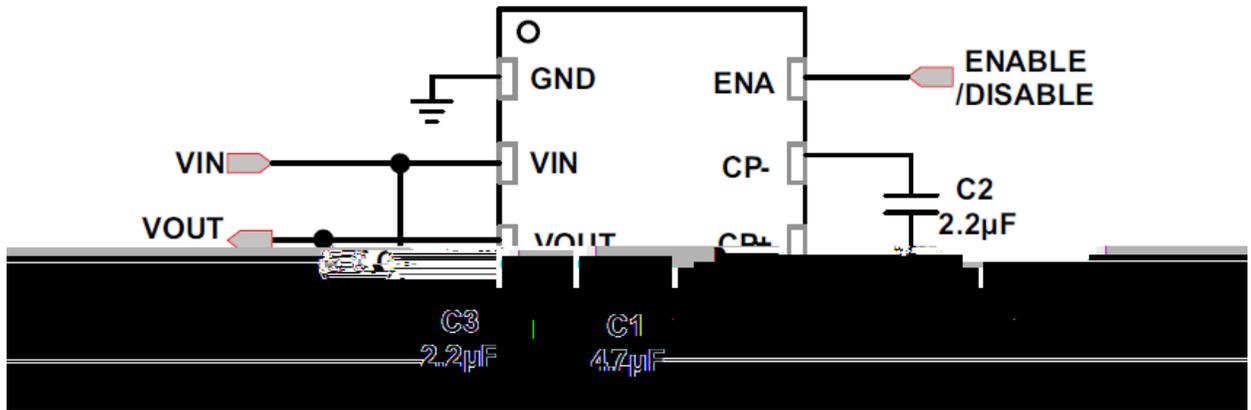
Figure 44: The following is from the datasheet: 5V/140 mA Charge Pump Device; this is found on the Texas Instruments website.

The TPS60151, like, the other regulators also benefits greatly from input and output capacitors to ground. C_2 in this case is a flying capacitor which is required for a charge pump, boost-up regulator. This is where all the charge is stored and released to boost-up the voltage. Similarly, surface-mount ceramic capacitors were used because they will reduce ripple, longer lasting, spacing saving, and reduced   resistivity.
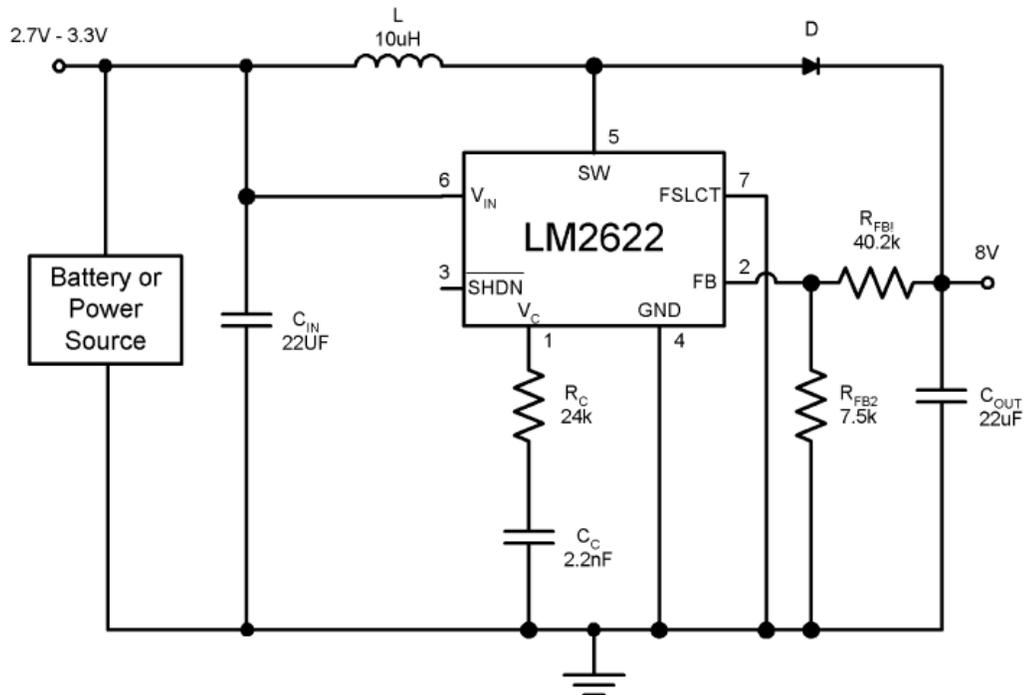
Figure 45: Passive Network Design for the LM2622.

The LM2622 is a step-up DC/DC converter with switch frequencies of 600kHz and 1.3MHz. The output voltage required (8V) can be generated from 600 kHz switching. However, duty cycle is important when dealing with switching; mainly, the duty cycle will determine the voltage output. Typically, like the schematic above the duty cycle is 50% this is normal for most switching regulators because 50% is a stable duty cycle. Many times if users would require a higher duty cycle many compensations would have to be made. When choosing inductors and diodes for the regulator ripple current, power dissipation, and overall efficiency are at stake. Thus, choosing an inductor that has saturation current rating higher than the peak inductor current expected is a must. Inductors used for this design are low EMI inductors with a ferrite type closed core. These are toroid and encased E core inductors. This is because the output ripple voltage is affected by the ripple current. Moreover, using Schottlky diodes is key for this project. This is because Schottlky diodes have much lower voltage drop than other diodes (typically half) and that will decrease power dissipation and increase efficiency. However, it should be noted that Schottlky diodes work much better in lower voltage schematics which is why it works well with ACE-Com. Capacitors tied to the input and output can range anywhere from 22-47 µF for this specific example 22 µF were chosen. However, those values can be increased if needed, and basically it would be a choice of the designer. Also, capacitors with very low ESR, like ceramic capacitors, were used because with a switching regulator there will be a pole and a right-half plane zero. Calculated by:

$$f_{P1} = \frac{1}{2\pi(R_{ESR} + R_L)C_{OUT}} \text{ (in Hz)}$$

$$f_{Z1} = \frac{1}{2\pi R_{ESR} C_{OUT}} \text{ (in Hz)}$$

A current mode control boost regulator (LM2622) will have a RHP zero. If a low ESR capacitor is chosen it can almost be neglected. However, this zero can be detrimental to the control loop, and to ensure that it will not cause any issues the control loop should have a bandwidth less than half the frequency of the RHP zero. Calculated by:

$$RHPzero = \frac{V_{OUT}(D')^2}{2\pi I_{LOAD} L} \text{ (in Hz)}$$

Similarly, layout is an issue as well when dealing with voltage regulators and RF communication. C_{IN} should be as close as possible to the IC (to reduce copper

trace) this will make less ripple voltage. If V_{IN} is high a bypass capacitor around 100 nF should be placed in parallel to C_{IN}. This bypass capacitor will block any high frequency noise by passing it to the ground plate. Moreover C_{OUT} should also be placed as close as possible to the IC. The feedback network R_{FB1} & R_{FB2} should be kept very close to the IC and as far as possible from the inductor. This is because copper trace near the inductor will cause extra noise. So, put the feedback network and inductor on opposite sides of each other. Thus, connections to the inductor and diode need to be as short as possible because high impedance can cause power dissipation and poor efficiency. Make all power traces as short and direct as possible; also make t1(im)-4(3-3( )-1r)-2racedect as pus,

communication with the CC2500. Since the CC2500 does transmit two signals in 180° phase difference there needs to be a balun on the transmitting output to lead one of the signals by 90° and lag the other by 90° or else the output signal will be very noisy and weak.

Considering layout, the top layer was used for signal routing and the open areas were filled with metal connected to ground using vias. Specifically the area under the chip was used for grounding and was connected to a bottom ground. This enables good thermal performance and keeps inductance low to ground. These all factor in to the RF performance because too high thermal temperatures can cause too much noise. Decoupling capacitors were placed close to the supply pin it is supposed to decouple. The power was routed through the decoupling capacitor for additional filtering of the power supply. Each via drilled has a decoupling capacitor to make up for the inductance increase.
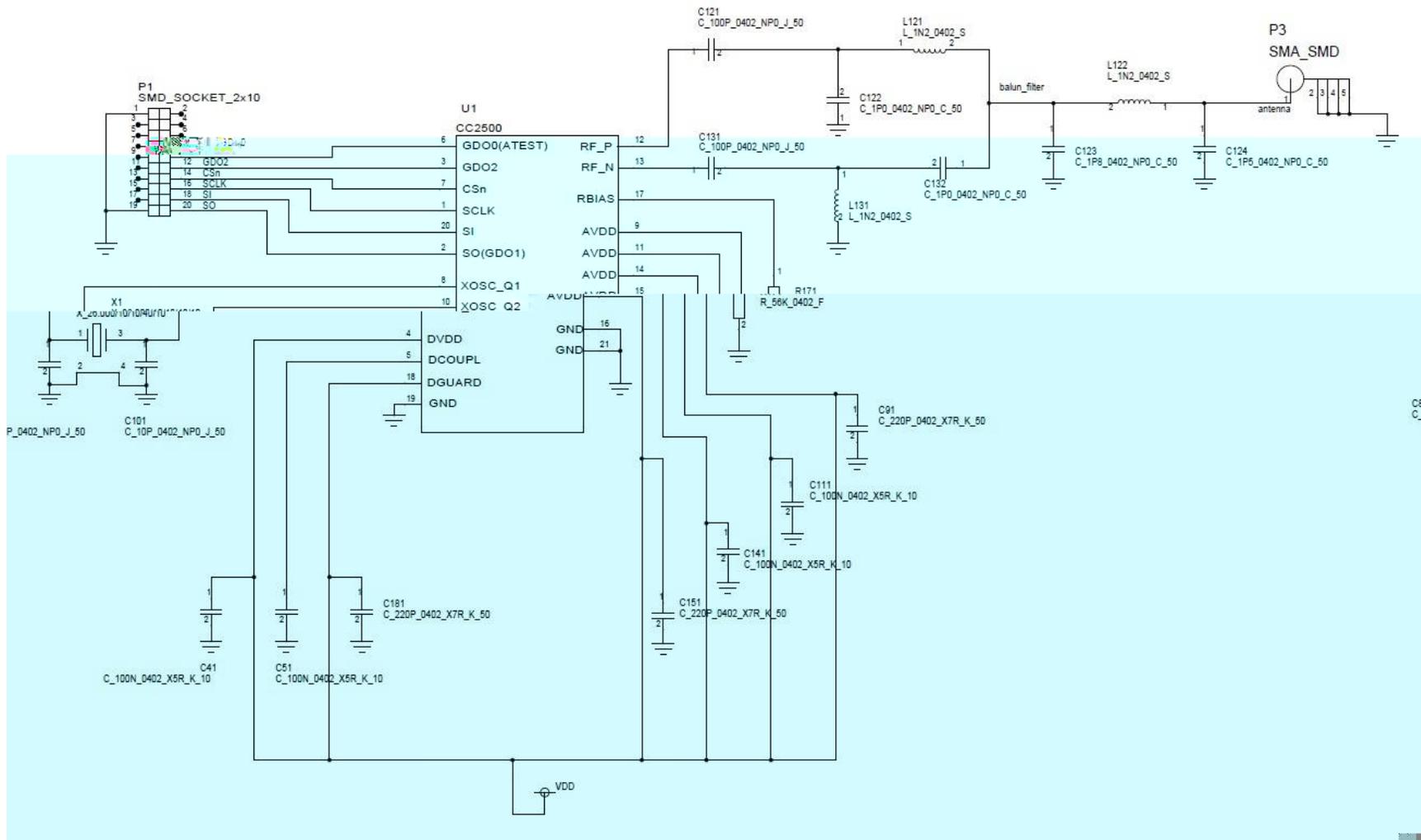
Figure 45: Passive Network Design for CC2500
(Taken from datasheet)

The parts used in the passive network and some of the ICs are shown. The components were chosen to boost performance after solving for values of required components. Only ceramic surface-mount capacitors were chosen due to low ESR and high endurance.

Potentially, the CC2510 could be the transceiver of choice for the ACE-Com system. Thus, a design schematic must be made for it as well considering that the transceiver maybe the most important part of the entire system. It should be noted, that there is no need for a balun on the output transmitter of the CC2510 because it comes with an on board balun that is already tuned to the phase difference in output signals.

Considerations for the layout around the CC2510 are similar to the CC2500 because it is an RF device. Thus, special considerations will be made to suit. Similarly, to the CC2500 the top layer should be suited for signal routing and open areas filled with metal connections to ground using vias. Also, the area under the chip should be used for grounding, and connections should be made to a bottom ground plate. Decoupling capacitors should be placed as close to supply pins to reduce extra trace. Make power routes short and very wide to reduce any impedance, but allowing the current to flow easily, and keep thermal noise down. It should be noted that ground plates should be very large to reduce inductance; Also, make several ground plates to reduce bounce-back/feedback which create extraneous noise.

4.15 Antenna

After research and many computer simulations it has been decided to go with an inverted F design antenna. This is mainly because of its omni-directional signal properties, and overall good gain (2.2-3.2 dBi). When designing the antenna with NScrypt materials, gain, and layout were all key factors.

Specifically pertaining to materials the 3D printed monopole antenna (provided by NScrypt) was to use a copper blend (this is a RF industry standard) this is because the copper blend is useful for transmitting and receiving. Also, the copper blend is an industry standard to create antennas, like the inverted F,

note that materials in the dielectric and substrates, like CB028, can be blended together using the modern technologies of NScrypt. Typically, materials, like SLA resin, are not blended together in traditionally made parts. Blending material will clearly make an improvement because mobility will be much better in a blended substrate rather than non-blended, and also since the impedance matching will be much easier since there will be a lot less reflection; reflection is a huge deal because when working with RF signals users would want to reduce reflection as much as possible.

While working with NScrypt gain was another design component to consider.

Because gain was thought to be easily tuned due to the fact NScrypt technologies was thought to allow easy to modify products, and with an overall understanding of antennas, and the resources of NScrypt scientists. The main reason gain should be tuned is due to power consumption. Typically, higher transmit and receive gain will require higher power budget. Since the power budget is 6.0V before any regulations the antenna chosen will have a gain of 2.2 dBi because typically when the antenna is active which ACE-Com system will mainly be using. Typically, higher gain antennas require more current which in turn requires more voltage while active, also it should be noted that ACE-Com is utilizing a center frequency of 2.4 GHz which is very typical transmitting and receiving   frequency.

Layout with RF components is clearly key mainly due to the fact that the antenna is transmitting RF signals and it should be noted that leads connecting to the antenna from the balun were made as short as possible. A grounding base plate was made as large as possible to reduce inductance, and when vias and holes are drilled decoupling capacitors were placed to reduce inductance as well. Overall, the layout of the entire PCB had very short leads because impedance is a   huge   factor   when   working   with   any   sort   of   antenna.

4.16 Balun

For the ACE-Com system design chosen for this project, the use of a balun was necessary. This is true due to the fact that the CC2500 has been chosen for the transceiver. The balun uses an electromagnetic coupling to transform the unbalanced signal into a balanced signal, and vice versa. The balun is physically be placed in between the antenna and the transceiver in the ACE-Com unit. The

components, unseen to the user. Many baluns are external and therefore visible to   the   user,   as   an   accessory   would   be.

Baluns can vary greatly in shape and size, so it was important to choose one that matched the CC2500, fits neatly into our design, and is able to connect to the antenna. After consulting with nScrypt, the Anaren 0404 (BD2425N50ATI) balun was chosen. This particular balun is optimized for the Texas Instruments CC2500 and is also very convenient because of its ultra low-profile design. The BD2425N50ATI is a subminiature part designed for differential inputs and outputs. The unbalanced port impedance of this balun is 50 Ohms, and the balanced port impedance is 127+j34 Ohms. These specifications are perfect for the CC2500, which means that they are also perfect for ACE-Com.

The Anaren balun can be implemented in several ways including a lumped element, using 0201 matching components, and by using 0401 matching components. The implementation using the matching 0201 components was chosen for several reasons. The most significant factors were that detailed specifications were explicitly given to us for the 0201 implementation by Wade

Smith, the design engineer who formally worked for nScrypt and had worked on the projects similar to ACE-Com. The other significant factor was that the 0201 component implementation takes up much less space on the PCB board. Table 10 below shows the comparison of the three implementations and components they use.

	Lumped Element	0402 Matching Components	0201 Matching Components
Components Used	6 Capacitors 3 Inductors 9 Total	1 Balun 1 Capacitor 1 Inductor 3 Total	1 Balun 1 Capacitor 1 Inductor 3 Total
PCB Area	.592 sq. mm	.287 sq. mm	.097 sq. mm
Space Savings Based on Lumped Element Design	0%	52%	84%

Table 10: Comparison of Three Balun Implementations
(from Anaren Rev B datasheet)

The design chosen uses the BD2425N50ATI with a 10 nH inductor and a 5.6 pF capacitor. The CC2500 has two balanced input ports, and the 10 nH inductor will be connected across them. The capacitor was used at Pin 1 as a DC block, or ground. The balanced lines from the transceiver go to Pin 3 and Pin 4 of the balun. This is illustrated is Figure 48 below.

CC2500 Chip Impedance

CC2500, "RF_P", pin 12   CC2500, "RF_N", pin 13

L=10nH

Pin=4   Pin=3

Pin=1   Part= [BD2425N50ATI]   Pin=2

Connector or Antenna

C=5.6pF
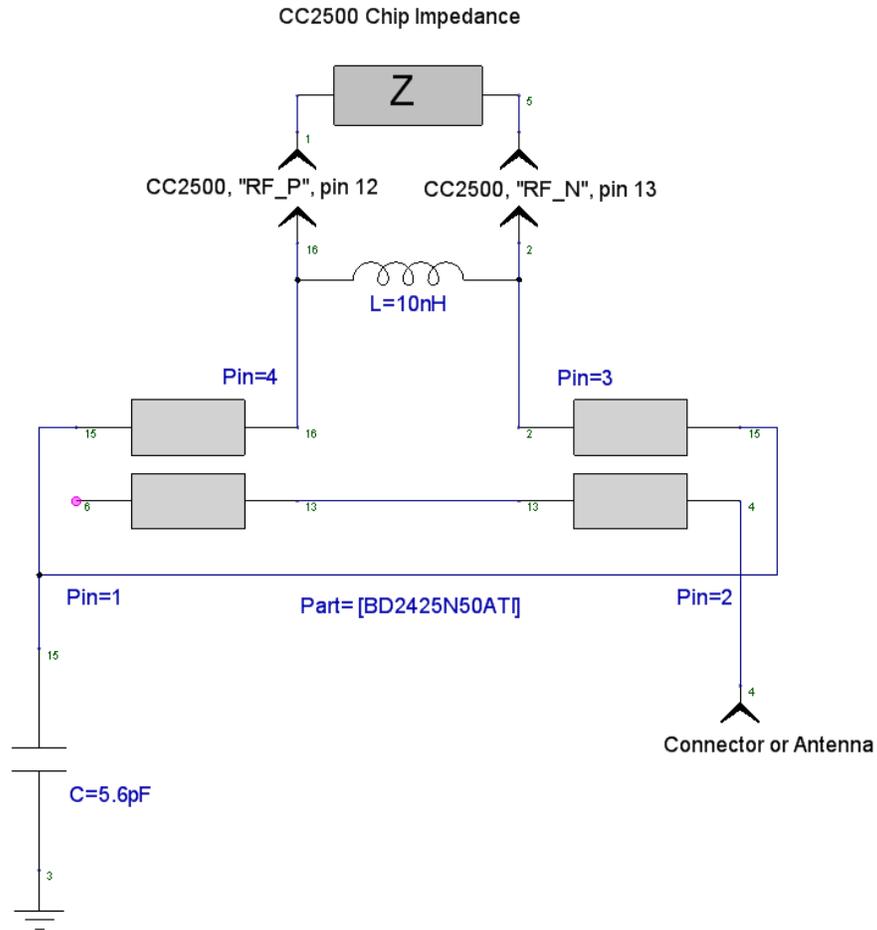
Figure 48: Anaren Balun Schematic (taken from Balun Rev B datasheet)

4.17 Push Buttons and Switches

In order to interact with the physical unit, several buttons and switches were implemented. These are needed in order to turn the unit on, adjust the volume, enable the LCD backlight LED, and change the current running mode of the system (TX or RX mode). Specifically, the ACE-Com system features two push buttons, a double throw rocker switch, and a 10   potentiometer. The table below lists all of these parts, along with what their functions will be. The specific model numbers for these parts are in the bill of materials table in section 12.2.

Part	Description of Function
Push Button 1	This button will be used to change the ACE-Com unit from transmit mode to receive mode.
Push Button 2	This button will enable the LCD backlight LED.

Double Throw Rocker Switch	This will be the power switch, turning the unit on and off.
10 Potentiometer	The potentiometer will be used to control the volume output.

Table 11: Description of Purposes for Buttons and Switches

The downside to this design is that it is not very efficient. As byproducts, the cost is driven up while more space is occupied on the exterior of the ACE-Com unit. This also causes a messier design. The end goal of this design will be to modify it to the following second method of implementation: two push buttons and a five-

take pictures while the other is used to transmit the images. In all other modes, the first button will be a push-to-talk button. The volume control will be done digitally. When in any of the three voice modes, the second button will allow the user to step into a volume control menu.

5 Design Summary

Hardware design was such a critical element in the overall design. When it comes to choosing components based on values, materials, cost, physical size, availability, capabilities, previous knowledge, and/or ease of use it culminates to the end design. Which when summed up was not easily prototyped and not easy to adjust components and replacing and switching components was not as easy as previously anticipated, specifically surface mount technology was a lot harder to work with in the beginning stages of prototype and samples, however, due to the available components, no other options were available. Also, it was considered that the 3D printed parts may/can be switched out with the more traditional parts. This was not as true as previously anticipated due to the difficulty of printing components. Moreover, when a 3D part is switched with a traditional part the passive network requirements may change. Thus, each component was not interchangeable with ease, and with printed parts this was troublesome. Moreover, layout was an important factor when working with RF signals and inductors. Special design arrangements had to be carefully thought out due to the fact that interrupting or extraneous noise is a burdensome factor. The ACE-Com design summary is illustrated in Figure 49 below.
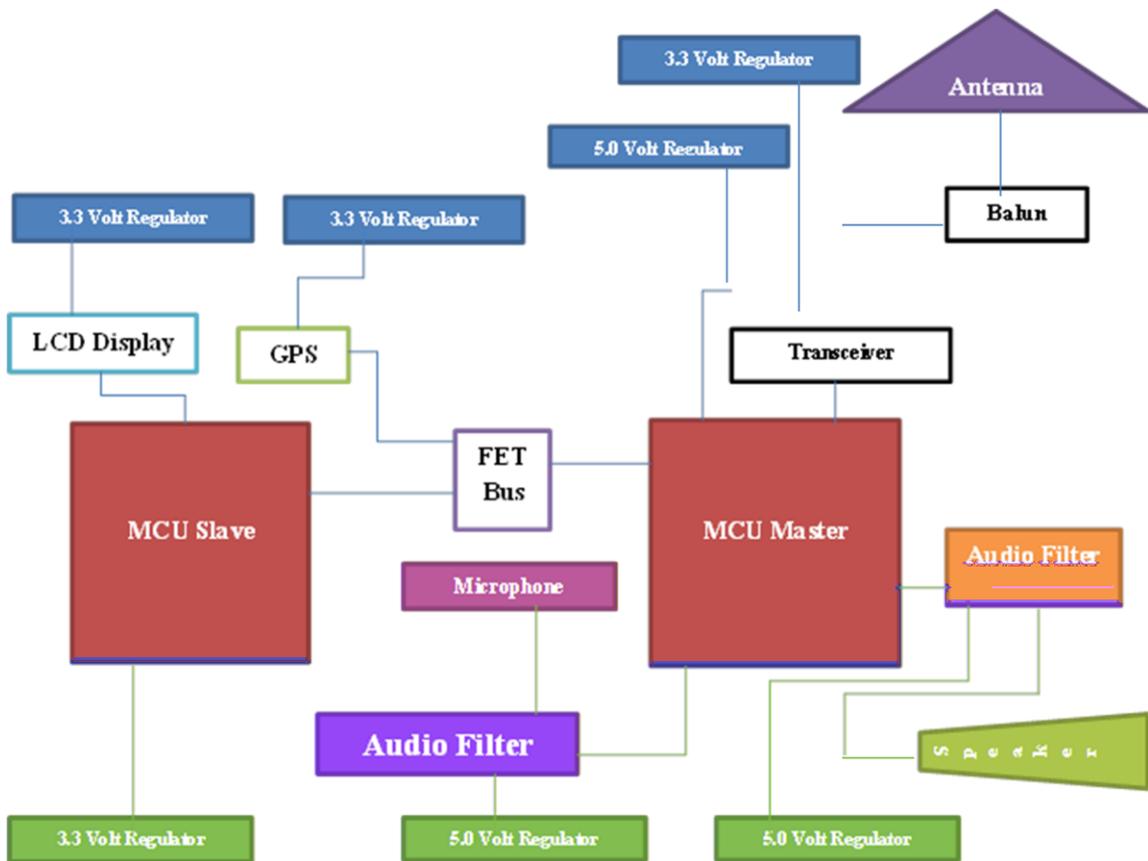
Figure 49: Hardware Design Summary

Software design was essential to make the entire ACE-Com system functional. Firstly, the programming had a simple main program for each microcontroller; this helped speed up the overall processes of the microcontrollers. Specifically, in the main programs: these programs called functions based on timing and physical interface (pressing a button). Thus, in the main functions, the code only calls subroutines then which those subroutines caledl libraries and small loops to perform functions. For example: suppose that the ACE-Com system has been turned on and has been in receive mode; then if the user uses the push-to-talk button that physical interface will call a function in the main code to enable the transmitting on the transceiver.

6 nScrypt Technologies

Since one of the main focuses of the design of the ACE-Com system is the incorporation of revolutionary Printed Circuit technologies as created by nScrypt. The subsequent sections outline the description, capabilities, and how the ACE-Com system would implement these new technologies, had they been successfully completed.

6.1 Description of Technologies

3D printing is a new innovation of the 20th century. In which, solid materials are pumped out onto a surface in accordance to CAD files which the printed files are saved. NScrypt, the main sponsor, is a manufacturer of micro dispensing pumps and micro dispensing systems. Mainly their products are used in 3D printing, direct printing, and micro dispensing, and these processes are used in many industries such as: electronic packaging, solar cell metallization, life science, and chemical/pharmaceutical industry through precise material manipulation, mixing, and processing.

3D printed antenna, is an up and coming and growing quickly. Recently, a partnership between USF and Harris Corporation discovered a simple design, dipole antenna that would be printed on a tetrahedron. Specifically, the antenna is designed and fabricated on liquid crystalline polymer (LCP) and also the same antenna design fabricated on cardstock paper (in which silver deposits were printed onto parts of the paper beforehand to increase the dielectric constant).
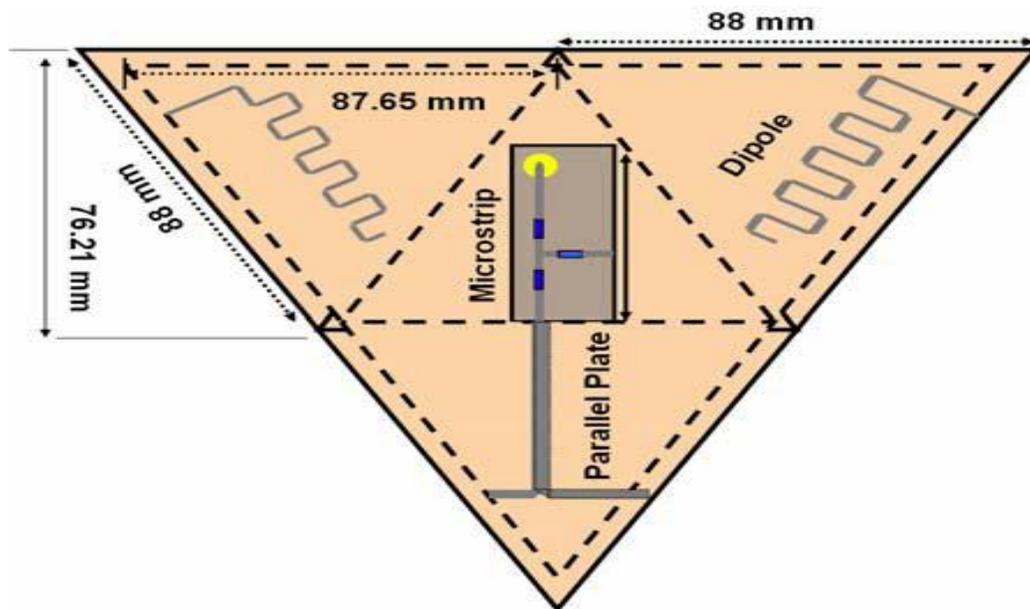
Figure 50: The following is a previous work of NScrypt engineers and shows the capabilities of the 3D printed technology in RF communication.

Above is the unfolded view of the 3D tetrahedron antenna. This case is interesting and relevant to the project because in their results show that 3D printed antennas work very well and the cost of production is much less than buying an antenna with similar specifications. Also, since these antennas could be manufactured for a very-low cost of $0.50 the product could be used for impromptu usage for a gain boost, and these antennas are easily disposable

because they are made so economically. Along the same lines, antennas like the 3D tetrahedron work well for products like ACE-Com because it is easily customized; because one would have to create a new CAD file and print their new antenna with new specs. In this specific experiment, it was discovered that inkjet style printing of antennas could be an even cheaper and faster fabrication process.

One of the engineers working on the 3D tetrahedron also works for NScrypt which is a great asset to the project, and recently NScrypt has designed several antennas, but specifically a simple, monopole antenna specifically for more economical purposes. This specific antenna, 3D printed monopole-antenna, designed by Wade Smith, and Mike Newton, was purposely designed to work with the CC2500. In which the NScrypt   3D printing device, NScrypt tabletop 3D printer, will produce the antenna, the dielectric and metallic layers encasing the transceiver. Essentially, the NScrypt tabletop 3D printer can put together a PCB if all the ICs are provided and placed in correct spacing based by their placement machine by reading the computer files. Below is a large scale flowchart of how the specific antenna and transceiver packaging is produced.
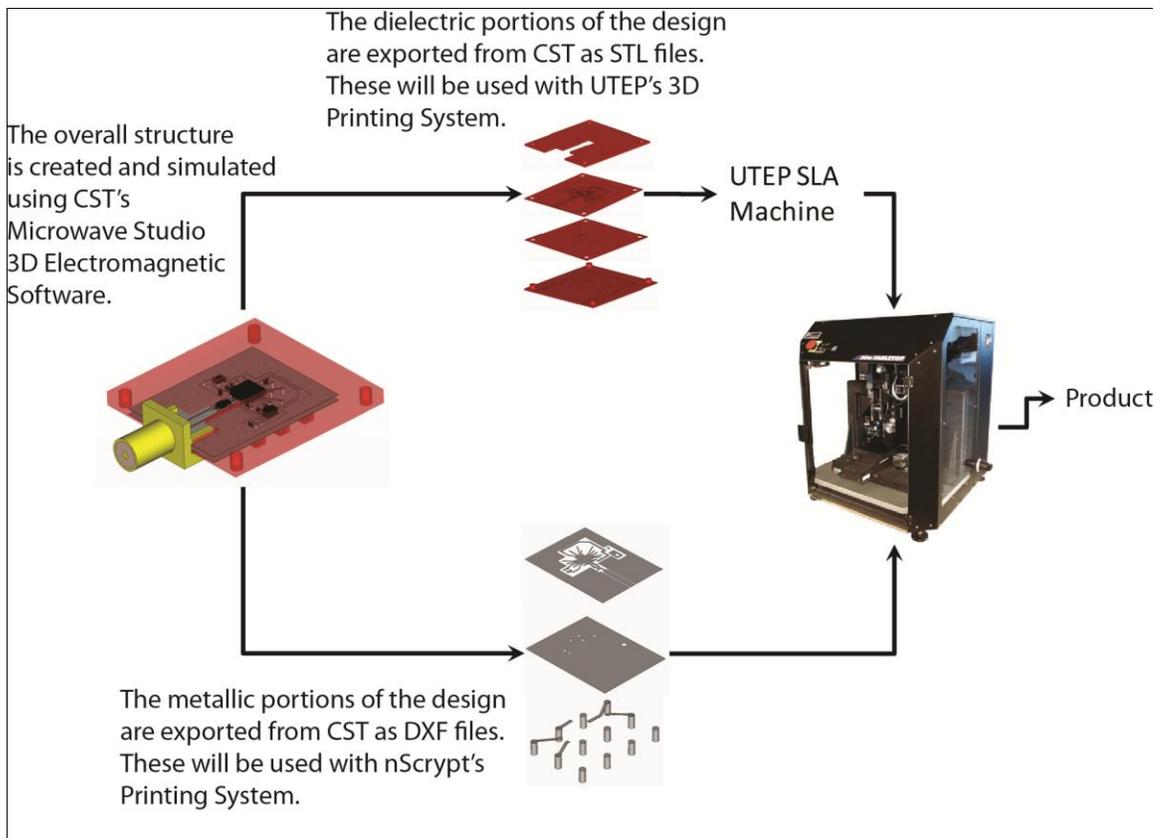
Figure 52: This following figure is showing the general steps in which NScrypt technologies will develop the 3D transceiver.

Specifically, the 3D printed monopole antenna has a dielectric made from

antenna does have problems since it is so simple; this is mainly due to the losses in the printed metal and high loss tangent of the SLA dielectric material. Of course NScrypt and the designers of the antenna knew the capabilities of the CC2500. So, they created an antenna around its technical capabilities, and considering the CC2500 is mainly used for wireless devices, like keyboards and mice, the gain of the antenna was made accordingly. It should be noted, that

working printed-RF communication device where range was not a motivation factor-too much. Thus, a new antenna designed by NScrypt using an evolutionary algorithm technique which will optimize an antenna to work with the given materials; the algorithm technique is mainly for bent monopole antennas; in which, the mathematics will be able to show the where the bends on the antenna should be made to increase the efficiency and the wavelength. This is a very important factor for the project and this specific product. Since the same materials are being used and the manufacturing processes will be almost identical the price will be very similar, and the performance of the new antenna, the 3D printed bent monopole antenna will be an optimal fit for the project and budget.

Typically, when choosing an antenna for a project choosing a type of antenna is first the most important part. Asking yourself what can this project budget technically, economically, and layout. Since antennas deal with RF the layout of the PCB is extremely important due to interferences with the signal. After that calculations must be made to see if an embedded antenna would be better or an antenna on the outside layer of the dielectric. Overall, for the purpose choosing a YAGI PCB antenna would have probably had the best tech specs and the budget in layout would have worked out. However, when working with sponsors it is important to work with what their parameters are; in this case, nScrypt is using specifically a monopole antenna due to simplicity in development and economic value, respectively. Also, typical YAGI PCB antennas are about $30+ each listed on amazon.com. Of course for later experiments it must consider the 3D printed bent monopole antenna to replace the 3D printed monopole antenna.

Moreover, it theoretically chosen that the YAG
antenna designs: single ended, meandered inverted F antenna (MIFA), ceramic chip, differential, inverted F antenna; The YAGI design had the best gain between two devices because it is a directional antenna. Typically, the YAGI design when pointed within the typical off-bore sight angle the gain is around 7dBi, and more omni directional antennas range around 2-3 dBi gain. Of course,

position in times of communication which can become burdensome.

Thus, if there had been a choice on any omni-directional antenna for the project design. ACE-Com has adopted the inverted F antenna. This is because the IFA design fits in the layout of the PCB and the gain is overall better than the simple monopole design, but the IFA is much more expensive as well. Typically, the 3D printed monopole antenna would cost buyers $1.50 if they were to buy from NScrypt directly. Obviously, this is a large margin between the two desired antennas, and again total cost is a large factor with the project. Essential IF and PIF antennas are bent monopole antennas anyway, and in this case this is what NScrypt is designing for further testing.

A similar antenna to the IF is the PIF (planar inverted F). The PIF has a quarter-wave patch to ground which is the main design around the PIF. This patch specifically, will not force current to zero. Thus, the antenna has the same current and voltage distributing as a half-wave patch antenna. The gain is much reduced however this is because the fringing fields which are the main source of the RF are shortened. Designing a simple PIFA is easy:

$$L1 + L2 - W = \frac{\lambda}{4} = \frac{c}{4f\sqrt{\varepsilon_r}}$$

Where L1 is the length of the plane, L2 is the width of the plane, W is the width of the shortening post, ε_r is dielectric with permittivity, λ is wavelength, f is frequency, and c is the speed of light.

6.2 Components to be Printed

Printing each component took several trials with little to no success. Since the technology is so young, there are many unforeseen problems which arose during fabrication. Since this is the case, not any component made it to the final design as a printed part.

First and foremost, it is known that these technologies are highly capable of printing traces onto kapton tape. This means that most likely, every wire in the final build-up of the ACE-Com system might replace every wire (excluding wires which come attached to components, i.e. battery leads or GPS cable) with printed traces. These printed traces would be able to act as the wiring from the final motherboard to each user input (buttons and switches), the display, the camera connector, the 3.5mm headset connector, and to each printed component. These printed cables would be able to be routed along the walls of the casing. By doing this, the mess which can result from using traditional copper

wiring can be eliminated. However, due to the unforeseen difficulties in printing the transceiver and antennae, these designs were abandoned.

The main components to print were the transceiver and RF antenna. NScrypt has already come far in printing a package for the CC2500 transceiver as well as a 2.4GHz antenna. Advancements were made in printing these parts, however success was not achieved. After learning how to print the kapton interconnections and fine tuning the transceiver and antenna, it would be much easier to design the rest of the printed components from scratch for future designs.

After successfully printing the antenna and transceiver, the next component to print will need to be something simple. When attaching components to the printed materials, a conductive epoxy paste will need to be applied by hand to each mounting pad. One slip up while applying this paste has the potential of creating a short circuit between two component leads which should not be connected and could result in ruining the sample. Furthermore, shorting two leads only becomes more likely when dealing with components with closely spaced leads. This means that the next component to be printed should be something which primarily uses through-hole components and have widely spaced leads. Due to these reasons, the first component to build using printed technologies could be the audio filter/amplifiers component. This component consists solely of op-amps (which can be found in through-hole DIP packages), resistors and capacitors (which can both be found in through-hole packages.) After working out any issues from printing this component, which only uses through-hole parts, design of the next printed component can begin.

The next component to print may be the power supply. This is because this will be primarily composed of voltage regulators which can be found in TO-220 through-hole packages. However, despite being comprised of through-hole parts, this component may cause some issues during printing due to the fact that so much power will run through this component. This may cause some unexpected electromagnetic anomalies which may prove difficult to overcome.

Once the power supply is successfully complete, all components which use through-hole components would be printed. From here, the next component to design will have to use the surface mounted components. As was stated above, this may be difficult because of the close spacing of the pads on surface mount devices. As was stated above, the epoxy will have to be carefully applied to each pad individually. After applying the paste on each pad, the conductivity between each trace will need to be checked to ensure no traces are incorrectly shorted together. If they are shorted together, the sample will have to be discarded as it will be unusable.

The two components which primarily use surface mounted devices are the power management and microcontroller circuits. Since the power management IC has a

smaller number of contacts, it will be designed and built first. If this design is too difficult or time-consuming complete, this design will be set aside and design of the microcontroller circuit can begin.

Once all of the components listed above are successfully printed, focus could be diverted to improving the design. From here, time may be devoted to optimizing the layout of the system as a whole to make full scale production easier and faster. For example, the design will initially have each user button or switch mounted independently to the case and connected to the rest of the system using a kapton cable. These may be able to be redesigned into a unit which contains all of these interface devices and mates them all to one single kapton cable. By doing this, production of the ACE-Com system will be more streamlined and will result in lower production costs due to the ability to produce them faster.

7 Traditional Prototype Testing

technologies, the design of the ACE-Com system was verified through simulations. This ensured that the performance issues encountered during the printing process is solely related to the printing process and unrelated to the circuit design. To do this, several hardware and software tests were performed on the traditionally built prototype. The subsequent sections outline these tests.

7.1 Hardware Testing

The subsequent sections outline the testing that was performed to verify the component selection and interconnection of the ACE-Com system. Furthermore, these tests helped us to identify optimum operating conditions for certain components.

7.1.1 GPS Testing

Testing the GPS part and making sure it works properly, GPS devices are known that their sensitivity and accuracy are affected by climate and environmental conditions. By climate, it is meant clear sky or foggy one. Also, GPS affects by many things like tree, earth surface, buildings, and sky heat. Raining will be a drawback case because satellite signals get attenuated dramatically during rain. It is needed to check for errors in the GPS data through walking which will be a challenge to the GPS device accuracy. The error percentage has to be check that it

o during testing, a Garmin GPS navigator will be used to see if values got are the same with some errors of 3 or 4 meters. Moreover, after checking the walking case, the values of the device is moving fast like due to a moving car must be checked too.

The GPS chip also comes with its testing board which test the sending and receiving of the data from and to the GPS chip.

After all of our GPS testing, we found that the EM-408 was not as accurate as we had thought it would be from our research. Our test found that it was generally only accurate up to 10 meters at its most optimum. This could only be achieved in clear weather.

7.1.2 Image Capture/ Transmission

Due to time constraints, the camera was not implemented into the final ACE-Com system; however, if it were to be implemented in the future, this is how the camera would be tested. The first thing to do when testing the imaging capabilities of the ACE-Com system is to find the optimum parameters for operation. During this portion of the test, the camera will not be connected to the rest of the ACE-Com system. Instead, it will be connected to a laptop via USB. This will allow easy adjustment of the image size and compression ratios.

The first thing to do is download and install the X-CTU software from the LinkSprite website. This software will allow interface with the camera via a TTL USB cable. The TTL end of the cable will be soldered to a connector which mates to the LinkSprite camera. Once installed on the laptop, the camera will

successfully powered up. This message will be displayed on the X-CTU software. Now that the device has been powered up, the LinkSprite GUI can be launched

The first parameter which must decided on is image size. This will adjust the number of pixels in each image. For this parameter, the camera has three options: 160*120, 320*240, and 640*480. Ideally, the ACE-Com system will be able to use the largest size (640*480). This will ensure the best image quality. During testing, the image size parameter will begin with this largest size and testing will begin using various compression ratios. Testing will begin at the highest compression ratio, which will yield the smallest file size and worst image quality. From here the camera will begin taking images of samples of text and human faces using the X-CTU software. The compression ratio will be reduced until the text images are fully legible and the faces are very recognizable by a panel of volunteers. They must be able to read the text and correctly identify the faces. From here, testing will begin adjusting the file size. The ACE-Com system will need to hold approximately 100 images on a 2GB SD card, so each image should be less than 20MB. If the images are larger than this, the image size will be reduced and the compression ratio will be adjusted until a useable configuration is found. The parameters determined here will be programmed into the camera subroutine to be used during operation of the ACE-Com system.

Next, it must be ensured that the images are capable of being stored to the SD card. To do this, pictures will be taken with the camera via the microcontroller. The image should leave the camera and enter the microcontroller as a JPEG file being transferred through TTL. The microcontroller will convert this image into SPI signals and write the image to the SD card. Once on here, the images should be able to be pulled right off of the SD card using a laptop. The JPEG files should be able to open using any image editing software (i.e. Paint). Once the images are opened, the image quality can be reevaluated to determine whether or not the image size and compression ratio settings should be modified.

The next portion of the imaging section which must be test is the transmission portion. To test this portion, images will be uploaded from a laptop to the SD card prior to installing it to the ACE-Com system. This will ensure that the file is able to be opened on a laptop and is not corrupt. Next, the microcontroller will command the ACE-

image to the microcontroller to be encrypted and then out to the transceiver to be broadcast. To receive the files, the base unit will be used. This unit will connect the transceiver output to a laptop. Once the base unit receives the image, decrypts it, it will download the image into a specified location on the laptop. If the transmission has been successful, the images will be able to be opened from the specified location on the laptop using an image editing software (i.e. Paint).

Since images can only be transmitted and not received by the ACE-Com system, it is not necessary to test any image receiving capabilities. Successful capture and transmission of images indicates full functionality of the imaging capabilities of the ACE-Com system.

The aforementioned tests will be conducted in the Senior Design Lab at UCF. Volunteers used to verify image clarity will be found in the Senior Design Lab and surrounding areas.

7.1.3 Audio Capture/ Transmission

To test the Audio Capture/Transmission portion of the ACE-Com system, a series of sample waveforms to pass through the system was created. These were
The first set of samples will be recordings of spoken words. The frequency spectrum of these samples was measured to ensure that they cover the full spectrum of human speech (30Hz   3kHz). The next set of samples was recordings of different noises the user should expect to see during a combat situation (i.e. gunfire, explosions, etc.) During each test, one of each sample set will be sent simultaneously through the system.

First, the amplitude of the output signal from the headset must be measured. This will give a baseline of where to set the input signal amplitude for the rest of

our tests. To do this, the 3.5mm plug was connected to an oscilloscope probe and someone spoke into the microphone with a normal speaking voice. The amplitude of the signal will be the amplitude to set the input signals to during the rest of testing. Since the speaker/microphone assembly is interchangeable, all further testing will be performed without this component.

examined. The input signals will be combined and sent into the system via the 3.5mm jack where the headset is normally plugged into. First, the input signal will pass through the speech filter. The first test point will be at the audio filter/amplifier output. Here, the output of the audio filter will be monitored using a frequency spectrum analyzer to ensure proper performance of this component.

the portion under 30Hz and under 3KHz filtered out. Since these are first order filters, the slope rate should be approximately 20dB/decade. The -3dB points should be at 30Hz and 3KHz.

Since the ACE-
amplitude of the output signal should be equal to the input signal. From here, the audio signal will pass into the amplifier designed by TI. Since this was designed

the correct output. However, to verify this, the output will be measured and should have a V_{pp} of approximately 6V. After this amplifier, the signal will pass to the ADC and eventually into memory. At this point, the audio signal is digital and must be decoded to be verified.

To test the signal that has been transmitted, the base unit will be used. The base
ill be identical to that of the ACE-Com system, only the signal will be captured by an antennae and transceiver and will travel to the microcontroller to be decrypted. After being decrypted, the DAC will convert the signal back into an analog signal before passing through another speech filter to another 3.5mm female jack. Test points will be placed in between each component so that measurements can be taken at all points. The final output signal will be measured and should match the filtered input signal. Furthermore, the signal should be clean and audible when a speaker is attached. To verify that the signal is audible, various test volunteers will listen to a transmitted audio sample and will have to correctly repeat the message.

Next, the receive portion of the ACE-Com system will be tested. This test will be very similar to the transmission portion only backwards. The difference will be that this time, the input signal will be sent through the base unit to the ACE-Com system. Again, test points will be

the correct signal. Once received on the ACE-Com system, the signal will pass to the microcontroller to be decrypted and converted to and analog signal before passing through the audio filter (further cleaning up any noise experienced during

transmission), to the amplifier and out to the headset. During testing, the

used as a volume control for the user. Initially, this potentiometer will vary from
10-   of
the spectrum, an ideal range to set the potentiometer at will be identified. The
range will set the volume all the way down to mute and high enough to be clearly
audible without damaging the speaker or distorting the signal.

During troubleshooting of these steps, the signal will be traced starting at the
source and ending at the output. For example, errors during the transmission
portion will first be examined at the input signal. If no signal is measured going
into the speech filter, there must a problem in getting the signal from the headset

measured (because it is the next step in the processing of the audio signal). This
process will continue until reaching the output speaker at the base unit.
Troubleshooting in this method will help isolate the problem faster and without
making unnecessary adjustments to other components.

Part of the goal of the ACE-Com system is to eliminate background noises which
may make it difficult for the user to communicate critical situational information.
Once it has been verified that both transmit and receive portions of the ACE-Com

performance. If it is determined that the external noise makes the signal
inaudible, further filtering will be used. Since the ACE-Com system aims to
eliminate gunfire and other combat noise, it is likely that some of the most
interfering noise may be isolated to specific frequency ranges. To determine
these frequencies, a frequency spectrum of the noise samples created will be
measured. Any frequencies within the speech range which have high amplitudes
in the noise samples will be marked. Band reject filters following the schematic of
Figure 52 will be built and applied to further eliminate excess noise. These filters
will be added between the input/output port for the headset and the speech filter.
Again, the samples will be aurally inspected to ensure they are clearly audible
through the headset. After inspecting, the filter can be modified until optimum
performance is achieved. Furthermore, several of these filter can be linked
together to block each frequency through which noise is present. Since the
system has been verified without these filters, any problems encountered during
this inspection will be occurring within the band reject filters. Retesting of the
entire system is not required.
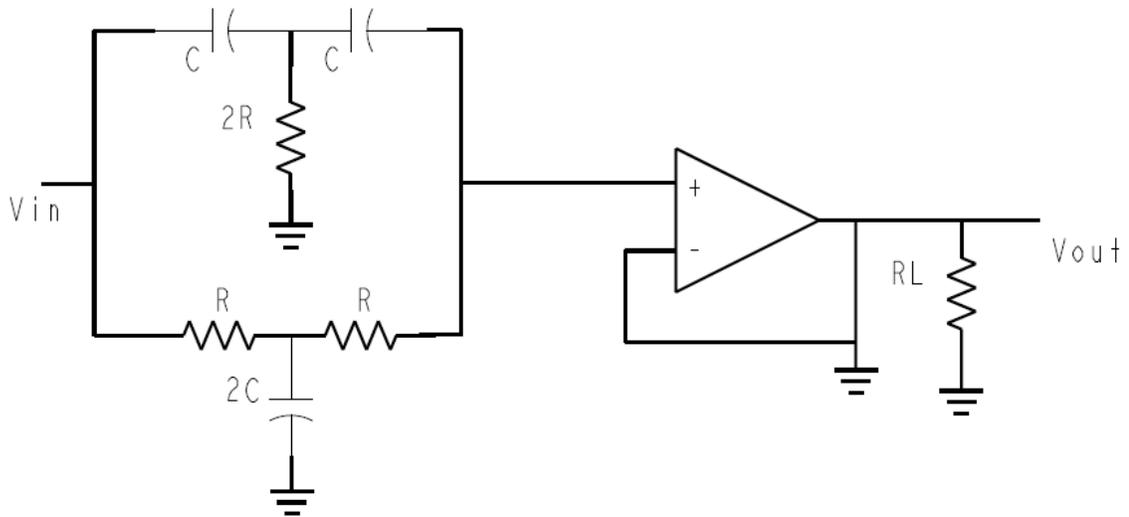
Figure 52: Notch Filter Schematic. The information used to create this schematic was found in Band Stop Filter (21.)

For this schematic, the values of R and C will follow the following equation:

Where Fc is equal to the frequency to reject in Hz. The information used in

)

The aforementioned tests will be executed within the Senior Design Lab at UCF. Measurements will be taken using the oscilloscopes provided within the lab. Verification of proper ADC and signal transmission will be done by inspecting the memory locations using the TerraTerm software. The volunteers used to verify clarity of the audio signals will be found within the Senior Design Lab and surrounding areas.

7.1.4 RF Testing

To test the RF system, it took a series of testing processes inside the lab and at the open field area. First, in the lab, the testing devices will be used of the RF ab to test first the antennas that will be use; the antenna gains are close to calculations and datasheets. Also, the reflected power at the connecting junctions will be tested too. Also, the portable part must be tested and through computer software to measure the power of signal sent by the device. Moreover, it has to be checked that the base is working properly and receiving power from the portable part; of course the portable device and the base are synchronized and working on the same frequencies. In addition, the project will be designed as whole device without antennas , and the spectrum analyzer will be used in the place of antennas to check if the circuit sends the proper signals with the proper frequency to the antennas or not. After finishing the in lab testing,

at field testing will take place. The field testing will basically aim to find the coverage distance in which the device works properly. For instance, the range covered by the device is close to what the original design promised and errors due to the difference between the calculation and reality; also, why there are errors. In addition, the design should be checked that all the parts are working together and no over heat. Finally, testing the device in its three modes and that it shifts

the communication in any mean. Also, the project can be compared by getting walkie talkies with the same ranges to compare and contrast with.

```
 ┌──────────┐                              ┌──────────┐
 │  ACE-    │      ↗        ↘              │ ACE Com  │
 │  Comm    │                              │          │
 │          │      ↖        ↙              │  Base    │
 │ Portable │                              │          │
 │ device   │                              │          │
 └──────────┘                              └──────────┘
```
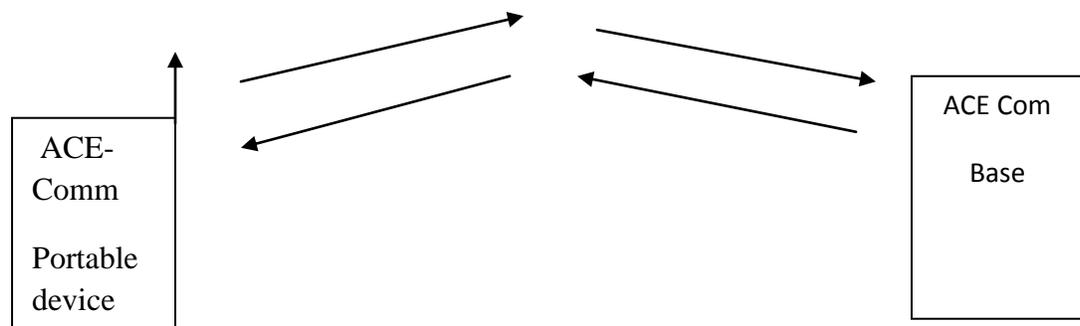
Figure 53: block diagram showing the portable device and the base that ACE-Com has

Also, after testing the range and the antenna efficiency of communication, the communication inside building must be tested by keeping the base station at the senior design lab and use the portable part in the ground floor at eng building to see if the signal will get attenuated or blocked.

This is needed to check the value of attenuation of the signal during rains, so the device will be tested during a rainy day, or a virtual rainy day will be created as it is expected the device to be used in a wet atmosphere.

In addition, the impact of the surrounding noise on the device must be tested: noises come from different sources like microwaves, cell phon

Therefore; the device will be tested close to a microwave and reported the effect of the microwave on the sending and receiving signals. Checking also the interference from cell phones must be done; project has to be able to resist the interference.

problems with our schematic design. In order to overcome this significant obstacle, it was necessary to redesign our audio filters, test them using an oscilloscope, and solder them ourselves to through-hole boards.

7.1.5 Transceiver

Testing the transceiver was difficult. However, for this the system will use

Specifically, ACE-Com
software is designed for the CC1100 CC2540 and testing purposes and initialization. Assuming everything is wired correctly to and from the EB testing can be quite easy. First, Power the evaluation board using the on-board voltage regulator; the evaluation board (EB) can be powered in many different ways. ACE-Com will use the USB power bus because it is easy to access and is automatically drawn from the end-   PC, and because this is just for testing the CC2500, respectively.

First, to test the range; plug in a CC2500 into each of the EBs in this case use two EBs for two-way communication. Then connect the antennas provided in the

program. Select the frequency to be used (in this case 2.4GHz because it is for the CC2500). Setup an ID for each of the EBs, but they have to be the same if they want to communicate with each other. Set a number of packets to be transmitted and received. The board that you have configured all the above should be the master mode. Configure the 2nd board as the slave mode. Now, start the text by scrolling to
number of packets have been transmitted or until 100 consecutive packets have been lost. Thus, it will be quite easy to measure the range.

Second to will test the RF, connect RF measurement equipment to the SMA connecter on the EM. Then turn on SmartRF Studio 7 and connect the EB to a PC using the USB interface. Then find the CC2500 under the EB section in the software; then in this window select settings then perform test then adjust registers.

After testing the RF, to will test the output power. Keep the setup the same as testing the RF. Except now connect the antenna port on the EM board to a spectrum analyzer using a 50-ohm RF coaxial cable. Then it will be easy; just use the simple TX function in the software on the PC and set the RF chip to emit a specific frequency you desire.

Lastly, check the sensitivity. To measure the sensitivity a BER (bit error rate) test is needed. Connect the BER tester to receive data from the EB. Typically the transceiver should be configured to operate in non-buffered mode. The BER tester will display the number of errors from the EB. To find the sensitivity limit an RF signal generator should be decreased in power until the BER equals 1E-3.

The transceiver software was proven to work using an oscilloscope, but ACE-Com was never successful in using the transceiver to send audio. This is believed to be due to the fact that the PCB design was flawed. The software was   -   to be successful.

7.1.6 Antenna

The antenna was never tested due to the transceiver never being properly implemented; however, if the transceiver were enabled on a functional PCB, the following paragraphs describe the tests we would run through in order to test the antenna.

Firstly, assuming the entire system is responding well and working the antenna should be the last item to test. This is mainly because after the output balun the center frequency might be changed a little bit. Thus, an antenna should be tuned to that frequency. So, it is important to have the system working and running well before trying to test the system with the antenna.

However, pertaining to the antenna specifically there must be a test procedure to test the receiving capabilities and the transmitting capabilities and the increase of range that it will provide to the communication. Clearly, assuming the system will work well then assuming the antenna is tuned to the correct center frequency. Thus, after the antenna is connected to test the range testing will be done outdoors. This is because the target end-user of the ACE-Com system will be outdoors. Typically, the environment may or may not be dangerous thus testing in a forest or a tree filled area is important. Testing will be done in the arboretum behind engineering-3 building (Harris building). Testing will be done by a small

strength because some test subjects will have different options to determine the

distance will be measured and averaged between all the test subjects to find the acceptable range the antenna adds to the system.

Simulating environment is important thus high air temperature, high humidity, rain conditions, freezing air temperature, arid environment, and high altitude. Thus to simulate high air temperature and high humidity a typical summer day in the arboretum at UCF will be acceptable. To simulate rain conditions ACE-Com will be tested during a rainy day. However, to simulate different rain conditions man made simulation may be required to test different intensity levels of rain. To test freezing air temperature ACE-Com will be tested in a large walk-in freezer typically those freezers found at large whole-sale food markets, like, Costco or Restaurant Depot. To simulate arid conditions ACE-Com will be tested in the basketball arena at UCF because the humidity is very low inside. To test high altitude conditions ACE-Com will be tested on top of a skyscraper in downtown.

ACE-Com will use an omni-directional antenna. Thus, to test the omni-directional properties test subjects will be required to test signal strength and signal range in

a 360° pattern. Thus, to test this property a system will be made thus that test subjects will stand the maximum acceptable range calculated during the first test. Thus walk around a circle at that distance. A circle will be drawn with accuracy from the two test subjects. After the test has been performed one time it must be performed again this time with the stationary subject will be the one moving in the circle.

7.1.7 Display

To test the display many features were tested and simulated. First, the LCD screen is connected and working properly testing the backlight was first. Programming the MSP430 to tell the display after an amount of time (10 seconds of idle use) the backlight will turn off. This is mainly because the backlight is a huge power drain, and ACE-Com is a project that will be a long-lasting portable device. Also because the LCD is a serial display ACE-Com will adopt many libraries for programming letters, commonly used shapes, like battery gauge. In the main routine of code, there will be subroutines to control the backlight, calling libraries, showing battery gauge, showing RF channel frequency.

To test the readability the LCD display was turned on and operated on top of a UCF parking garage on a sun-lit day at 12 noon. This time of day will be optimal to test the day time readability due to the fact that Florida is quite sunny. It should be noted that the display will be tested with the backlight on and off. There will be a message transmitted to the display. Test subjects will determine if the string of letters and characters is readable or not. To test specifically this function a small population of test subjects will be acquired 10 people. To test the readability at night time the LCD display will be turned on when the sun has completely gone

Florida summer; the sun will set later than usual. Thus, testing will have to be done late at night, possibly 10 PM. Again, the display will be tested with backlight on and off; if the display is deemed readable that would be optimal. However, if it is deemed un-readable by test subjects code will have to be designed to turn the backlight on during night hours. Thus, a light sensor might have to be installed for this feature.

Testing the battery life and power consumption will be complicated. It should be considered the fact that the LCD will be programmed to turn off and on the backlight when needed. Thus, to simulate this test will be a challenge, but as designers the simulation will be as real-world as possible. First and foremost, testing outdoors is mandatory this is to make the usage more realistic. Thus, to test the battery life it must be considered to turn off and on the backlight throughout testing period and to regulate this there will be a battery life program in the microcontroller. This program will specifically drain the battery as fast as possible to make a minimum battery life rating, and then another program will be enabled to make the battery last as long as possible while the LCD is still active. Thus, there can be a maximum and minimum battery life with normal operations.

After testing the LCD in various lighting scenarios, it was found that the display was fairly easy to read at any given time of day. In dark areas or times of day, it was necessary to use the backlight to be able to easily read the display.

7.1.7 Voltage Regulators

Testing the voltage regulators is important because with different efficiency ratings on each regulator it is imperative that there is an accurate reading. This is because each device that will require a voltage regulator requires a specific amount of voltage to turn on the device. Thus, if that amount is not reached due to low-efficiency then the product cannot be used properly.

Thus, to test the regulators there must be a plan of action, and that plan is to put the power supply (a battery pack) of the ACE-Com communication system and connect it to the regulators as stated by the design section (with the passive networks). And on the output a volt meter will be used to measure the regulated output. This will be an acceptable test also to measure the efficiency of the regulators as well.

Moreover, testing was continued by using the same inputs and measuring the outputs on the oscilloscope. This test showed if there is any exterior noise. Which there was, but this presented the opportunity to mitigate that noise.

7.2 Software Testing

The tests outlined in the subsequent sections verified the design of the ACE-Com was not inherently tested during the Hardware testing. Primarily, these tests were intended to verify proper manipulation of the data received by the microcontroller.

7.2.1 GPS Data Management

When handling the GPS data, there are several steps which were taken to get the user the information they need. The GPS module outputs the position in terms of ASCII characters, which cannot be used to perform the calculations necessary. Therefore, the first test to run on the ACE-
management routine is to verify that the system is able to convert the ASCII characters into useable data. To do this, the ACE-Com system first needs to acquire a data sample from the GPS module and store it to the microcontroller RAM. Next, the data will run through the conversion subroutine. Once this subroutine has been executed, the new data should match the data from the GPS, just in different forms, i.e. if the input from the GPS is:

$GPGGA,161229.487,3723.2475,N,12158.3416,W,1,07,1.0,9.0,M,,,,0000*18

The output of the GPS Data Conversion Subroutine should place 3723.2475 as a binary number of 22 bits in millionths of radians in the User Lat Pos location in

memory, a value of 1 in the User N Ind location, 12158.3416 as a binary number in the User Long Pos location, a 0 in the User E Ind location, and a value of 9 in the User Alt location. By comparing the two data sets, the conversion

Next, the ACE-Com system needs to convert this data further. For the latitude and longitude coordinates, the microcontroller needs to convert from degrees to millionths of radians. To do this, the software multiplies the angles by $2*pi*10^6/360$ (this value is a constant stored in flash memory). Furthermore, the microcontroller will add direction to these coordinates using the N/S and E/W indicator bits. If the N/S indicator bit is 1, indicating North, the latitudinal coordinate should be positive. If it is 0, indicating South, the latitudinal coordinate should be negative. Likewise, if the E/W indicator bit is 1, indicating East, the latitudinal coordinate will be negative. If it is 0, indicating West, the latitudinal coordinate will be positive. For the altitude, the microcontroller will need to add the radius of the Earth to the altitude obtained from the GPS data. This value will only be used in the event that the altitude is in the kM range. During testing, the data in memory will be inspected to verify proper conversion.

Now that it has been verified that the software load is able to successfully convert the GPS data into a usable form, it needs to be verified that the ACE-Com system can transmit this data. To do this, the ACE-Com system will run the GPS data transmit subroutine. This subroutine will run the data through the encryption software load and then to the transceiver to be transmitted. The base unit will take the incoming signal from the ACE-Com system, decrypt it through the decryption software, and verify that it matches the data sent from the ACE-Com system. After verifying this, this process will be repeated from the base unit to the ACE-Com system to ensure that it can receive the GPS data as well as transmit.

The data received from other ACE-Com units will already have been converted into a usable data form. All that needs to be done is save the data to RAM memory and perform the operations. The software should save the data in the User2 data locations. To verify this, these memory locations will be monitored and compared to the GPS data being transmitted to the system. Once it has been confirmed that the correct data is being stored in memory, testing can move on to checking the calculations and output. First, the software will find the average of the two altitudes. To do this, it will add the value in User Alt and User2 Alt together and divide by 2. This result will go into the Avg Alt location in memory. Next, the software will subtract the User2 Lat Pos value from the User Lat Pos value and multiply this value by the value in Avg Alt. This result will be placed in the Diff N/S location and indicates the distance between the two points along the North/South Axis. A positive value indicates that the User 2 position is

longitudinal coordinates. For this operation, a negative result will indicate that

E/W location. Next, these coordinates will be converted into polar coordinates and placed in the Diff Pol R and Diff Pol A locations.

The final test of the GPS Data Management software will be to calculate the difference between it and a location sent to it via the base unit. To do this, the microcontroller software will first take in GPS data from the GPS module. Then the tester will select a location in which there is a known distance and direction and calculate the correct GPS data for it. Next, these coordinates will be converted into the correct format for the ACE-Com system and will be transmitted through the base unit to the ACE-Com system. By monitoring the RAM locations for GPS data and comparing the end result to the known distance and direction, it can be verified that each process is functioning correctly, thus verifying the functionality of the ACE-

The aforementioned tests will be conducted within the Senior Design Lab. In order to verify that the values stored in data, a laptop will be used using the TerraTerm software.

7.2.2 Encryption

Due to time constraints, encryption was not implemented in the final ACE-Com system. If this were to be implemented, the following paragraphs describe how it would be tested.

First, testing for reliability which means that the information encrypted is the same information decrypted. Also, the information must be kept secure and unrevealed except to the device that has the key to decrypt.

Also, the packet of the mixed of the voice and GPS data has to be tested after encryption and decryption; packets must be encrypted rightly by testing; the encryption and decryption are working properly. After decryption, the separating software, separates voice data and GPS data from the mixed packets, must be working effectively to deliver every part of the data to the right place: voice to the speaker and GPS data to the display with the right timing.

7.2.3 Display

Once everything was working, well testing libraries and software were important as well. Thus, ACE-Com used many different libraries found on the sparkfun website. This is because on the display will be showing a menu of options. For example: it would be desired to show the battery life in a form of a percentage, and the amount of time left that the device can be used. Also, the display will show different channels that the RF device is communicating on, like, channel 1, channel 2. This is important to show because transmitting and receiving will have to be on same channel to communicate. It should be noted, that the Nokia LCD is a serial display, but there are many libraries on the sparkfun website that allow all

8 nScrypt Prototype Testing

8.1 Overview

Once we have completely built and tested the prototype using traditional methods and technologies, we will need to do the same process with the prototype built using nScrypt parts. The design using nScrypt parts will need to be able to do everything that its traditional equivalent is capable of doing. The

8.3 Antenna

Once the transceiver has been proven to operate and transmit at the proper frequency, the antenna will be implemented into the circuit. Once implemented, the ACE-Com system will be complete. In order to test the antenna, the nScrypt prototype will be tested by communicating with the traditional design prototype. If the transceiver, along with all of the other components, were proven as fully functional in both prototypes, then the addition of the antenna should be seamless. If the prototypes are not properly communicating with each other, then the antenna will have to be redesigned.

Once the antenna has been integrated into ACE-Com, its capabilities will need to be tested. These capabilities include range and signal strength in various weather conditions. We will test the nScrypt 3D printed antenna in sunny, cloudy, and rainy weather, in order to properly compare it against the prototype using traditional components. The sunny environment will be tested first. This environment will give us a baseline for the antennas range in sending and receiving data. The system will be tested at increasing horizontal distances first; using an open field will be the most accurate. The ACE-Com system will be tested in every direction in order to test that the antenna is properly sending data in a circular path, as opposed to heavily leaning towards one direction. This is illustrated in Figure 55 below. Then it will be tested at increasing vertical distances using a tall building with open space between floors, such as the engineering atrium or a parking garage. If the ACE-Com system is still working accurately at peak heights, a building in downtown Orlando will also be used, since they are much taller than the buildings on the university campus.
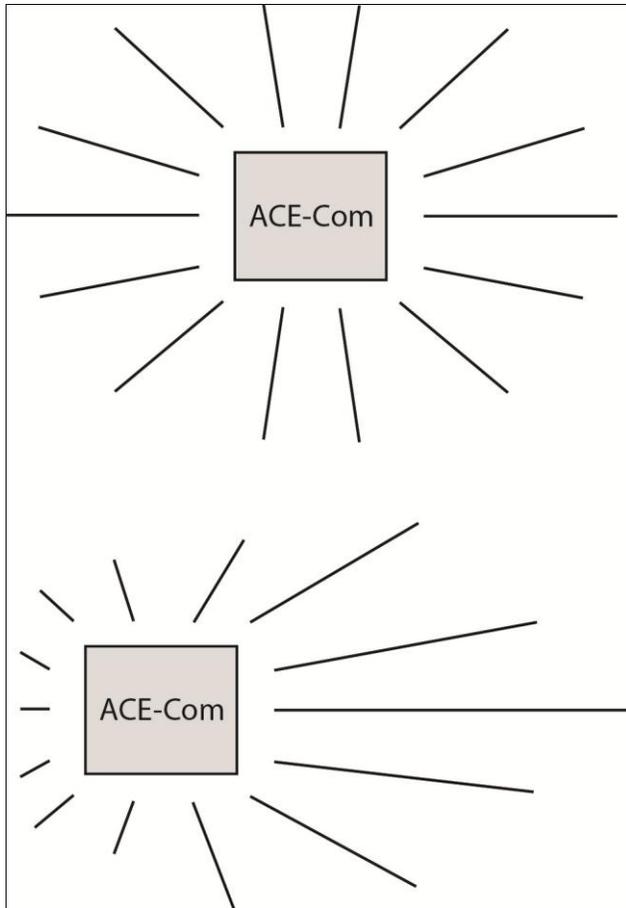
Figure 55: Good (top) and Bad (bottom) Transmission Direction and Range

The cloudy and rainy environments will tell us how well the printed components can send and receive data without increasing the signal-to-noise ratio past an unacceptable value. Weather plays a large role in signal strength and quality of an RF signal, so it is necessary to test for these situations. Since testing will occur during the summer months in the state of Florida, it will not be difficult to wait for a rainy day. The same tests will be done as were done in sunny weather, while noting any significant changes. These tests will be done a third time during cloudy weather. The last tests that will be done will test the range and strength of the signal through different materials. ACE-Com will be tested inside several buildings in order to determine its ability to send data through walls. The buildings chosen will vary from very thin sheetrock walls to dense walls made of cinderblock.

9 Final Prototype Construction

The final prototype was constructed almost entirely on through-hole boards that we soldered ourselves, due to

and usable to the extent intended. The final prototype used for the presentation was on these hand-soldered through-hole boards, as well as partially on our PCB while shorting certain lines. Our initial intended PCB is extensively outlined in the subsequent paragraphs of this section.

Once each component for the ACE-Com system is built, the entire system will be ready to be assembled. The final product should be able to meet the environmental requirements as specified above. In order to meet some of these requirements, several obstacles will need to be tackled from a mechanical standpoint. Since these are mechanical requirements, they are not the focus of the ACE-

The first thing to do is choose a case. This case needs to be large enough to hold each of the components, but should still be small enough such that the user will be able to comfortably carry the unit. Ultimately, the final size of the ACE-Com system will be determined by the overall sizes of the components which were printed using the nScrypt technology and the resulting final board size, but io Shack will be used. Figures 56 and 57 shows how each of the final components will be mounted into the case. This configuration assumes that all components except the Power Management and Microcontroller circuits are converted to printed parts.
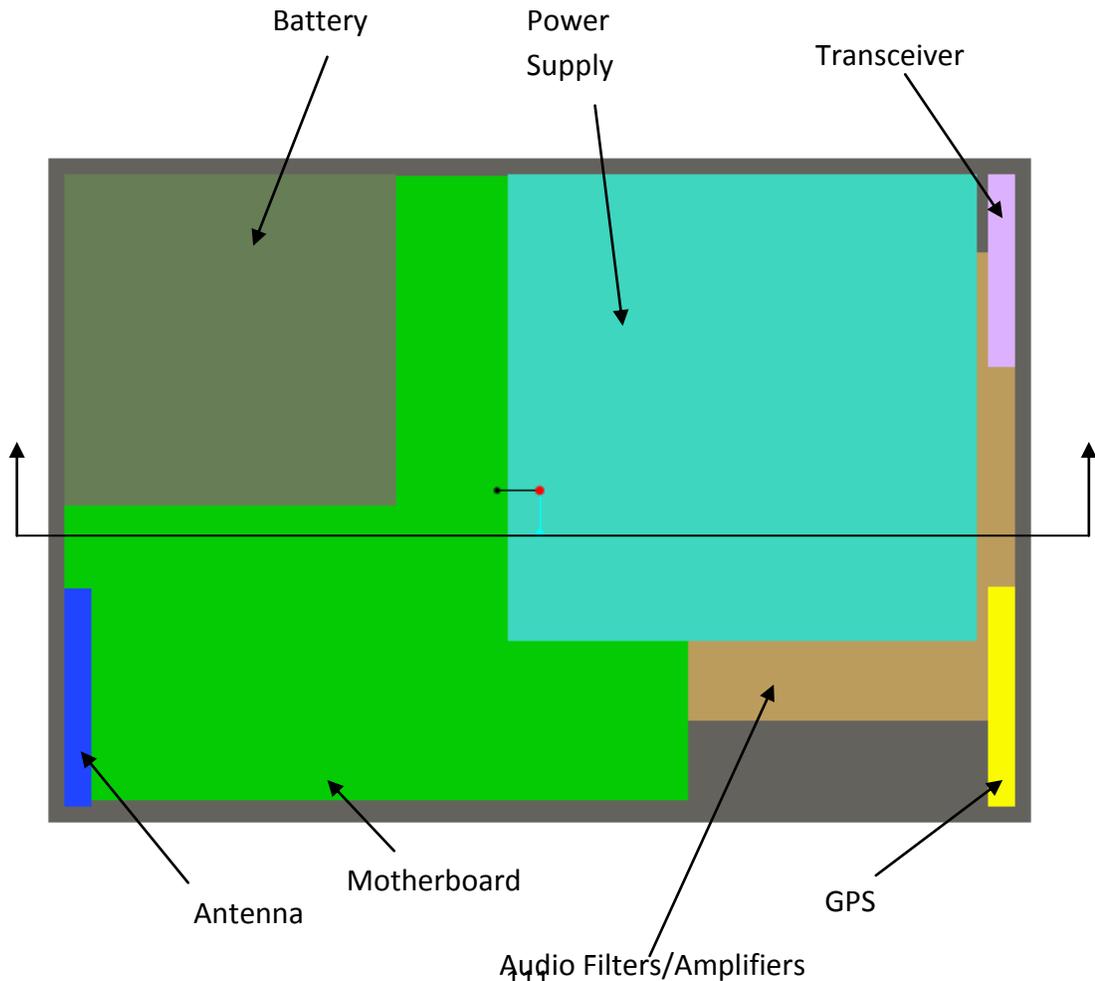
Figure 56: Top View of Expected Main Unit layout. Mounting Hardware Not Shown.

Display
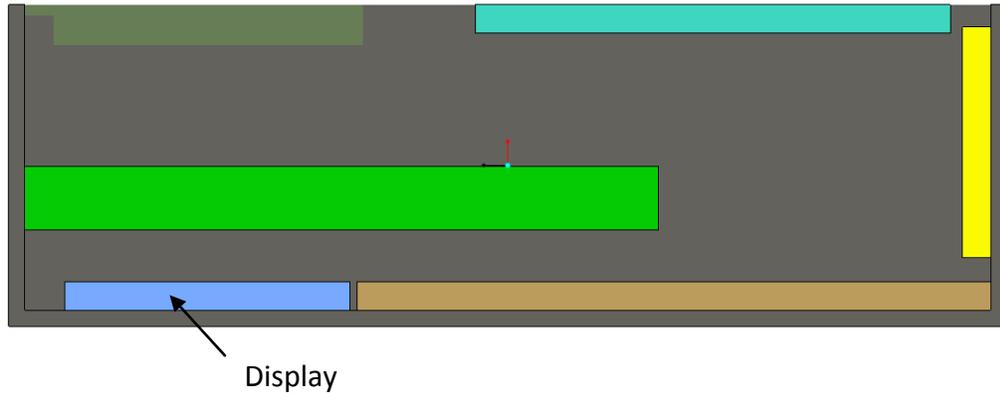
Figure 57: Cross Sectional View of Expected Main Unit. Cross Section Taken Along Plane Indicated in Figure 56. Mounting Hardware Not Shown

The component package dimensions used in Figures 56 and 57 are what is expected to be real and are outlined in Table 12. Since the package sizes for the motherboard, audio filters/amplifiers and power supply will need to be determined during the process of designing the printed components, the dimensions used are estimations of what will actually be used in the final product of the ACE-Com system. These dimensions were derived by using the existing printed transceiver design. Since the height of the component will most likely be similar to that of the transceiver, it can be used as the same height for the rest of the components. Next, the other dimensions can be derived by comparing the size of the main transceiver component to the size of the final component. The length and width of the nScrypt CC2500 transceiver are approximately seven times larger than the same dimensions on the CC2500 package. From here, it will be assumed that the length and width of the rest of the components will be approximately 7 times larger than the length and width of the packages of the main parts in the component.

Component	Height	Width	Length
Motherboard	10mm	100mm	100mm
Audio Filters/Amplifiers	4.5mm	100mm	75mm
GPS Module	8.3mm	35.4mm	36.4mm
Transceiver	4.5 mm	30mm	31mm
Power Supply	4.5mm	75mm	75mm

Antenna	4.5mm	20mm	35mm
Display	5mm	45mm	45mm
Battery	6.35mm	53.34mm	53.34mm

Table 12: Package Dimensions Used in Mounting Analysis

In addition to this case, an additional smaller case specifically to house the camera will be needed. For this, the Hammond 1551MBK box will be used. This

Now that a case has been selected, each component will need to be mounted into the case. Components which do not have any exposed leads can be mounted directly onto the box. To do this, holes will be drilled into the case in the
a screw
will run through the case and component and secured on the other side with a washer, spring-lock washer, and nut. For the components with exposed leads, standoffs will be used to raise the component away from the case. This will prevent the leads from becoming damaged from being pressed down onto the case. The standoffs will be secured onto the case using screws and then the component will be secured to the other side of the standoffs using similar screws. The display will be mounted into a hole drilled out of the face of the case and will be mounted using screws and a washer on the outside surface and a washer, lock-washer, and nut on the interior. Push buttons and switches will be mounted using their specific mounting features. Table 13 outlines the predicted necessary mounting hardware for each component.

Component	Quantity of Each Part Required				
	Screw	Washer	Lock-Washer	Nut	Standoff
Motherboard	8	8	4	0	4
Audio Filters/Amplifiers	4	8	4	4	0
GPS Module	2	4	2	2	0
Transceiver	2	4	2	2	0
Power Supply	4	8	4	4	0
Antenna	2	4	2	2	0
Display	4	8	4	4	0
Battery	4	8	4	4	0
Total	30	52	26	22	4

Table 13: Mounting Hardware

Once everything is mounted and connected, the process of sealing the case to prevent water damage will begin. To do this, Loctite will be applied to cover all screw heads, around all connectors and along the surfaces where the case and case lid meet. This will prevent any water from entering the ACE-
enclosure. Unfortunately, water may be able to enter through the push buttons, which cannot be coated in the Loctite. If this becomes an issue, different push-buttons will be selected.

9.1 Final Software Loading

In this project, JTAG was used to program the microcontrollers for the first time on several sessions of testing for software program for each feature; GPS tracker, camera, and display. JTAG is used because it is easy to implement Design-For- Testability (DFT) rules; design analysis before layout, full control over the test process, quick diagnoses, and program code in flash devices. All these advantages led TI to recommend it to be used in program the microcontrollers. The connections between the JTAG and the MSP430 microcontroller are shown in the figure below.

A   Make either connection J1 (if a local target power supply is used) or connection J2 (if powering the from the debug/programming adapter).

B   The device RST/NMI/SBWTDIO pin is used in 2-wire Spy-Bi-Wire mode for bidirectional debug communication with the device and that any capacitance attached to this signal may affect the ability to establish a connection with the device. The upper limit for C1 is 2.2 nF when using current TI FET Interface modules (USB FET).

C   R2 is used to protect the JTAG debug interface TCK signal against the JTAG security fuse blow voltage that is supplied by the TEST/VPP pin during the fuse blow process. In the case that fuse blow functionality is not needed, R2 is not required (becomes 0 Ω), and the connection TEST/VPP must not be made

Figure 58: JTAG to MSP430 Interconnection. Taken from http://processors.wiki.ti.com/index.php/File:MSP430_JTAG_2_wire_pinout.JPG

Software Operation as mentioned in Programming a Flash-Based MSP430 Using the JTAG Interface: The host controller stores the JTAG communication protocol code as well as the target program in its flash memory. The programming software (S/W) itself occupies about 3.5 KB, so approximately 45.5 KB remain for the target device program. The replicator host can be loaded with the target source code via the flash emulation tool (FET) or the MSP430 serial programming adapter. The basic functionality of the programmer is as follows:

Pushing the GO button generates a hardware (H/W) reset and starts the host

the target device. While the system is active, two LEDs on the programmer board are on; after successful completion only the green LED is on. If an error has occurred or communication to the target device has failed, only the red LED remains on. The entire procedure takes approximately 3 seconds for a target program size of 8 KB. (Some code not strictly required to erase/program/verify the target MSP430 is executed at the end of the Replicator.c source file, increasing the specified programming times. These additional instructions can be customized to fit the individual system programming requirements.) To achieve optimum performance, the JTAG communication protocol uses the SPI module on the host MSP430F149 for the basic JTAG data shift function. To simplify code portability to alternative host platforms, this shift function is also provided in the attached code as a software loop using the general-purpose I/O port functionality as an alternative.

The programming S/W is partitioned in three levels and consists of five files in addition to the target program:
Top level: Specifies which programming functions (erase, program, verify, blow fuse) are to be executed.
Replicator.c: Consists of the main section, which can be modified to meet custom requirements. In the main section of this program, the target device is completely erased, checked for successful erasure, and programmed. Programming loads

space. (The provided Target_code.s43 file simply flashes port pins P1.0 and/or P5.1, which drive the LEDs on the socket board provided with the FET tools, available from Texas Instruments
MSP430 Group. This is the compiled FETXXX_1.s43 example code file.) This file must be replaced by the required user program and added to the project in order be complied and loaded into the host. To demonstrate the capabilities of the MSP430 JTAG interface, additional code is included, which manipulates the I/O-ports and RAM of the target device. These routines can be used to test the target device and PCB for successful communication.
JTAG functions: All MSP430-specific functions are defined here. These files should not be modified under any circumstance.
JTAGfunc.c: Contains the MSP430-specific functions needed for flash programming
JTAGfunc.h: Contains constant definitions and function prototypes used for JTAG communication.
Low-level functions: All functions that depend specifically on the host controller (JTAG port I/O and timing functions) are located here. These files need to be adapted if a host controller other than the MSP430F149 is implemented.
 LowLevelFunc.c: Contains the basic host-specific functions
 LowLevelFunc.h: Contains host-specific definitions and function prototypes

Programming operation: Following is a step-by-step procedure that demonstrates how the JTAG replicator programmer could be used together with any MSP430 FETXXX development tool using the IAR MSP430 development environment:?

1. Generate the user.txt file of the target program in the target project using the IAR Linker with following options which are to be set from the IAR Workbench:
   Project -> Options -> XLINK -> Format: Other: Output Format: msp430-txt
   Run Make.
   The output file user.txt is located in the target_dir\exe\ directory.

2. Convert the user.txt file to user.s43 using the FileMaker.exe conversion program (provided with this application report) and copy it to the programmer project directory.

3. Open the programmer project in the IAR Workbench.

4. In the project window the default file Target_Code.s43 must be replaced by the user.s43 user program.
Delete   Target_Code.s43   from   the   project   window.
Add the target code file user.s43 to the programmer project space.

5. Run Make from the programmer project environment.

6. Download the programmer object code into the host controller by starting C-Spy using the FET.

7. The programmer can be disconnected from the FET after download is complete

8. Connect power and the target device to the host system and push the GO button to program.

Hardware Setup: The hardware (H/W) consists of the host controller MSP430F168, five semiconductor relays, two voltage regulators and two JTAG interface connectors. An external power supply delivering 8 V to 10 V dc at 200 mA is required for operation. To achieve maximum programming speed, the host controller MSP430F149 runs at a maximum CPU clock frequency of 8 MHz, provided on LFXT1. CPU operation at this frequency requires a supply voltage of 3.6 V for the host controller, which is provided by U3 in the schematic. The host is programmed via a dedicated JTAG port labeled Host JTAG. The target MSP430 device is connected to the host controller/programmer through the remaining 14-pin connector labeled Target JTAG, which has the same standard signal assignment as all available MSP430 tools (FET and PRGS tools). The host supply voltage of 3.6 V is also available on pin 2 of this connector, eliminating the need for an additional supply for the target system, but does not have to be used at the target. At a minimum, the four JTAG signals and GND

must be connected. (On devices requiring the TEST pin, the TEST signal also must be provided from the programmer to the target MSP430 device.) To enable programming of all MSP430 flash-based devices including a JTAG access fuse, five semiconductor relays are used which are controlled by the host MSP430. Relay U4 controls VPP on devices with a TEST pin; U5 connects VPP to TDI on devices not requiring a TEST signal. U6 isolates the host controller from the target TDI pin while VPP is connected to the target TDI input.U7 connects the host TDI signal to the target TDO pin while the fuse is programmed (for devices without a TEST pin). U8 controls availability of VCC to the target device. The host controller program includes delays, which consider a relay switching time of

drop during fuse programming. While the fuse is being programmed, a maximum

TEST pin, depending on the target device). [46]
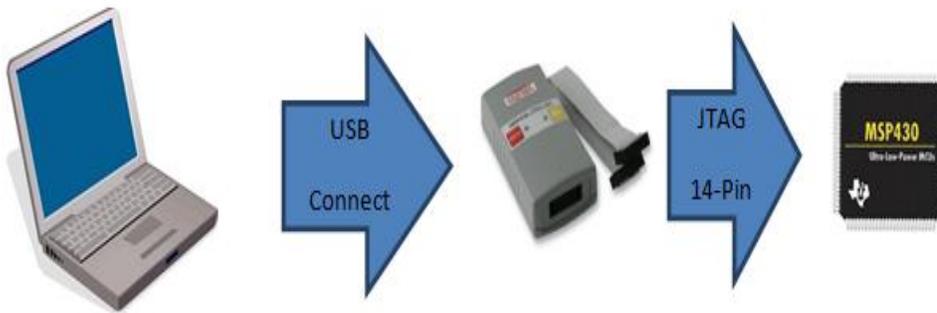
Figure 59: Block Diagram for final Programming via Laptop and JTAG

10 Traditional vs. Printed Prototype

One of the primary purposes of designing the ACE-Com system was to verify the printed circuit technologies. The subsequent sections outline the advantages and disadvantages of using these technologies vs. traditional methods.

10.1 Advantages to Printed Components

y in the future and for now, are idealistic. That is not to say that there are not currently real advantages to utilizing this method.

With access to one of these dispensing systems for 3D micro printing manufacturing, creating new parts is as simple as changing the design on a

then the physical process of creating the actual board. When using printed

laminated onto a substrate, soldering parts together, and most of the other tasks that come before the actual building of a part. If a company wanted to alter a part, which may be needed for various reasons, they would have to go through a lot of effort in order to do so; however, printing technology allows for new parts to be printed immediately after the design has been completed. Since the substrate

have to consider otherwise. After all is said and done, printed technology creates new parts faster than using traditional methods.

Printed technology also allows for several materials to be mixed and matched throughout a design. This can greatly improve the design process as well. Impedance matching, for example, can be simplified by mixing materials on a connection. This would reduce reflection since the signal would not be encountering an abrupt change in the impedance of the different materials. The mixing of the materials can be seen in the Figure.
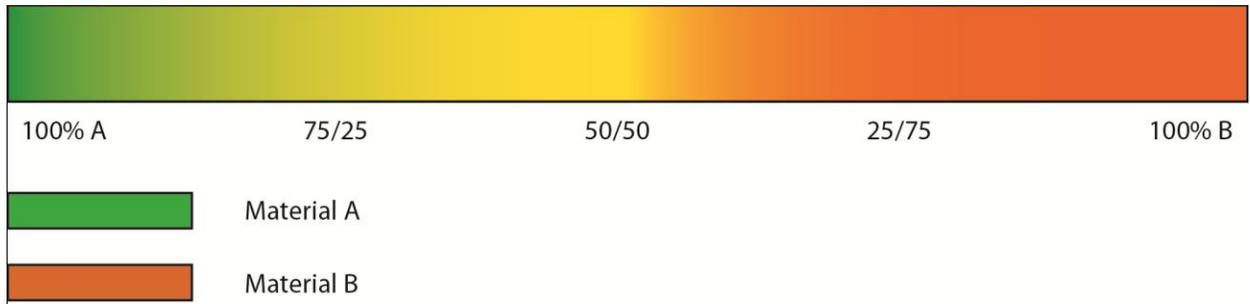
Figure 60: Impedance Matching with Mixed Materials

The last major advantage of printed technology is one that every manufacturer in the world takes into consideration: the price. Printed technology is much cheaper to produce from start to finish than technology made in a traditional manner. The industry standard is to create automated machinery to mass produce parts once they are designed. This is not only time consuming, but very expensive. With this new method of 3D printing, any number of different parts can be printed from the same machine, as opposed to needed several production lines for each part.

10.2 Disadvantages to Printed Components

Right now, the types of designs that can be printed are severely limited. This is due to the fact that it is a new industry and many things have not been designed

large hindrance and obstacle. They are in the process of creating designs that will allow them to push their boundaries and capabilities, but it will more than likely be several years before any substantial products can be made of entirely printed parts and materials.

While creating new designs, prototypes, and products may initially be faster

be faster at mass producing parts. You could use several 3D printing machines to output large quantities faster; however, this would greatly increase the cost of creating new parts. This is all said with a disclaimer: since this printing technology is so new, there is not much information available to compare the mass production of parts using one method versus another.

The disadvantages of this new technology are very clear when you add in the fact that a successful print has yet to be made. The technology is very promising, but lots of work is yet to be done to complete a printed RF design.

11 Administrative Content

A critical step in the process of designing the ACE-Com system, or any other system, is to outline certain non-design oriented parameters. These parameters include estimated timelines, budget analyses, and the compilation of the parts which will go into the ACE-Com system. The subsequent sections outline these parameters.

11.1 Milestones

Table 14 and Table 15 below show a week by week outline where the major milestones and objectives for both semesters of Senior Design can be viewed. Week 1 begins in early January, 2012, while week 32 ends in late July of the same year. There are discrepancies in this timeline are caused by breaks in which there are no classes, such as the week for Spring Break in early March, and the weeks between Senior Design I and Senior Design II in early May. These weeks will slightly skew the tables if they are compared to a calendar, although work on ACE-Com will continue on through any breaks from traditional classes.

Senior Design I																
Task	Week															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Group Identification	█															
Project Brainstorming	█	█														
Define project direction		█	█													
Meet with nScrypt			█			█		█		█			█			█
Define goals and objectives		█	█													
Define product specifications			█	█	█	█	█	█								

Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Project proposal			█	█												
Initial Design Document			█	█	█											
Background research on relevant technology				█	█	█	█	█	█	█	█					
Organize and distribute workload			█	█	█					█	█	█		█		
Senior Design I Final Paper								█	█	█	█	█	█	█		
Parts selection								█	█	█	█	█	█			
Vendor selection											█	█	█	█	█	
Acquiring Parts												█	█	█	█	█
Development											█	█	█	█	█	█
Testing individual parts														█	█	█
Programming													█	█	█	█
nScrypt training							█									█

Table 14: Senior Design I Milestones

Senior Design II																
Task	Week															
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Testing Traditional Components	█	█	█	█	█	█	█	█	█	█	█					
Finalizing nScrypt printed component design	█	█	█	█	█	█	█	█	█	█	█	█	█	█		
Programming	█	█	█	█	█	█	█	█	█	█	█	█	█	█		
Finalize schematic layout			█	█	█	█	█	█	█	█	█					
PCB design and build				█	█	█	█	█	█	█	█					
Testing 3D printed components					█	█	█	█	█	█	█	█	█	█		
Final assembly of the traditional prototype						█	█	█	█	█	█	█	█	█	█	

Task																
Testing assembled product (traditional)							▓	▓	▓	▓	▓	▓	▓	▓	▓	
Final assembly of the 3D printed prototype								▓	▓	▓	▓	▓	▓	▓	▓	
Testing assembled product (3D printed)									▓	▓	▓	▓	▓	▓	▓	
Final adjustments											▓	▓	▓	▓	▓	
Final presentation													▓	▓	▓	
Website design															▓	▓

Table 15: Senior Design II Milestones

11.2 Budget and Bill of Materials (BOM)

nScrypt. Mike Newton has backed our group from the beginning, and he said that they will pay for everything that we do in their lab, as well as a portion of what we

P6.8KBBCT-ND	6.8 kΩ Resistor	2	$0.14	$0.28	Digi-Key
P33KBACT-ND	33 kΩ Resistor	2	$0.09	$0.18	Digi-Key
P150KBACT-ND	150 kΩ Resistor	2	$0.09	$0.18	Digi-Key
P47KBBCT-ND	47 kΩ Resistor	3	$0.14	$0.42	Digi-Key
495-2484-2-ND	2200 pF Capacitor	7	$0.08	$0.56	Digi-Key
PCF1461DKR-ND	150 pF Capacitor	4	$0.50	$2.00	Digi-Key
495-2481-3-ND	0.1 uF Capacitor	15	$0.08	$1.20	Digi-Key
718-1748-1-ND	47 uF Capacitor	4	$0.54	$2.16	Digi-Key
PCF1468CT-ND	560 pF Capacitor	2	$0.58	$1.16	Digi-Key
399-3734-1-ND	10 uF Capacitor	3	$0.79	$2.37	Digi-Key
LinkSprite LS-Y201	Camera	1	$49.95	$49.95	Sparkfun electronics
EM- 408	GPS	1	$64.95	$64.95	Sparkfun electronics
EM408 SMD connector	Female Jack	1	$1.95	$1.95	Sparkfun electronics
ANT-24G-WHJ-SMA	2.4GHz Antenna	1	$12.88	$12.88	Newark
TLV2252	Amplifier	1	$1.92	$1.92	Digi-Key
P1.0KW-1BK-ND	1 kΩ Resistor	5	$0.33	$1.65	Digi-Key
P18KBBTB-ND	18 kΩ Resistor	3	$0.14	$0.42	Digi-Key
P56KBBCT-ND	56 kΩ Resistor	2	$0.14	$0.28	Digi-Key
P4.7KW-3TR-ND	4.7 kΩ Resistor	1	$0.11	$0.11	Digi-Key
CT2268-ND	100 kΩ Potentiometer	1	$1.51	$1.51	Digi-Key
P10392TB-ND	4.7 uF Capacitor	3	$0.43	$1.29	Digi-Key
338-2627-ND	470 pF Capacitor	1	$2.77	$2.77	Digi-Key
26M5749	5.6 nF Capacitor	1	$0.15	$0.15	Newark
SN74CBT16244CDL	16 bit Bus FET Controller	2	$2.14	$4.28	Newark
8532MZQE2	Push Button	3	$4.92	$14.76	Digi-Key
N5040R 2	Push Button Cover	3	$3.85	$11.55	Digi-Key
A101J51ZQ0004	Double Throw Rocker Switch	1	$4.03	$4.03	Digi-Key
A10305RNZQ	Triple Throw Rotary Switch	1	$2.88	$2.88	Digi-Key
AT4103G	Rotary Switch Knob	2	$2.00	$4.00	Digi-Key
PRT-10117	SD Socket	1	$3.95	$3.95	Sparkfun electronics
270-1806	6"x4"x2" Project Box	1	$5.29	$5.29	Radio Shack
1551MBK	1.38"x1.38"x0.79" Project Box	1	$1.57	$1.57	Newark
PMS 632 0050 PH	6-32 1/2" Screw	30	$0.03	$0.90	Digi-Key
3201K-ND	#6 Washer	52	$0.07	$3.64	Digi-Key

41718	Spring Washer, 5 Pcs	5	$1.19	$5.95	Lowe's
137428	6-32 Nut, 4 Pcs	6	$0.68	$4.08	Lowe's
6RB99	1/4" Standoff 6-32	4	$0.45	$1.80	Grainger
908570	Silicon Waterproof Loctite	1	$6.87	$6.87	Amazon
5110	Nokia Graphic LCD	1	$9.95	$9.95	Sparkfun electronics
CC2500RTKR	Transceiver	1	$1.86	$1.86	Digi-Key
UMK105CG101JV-F	100pF Capacitor	3	$0.06	$0.18	Digi-Key
UMK105CG100DV-F	10pF Capacitor	5	$0.07	$0.35	Digi-Key
JMK105BJ105KV-F	1uF Capacitor	3	$0.12	$0.36	Digi-Key
UMK105B7221KV-F	220pF Capacitor	3	$0.05	$0.15	Digi-Key
MLG1005S1N0S	1nH Inductor	3	$0.16	$0.48	Digi-Key
FB43-110-RC	Ferrite Bead 1kΩ	1	$0.11	$0.11	Digi-Key
1050524-1	SMA Connector	1	$7.56	$7.56	Digi-Key
405C11A26M00000	26 MHz Crystal Oscillator	1	$1.19	$1.19	Digi-Key
SDSDB-2048-A11	2GB SD Card	1	$5.59	$5.59	Amazon
BD2425N50ATI	Balun	1	$0.49	$0.49	Digi-Key
MLK1005S10NJ	10nH Inductor	1	$0.06	$0.06	Digi-Key
C0603C0G1E5R6D	5.6 pF Capacitor	1	$0.24	$0.03	Digi-Key
LP5951MF-1.3	Voltage Regulator	1	$0.20	$0.20	Digi-Key
ERG-2SJ513	51kΩ Resistor	1	$0.34	$0.34	Digi-key
MFR-25FBF-30K1	30.1kΩ Resistor	1	$0.10	$0.10	Digi-key
UMK105CG150JV-F	15pF Capacitor	1	$0.10	$0.10	Digi-key
EMK107F225ZA-T	2.2uF Capacitor	3	$0.22	$0.66	Digi-key
TPS73001DBVT	Voltage Regulator	1	$0.91	$0.91	Digi-key
TPS60151DRVR	Voltage Regulator	1	$1.60	$1.60	Digi-key
LM2622MM-ADJ/NOPB	Voltage Regulator	1	$3.03	$3.03	Digi-key
LBR2012T100K	10uH Inductor	1	$0.11	$0.11	Digi-key
LMK316F226ZL-T	22uF Capacitor	2	$0.35	$0.70	Digi-Key
CF14JT24K0	24kΩ Resistor	1	$0.08	$0.08	Digi-key
ERG-3SJ752A	7.5kΩ Resistor	1	$0.11	$0.11	Digi-key
RNF14FTD40K2	40.2kΩ Resistor	1	$0.15	$0.15	Digi-key
RB886GT2R	Schottky Diode (5V)	1	$0.46	$0.46	Digi-key
ERG-1SJ101	100Ω Resistor	2	$0.32	$0.64	Digi-key
BQ27010DRKR	Zener Diode (5.6V, 200mA)	1	$0.12	$0.12	Digi-key
ERG-2SJ103	10kΩ Resistor	1	$0.35	$0.35	Digi-key
MPR5JB20L0	0.02Ω Resistor	1	$0.76	$0.76	Digi-key

BQ27010DRKR	Voltage Gauge	1	$3.60	$3.60	Digi-Key
PCB		4	$325.00	$1300.00	4PCB
Total			$558.70	$1582.44	

Table16: BOM, Prices, and Vendors

12 Conclusion

The subsequent sections outline the overall summary of the ACE-Com system as well as possible improvements which can be made to the system. These improvements were not implemented in the final of the ACE-Com system due to cost and time constraints.

12.1 Possible Improvements

As the project progressed throughout the semester, several decisions had to be made that ended up scaling down the ACE-Com system in several aspects. With more time, upgrades to hardware could be implemented to improve usability and functionality for the user. The main components that would drastically increase the value of ACE-Com are the microphone and camera. The microcontroller would also need to be upgraded in order to be able to handle the data flowing through it.

A more expensive microphone would allow for higher quality audio to be transmitted. It would also be possible to implement a microphone that directly converts the audio into a digital signal. This would eliminate the need to use the microcontroller for analog to digital conversion. The higher quality microphone would be able to capture audio at a much higher sampling rate with very little signal quality loss. Since it is most likely that a camera will not be implemented in the final design of ACE-Com, it would be a significant improvement to include a camera. A camera was included in the initial design, but several complications led to removing it since it was not the focus of ACE-Com and would overly complicate the design. By being able to implement a camera into the final design as originally intended, the user will be able to capture relevant information and share it with his team. If time allows, ACE-Com will be fitted with the camera selected in the Bill of Materials; however, it will still not be able to do everything that was originally intended. The ACE-Com system will be able to capture images and store them to a memory card, but limitations will not allow for the images to be sent wirelessly to other systems. These limitations include the memory space on the MSP430, as well as the sending and receiving capabilities of the CC2500.

In addition to all of the traditional hardware improvements that could be made to ACE-Com, the printed 3D components from nScrypt could also be improved. As it stands, ACE-Com will use a transceiver that is fully embedded in a 3D printed

substrate. It will also use a fully 3D printed antenna. With several more months to work on fabrication issues, it would be possible to embed several more ACE-Com components into a 3D printed substrate. This could even lead to the casing being printed with the components embedded into it. This improvement would greatly increase the usefulness of ACE-Com in emergency situations because it would be possible to print the casing to fit into a specific uniform of outfit. Imagine a SWAT team being able to go on any given mission and having a means of constantly communicating with all other team members without having to worry about holding or losing the communication device.

The only other improvements that could be made to ACE-Com are not related to the electrical components, and therefore not relevant to senior design. As a quick note, it would be very practical to embed ACE-Com is a casing that is resistant to several weather extremes, such as water and fire. A rugged and durable case would go along the same lines, seeing as a device for emergency communication is likely to not be treated in the most gentle of fashions.

12.2 Project Summary

In conclusion, ACE-Com will be a conglomeration of old and new technologies. RF communications, in the form of walkie-talkies, has been around since World

a handful of years. Design and development for this printing technology is in early stages at best, and has a long way to go before it is widely manufactured and produced. NScrypt is responsible for manufacturing and selling highly accurate micro-dispense machines that are constantly pushing the boundaries of this field. Mr. Newton has been generous in his sponsorship of Group 8 with the end goal of furthering the proven capabilities of what these machines can print.

As the semester progressed, nScrypt and Group 8 came to a clear ACE-Com was going to fulfill them. With that said, ACE-Com is a system that can adequately combine

antenna can work will help legitimize 3D printing technology as a viable method of manufacturing electrical systems. This communication device was purposefully designed in a very straightforward and simple way. This was done in order to more directly be able to focus on the accurate implementation of the 3D printed components.

Once the purpose of ACE-Com had been established, it was time to determine the functionality and design of the system. As far as nScrypt was concerned, they did not have much input in what the function of the project was. As long as it properly tested the 3D printed components, the project could go in any direction we wanted. Once the walkie-talkie base model was decided upon, it was time to choose components. This process was slightly more limited, since it would highly determine how the design transferred over into the 3D printed world. In order to

simplify the process as much as possible, the CC2500 and MSP430 were chosen. NScrypt had worked with these parts in similar designs in the past, although they had several fabrication issues when implementing their design.

The black box physical unit which encases the design will be portable and handheld. The outside of the box will feature a Nokia 5110 LCD display, multiple Omron B3U push buttons, a whip antenna, a 3.5 mm input jack for a headset, and a cover for the batteries. The black box will connect to a headset featuring a microphone and headphones. The user will interact with the unit via the B3U push buttons. These will enable the user to change certain settings, such as the running mode of ACE-Com, volume level, and to view certain GPS settings. ACE-
capabilities, as well as communicate with one another as you would with any walkie-talkie.

Once ACE-Com is completely tested and built using traditional methods, it will be

work put into ACE-Com will be. It is very difficult to get the printed components to communicate at the intended frequency, due to warping during the printing

attempted to manufacture a similar product. ACE-
design enough to overcome any of these issues. In the end, it may be necessary to alter the antenna design to compensate for the warping.

With both the traditional and 3D printed component ACE-Com prototypes completed, users will be able to communicate wirelessly over a 2.4 GHz frequency. This easy-to-use system will function similarly to any standard walkie-talkie system. ACE-Com will also have given nScrypt a real-world product that uses their unique printing capabilities in its design.

Appendix A: Permissions

Permissions for EM-408 Data:

lunk Sweep ▾ Mark as ▾ Move to ▾ Categories ▾ | 🖶 ⟳ Options ▾ ❓

lliang@usglobalsat.com 🔍 ⟱

tes | Groups | Newsletters | Everything else « Arrange ▾

re[2]: EM-408 ⬇ ⬆ | Full view

☐ Larry Liang   Add to contacts 4/04/12 🔻
To Ramy Athanassios Reply ▾

Hello Ramy, [Show details]

Take this email as expressed permission to use the EM408 Schematics.

Best regards,
Larry Liang
Director of Business Development / CMO
Sales & Marketing NA
....
USGLOBALSAT, INC.
14740 Yorba Court
Chino, CA 91710
(O) 888.323.8720
(O) 909.597.8525 x106
(F) 909.597.8532
lliang@usglobalsat.com
www.usglobalsat.com
Skype: **usglobalsat_lsl1**

Permissions for Whip Antenna Data sheet:

Permissions from Texas Instruments Pending:
Email sent:

Christopher Marchese 1:47 PM (13 hours ago)

to copyrightcouns.

To whom this may concern,

I am Chris Marchese and I am currently designing a system using several TI components for a Senior Design project at the University of Central Florida. Part of the design requires documentation of the design including schematics, specifications, etc. With your permission, we were hoping to be able to use schematics and information from the datasheets of the following components:

MSP430F168 Microcontroller
CC2500 Transceiver
CC2510 Transceiver

SN74CBT16244	FET	Bus	Switch
TL072	Low	Noise	Op-Amp
TLV2252	Low	Power	Op-Amp
LP5951	Voltage		Regulator
TPS3001	Voltage		Regulator
TPS601515V	Voltage		Regulator
LM2622	Voltage		Regulator
bq27010	Battery		Gauge
bq3055	Battery		Gauge
and	bq24158	Battery	Charger

In addition to these datasheets, schematics and information from the following Application Notes may alse r

Appendix B: Datasheets

GPS:

1. GPS   Engine   Board   EM-408:

Microcontroller:

2. MSP430x15x,   MSP430x16x:

Audio Filter:

3. TL072,   Low-noise   JFET-input   Op-Amps:

4. TLV225x,   Very   Low-Power   Operational   Amplifiers:

Camera:

5. LinkSprite   JPEG   Color   Camera   Serial   UART   Interface:

Display:

6. Intelligent   LCD   Module   Specifications:
http://www.crystalfontz.com/product/CFA735TFKKR

7. PCD8544   LCD   Controller:

Transceiver:

8. CC2500   Low-Cost,   Low-Power   2.4   GHz   RF   Transceiver:
http://www.ti.com/lit/ds/symlink/cc2500.pdf

9. CC2510 Low-Power SoC (System-on-Chip) with MCU, Memory, 2.4GHz RF   Transceiver,   and   USB   Controller:
http://www.ti.com/lit/ds/symlink/cc2510f32.pdf

FET Bus Switch:

10. SN7CBT16244C 16-Bit FET Bus Switch:

Appendix C: Online References and Application Notes

Audio Filters/Amplifiers:

19. Solid State Voice Recorder Using Flash MSP430:

20. Filter Circuit for Human Speech:
-circuit-for-human-

21. -stop-

Memory:

22. Interfacing the MSP430 With MMC/SD Flash Memory Cards:

Encryption:

23. Benefits of Hardware Encryption:
-circuit-for-human-

24. Types of encryption: http://www.edgetechcorp.com/aes-hardware-encryption/

Battery:

25. How Lithium-ion Batteries Work:
-tech/lithium-ion-

Microcontroller:

26. MSP430 JTAG 2 Wire Pinout:
.php/File:MSP430_JTAG_2_wire_pinou

Camera:

27. Step-by-Step Tutorial for Using LinkSprite JPEG Color Camera Serial UART Interface Model LS-Y201:

RF Communications:

28. Radio Communications In the Digital Age:

Age%20-%201_tcm26-

Power Gauging:

29. MSP430 Microcontroller Software for Handheld Fuel Gauges and Battery Authentication Products: http://www.ti.com.cn/cn/lit/an/slva413a/slva413a.pdf

Display:

30. MSP430-169LCD Starterkit Development Board: http://www.olimex.com/dev/msp-169lcd.html

Transceiver:

31. Errata Note CC2501Fx/CC2511Fx: http://www.ti.com/lit/er/swrz014c/swrz014c.pdf

32. Two Way Audio Communications using the CC2510: http://www.ti.com/lit/an/swra225b/swra225b.pdf

33. Using I^2S In CC111xFx and CC2511xFx: http://www.ti.com/lit/an/swra183/swra183.pdf

34. http://www.ti.com/lit/er/swrz002d/swrz002d.pdf

35. MSP430 MCUs, Passive RF and Low-Power RF Solutions Guide: http://www.ti.com/lit/sg/slyt265f/slyt265f.pdf

36. Basic RF Testing of CCxxxx Devices: http://www.ti.com/lit/an/swra370/swra370.pdf

37. SmartRF Studio 7 Overview: Low Power RF Development Tools: http://www.ti.com/lit/ug/swru195b/swru195b.pdf

38. SmartRF Studio 7 Hands-On user Guide and Tutorial: http://www.ti.com/lit/ug/swru194b/swru194b.pdf

Antenna:

39. http://www.ti.com/lit/an/swru120b/swru120b.pdf

40. Origami Packaging Novel Printed Antenna Technology for Ad-hoc Sensor Applications (Authors: Melais, Weller, Newton, Smith, Gemlen)

41. YAGI   PCB   Antenna:
http://www.ti.com/general/docs/lit/getliterature.tsp?literatureNumber=swrr
074&fileType=zip

Voltage Regulators:

42. Application   Note   1486   LP5951   Evaluation   Board:
http://www.ti.com/lit/an/snva169b/snva169b.pdf

43.   -359,   TPS60151EVM-359:
http://www.ti.com/lit/ug/slvu268c/slvu268c.pdf

44. Application Note 1198 LM2622 Step-Up DC/DC Converter Evaluation
http://www.ti.com/lit/an/snva039b/snva039b.pdf

Balun:

45. Anaren 0404 (BD2425N50ATI) Balun Optimized for Texas Instruments
CC2500   Transceiver:
http://www.anaren.com/sites/default/files/uploads/File/Ann_CC2500_Rev_
B_0.pdf

JTAG:

46. Programming a Flash-Based MSP430 Using the JTAG Interface
http://www.ti.com/lit/an/slaa149h/slaa149h.pdf