UCF

College of Engineering & Computer Science

HINT

Home Interactive Notification Tracking

Senior Design I – Group B

Ramon Jimenez (EE)

Maria-Camila Nuñez (EE)

Mannuel Cortes-Irizarry (EE, CS)

Table of Contents

List of Figures

List of Tables

1 Executive Summary

In order to alleviate the never-ending battle of reminding, nagging and imposing consequences to get your children to be organized and complete chores, the Home Interactive Notification Tracking system is meant to assist the homeowner in effectively teaching their children to be responsible and well-kept around the home. The HINT vision is to allow the user to set up notifications through a web interface detailing chores for every room in the home that the user wants the child to achieve interactively throughout the day. The system is divided in three parts, the central hub, remote modules, and a small wearable that will go on the person achieving these notifications.

The modules will be placed in every room in the home or intended rooms of purpose appealing to the user, which will wirelessly communicate to a monitoring station database where the person in charge will set up a schedule for the day to day tasks. For the realization of proof of concept, these tasks will already be hardcoded with future intents to scale up the project so that the users can remotely sign on through a web application and/or phone application. These tasks will come out as notifications for the child to execute accordingly. The way the module will come to life is through a proximity detecting RSSI system with ZigBee communication. Through a wearable that can be worn on the wrist, and a motion detecting module, the system will immediately know when a user is nearby. The modules in each room are intended to be intuitive to use, compact enough to fit on a nightstand and an affordable alternative to existing home notification systems. Its features include an interactive liquid crystal display (LCD) screen on module that displays the notifications, a buzzer that goes off once the notification is displayed on the screen, a button with a light emitting diode (LED) that turns on after the task is displayed awaiting user interactive response once task is completed, and a motion sensor that works in conjunction with the wireless communication to locate proximity of the user to accurately send out tasks when the user is within appropriate range.

Implementing the LED button is a big part of HINT to enforce interaction with the system, thus also serving as data collection through time stamps and number of completed tasks to visualize the efficiency the system has had on the user's personal growth improvement. Data collection is one of the main tasks of the central hub, which will be stored on an SD card for the purpose of the project. The way the data is collected and what it wants to utilized towards is completely up to user, therefore giving HINT a customizable approach. The wearable also has a few features to enhance the child's experience such as audio, vibration.

The Home Interactive Notification Tracking system is a solution to allowing the parents to take an active role in teaching their children responsibilities in a way that successfully combines technology and parenting into one, which in return is more appealing and satisfactory for the children since they are constantly surrounded by technology advancements.

Communication devices will form the foundation for the wireless aspect of HINT, thus an investigation into the advantages of different communication modules is required to realize the envisioned system. A network protocol will need to be planned out and implemented in order to form a unified system from the independent modules. Important research and critical design decisions will go into the development of the printed circuit boards that will provide the foundation for all the hardware of HINT. The development and production of this system will have to conform to the budget available. Our boards and parts will be designed so that they are easy to replicate and manufacture. This system's design philosophy will emphasize ease of use, affordability, and effectiveness.

2 Project Description

This project aims to make notification tracking and task learning fun and interactive. With all of the "noise" in the modern-day world, notification tracking has become one of technology's hottest commodities. HINT hosts such notification tracking with the twist of being interactive with the user, primarily children learning chores and organizational tasks.

The system will interact with the user in ways that stimulate more of the senses than traditional notification tracking. Sight, touch, and hearing will be triggered beyond the typical stimulation level to produce a more natural response from the user, as if another person is telling them what to do. Such interaction with the senses will make the response more rapid, effective, and pleasant than the trained automatic response of the average notification system on a computer or handheld device.

The project seeks to eliminate, or at least reduce, notification bypassing. This is accomplished by using a central hub, a sensor module, and a small wearable device around the home, or a room of choice. The collaboration of these devices will be used to apply interactive pressure to the user, so that the task will be completed. The communication between the devices also helps determine if the task was or was not completed when it needed to be.

The log of completion will be kept, and can be accessed by the parents via data storage transferred to a computer. Tasks can also be scheduled on the system to trigger notifications or alerts at specific times.

2.1 Project Motivation

The Home Interactive Notification Tracking system takes inspiration from the effects of parenting it has had on children growing up to become adults. Children, often unrelenting in their resistance, can wear parents down. Parents may be reluctant to engage in continuous struggles for the fear of damaging their relationship with their children, reluctant to add pressures to their children, or believing their children are too young to take on responsibilities.[1] This is where HINT would come in to facilitate that communication between the children and parents while making it interactive and fun at the same time. Research indicates that those children who do have a set of chores have higher self-esteem, are more responsible, are better able to deal with frustration and delay gratification; all of which contribute to greater success in school. Overall, involving children in household tasks at an early age can have a positive impact in later life.

Personal motivation for group members is the opportunity to learn about all the technology involved to realize this project, both hardware and software. Learning about the use of integrated circuits, printed circuit board (PCB) design, power system design, implementing wireless data communication, and computer programming as well as being able to apply all concepts and the digital system design learned in the classroom together is the most significant motivation for the group members.

This project not only serves as a means for group members to exercise our skills and prepare us to apply them once we are practicing engineers, but it is also a means to jump-start a journey to another project that will utilize similar design to this present one with a gratifying end goal of improving other's lives.

2.2 Project Objectives and Goals

In order to ensure homeowners and their families to have the best overall experience with HINT, a clear understanding of our goals should be explained and put into perspective. HINT does not only aim to notify users of tasks needed to be done around the home, it enforces them. The system will be designed such that the notifications will not be ignored, hence that is when interactive and tracking work jointly on a common goal. To illustrate, let's say the child sees the notification and puts it off, and after a while forgets about it and walks out the room. The module in the room will contain a motion detector sensor that will pick up that the child is walking away and thus according to how the user customized the system a couple actions may take place. The module may output a sort of buzzer for alert triggering that will activate a sense of hearing, or the wearable may vibrate to symbolize something was forgotten, thus triggering the sense of touch, or the module's button may output some sort of lighting scheme thus triggering the sense of sight.

2.2.1 Overview

A high-level system description will allow end-users to visualize what they are able to do. The diagram pictured in *Figure 1* shows this system. When the user wants to begin interacting with HINT, they will utilize the web page provided for it. The central component of HINT is the central hub which will be the brains of the system. Its job will be to take commands from the user and relay them back to the endpoints, also called the modules. These modules will output those commands as they detect that an individual is in the room with the help of the wearable device on the user. Each module will be tailored according to the room they will be placed in. Together the central station, the modules, and the wearable will form a network through the home and will communicate wirelessly to one another.

2.3 Requirements and Specifications

The design shall conform to the following requirements and specifications and will adhere to industry standards wherever applicable. The Senior Design panel, the project sponsor, and the design team impose these requirements. Among these requirements are low cost hardware, user-friendly interfacing, functionality, testability, and reliability. In addition, a workload requirement for three group members must be met. This includes avoiding excess workload, as well. The word “shall” indicates that the final system design will meet the given requirement.

2.3.1 Functional Requirements

The final system is required to meet various functionality requirements to meet user acceptance. Functionality requirements are end-level specifications that specify how the product will work overall. They are as follows:

- The system shall have wireless communication between the central hub, module, and wearable device.
- The module shall be able to determine if the wearable device is in the same room or within proximity.
- The range and motion sensor on the module shall have a detection range of no less than 15 feet.
- The module shall have a liquid crystal display (LCD) to display notification information at the programmed times.
- Tasks shall be able to be programmed or pre-set on the central hub.
- The system shall keep a log of notification history and response (completion) tracking in local data storage.
- The system shall use sensory input and output, involving hearing, sight, and touch, on both the module and wearable device, to deliver notifications to the user.

2.3.2 Physical and Technical Requirements

The hardware of the design shall meet power, grounding, interfacing, and packaging requirements and specifications. Note that interfacing includes all hardware related to communication requirements and standards, both on-board and board-to-board. Signaling techniques and naming conventions are also part of this hardware specification.

- On-board power supplies shall have a standby life of at least five hours.
- On-board power supplies shall be replaceable or rechargeable.
- Auxiliary AC adapter power supplies shall be compatible with standard electrical outlets.
- Radio frequency (RF) communication circuitry, especially antenna circuitry, shall be isolated from other power and signal circuitry.
- Integrated Circuit (IC) power rails shall be filtered from noise.

- Ground shall be "flooded" on the printed circuit board (PCB) ground planes to serve as a quick and constant reference for data voltage signaling.
- Single-point grounding techniques shall be used to tie any analog, digital, and chassis grounds together and avoid ground loops.
- All hardware shall contain a JTAG interface to program the controller.
- There shall be a range of no less than 75 feet between any two wireless devices in the system.
- All controllers in the system shall be capable of driving wireless transmitters and receivers.
- All controllers shall be low power, with minimum sacrifice to performance.
- The central hub shall accommodate a removable memory unit.
- The wearable device PCB shall be no larger than 30*mm* x 20*mm* x 5*mm* and less than 1/8 lb.
- The module PCB shall be no larger than 200*mm* x 100*mm* x 100*mm.*
- The center hub PCB shall be no larger than 120*mm* x 120*mm* x 40*mm.*
- The central MCU shall conduct a Built-In Self-Test (BIST) upon startup to verify all interfaces are working properly.

2.3.3 Reliability and Maintainability

Recognition of reliability and maintainability as vital factors in the development, production, operation, and maintenance of today's complex systems has placed greater emphasis on the application of design evaluation techniques. An analysis of a design for reliability and maintainability for our project can identify critical failure modes and causes of unreliability and provide an effective tool for predicting equipment behavior and selecting appropriate logistics measures to assure constant satisfactory performance.

A reliability prediction is performed in the early stages of development of a project to support the design process. Performing a reliability prediction provides for visibility of equipment reliability requirements in the early development phase. An accurate prediction also provides an awareness of potential equipment degradation during the equipment life cycle. As a result of performing these predictions, equipment designs can be improved, costly over-designs can be prevented and development testing time can be optimized.

For the intent of HINT performance of reliability prediction for electronic equipment will be well established by research and development. We will be using MIL-HDBK-217 which is a great source that has been developed for predicting the reliability of electronic equipment. Development of this document was made possible because the standardization and mass production of electronic parts has permitted the creation of valid failure rate data banks for high population electronic devices. Such extensive sources of quality and reliability information can be used directly to predict operational reliability while the electronic design is still on the drawing board.

A powerful technique for electronics equipment evaluations that identify equipment failure modes, their causes, and the effect each failure mode will have on system performance is an analytical tool such as the Failure Modes, Effects and Critically Analysis (FMECA). The application of design evaluation techniques can provide a sound basis for determining spare parts requirements, required part improvement programs, needed redesign efforts, relocation of resources and other logistics measures to assure that specified reliability and maintainability requirements will be met.

2.3.4 Testability

An important component of maintainability is testability, widely defined as a design characteristic that allows the status of an item to be determined such as operable, inoperable, or degraded, and the isolation of faults within the item to be performed in a timely and efficient manner. The design must be such that testing is efficient in terms of detecting and isolating only failed items with no removal of good items. The removal of good items is a problem in many industries, with obvious impacts on troubleshooting times and repair and logistics costs. Therefore, planning for Built-in-Tests (BIT) at all levels within the system design will allow the group to be more proactive in identifying and fixing possible failures right away without having to guess and check once the construction of the prototype is completed.

BIT is becoming an important process of system design for a number of reasons. First, surface mount devices (SMDs) are increasingly being used in the design of circuit cards. The use of SMDs, and devices with higher packaging density (including double sided boards), decreases the accessibility required for guided-probe testing, while increasing the risks of such testing. Incorporating BIT in such designs thus becomes critical to effective diagnostics. Second, many component vendors of integrated circuits, such as Application Specific ICs are incorporating some form of BIT into their designs. Doing this will increase the vertical testability of an entire system.

The most important factor in BIT design is early planning. Without planning for BIT early in the life cycle, it will be harder to maximize any advantages offered by the use of BIT while minimizing any negative impacts such as increased design cost, higher hardware overhead, and increased failure rate. Ensuring that a product is testable requires adherence to some basic testability design principles. A list of some of the most common testability design principles follows.

- Physical and functional partitioning – The ease or difficulty of fault isolation depends to a large extend upon the size and complexity of the units that are replaceable. Partitioning the design such that components are grouped by function such as a function implemented on a single replaceable unit or by technology such as analog or digital whenever possible will enhance the ability to isolate failures.

- Electrical partitioning – Whenever possible, a block of circuitry being tested should be isolated from circuitry not being tested via blocking gates, tristate devices, relays, etc.

- Initialization – The design should allow an item to be initialized to a known state so it will respond in a consistent manner for multiple testing of a given failure.
- Controllability – The design should allow external control of internal component operation for the purpose of fault detection and isolation. Special attention should be given to independent control of clock signals, the ability to control and break up feedback loops, and tri-stating components for isolation.
- Observability – Sufficient access to test points, data paths and internal circuitry should be provided to allow the test system to gather sufficient signature data for fault detection and isolation.
- Test System Compatibility – Each item to be tested should be designed to be electrically and mechanically compatible with selected or available test equipment to eliminate or reduce the need for a large number of interface device (ID) designs.

2.4 Constraints

Constraints are defined as a restriction that accurately depicts the projects limitation, which includes more than just pure physical limitations. This project requires identification of ABET various realistic design constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.[2] Thus there must be clear evidence in the design project that the constraints relevant to it are addressed.[2]

2.4.1 Economic Constraints

These constraints relate to impact economy, budget, and cost of the project which will be the biggest hindrance in the development of HINT if it does not stay within manufacturing costs. The group is funded and given a budget of $1000. Therefore, even though the parts and components needed to realize the design are relatively economical, the overall price of the product must remain under that limit. When speaking of economic constraints, it is also important to consider prices of similar products on the market to try and minimize expenditures. The cost constraint forces all of the parts considered to be cost effective, and that the project itself is reproducible in an economical manner. To illustrate, throughout the project there was a couple cost versus performance topics that would be brought up when researching parts and manufacturing methods because there were many electronics components needed to consider to satisfy all features we wanted to incorporate. In a way these discussions greatly improved our design because it forced us to consider the most necessary qualities rather than just because the group wanted that certain component in it. This will greatly come in handy because if it would not have been enforced and things were to go wrong during the development such as cause us to reevaluate our research and have to repurchase a whole other set of hardware, it would set our whole milestones schedule back, thus not meeting deadlines.

2.4.2 Political Constraints

In this case, one needs to understand how engineering and political activities interact, and how to work effectively in this environment. The software/hardware designs we are using are being developed under the funds of a non-profit organization, Kaizen Matters. It is therefore important that the funds are carefully monitored.

2.4.3 Ethical, Environmental, and Sustainability Constraints

Environmental constraints are giving consideration to the ways that a product impacts the environment, from its manufacture to its disposal. Sustainability constraints are the process of developing engineering devices, products, and systems that use the resources available to it to meet the needs of the present without compromising the ability of future generations to also meet their own needs. Specifically answer in what ways the product may be reused and/or recycled at the end of its lifetime.

2.4.4 Manufacturability Constraints

This constraint is primarily concerned with designing a product in such a way that it can be realized efficiently, reliably and within acceptable costs. This can include redesigning a product to reduce the number of parts, simplify fabrication, or utilize common parts and materials. Our design is limited to the technology commercially available to us since we do not own any advanced prototyping tools.

2.4.5 Safety and Health Constraints

These constraints can pertain to the selection of electronics with low safety risks, and materials which endure heavy shock/impact. It is necessary when selecting components that offer protection circuits and performance standard such that there is a safe backing if any malfunction arrives. The use of solder rework stations are necessary for this project, which have the potential of any safety hazards to any of the group members as we try to realize this project. Moving forward, caution will be exercised when using these tools as well as being completely aware of our surroundings when it comes to emergency exits and fire extinguishers. Gloves and safety glasses will be worn at all times when using these tools.

2.5 Standards

Standards are published documents that establish both procedures and specifications to ensure consistency and compatibility among technologies. Standards centralize technologies used throughout the industry world. This section is an exposition on some of the standards related to HINT which influenced our design choices when considering cost and the time to develop sub-systems for the project. The design is adhering by these standards.

2.5.1 Electrical Safety

Our system, just like any other system, has to be safe for the designers themselves who already have an understanding of the dangers and risks of electrical systems, but also for the user who will be the person in most contact with the system through its operation period. A simple safety mechanism such as an enclosure for the system will prevent any electrical contacts from being shorted due to outside influences. Fuses and breakers provide a secondary means of protection in case a short or fault were to occur, were excess current would overheat a conductive filament or trip a breaker, thus terminating that connection. Other very important and relevant Occupational Safety & Health Administration (OSHA) standards of safety for electrical related subsystems and interaction with them include[3]:

- Electrical Power Generation, Transmission, and Distribution – This standard regulates the operation and maintenance of electric power generation, control, transformation, transmission, and distribution lines and equipment.[3]
- Electrical Protective Devices – This standard regulates the design requirements for specific types of electrical protective equipment such as rubber insulating blankets, rubber-insulating matting, rubber insulating covers, rubber-insulating line hose, rubber insulating gloves, and rubber insulating sleeves shall meet certain requirements listed further in the documented standard.[3]
- General Requirements – This standard regulates basic requirements of electrical subsystems and allowing examination to ensure standards are met.[3]
- Wiring Design and Protection – This standard regulates the labeling of device wiring and protection in product design, which also ensures that the proper grounding terminal connections are labeled.[3]
- Wiring Methods, Components, and Equipment for General Use – This standard regulates conductors that are not an integral part of factory assembled equipment such as cable trays, cable armor, enclosures, frames, fittings, and other noncurrent-carrying parts that are to serve as grounding conductors, with or without the use of supplementary equipment. It also states the necessity of their bounding to ensure electrical continuity.[3]
- Hazardous (Classified) Locations – This standard regulates requirements for electric equipment and wiring in locations that are classified depending on the properties of the flammable vapors, liquids, gasses, or combustible dusts or fibers that may present the likelihood of a flammable or combustible concentration quantity to be present.[3]
- Use of equipment – This standard regulates the use of plug and cord connected equipment, including flexible cord sets, such as extension cords.[3]
- Safeguards for Personal Protection – This standard regulates the use of personal protective equipment. It also states that employees working in areas where there are potential electrical hazards shall be provided with, and shall use, electrical

protective equipment that is appropriate for the specific parts of the body to be protected and for the work to be performed.[3]

2.5.2 Communication

Communication in electronic design is defined as the relaying of information between any two nodes. HINT implements various communication standards, both wired and wireless, to communicate from component to component. The communication standards adhered to in the design are defined as follows:

I²C Communication Standard: I²C is a serial protocol for a bi-directional two-wire interface to connect low-speed devices like microcontrollers, EEPROMS, A/D and D/A converters, I/O interfaces and other similar peripherals in embedded systems.[4] The protocol is more complex than that of SPI or UART. In order for devices connected on a bus to be recognized the signal information must adhere to certain protocols. The messages over the communication wires are broken into an address and a data frame. Data frames are 8-bit data messages that are between the master and slave system, while the address frame is responsible for master to data directory. It is also the first in any newly initiated communication sequence. 7

- **SPI Communication Standard**
- **UART Communication Standard**
- **802.15.4 ZigBee Communication Standard**

2.5.3 Electromagnetic Interference and Electromagnetic Compatibility

In order to guarantee that electronic circuits will perform as they were designed, they must be protected from electromagnetic interference (EMI). Circuits must not radiate emissions that can threaten or degrade the performance of other equipment, and since systems must share the electromagnetic spectrum, rules have been established to ensure a safe environment for all. These rules are called the electromagnetic compatibility (EMC) standards. They guarantee that electronic equipment can move freely without any degradation in performance, as well as without interfering with other systems. Making sure that your system meets these standards can be costly, but it can also secure the economic success of the project.

Electromagnetic interference can be either radiated or conducted. Radiated interference travels in the form of radio waves, and is called radio-frequency interference (RFI). Conducted interference comes from the magnetic field generated by current flow in cables carrying signals and power. Physical shielding provides signal attenuation (a weakening of radiated interference) through the reflection and absorption of electromagnetic waves (Electromagnetic waves have both an electric (E) field and a magnetic (H) field. In the E field, attenuation by reflection improves with conductivity. It is adversely affected by increases in frequency, permeability, and distance from the signal source. In the H field, increasing conductivity, frequency, and distance from the source are beneficial, as is decreasing permeability.

Compliance with the EMC standards requires EMI protection at four levels: the component level, board level, system level, and overall system level. Electronic circuitry, power sources, motherboard/backplane interconnect systems, and thermal management are all part of Level 3 systems.

There are three requirements that a country will apply to products to ensure the keep to the compatibility of electromagnetic standards.

- Verification: It ensures that the product has been tested to comply with the electromagnetic compatibility standards.
- Declaration of Conformity: It ensures that the vendor of the product has conformed said product to EMC standards.
- Certification: This ensures that the test results of the product from a trusted laboratory have been examined by a third party to ensure it meets EMC standards In the United States authoritative jurisdiction varies by administration depending on the product, and their steps for approval vary accordingly.

Some of the standards revolving around EMI deal with the antenna factors and antennas used for radiated emission measurements of electromagnetic interference (EMI) from 9 kHz to 40 GHz are provided. Antennas included are linearly polarized antennas such as loops, rods (monopoles), tuned dipoles, biconical dipoles, log-periodic dipole arrays, hybrid linearly polarized arrays, broadband horns, to name a few.

2.6 Funding

In order to approximate a cost for the overall project, a budget containing the names, quantities, and estimated costs of all the major parts of the project was made. This itemized breakdown allowed us to get budget funds that cannot exceed past $1000 from Kaizen Matters. This contribution takes a lot of financial burden off the group members, which is why the group will try to keep costs significantly small as well as maximizing cost efficiency. Although, if the group is not able to stay within the present budget during the manufacturing process, there might have to be a new proposal presented to Kaizen Matters to compensate for the rest of the money needed. If that is not realizable, then the rest of the expenses will have to be divided among the group members.

2.7 Project Block Diagram

The block diagram for the system is broken down by designer responsibility in ***Error! Reference source not found.*** below.

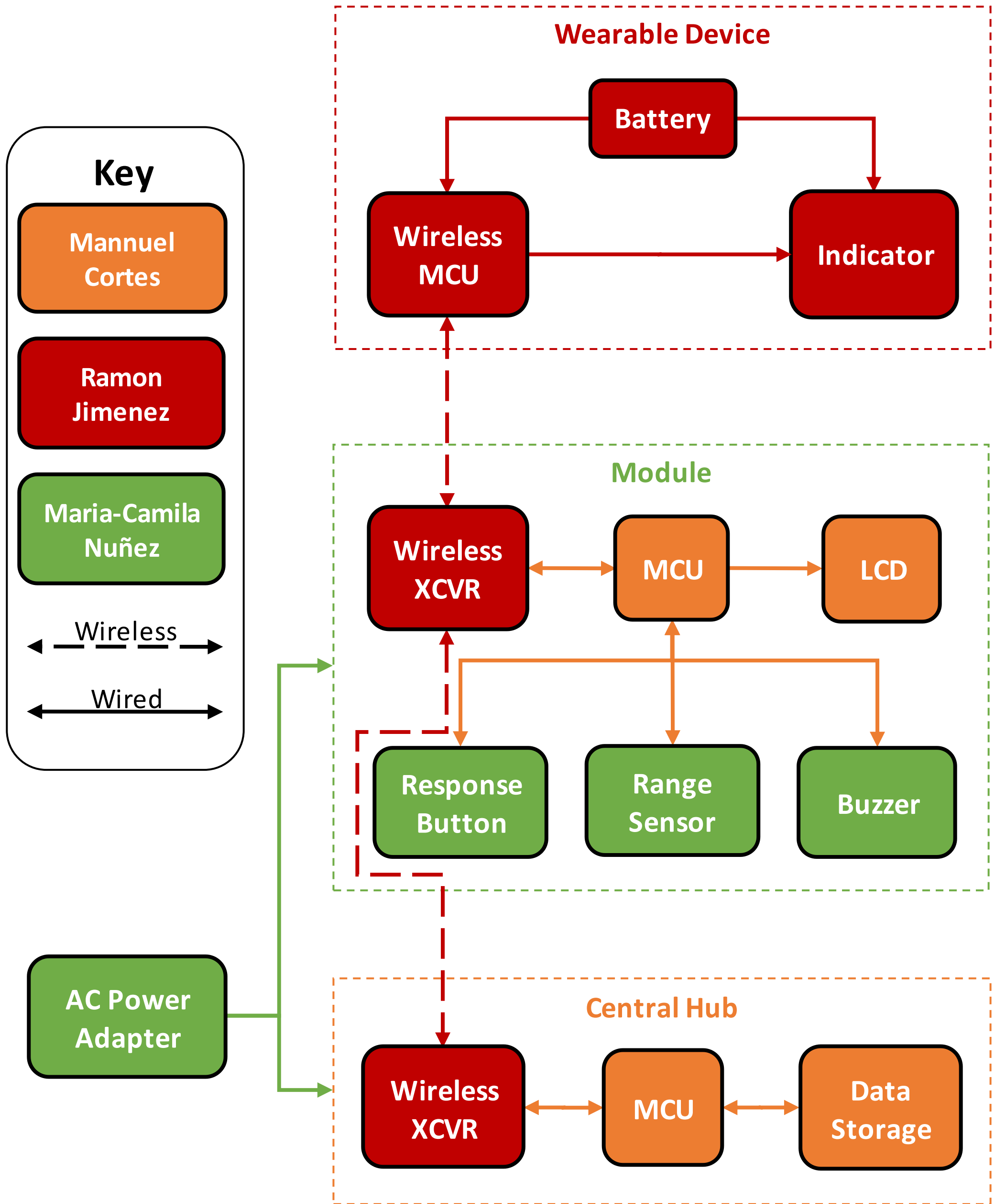

Figure 1: HINT Block Diagram

3 Research Related to Project Definition

The first design steps in system development are researching similar systems, laying out the hardware architecture, and selecting parts. As an IoT network, HINT will have discrete hardware units acting as a single, higher-level system. These hardware units include the controller, the communication receivers and transmitters, the modules for general purpose I/O (GPIO) and sensory I/O, the wearable device, and necessary power supplies. Once the hardware network is established, research for integrating software and algorithms is required. This will give the hardware its purpose. The entire system will then be packaged into a final, presentable, and functional product.

3.1 Existing Similar Projects and products

Prior to beginning development on the Home Interactive Notification Tracking system's design, we found it essential to consider alternative and already existing solutions. Taking into account if a similar product exist and satisfies the goals of our project, it may be possible to extract inspiration from their design to improve ours. Additionally, being able to follow different processes taken that outline failures or successes of similar projects can potentially mold our project into a highly sought after product in future markets.

3.1.1 Clarity Notification Systems

While conducting research related to similar designs the group came across Clarity Notification Systems. This system is compromised of the Visual Alert System, which includes the AlertMaster™ Audio Alarm Monitor, AlertMaster Personal Tactile Signaler, and AlertMaster Door Announcer.[5]

The Visual Alert System (AL10™) is for the deaf or people with profound hearing loss. The AL10™ alerts you of visitors to your home, telephone calls, and has optional accessories that can alert you to an audio alarm, a crying baby or the presence of an intruder. It is easy to use, secure and involves superior technology. The AlertMaster Personal Tactile Signaler is for use with the AL10™ which is a portable vibrating notice and tactile pad for any kind of alert from the Visual Alert System.[6] The AlertMaster Door Announcer is for use with the AL10™ which notifies user of an intercom, doorbell/chime or door knock from the Visual Alert System.[7]

Some of its overall features as a whole include[8]:

- Sensors that monitor the door bell and knocks on the door to alert you of visitors
- Alarm clock with snooze and vibrating alert features to wake the deepest of sleepers
- Monitors the specific sounds made by babies or young children
- The audio alarm monitor will notify you of any loud or unusual sounds
- The motion detector will monitor a large area and notify you of any unexpected movement
- The security light control can be set to turn on or off lighting around the home at selected times

Feature	Clarity Notifications	HINT
Hardware	Console unit and accessories	Central hub, remote sensor(s), and wearable device
User Interface	LCD display	LCD display
Communication	Wireless	Wireless
Alerts	Motion detection, unusual sounds, light control	User-defined notifications
Outputs	Audio, display, light, vibration	Audio, display, light, vibration

Table 1: Clarity Notification and HINT comparison

3.1.2 Eton ZoneGuard+

Eton ZoneGuard+ is another wireless home alert system. While the purpose of the system is to provide weather notifications, the functionality and hardware architecture of ZoneGuard+ is similar to that proposed by HINT. Both Systems embody the master-slave model of communication and are designed for the average household.

ZoneGuard+ is set up with a base station that is the main system controller (master) and modules that receive data to output to the user (slaves). Any number of modules can be paired to a single base station. The user can program up to 25 locations to receive weather notifications for, and they will be notified through the modules. The modules communicate wirelessly to the base station, and have audio outputs. The base station has a synchronized visual display to alert the user of the specific event occurring. The system also has a light notification output, color coded to relay different warning levels.[9]

Additional functionality of the Eton ZoneGuard+ includes an AM/FM/WB radio and digital alarm clock. *Table 2* characterizes the major implementation features of ZoneGuard+ and HINT. Note that the architecture is very similar to the HINT layout. The only additional feature not compared is input, since that is not a feature offered by the ZoneGuard+.

Feature	Eaton ZoneGurd+	HINT
Hardware	Base station and small module(s)	Central hub, module(s), and a wearable device
User Interface	LCD display	LCD display
Communication	Wireless	Wireless
Alerts	Weather	User-defined notifications
Outputs	Audio, display, light	Audio, display, light, vibration

Table 2: Eaton ZoneGuard+ and HINT Comparison

3.1.3 Wireless Home Control System

While conducting research related to similar designs the group came across Wireless Home Control System. This is a previous senior design project that aimed to improve the quality of life for people in their homes. It was developed to be an easy to use system that allows people at their home interact with their appliances without having to be in front of them. They aimed for a few of the same solutions as our project which is to be interactive, reliable, and of minimum cost. Some examples that this system performs is for the user to be able to turn on their lights and/or outlet with the press of a button and/or voice command from their mobile phone, should be able to turn on their coffee pot from their phone when they first wake up, and user should be able to unlock the door without having to get up if someone knocks on it.

This system can be interacted with by a mobile application or the included LCD screen. The phone is attached to the system through a Bluetooth connection, and the LCD screen is connected to the central base station of the project. The control modules designed for this project allow for all the activation of appliances around the home. Each control module is also tailored for the interaction of a specific device, such as control modules for toggling outlets, toggling lights, unlocking the front door, and monitoring sensors.

Feature	Wireless Home Control System	HINT
Hardware	Core appliances	Central hub, remote sensor(s), and wearable device
User Interface	Mobile application, LCD display	LCD display
Communication	Wireless	Wireless
Alerts	Home automation	User-defined notifications
Outputs	Any output of pairable devices	Audio, display, light, vibration

Table 3: Wireless Home Control System and HINT comparison

3.1.4 Estimote

Estimote Beacons are small sensors that provide iBeacon functionality. They contain wireless sensors to communicate to applications on smartphones through their antenna and use location detecting algorithms to send notifications to applicable nearby users on their device. Inside each Estimote there is a 32-bit ARM Cortex M0 CPU, memory, Bluetooth Smart module, and temperature and motion sensors.[10] Being that the Bluetooth Smart modules are Low Energy certified they operate on coin cell batteries that provide up to 3 years of operation. They provide user detection up to 50 meters through Received Signal Strength Indication (RSSI). Signal strength between the user's mobile phone and the beacon is determined and notifications are pushed whenever the programmed signal strength limit is reached. Bluetooth Smart does not require pairing so a mobile phone can communicate to multiple beacons at once without permission being requested to pair.

The Estimotes are programed by the user using the open SDK provided. This technology is directly related to what HINT will be because we aim to do the same thing, except with a wearable. Understanding the way this system works we could implement an efficient system to meet our requirements not only with a wearable, but possibly through a smartphone application as well.

3.1.5 Samsung SmartThings

The Samsung SmartThings product is another IoT structure with a similar architecture proposed by the HINT project. The highlight of the product is home automation and green living. With a network of devices throughout the home and powerful, user-friendly software applications, SmartThings allows for easy home security, monitoring, and regulation.

The network of devices consists of a hub, multiple remote devices to be controlled, and mobile applications for multiple platforms. SmartThings connects with many different wireless protocols for user convenience. The system works through Wireless Fidelity (Wi-Fi) for easy control from a mobile device. Similar to SmartThings, future growth plans for the HINT design includes pairing multiple modules to a single central hub, allowing for a mesh of module “nodes” and tracking throughout multiple rooms. Other plans include expansion to Wi-Fi communication for cloud data storage and a web user-interface for controlling tasks and notifications on the system.[11]

The hub can communicate with each paired device through ZigBee and Z-Wave communication. This is a smart move, since it helps eliminates the more complicated Wi-Fi design from where a simpler protocol is more than sufficient. The system is also compatible with IP-accessible devices. This flexible architecture allows mother manufacturers' devices, in addition to Samsung's own, to be connected to the SmartThings Network. Table 4 below shows the similar features of SmartThings and HINT. Note that system input comparisons are omitted since SmartThings is not interactive in the sense that HINT is.

Feature	Samsung SmartThings	HINT
Hardware	Hub and pairable devices	Central hub, remote sensor(s), and wearable device
User Interface	Mobile application	LCD display
Communication	Wireless	Wireless
Alerts	Home security and automation	User-defined notifications
Outputs	Any output of pairable devices	Audio, display, light, vibration

Table 4: Samsung SmartThings and HINT Comparison

3.1.6 Related Wearable Technologies

While researching related technologies we found 2 open-source projects that are viable products we can build off of. Both products are packed with features and their design resembles what we aim to accomplish.

ARM mbed Wearable: The mbed wearable is an open-sourced project aimed for the application of health and activity trackers. Its form factor provides the look and feel of a smart watch. It features an ARM Cortex-M3 Processor running their own mbed operating system, 9-axis motion sensor, GPS module, biometric scanner for security, NFC integration, Bluetooth LE, and an LCD display.[12] The processor handled all RF communications, sensors, and user interfaces. From the supplier, this device is slated to deliver a battery life up to 8 weeks. Their design is modular as to allow features to be added or removed with ease. It also includes a vibrating motor, a RGB LED, and magnetic buzzer in the design which is what one of our goals was.

F*watch: The F*watch is an open-source project that targeted hiking and timing applications. It features an ARM Cortex-M3 processor, GPS module, pressure sensor, 3D-accelerometer, 128x128 pixel LCD display, compass, and Bluetooth LE.[13] The design also has a buzzer and vibrating motor. The original design is a 4-layer PCB because it contained many components in a small wrist size format. It also had a rechargeable battery and a micro SD slot for a memory card.

3.2 Microcontrollers

At the heart of every electronic architecture, especially IoT networks, is a controller (or group of controllers) that governs the entire structure. These controllers are usually in the form of an integrated circuit (IC). The three biggest players in the field of electronic controllers are the microprocessor (MPU), the microcontroller (MCU), and the field-programmable gate array (FPGA). They are programmable (and re-programmable for that matter), making these preferred over custom hardware, namely application specific integrated circuits (ASICs). These chips are responsible for receiving, processing, formatting, and transmitting data and control signals. The controller has power over all interfaces between itself and all the peripherals, and even the interfaces between peripherals.

Since HINT is not using solely discrete digital signals for interfacing, and since floating-point data will be processed and stored, an FPGA is not ideal for our application. In addition, we will need a lot of data packets to initialize and control wireless communication. For these reasons, FPGA research is omitted from this section. The MCU and MPU are reasonable controllers in the design, and are compared briefly. Features to take into consideration when comparing controllers are supported peripherals, performance, pin count, pin partitioning (like signal function), on-chip memory (or lack thereof), power consumption, cost, and development support (i.e. development board availability).

There a few major differences that separate MPU's from MCU's. An MPU has only a CPU on-chip, whereas an MCU has memory and other peripherals on-chip.[14] The lack of peripherals in an MPU allow for more processing power, at the cost that more chips are needed on the PCB to support the processing. External RAM memory also allows memory to be larger, and potentially upgradable if on a dual-inline memory module (DIMM) or similar connecting board.

All three devices in the HINT architecture will need a controller. The controller on the central hub's PCB will govern the entire system and store a log of its activity in local memory. The second controller, on the module PCB, will receive the governing signals from the central hub and govern the module's local I/O, as well as the communication to the wearable device. The controller on the wearable device will receive control signals from the module, and will aid the ranging and proximity detection. There are a few sensory outputs from the controller that will be implemented on the wearable device, as well. The three controllers are required in order to support the wireless communication between the subsystems of HINT. This makes HINT a true IoT design.

Due to the master-slave network and the split control, it has been determined that MCUs on all three devices will be more than sufficient. The processing power and memory needed for the HINT algorithms is minimal. There will also be external memory storage on the hub that alleviates memory usage of the central MCU. This decision simplifies software development and reduces the amount of hardware components in the design.

The following sections will be comparing MCUs and their specific features to determine if they satisfy the HINT system requirements and specifications. A brief explanation of the features and their uses is necessary here to understand what to look for in specific components.

Memory: Memory is a big feature of MCUs because there is usually no off-chip memory to supplement it.[15] As noted earlier, it is what separates MCU's from full MPU's. Different types of memory available on MCUs are Random Access Memory (RAM), Flash Memory, and Electrically Erasable and Programmable Memory (EEPROM). RAM is the memory that is accessed consistently during program runtime.[16] RAM is volatile memory that is wiped when power is disconnected and comes as static RAM (SRAM) or dynamic RAM (DRAM). The difference between the two is that DRAM needs a controller to refresh the memory constantly, yet is cheaper. However, SRAM is typically the memory used in MCUs. Flash memory is non-volatile and is used to store the MCU configuration and program data. It cannot be edited during program runtime. On system startup, the necessary program instructions and data are copied to SRAM and executed from there, since SRAM is faster than Flash. Much like Flash, EEPROM is non-volatile. It is used to store long-term data that is not modified often. In addition, both Flash and EEPROM memories have limited lifetimes. They can only endure a certain number of read and write cycles before electrically failing. Table 5 below compares the top players in microcontroller memory. Different components in our system will require different amounts of memory, and this is further discussed in section *0*.

Memory	Volatile	Writable	Erase Size	Life Cycles	Speed	Use
SRAM	Yes	Yes	Byte	Unlimited	Fast	Runtime instructions and data
DRAM	Yes	Yes	Byte	Unlimited	Moderate	Runtime instructions and data
EEPROM	No	w/ device programmer	Byte	Limited	Fast read; slow erase/write	Configuration values and infrequently changing data
Flash	No	w/ device programmer	Sector	Limited	Fast read; slow erase/write	Configuration and startup data

Table 5: Comparison of MCU Memory Types

Architecture: MCU architecture includes clock frequency specifications, data widths, instruction set characteristics, and functional hardware circuits. Clock frequency defines how quickly data moves through gates. In conjunction with the instruction set architecture's (ISA) clocks per instruction, the clock frequency can be used to measure performance and speed of specific MCU operations. An "N-bit" MCU is defined as having N bits on the data bus.[17] Higher bit widths generally result in more powerful processing cores and more throughput. Additional features to look for in MCU architecture are unique hardware circuits, like a custom hardware multiplier in the arithmetic logic unit (ALU).

Peripheral Features: Peripheral features and integrated transceivers heavily contribute to the electronics designer's MCU choice. In a typical design process, the peripherals, or I/O to the MCU, of a PCB are defined and then the MCU is selected. If many complicated peripherals are involved in the design, selecting a smaller, lower-end MCU might not suit the design. Typical MCU communication peripherals are SPI, I^2C, and UART interfaces. As described in the communications standards section, these are signaling standards between an MCU and other components. Another good peripheral is pule-width modulation (PWM).[18] This is used to vary the duty cycle of the digital output, which is essentially a square wave. An advantage of this is providing analog outputs. Peripheral functions, like embedded ADCs, DACs, oscillators, and temperature sensors, are also important to look for.[18] Some unique MCUs have embedded transceivers (like radio-frequency transceivers, for example), which helps combine multiple chip functionalities on a single IC. While MCU's at heart, these controllers are truly SoCs. Peripheral features are also limited by pin counts, however, which is discussed with MCU packaging later in this section.

Library Support: Software library support is key in embedded development and makes certain MCUs more suitable for specific applications than others. Library support generally comes from the MCU manufacturer, but can also be found from open-source development (third-party) projects. Specific library support examples are peripheral software drivers that initialize and control communication with another device (an LCD driver, for example). These libraries can support MCU integration with higher level software applications, as well.

Packaging: MCU packaging refers to the physical characteristics of the component. Dimensions, PCB mounting style, and pin count can be constraints on a specific design, and can drive the selection of specific MCUs. For smaller designs, surface-mount technology (SMT) or ball grid array (BGA) packages might be preferred. They are smaller but a lot more difficult to hand solder. If size is not a big constraint, the most popular packaging style is dual in-line packages (DIP), specifically plastic DIP (PDIP). These are larger, through-hole parts and generally stick out more from the PCB. On the positive side, these are trivial to solder and can be prototyped on a breadboard extremely easily. Pin count refers to the number of connections the chip makes with the PCB. These are signals that are routed elsewhere on the board. A large portion of the pin count are GPIO and interface pins, which tie back directly to supported peripheral devices. With a higher pin count, the MCU can integrate with more peripheral devices.[19]

Power: Power consumption can be a critical constraint for a design. While more and more MCUs are focusing on low-power characteristics, current draw is still an important specification to look at. MCUs generally have different power modes, so noting all of them will be useful for comparisons.

3.2.1 Texas Instruments MSP430F5

Texas Instruments offers a variety of cost-effective and relatively high-performing MPU's and MCU's. The MSP430 MCU is an educational favorite because of the availability of the Launchpad, the development board for the MCU.

The TI MSP430FG5 series is a higher-performance line of the MSP430 family. This is a good candidate for the module's MCU. The chip offers an abundance of Flash memory for configuration data, RAM for runtime, GPIO for the other board interfaces, and low power consumption.

Memory: The MSP430FG5 line is a heavy duty lower-end MCU when it comes to storage. The line comes with up to 512 KB of Flash memory and 66KB of SRAM.

Architecture: This MSP430 runs up to 25 MHz and implements 16-bit reduced instruction set computing (RISC). The MCU also contains a 32 x 32 bit hardware multiplier.

Peripheral Features: Communication peripherals include UART, SPI, and I^2C ports. This MCU also contains full speed Universal Serial Bus (USB) 2.0 peripherals. ADCs and DACs are also embedded to support analog and digital I/O.

Library Support: Texas Instruments offers a variety of development libraries for these MCUs, including peripheral interfacing drivers, USB packages, and capacitive touch software.

Packaging: Packaging options for our design include a 40-pin quad flat no leads (QFN) package and a 38-pin thin shrink small outline package (TSSOP).

Power: The line generally has a 195 µA/MHz active current draw. With a 3 V supply, the MCU line has a maximum current draw of 6.6 mA (Flash execution) or 3.6 mA (RAM execution) in active mode. It has a real-time clock (low power) mode around 2.5 µA.

3.2.2 Atmel ATmega328

Atmel offers a few general purpose MCUs with widespread development support. ATmega328 is a good candidate for the module’s controller, as it has been proven to work with countless peripherals with its development board, the Arduino Uno. The device supports all the requirements of the module subsystem. Below is a breakdown of the ATMega328 capabilities.[20]

Memory: This ATmega offers a fair amount of memory. Storage includes 32 KB of Flash, 1 KB of EEPROM, and 2 KB of SRAM.

Architecture: The MCU runs up to 20 MHz and implements an 8-bit Atmel AVR core with advanced RISC architecture. It contains 32 8-bit general purpose registers, as well as a 2-cycle multiplier.

Peripheral Features: Communication peripherals support I^2C, SPI, and USART (which includes a UART). The MCU contains embedded ADCs to support the analog inputs, as well as PWM. Other peripherals include an on-chip oscillator and a temperature sensor.

Library Support: There are countless ATMega software libraries available, thanks to the Arduino Uno support teams. These range from RF interfacing to LCD driving. Atmel also supplies libraries such as capacitive touch and QMatrix acquisition libraries.

Packaging: The package of interest for this project is the 28-pin PDIP package, containing 14 digital pins (6 PWM) and 6 analog pins for general purpose use.

Power: With a 5 V power supply, and active at 8 MHz, the ATMega has a mximum current draw of 9 mA. It has a typical power-save mode draw of 0.9 μA at 3 V supply.

3.2.3 Texas Instruments MSP430F2

The MSP430F2 series is a lower-end line of the MSP430 family. This MCU is being considered for all 3 components in the HINT system: the central hub, the module, and the wearable device (if using a standalone MCU). Selection of this device would require less processing duties.[21]

Memory: The MSP430F2 line comes with up to 120 KB of Flash memory and 8KB of SRAM.

Architecture: This MSP430 runs up to 16 MHz and implements a 16-bit RISC architecture. The MCU also contains a 16 x 16 bit hardware multiplier.

Peripheral Features: Communication peripherals include UART, SPI, and I^2C ports. ADCs and a DAC are also embedded to support analog and digital I/O. This MCU also contains a temperature sensor.

Library Support: Texas Instruments offers a variety of development libraries for these MCUs, including peripheral interfacing drivers, energy libraries, graphical user interface (GUI) packages, and capacitive touch software.

Packaging: Packaging options for our design include a 14-pin DIP package and a 20-pin or 28-pin TSSOP package.

Power: The line generally has a 200 μA/MHz active current draw. With a 3 V supply running at 1 MHz, the MCU line has a maximum current draw of 455 μA (Flash execution) or 300 μA (RAM execution) in active mode. It has a real-time clock (low power) mode around 0.7 μA.

3.2.4 NXP LPC810M021FN8

The NXP LPC810M021FN8 is a small-package, low-power, yet relatively high performance MCU. This MCU is being considered for the wearable device, in the case that it has a standalone MCU An embedded RF transceiver is preferred, but the realization is still under research. More information on the wireless MCUs is available in section *3.3*.[22]

Memory: This NXP MCU contains 4 KB on-chip programmable Flash memory, as well as 1 KB of SRAM memory.

Architecture: The LPC810M021FN8 runs up to 30 MHz and implements a 32-bit ARM Cortex-M0+ architecture. The MCU also contains a speedy, single-cycle hardware multiplier.

Peripheral Features: Communication peripherals include USART (including UART), SPI, and I^2C ports. Other peripherals include an on-chip oscillator.

Library Support: NXP provides development libraries for these MCUs, including peripheral interfacing drivers.

Packaging: The package of interest for this MCU is the 8-pin PDIP package, which is small for the wearable and easy to prototype. It is roughly 6.48 x 9.8 mm^2. The component is also available in a 16-pin TSSOP package, allowing for extra I/O.

Power: At maximum (active) frequency and a 3.3 V supply, the current draw is typically 3.3 mA. Deep sleep mode at room temperature will draw 300 μA.

3.2.5 MCU Comparison

Below,

Feature	MSP430F5517	ATmega328	MSP430F2410	LPC810M021FN8
Max Clock Frequency	25 MHz	20 MHz	16 MHz	30 MHz
Data Bus Width	16-bit	8-bit	16-bit	32-bit
Memory	96 KB Flash 8 KB SRAM	32 KB Flash 1 KB EEPROM 2 KB SRAM	56 KB Flash 4KB SRAM	4 KB Flash 1 KB SRAM
Interfaces	UART SPI I2C	USART SPI I2C	UART SPI I2C	USART SPI I2C
Analog I/O	Both	Input	Both	none
Digital I/O	Both	Both	Both	Both
GPIO Pin Count	63	20	48	6
Package	LQFP	DIP	LQFP	DIP
Low Power	Yes	Yes	Yes	Yes
Special Features	USB 2.0 32-bit multiplier	N/A	N/A	Single Cycle Multiplier
Software Support	Abundant	Abundant	Abundant	Moderate
Unit Price	$9.76	$3.38	$8.73	$3.10

Table 6 compares the features of the top MCU candidates for the HINT design. Specific models of the families researched above have been chosen, based on the needs of our system. Note that power consumption is not accurately compared (due to unknown frequency of operation and manufacturer reporting differences). More in-depth research relating to power consumption is conducted in the power research and design sections. Also, it is important to keep in mind that the different components of HINT have different MCU requirements.

Feature	MSP430F5517	ATmega328	MSP430F2410	LPC810M021FN8
Max Clock Frequency	25 MHz	20 MHz	16 MHz	30 MHz
Data Bus Width	16-bit	8-bit	16-bit	32-bit
Memory	96 KB Flash 8 KB SRAM	32 KB Flash 1 KB EEPROM 2 KB SRAM	56 KB Flash 4KB SRAM	4 KB Flash 1 KB SRAM
Interfaces	UART SPI I^2C	USART SPI I^2C	UART SPI I^2C	USART SPI I^2C
Analog I/O	Both	Input	Both	none
Digital I/O	Both	Both	Both	Both
GPIO Pin Count	63	20	48	6
Package	LQFP	DIP	LQFP	DIP
Low Power	Yes	Yes	Yes	Yes
Special Features	USB 2.0 32-bit multiplier	N/A	N/A	Single Cycle Multiplier
Software Support	Abundant	Abundant	Abundant	Moderate
Unit Price	$9.76	$3.38	$8.73	$3.10

Table 6: MCU Comparisons

3.3 Wireless Communication Technologies

In order for HINT to effectively meet its objective, we must implement a communication system to be able to transfer information between the three components as shown in ***Error! Reference source not found.***. This required our team to do research on the types of wireless communication technologies available. Wireless communication was the best choice since the components can be in relocated and the difficulty of having to hook up cables again and again can be a nuisance. Based on the following research we will decide on what method of wireless communication is best for our design.

3.3.1 Radio-Frequency Identification

Radio-frequency identification (RFID) uses radio waves to automatically identify people or objects.[23] Both active and passive RFID communication systems are comprised of a reader, tag, and an antenna. They have various ways to operate: low frequency (LF), high frequency (HF), and ultra-high frequency (UHF). There are also two categories that you can split RFID systems into, passive and active.

RFID tags classes include Electronic Product Code (EPC) Classes 1 through 4.[24] EPC Class 0 is also called Gen 1. These tags are write once and read many times (WORM). This class is only programmed by the factory and cannot be programmed in the field. EPC Class 1 is Gen 1 and Gen 2. EPC Gen 2 though implements a write many read many (WMRM) type of memory. The minimum memory is 256 bits and 96 bits are reserved for the EPC number. Gen 2 tags have a more improved tag identification when compared to Gen 1. It eliminates duplicated reads during multiple tag scans. They are read up to 10 times faster than Gen 1 and provide a high read rate on tags. EPC Class 2 tags are Gen 2 Class 1 enhanced tags. They feature an extended TAG ID (TID) user memory with the already existing Class 1 Gen 2 benefits. EPC Class 3 tags are passive tags that are battery-assisted to help supply power to the tag and even possible sensors that may be present. Depending on the tag, it may even contain a sensor with data logging capabilities as well. The final class, EPC Class 4, is active tag technology. The tag itself contains a battery and it can initiate communications with other tags or a reader. They contain an EPC identifier, TID, access control, a battery, transmitter, and optional memory. Memory ranges within all tags and can be reserved memory, EPC memory, TID memory, or user memory.[24]

Reserved Memory: This memory stores two 32 bit passwords, kill and access. The access password toggles write capabilities on or off, while the kill password disables the tag altogether.

EPC Memory: The EPC code is stored in this memory and it is 96 bits. EPC memory is the first writable memory bank.

TID Memory: The unique tag ID number is stored within this memory portion. When it's IC is manufactured the manufacturer sets the TID associated to the tag. This memory cannot be changed by any means.

User Memory: Certain ICs have extended user memory that can be used to store more information. This is in extension to the EPC memory that the tag may already contain. Typically, the memory is no more than 512 bits. Some tags are manufactured that contain 4K or 8K bytes of memory.

The selected tag impacts our sponsors design so it is vital we ensure we select the right one for the job. In the following sections we dive a little deeper into the two systems as well as their pros and cons.

3.3.1.1 Active vs Passive Compare

3.3.1.1.1 Passive RFID

Passive RFID systems consist of a RFID tag that has no battery because the power is supplied by the system that is reading the tag. Radio waves sent out from the reader hit the RFID tag and generate power through a coiled antenna inside the tag by forming a magnetic field.[25] This in turn provides the power necessary for the tag to transmit the information that is needed to be read by the RFID reader. This is the technology that the Sunpass mini toll system uses. Their operation frequency ranges from 125 – 134 KHz (LF), 13.56 MHz (HF), and 865 – 960 MHz (UHF).

Low frequency systems have an extremely long wavelength, but have short read ranges. The read range is approximately 1 to 10 centimeters. This type of frequency is more commonly used with animal tracking and is not affected much by water or metal.[26]

High frequency systems have a medium wavelength with a read range from approximately 1 centimeter to 1 meter. Applications such as data transmissions, access control, passport security, etc. use this type of system. In short, applications that do not require a long read range.[26]

Ultra high frequency systems utilize short high energy wavelength to transmit over long ranges. They can typically be read from approximately 5 to 6 meters. The size of the tag is directly proportional to it's transmit range. In other words, increasing the size of the tag can increase its transmit rage. Some applications include race timing, file tracking, laundry management system, etc.[26]

The advantages and disadvantages of using a passive RFID system are shown in *Table 7*: Passive RFID Advantages vs Disadvantages.

Advantages	Disadvantages
No battery is needed for it's function. This allows the tag to have a long lifespan.	The range in which the tag can be read is not very long; distance varies per application usage, usually a few feet.[27]
Tags are inexpensive	Sensors that can use electricity for power may not be possible to include
Size of a tag can be very small making it easy to implement in a design where space is limited	Have difficulty sending data through liquids or metals

Table 7: Passive RFID Advantages vs Disadvantages

3.3.1.1.2 Active RFID

Contrary to passive RFID, active RFID systems require a power source to provide the energy needed for the signal to be sent. This power source can be a battery, but it is also possible to design one that has an external power source. The read range for active RFID is much farther than that of a passive one since it has a power source for the signal being emitted. Active RFID has two main frequencies that it can use, 433 MHz and 915 MHz.[26] A lower frequency is generally favored over the higher one due to the long wavelengths that would allow the signal to travel better through materials such as water and metal. Two different types of RFID tags are available for the active system, transponders and beacons.

With transponder tags the reader sends out a signal first, and then an active transponder sends back a signal with the information that is pertinent. These types of tags are efficient due to their ability to conserve battery life when a tag is not within range of a reader. Active RFID Transponders are commonly used in secure access control and in toll booth payment systems.[27]

Beacon systems do not wait for a reader signal to come in before sending pertinent information. Rather, the tag sends out specific information ever couple seconds (3-5 seconds). These tags can be read over hundreds of meters away, but are often set to low transmit power to conserve battery power.

The advantages and disadvantages of using an active RFID system are shown in Table 8: Active RFID Advantages vs Disadvantages.

Advantages	Disadvantages
Can be read at long distances up to hundreds of feet	Needs a battery to function
Contains the highest data bandwidth	Larger than passive RFID system
Depending on it's purpose you have transponder and beacon application methods	More expensive when compared to passive RFID system

Table 8: Active RFID Advantages vs Disadvantages

3.3.1.2 RFID Components

When considering an RFID reader and tag we must take into account size, range, and cost. Our biggest constraint is the tag because it will be placed within the wearable, so a tag candidate should meet our design and range constraints. It is also important to understand that the range requirement we need to meet impacts our part decision.

3.3.1.2.1 RFID Tag

The following parts are the possible choices for the RFID tag. View Table 9: RFID Component Comparison for a summary on key design parameters we have compared.

Omni-ID Flex Label RFID Tag: The Omni-ID Flex Label RFID tag is a low profile tag that provides an operating frequency of 902 – 928 MHz and is compliant to the ISO 18000-6C standard. It provides the benefit of being a low profile tag with a read distance up to 5 m (16.4 ft.). Its memory includes EPC 96 bits, User 512 bit, and a TID 64 bit. Features include a knock and splash resistant design, a weight of 2.9 grams, and an operating temperature of +5° to +40°C. The dimensions measure 3 x 0.6 x 0.11 in.

Omni-ID Prox Label RFID Tag: The Omni-ID Prox Label RFID tag is a small form factor tag that provides an operating frequency of 902 – 928 MHz and is compliant to the ISO 18000-6C standard. It provides a read distance up to 1.5 m (4.9 ft.). Its memory includes EPC 96 bit, User 512 bit, and a TID 48 bit. Features include a knock and splash resistant design, a weight of 1.7 grams, and operating temperature of +5° to +50°C. The dimensions measure 1.38 x 0.39 x 0.19 in.

Omni-ID Exo 750 RFID Tag: The Omni-ID Exo 750 RFID tag is an extremely durable tag with a small footprint. It provides an operating frequency of 860 – 930 MHz and is compliant to the ISO 18000-6C standard. Its read range is up to 11m (36 ft.) Its memory includes EPC 96 bits, User 512 bits, and TID 64 bits. Features include a durable knock resistant design, a weight of 25.6 grams, and an operating temperature of -40° to +85°C. The dimensions measure 2.01 x 1.9 x 0.50 in.

Confidex Carrier Micro RFID Tag: The Confidex Micro RFID tag is a small sized special label with an adhesive backing. Its operation frequency is 860 – 930 MHz and it is compliant to the ISO 18000-6C standard. It provides a read distance up to 3.5m (11.5 ft.). Its memory includes EPC 128 bits and TID 64 bits. Features include water proof design design, small form factor, weight of 0.1 grams, and an operating temperature of -35° to +85°C. The dimensions measure 1.57 x 0.39 x 0.01 in.

	Omni Flex	**Omni Prox**	**Omni Exo**	**Confidex Carrier**
Operating Frequency	902 - 928 MHz	902 - 928 MHz	860 - 930 MHz	860 - 930 MHz
Read Distance	16.4 ft.	4.9 ft.	36 ft.	11.5 ft.
EPC Memory (bits)	96	96	96	128
User Memory (bits)	512	512	512	none
TID Memory	64	48	64	64

(bits)				
Weight (g)	2.9	1.7	25.6	0.1
Operating Temperature [C]	+5° – +40°	+5° – +50°	-40° – +85°	-35° – +85°
Water Resistance	Yes	Yes	No	Yes
Dimensions (in)	3 x 0.6 x 0.11	1.38 x 0.39 x 0.19	2.01 x 1.9 x 0.50	1.57 x 0.39 x 0.01
Cost	$39.00	$34.00	$29.00	$32.00

Table 9: RFID Component Comparison

3.3.1.2.2 RFID Reader

The following parts are the possible choices for the RFID reader.

AS3991 UHF RFID Reader IC: The AS3991UHF reader chip is an 64 pin integrated analog front end and data framing system for a 900 MHz RFID reader system.[28] It is designed for the implementation of a EPC Class 1 Gen 2 system and only requires a standard 8-bit microcontroller. It is compliant to the ISO 18000-6C standard, and also supports ISO 18000-6a/ISO 18000-6b as well. The chip provides an integrated low level transmission coding, low level decoders, data framing, and CRC checking. The operating frequency support for the AS3991 is 840 – 960 MHz. Max supply voltage is 5.5 V with an output current of ±100 mA. There are three power modes available as well: power down, normal, and standby.

The IC consist of complete digital and analog functionality for reader operation. A transmitter and receiver section is present within the IC with ISO 18000-6C digital protocol support. It also contains an on-board phase locked loop (PLL) section with integrated voltage control oscillator (VCO), supply section, DAC and ADC section, and host interface section. The PLL control system generates an output signal to match the phase of an input signal to maintain any error constant in the loop, or in the “locked” condition.

Communication between the transponder and the reader follows the reader talk first method. Upon powering up and configuring the IC, communication starts by turning on the RF field and transmitting its first protocol command. The modes associated with transmit and receive are Normal Data Mode and Direct Data Mode. Normal Data Mode has the data for RX and TX transferred through the FIFO register and protocol data processed is done internally while Direct Data Mode has data processed by the host system.

Indy RS500 RFID Reader IC: The Indy RS500 reader chip is a 32 pin surface mount IC that meets ISO 18000-6C standards applications. It supports all 900 MHz bands worldwide with a TX output power +10 to +23 dBm, RX sensitivity -65 dBm, and in a small form factor measuring 29 x 32 x 3.8 mm. It allows for the capability of reading at a distance greater than 3 meters when using a 6 dBi reader antenna and with applicable passive tags that can be read. The IC is shielded to ensure any unwanted radiation does not effect performance and to provide noise immunity in embedded environments.

RS500 is powered by a supply voltage operating in the range of 3.6 – 5.25 V to the VDC_IN pin (pin 11). The current consumption varies from approximately 600 mA (3 W) to approximately 100 μA (.5 W) and it is dependent on the operating mode the reader is running in. As long as the input voltage is stable there is no external bypass or bulk storage capacitance required since the power supply is internally bypassed and regulated.

For RF connectivity there is a single RF pin (pin 1) available that would need to be connected to a 50 Ω antenna through a controlled impedance connection of 50 Ω. The connection can include a connector and coaxial cable, a microchip transmission line to the PCB, or a SMT antenna.

There are two half-duplex UART interfaces. They are at the pins on the IC and are accessed using the following pins: UART1-RX, UART1-TX, UART2-RX, and UART2-TX. UART1 allows the host communication interface through IRI, and UART 2 implements the debug interface. RX pins are the inputs and the TX pins are the outputs for the RS500. The UART interfaces are 115,200 baud, with a 8-n-1 configuration. This means that there are 8 data bits, 1 stop bit, and no parity bit.

For power consumption there are a few different operating modes. The operating power modes are Active, Idle, Standby, and Sleep. Active mode is the only mode in which the RS500 can perform RFID reads which means power consumption would be higher if left on this mode. In this case Idle mode provides a fast transition to Active mode to begin RFID reads while consuming less power. Standby mode requires a General-purpose input/output (GPIO) or WKUP pin event to return to active mode and Sleep mode would only require a WKUP pin event.

3.3.2 Bluetooth

Bluetooth has grown to be very popular since its introduction in 1988[29] and it has become a standard feature included in almost all electronic technologies being released today. It operates on the unlicensed industrial, scientific and medical (ISM) band at 2.4 to 2.485 GHz which makes it usable by many manufacturers. Utilizing a spread spectrum, frequency hopping, full-duplex signal at a nominal rate of 1600 hops/second.[30] The spread spectrum form of wireless communication allows the frequency that is being transmitted to be varied, deliberately. This allows a greater bandwidth to be utilized compared to when the frequency is not varied. The chips themselves produce wavelengths that are bound to frequencies operating within a range for communication. Naturally this could be an issue if another device operates at, or close to, the same frequency so to prevent this the signal is spread out over a wider range of frequencies. The benefits of this frequency hopping allow us to utilize it fully in our design without the worry of signals being disrupted by other devices in the home. It's main purpose in our design would be for tracking and notification purposes.

Low power and range are other benefits to this type of communication. The most common minimum range for communication is at least 10 meters, or approximately 30 feet.[31] [32] It's ranges are classified by 'Class' and are shown in Table 10: Bluetooth Transmission Classes, along with the power requirements needed for it to work efficiently. Being that our product would be implemented inside a home, class 2 would be suffice for our needs. Should the product ever be implemented at a nursing home like facility class 1 would be the best option. Also, being that the power requirement to function is so low it adds to the benefit of using Class 2 in our design.

Class	Maximum Power	Operating Range
Class 1	100 mW (20dBm)	100 meters
Class 2	2.5 mW (4dBm)	10 meters
Class 3	1 mW (0dBm)	1 meter

Table 10: Bluetooth Transmission Classes

3.3.2.1 Bluetooth Components

Our design constraints on the wearable limit the selection of Bluetooth options possible for it, while the module's constraints are not as strict. We have to take into account the I/O pins and the MCU that would be driving it as well. The following parts are the possible choices for a Bluetooth component.

SESUB-PAN-D14580: The SESUB-PAN-D14580 is a 36 pin SMD micro module that provides 2.4 GHz Bluetooth V4.1 Low Energy connectivity. It has an ultra small package size of 3.5 x 3.5 x 1 mm. It is also available in IC package that can come in 34, 40, or 48 pin configurations. The 40 and 48 pin configurations include a ground plane.

- **Power:** Requires a supply voltage from 2.35 – 3 V. Its low current consumption while powered is a benefit at 5.0 mA for TX, 5.4 mA during RX, and while in the Deep Sleep mode consumption is at 0.8 μA. There is support for lithium and alkaline coin cell batteries with a 10-bit ADC for accurate measurements of the battery voltage.
- **Controller:** There is a 16MHz 3032-bit ARM Cortex-M0 high performance microcontroller.
- **Memory:** Includes 32 kB One-Time-Programmable (OTP) programmable memory, 84 KB ROM for BT stack, 42 KB system SRAM, and an 8 KB retention SRAM. The SRAM will provide faster access to data and retains data bits in its memory as long as it is being powered.
- **RF Characteristics:** The power level for output transmission is typically in the range from 0 to -1 dBm. Typical receiver sensitivity level for this chip is around -94 dBm.
- **Interface(s):** The number of GPIO pins varies depending on the package selected. You have the option of having 14, 34, or 32 pins. There are 2 UARTs with a hardware flow control up to 1 MBd, a SPI+ interface, and an I^2C bus at a rate of 1000 kHz or 4000 kHz.

Microchip RN4020: The RN4020 is a 24 pin SMT Bluetooth V4.1 Low Energy Module with an integrated antenna on the PCB. At a compact form measuring 11.5 x 19.5 x 2.5 mm, and a weight of 1.2 g. It has FCC, IC, CE and QDID certifications. Also, for applications that involve some sensors, there is an internal scripting capability to enable basic functions that can be implemented without the need for an external host MCU or software development tools. This means that there is no integrated controller. The main benefit of this module is the PCB antenna that eliminates the need for an external one.

- **Power:** Requires a supply voltage from 3 – 3.6 V with a typical voltage of 3.3 V. Current consumption varies depending on one of the possible modes it may be in: Dormant, Deep Sleep, Idle, and TX/RX active. The current draw for these modes is less than 700 nA, less than 5 μA, less than 1.5 mA, & 16 mA respectively.
- **Controller:** There is no controller associated with this module and it requires an external MCU for functionality.
- **Memory:** There is a 64 KB internal serial flash.

- **RF Characteristics:** The power level for output transmission is typically +7 dBm. Typical receiver sensitivity level for this chip is around -92.5 dBm. Average operation range is 100 meters. There is also an RSSI monitoring feature on this module. There is a max data rate of 1 Mbps over BT.

- **Interface(s):** There are 7 GPIO pins and provides a UART and SPI communication interface.

BlueGiga BLE112-A-V1: The BLE112-A-v1 is a 32 pin Bluetooth Low Energy module targeted for low power sensors and accessories. Dimensions for the module are 18.10 x 12.05 x 2.3 mm making it a small profile module easily applicable for our design. It has the capability of being used directly with a coin cell battery. It also supports 4+ simultaneous connections in master mode. There are various timers, including a watchdog timer, that are implemented with the CC2540 that the BLE112 uses.

- **Power:** Requires a supply voltage from 2 – 3.6 V. Current consumption during TX varies on the power being used to transmit, but it averages to 30 mA. During RX the consumption is 25 mA.
- **Controller:** The BLE112 is based on TI's CC2540 chip which integrates a low power 8051 microcontroller core that delivers high performance.
- **Memory:** Includes system programmable flash of 128 KB or 256KB, depending on the configuration selected. Also, there is a 8 KB SRAM provided to help with the retention of data.
- **RF Characteristics:** The power level for output transmission is +3 – -23 dBm. Typical receiver sensitivity level for this chip is around -87 – 93 dBm. There is also an RSSI monitoring feature on this module. There is a max data rate of 1 Mbps over BT.
- **Interface(s):** Provides a UART and SPI communication interface. Also has USART 0 and USART 1 that are each configurable over the UART or SPI interface.

Table 11: Bluetooth Component Comparison shows a summary of key decision parameters taken into consideration for the listed parts above.

BT Part	D14580	RN4020	BLE-A-V1
Supply Voltage	2.3 - 3 V	3 - 3.6 V	2 - 3.6 V
TX Current Consumption	5.0 mA	16 mA	30 mA
RX Current Consumption	5.4 mA	16 mA	25 mA
Other Current Consumption	Deep Sleep - 0.8 μA	Deep Sleep - 700 nA Idle - 5 μA	Power mode 1 - 235 μA Power mode 2 - 0.9 μA Power mode 3 - 0.4 μA
Controller	32-bit ARM Cortex-M0	None	8051 MCU Core
Memory	32 KB OTP 42 KB system SRAM 8 KB retention SRAM	64 KB internal Serial Flash	128/256 KB programmable FLash 8 KB SRAM
TX Power	-1 dBm	+7 DBM	+3 – -23 dBm
Receiver Sensitivity	-94 dBm	-92.5 dBm	-87 – 93 dBm
Serial Interface(s)	UART SPI+ I2C	UART SPI	UART SPI
Pins	36	24	32
GPIO	14 - 34	7	17
Dimensions	3.5 x 3.5 x 1 mm	11.5 x 19.5 x 2.5 mm	12.05 x 2.3 mm
Cost	$7.65	$8.84	$11.38

Table 11: Bluetooth Component Comparison

3.3.3 Near Field Communication

Near field communication (NFC) is a type of communication between devices that requires no contact. This contactless method allows for information to be sent without the need for a physical connection between devices. It utilizes electromagnetic radio fields like an RFID would, with the exception that it is designed for use by devices within close proximity to each other.[33] Operation frequency is 13.56 MHz over a short distance of about maximum 10 centimeters.[34] The implementation for it can either be a reader/writer mode, peer-to-peer mode (data exchange between two devices, or card emulation which is like a contactless payment/transportation card. It also is available in a few forms that will be briefly mentioned. They are available as tags and can be found in sticker form as well. NFC are very cost effective and with proper programming you can integrate it into your home for day to day task. There are also 3 forms that are available are: NFC-A, NFC-B, and NFC-F.[34]

NFC-A corresponds with RFID Type A communication. In Type A communication, Miller encoding, also known as delay encoding, is used with amplitude modulation at 100 percent. Using this set-up, a signal sent between devices must change from 0 to 100 percent to register the difference between sending a “1” and a “0.” Data is transmitted at 106 Kbps when using Type A communication.[35]

NFC-B is very similar to NFC-A. NFC-B corresponds with RFID Type B communication. Instead of Miller encoding, Type B uses Manchester encoding. Amplitude modulation is at 10 percent, meaning a 10 percent change from 90% for low to 100% for high is used. A change from low to high represents a “0” while high to low represents a “1.” [35]

NFC-F refers to a faster form of RFID transmission known as FeliCa. Commonly found in Japan, FeliCa is a technology similar to NFC but faster and currently more popular. It is used for a variety of services such as subway tickets, credit card payments, and identification at office buildings and other locations with limited access. [35]

3.3.4 Wireless Fidelity

Wireless Fidelity, more known as Wi-Fi, is the term used for certain types of wireless local area networks (WLAN) that use specifications developed by IEEE in the 802.11x family.[36] It works without any physical connection between the sender and receiver, but instead by RF technology. The frequency range for Wi-Fi is 2.4GHz – 5GHz, it depends on the amount of data that is on the network. When an RF current is delivered to an antenna, an electromagnetic field is created that then is able to propagate through space.[37] In order for a device to be connected to the network through the access point, they must be equipped with wireless network adapters. The Wi-Fi frequencies are broken into different types and are known as 802.11a, 802.11b, 802.11g, 802.11n, and 802.11ac. They each have their own specific range, frequency of operation, and speed associated. A comparison summary is shown in *Table 12*: Wi-Fi Standards Comparison for each of the above mentioned.

Wireless Standard	802.11b	802.11a	802.11g	802.11n	802.11ac
Popularity	3	1	2	2	1
Speed (Ideal)	Up to 11 Mbps	Up to 54 Mbps	Up to 54 Mbps	Up to 300 Mbps	Up to Mbps
Relative Cost	$	$$$	$$	$$	$$$
Frequency	2.4GHz - This frequency may conflict with other 2.4GHz devices	5GHz	2.4GHz - This frequency may conflict with other 2.4GHz devices	5GHz and/or 2.4GHz - Not all devices support 5GHz or include dual-band radios	5GHz
Range (Indoors)	115 ft.	115 ft.	125 ft.	230 ft.	230 ft.
Compatibility	Widest adoption	Incompatible with 802.11b or 802.11g	Interoperates with 802.11b networks Not compatible with 802.11a	Interoperates with b/g/a	Interoperates with a/n

Table 12: Wi-Fi Standards Comparison

Range can be affected by solid objects, such as walls, obstructing the signals path. How much the signal is attenuated depends on the material of the object it is passing through. For example, a wooden door may attenuate a signal by 6 dB but a concrete wall will attenuate a signal by 18 dB. The typical range associated with each is shown in *Figure 2.* Through this figure you can see the 802.11n Wi-Fi standard would be an optimum choice to ensure the projects success.

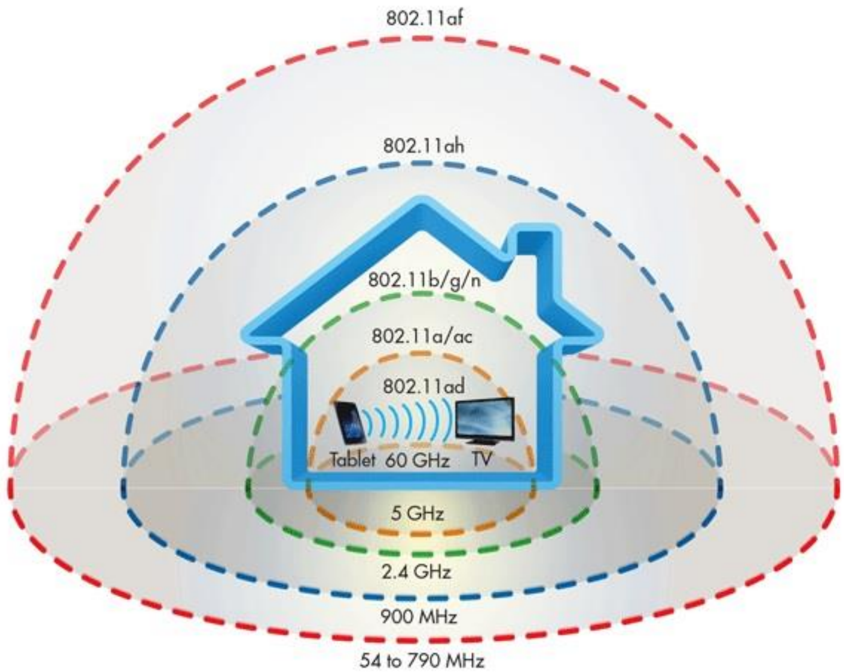

Figure 2: WiFi Range Diagram
Photo Courtesy of Microwaves & RF

3.3.5 ZigBee

ZigBee is a mesh network specification for low-power wireless local area networks that cover a large area.[38] It is an alternative to Wi-Fi and Bluetooth for some applications that don't require a lot of bandwidth. It was designed for when a low power consumption and high data throughput was needed on a low duty cycle device. Essentially it is used best for a home automation implementation since sensor-monitoring and control of applications, or devices, is where ZigBee's mesh network setup is needed most. It is commonly referred to as machine-to-machine communication and the Internet of Things (IoT). An example of this method of communication is a switch that turns on a smart light bulb. The two devices can communicate, even though they may not be from the same supplier, because the language is the same. It operates on unlicensed radio frequency bands and the IEEE 802.15.4 physical radio. The 2.4GHz, 900MHz, and 868MHz are also utilized for ZigBee.

Wi-Fi can be used to accomplish the same task as ZigBee, but there are some differences that should be noted. ZigBee is best for applications and devices that require low data rates, long battery life, and long range.[39] Wi-Fi doesn't do so well under these requirements. First of all, most devices that use Wi-Fi have a battery large enough to provide one to two days' use before they require a recharge. ZigBee applications can have a longer battery life, up to 7 years.[39] The bitrate is another factor in picking a method of communication. Wi-Fi has a 54Mbps max bitrate, while ZigBee has a 250kbps. As you can see something that requires heavy data flow would not be ideal for ZigBee and is taken into consideration when reviewing needs of our product. Range is the third difference between the two. Typically, a max range for Wi-Fi falls between 50-100 meters, depending on the standard that is being used, and ZigBee supports up to around 1,000 meters. This is possible because of the way the infrastructure is setup with the mesh network.

3.3.5.1 ZigBee Components

Our design constraints on the wearable limit the selection of ZigBee options possible for it, while the module's constraints are not as strict. We have to take into account the I/O pins and the MCU that would be driving it as well. The following parts are the possible choices for a ZigBee component.

Microchip MRF24J40MD: The MRF24J40MA is a IEEE standard 802.15.4 compliant RF transceiver module. It is a 12 pin surface mountable configuration module measuring 22.9 x 33 mm and has integrated power amplifier (PA) and low noise amplifier (NLA). On this module there is an integrated PCB antenna for communication with a low current power consumption. MRF24J40MD is compatible with PIC16, PIC18, PIC24, dsPIC33, and PIC 32 microchip microcontroller families.

- **Power:** Requires a supply voltage from 3.0 – 3.6 V. The current consumption is typically 140 mA while in TX mode and 32 mA while in RX mode. For low power applications there is a sleep mode that consumes 10 μA.

- **Controller:** Needs an external controller for functional use.

- **Memory:** No on board memory on this module.

- **RF Characteristics:** The power level for output transmission is typically +19 dBm with 45 dB TX power in control range. Typical receiver sensitivity level for this module is around -104 dBm with -23 dBm maximum input level. There is also an RSSI monitoring feature on this module. The max data rate provided is 250 kbps with a range up to 4000 ft depending on application.

- **Interface(s):** There are 3 GPIO pins and a 4 wire SPI serial interface with interrupt, wake, reset, power, and ground provided on this module.

Texas Instruments CC2530: The TI CC2530 is an IEEE standard 802.15.4 compliant system on chip (SoC) ZigBee IC chip. It is a 40 pin surface mount chip that, in whole, contains all the components of a computer or other system for functionality. The dimensions are 22.9 x 33 mm. It offers 3 power modes along with the active TX/RX modes. It requires an external antenna for functionality, and this is something that we would have to design or find. There are 5 additional timers, including sleep timer, that are included with this module.

- **Power:** Requires a supply voltage from 2 – 3.6 V. The typical current consumption is 3.4 mA with no active peripherals or transmissions. While doing a TX current consumption jumps to 28.7 mA at 1 dBm output power and 33.5 mA at 4.5 dBm output power. During RX mode current consumption is 20.5 mA at -50 dBm input power and 24.3 mA at -100 dBm input power. If timers 1, 2, 3, 4, or sleep timer are implemented it adds 90 μA, 90 μA, 60 μA, 70 μA, and 0.6 μA respectively to the total base current consumption.

- **Controller:** The CC2530 chip which integrates a low power 8051 microcontroller core that delivers high performance.

- **Memory:** Provides a 32, 64, 128, or 256 KB programmable flash configuration and an 8 KB RAM that provides retention of data in all power modes.

- **RF Characteristics:** The typical output power for the antenna is 4.5 dBm with a programmable output power range of 32 dB. Typical receiver sensitivity level for this module is around -97 dBm. There is also an RSSI monitoring feature on this module with a range of 100 dB. The max data rate provided is 250 kbps over the communication network.

- **Interface(s):** There are 21 GPIO pins and provides a UART and SPI communication interface. Also has USART 0 and USART 1 that are each configurable over the UART or SPI interface.

DIGI XBEE WRL-11215 RF Module: The 20 pin XBEE 802.15.4 RF Module is compliant to the IEE standard called out in its name. It provides both 2.4 GHz and 900 MHz functionality with point to multipoint network topology while providing the benefit of being a 20 pin through hole component. The dimensions for the module are 2.438 x 2.761 cm. The is no configuration needed with for this and the supplier provides testing and configuration software.

Power: Requires a supply voltage of 2.8 – 3.4 VDC. Current consumption during TX is 45 mA and during RX it is 50 mA. Max data rate over the network is 250 kbps.

Controller: There is no controller integrated into this modules design and it requires an external MCU.

Memory: There is no memory associated with this module.

RF Characteristics: The typical output power for TX is 1 mW (0 dBm) with an indoor range up to 30 meters. The RX sensitivity is -92 dBm.

Interface(s): Provides a UART serial communication interface.

Table 13: ZigBee Component Comparison shows a summary of key decision parameters taken into consideration for the listed parts above.

ZigBee Part	MRF24J40MD	CC2530	XBEE RF Module
Supply Voltage	3.0 -— 3.6 V	2 — 3.6 V	2.8 — 3.4 VDC
TX Current Consumption	140 mA	28.7 — 33.5 mA	45 mA
RX Current Consumption	32 mA	20.5 — 24.3 mA	50 mA
Other Current Consumption	Sleep Modes — 10 µA	Idle — 3.4 mA	Idle — 50 mA
Controller	None	8051 MCU Core	None
Memory	None	32/64/128/256 KB Programmable Flash 8 KB RAM	None
TX Power	+19 dBm	+4.5 dBm	0 dBm
Receiver Sensitivity	-104 dBm	-97 dBm	-92 dBm
Serial Interface(s)	SPI	UART SPI	UART
Pins	12	40	20
GPIO	3	21	None
Dimensions	22.9 x 33 mm	6 x 6 mm	32.94 x 22.34 mm
Cost	$15.90	$6.86	$19.00

Table 13: ZigBee Component Comparison

3.3.6 Wireless Communications Decision

Our project requires the system to acknowledge a user. With this in mind it was important to have a system that would provide a “two-step verification” method. Being that the module would be designed to detect any presence within its proximity, we needed the wearable to be the second method of verification of identifying a user. The first thoughts were that an RFID system would be the most efficient system to implement. With RFID we had the capability of assigning a tag identification number to a user, and once the sensor on the module scanned the tag it would provide the appropriate notifications. This proved to be less realizable as research continued because the system for reading tags at the distance we needed was proving to be too costly for us. In order to implement this system, we needed UHF compatible components. The antenna is what troubled us the most because not only were they the most expensive components, but having to design for an external antenna and the appropriate RFID reader would be more difficult.

After crossing RFID out, we were left to determine a way to provide a user identification system through one of our other choices. NFC was removed as a choice because its' read distance did not meet our design requirements. Wi-Fi was eliminated as well because it consumes more power since it is constantly connected to a network, or searching for one if one is not found. With a small battery it would not be the ideal choice. It would also be harder to implement it in the way we needed it. This left Bluetooth and ZigBee as our last two choices.

Bluetooth and ZigBee provided features we needed to meet our requirements and were the ideal choices since there were various modules and SoC components available. After further research the decision was made to use the Received Signal Strength Indicator (RSSI) capabilities offered by these two communication methods. It would allow us to determine the proximity of the user to enable appropriate notifications. After researching the components available for both, we have decided that the best method would be to use ZigBee. Bluetooth was almost selected due to its Low Energy technology, but we chose ZigBee because of the capability in producing an IoT product, and because it seems the least difficult system to implement. There are a lot of resources available online for reference when it comes to ZigBee as well.

3.4 Sensors

Sensors are devices that detect a change in its environment, input, and provide an output based on change. The input can be anything from light, temperature, pressure or heat, to name a few.[40] The output is normally a signal that can be sent wirelessly to a device or network. Depending on the physical input, the form of the output will differ.[40]

3.4.1 Passive IR Sensor

For products that need to detect when a person has left, entered or approached the PIR sensors are great. PIR sensors are used to detect motion from about 20 feet away. They are low power and low cost, have a wide lens range and are easy to interface with. A special note to keep in mind is that PIRs won't tell you how many people are around or how close they are to the sensor, the lens is often fixed to a certain sweep distance and they are also sometimes set off by house pets.[41] This motion detector does not send any signals; however, it detects motion based on a dramatic and quick change in heat energy. The sensor itself has two slots in it, each slot is made of a special material that is sensitive to IR. When the sensor is idle, both slots detect the same amount of IR, the ambient amount radiated from the room, walls, or outdoors. When a warm body passes by, it first intercepts one half of the PIR sensor, which causes a positive differential change between the two halves. When the warm body leaves the sensing area, the reverse happens, whereby the sensor generates a negative differential change. The infrared region on a wavelength spectrum is from 0.7 micrometers to 1000 micrometers.[42] Infrared sensors work in the wavelength of 8 micrometers to 12 micrometers while the human body omits infrared energy of 9 to 10 micrometers.[43]

3.4.2 Radar Motion Sensor

This is a radar based motion detector that uses ultrasonic sound waves or microwave radio energy to sense motion.[44] It sends out the acoustic waves and waits for the reflection of the waves. If there is a wave, then the wave comes back unchanged but if there is an object in the field then the waves will return disturbed. This technology is mostly used in automatic doors, security systems inside and outside, automatic lights, etc. Most radar based motion detectors use Doppler radar in RF frequency of 10.525 GHz.[44] They send out a RF signal toward the target and if there is movement the reflected signal will be compressed, increasing the frequency of the reflected wave. This device comes in many forms powered by 5-50V DC and some come with adjustable parameters to help sensitivity of the device which are all available online. Three sensors have been listed in Table 14 along with their specifications for comparison.

Sensor	HC-SR04	LV-MaxSonar-EZO	PING))) Ultrasonic Distance Sensor
Working Voltage (V)	5	2.5-5.5	5
Working Current (mA)	15	2	35
Minimum Range (cm)	2	15.2	2
Maximum Range (M)	4	6.45	3
Measuring Angle	15 degree	varies	20 degrees
Working Voltage (V)	5	2.5-5.5	5

Table 14: Radar Motion Sensor Component Comparison

3.4.3 Photoelectric Sensor

This is an equipment that provides non-contact accurate detection targets by discovering the distance, absence, or presence of an object. Photoelectric sensors are readily present in everyday life. They help to safely control the opening and closing of garage doors, turn on sink faucets with the wave of a hand, control elevators, open the doors at the grocery store, detect the winning car at racing events, and much more. These sensors detect change in light intensity. The type of light and method by which the target is detected varies depending on the sensor. Photoelectric sensors are comprised of a light source (LED), a receiver (phototransistor), a signal converter, and an amplifier[44], *Figure 3* demonstrates how these components interact in order form a working sensor. The phototransistor analyzes incoming light, verifies that it is from the LED, and appropriately triggers an output. Photoelectric sensors have three different useful types of sensing modes: opposed (through beam), retro-reflective, and proximity-sensing (diffused).

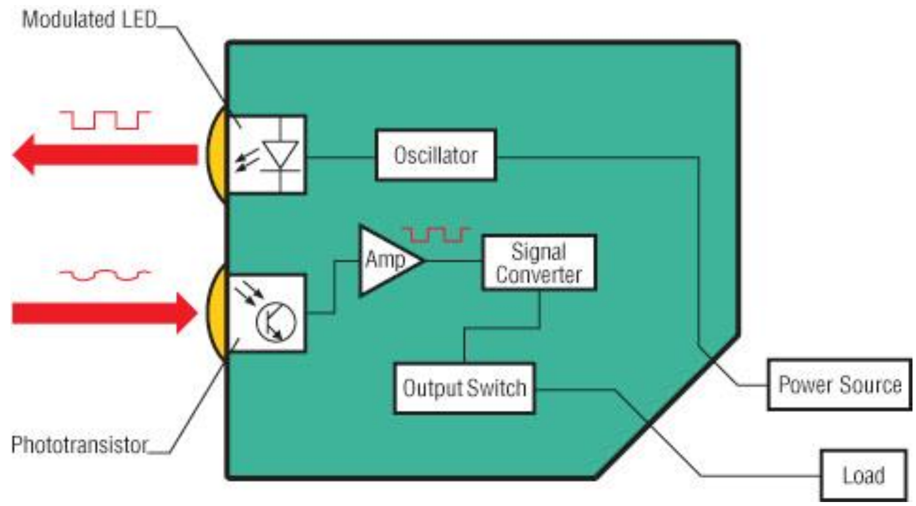

Figure 3: Internal Circuitry of Photoelectric Sensor
Pending permission from KTH Technology and Health

In diffused mode sensing, the transmitter and receiver are in the same housing. Light from the transmitter strikes the target, which reflects light at arbitrary angles. Some of the reflected light returns to the receiver, and the target is detected. There is a couple of advantages and disadvantages to this mode.

In retro-reflective mode the transmitter and receiver are also in the same housing, but a reflector is used to reflect the light from the transmitter back to the receiver. The target is detected when it blocks the beam from the photoelectric sensor to the reflector. This mode typically allows longer sensing ranges than diffused mode due to the increased efficiency of the reflector compared with the reflectivity of most targets.

In through beam mode, it uses two separate housings; one for the transmitter and one for the receiver. The light from the transmitter is aimed at the receiver and when a target breaks this light beam, the output on the receiver is activated. This is the most effective mode and allows the longest possible sensing ranges for photoelectric sensors. These sensors are available in a variety of styles, the most common includes one transmitter housing, one receiver housing, and one light beam between the two housings. The Table 15 below categorizes all three modes with their advantages and disadvantages in order to effectively choose a sensor that fits the purpose of HINT.

Name	Advantages	Disadvantages
Diffuse	• Transmitter and receiver are in same housing so only have to install at one point • Cost less than other modes	• Factors affect sensing range; less accurate than other modes • More setup time involved
Retro-Reflective	• Slightly less accurate than though beam • Very reliable • Sensing range is better than diffuse	• Must install two points on system: sensor and reflector • Slightly more expensive than diffuse • Sensing range is less than through beam
Through Beam	• Most accurate mode • Very reliable • Longest sensing range	• Must install two points on system: emitter and receiver • Most expensive due to purchase of both emitter and receiver

Table 15: Photoelectric Sensor Mode Advantages vs Disadvantages

3.4.4 Microwave Motion Sensors

These motion detectors are part of various security devices, which detect an intruder's motion. They emit microwaves into the specific region and detect any intrusion by analyzing the frequency of the received microwave after the reflection from the intruder. The guiding principle for most of these sensors is the Doppler's Effect, the detector circuit contains a transmitter, receiver and alarm/related circuit.[45] The transmitter sends off microwaves in the area which have a specific frequency. As they strike with an intruder moving with a certain velocity, the frequency and then the phase of the wave signal gets altered. Once the receiver receives the reflected waves, its phase analysis is done and consequently an alarm is triggered on if analysis depict phase change of wave signals. Uses of this motion detector include but not limited to: security issues and traffic law enforcement, monitoring light system of a house, and are used in door openings. Below is Table 16 describing the advantages and disadvantages.

Advantages	Disadvantages
Detector sense whether the intruder is moving towards or away from the detector	False alarms which occur due to slight vibrations of objects
Helpful sensing and differentiating between ordinary movement and intruder movement	Sensors do not operate continuously, they work in intervals
Can be used in harsh environments where heat cycles are not regular	Require continuous power supply; large expensive batteries
Detectors can combine with passive infrared detectors to become much reluctant to false alarms	Microwave radiations can easily penetrate through walls and holes so cannot be used for just a room

Table 16: Microwave Motion Sensor Advantages vs Disadvantages

3.4.5 Sensor Compare

There were two top sensors we considered, the Infrared sensor and the Ultrasonic sensor. The purpose of the motion sensor in the module is for it to work jointly with the ZigBee wireless communication for the module to output tasks when the user is within a certain proximity. Table 17 displays the comparison between our two top sensors.

Sensors	Advantages	Disadvantages
Infrared	Work only inside a building without direct sunshine	Cannot work accurately outside/inside under direct or indirect sunlight
	Work well in extremely noisy environment	Narrow beam width
	Can detect motion from about 20 feet away	Mostly work for detecting the proximity of an obstacle
	Low power and cost	Sensor reading is affected by color surfaces
Ultrasonic	Able to work accurately indoors	Fail in extremely noisy environments
	Can provide range data in serial, analog, and pulse width modulation	Oblique surfaces may cause glancing bounces to objects further away and give erroneous reading
	Sends out pulse of ultrasonic sound at a frequency of 41kHz therefore working in silence to human ear	Works best for detecting large objects
	Has a longer detecting range	Relatively much more expensive

Table 17: Infrared vs Ultrasonic Advantages vs Disadvantages

3.5 Liquid Crystal Displays

Liquid crystal displays (LCDs) are a typical communication interface between electronics and humans.[46] LCD They displays are found on everyday items, such as monitors, mobile devices, watches, and household appliances. LCDs have become mainstream technology because of the simple, thin appearance, light weight, and low power consumption relative to other display technologies.

As expected, LCDs are composed of liquid crystals that are sensitive to electric current and voltage. The liquid crystal molecule arrays react to the electrical signals, which are used to control light passage. These electrical signals are inputs, generally from an LCD controller (in our case an MCU). These signals control what is being displayed, specifically color and pixel or segment data, depending on the type of LCD. LCDs can receive signals that control the refresh rate and synchronization, as well.

LCDs can be reflective or backlit. Reflective LCDs have no light source, meaning they rely on external reflections. Backlit LCDs contain fluorescent tubes, or similar embedded components, that emit light.

LCDs can be common-plane-based or matrix style. Common-plane-based LCDs are meant for time displays or any screen that has repeating symbols or characters. A common type is an *N*-segment LCD display, where *N* segments on the screen (typically hexagonal) are controlled by a signal to form a character on the *N* segments. This LCD type is also referred as “segmented” in this document. Matrix LCDs consist of an array, or grid, with “row” and “column” type of signal references. At the intersection of each “row” and “column” is a pixel. This can be accomplished with passive matrices, containing only the liquid crystals and supporting structures, or with active matrices, containing thin film transistors (TFTs).

LCDs can be black and white (non-colored), greyscale, or colored. Non-colored displays can be controlled with discrete signals. One way of driving a greyscale LCD is adjusting voltage levels to display different shades of grey. A simple colored LCDs generally has three sub-pixels per pixel: red green, and blue. Different combinations of these colors create the visible color on the display.

For the HINT application, specifically on the module, it has been determined that a backlit and non-colored LCD will be the best option. A common-plane-based or simple matrix display is sufficient. There are no complicated user-interface requirements in place for this aspect of the design. The LCD only has to be able to output the notification. This can be done with text, for example. Below are some LCD module options for the design.

Electronic Assembly DIP162: Electronic Assembly offers a simple 2x16 LCD. It is a common-plane-based architecture. The screen is backlight capable with yellow/green, white, and blue light-emitting diode (LED) illumination options. The module comes as a DIP package module for easy testing, debugging, and PCB integration. This module includes Hitachi’s popular, general-purpose HD44780 LCD controller. The HD44780 is a digital component that drives the specific segments of the LCD, while the inputs to the module are higher level data segments coming from another system controller (in our case, the MCU). The module has a 4-bit and 8-bit interfacing capability. More of the product’s specifications can be seen in *Table 18,* at the end of this section.

Electronic Assembly DIP203: Electronic Assembly offers another simple 2x16 LCD. It is also a common-plane-based architecture. The screen is backlight capable with yellow/green, white, and blue LED illumination options. This module comes as a DIP package, as well. It includes Solomon Systech’s SSD1803 LCD controller. It is very similar to Hitachi’s HD44780. It has a 4-bit and 8-bit interfacing capability. More of the product’s specifications can be seen in *Table 18* at the end of this section.

Electronic Assembly LED5X46: Another LCD offered by Electronic Assembly is a 128x65 pixel LCD. It is composed of a dot matrix display architecture, which supports a finer resolution that the segmented displays. The screen is backlight capable with yellow/green, white, blue, red, amber, green, and configurable red-green-blue (RGB). LED illumination options. This module comes as a DIP package, as well. It includes a Sitronix ST756R matrix LCD controller. It is very similar to Hitachi's HD44780, but meant for matrix displays instead of segmented displays. It has a 4-bit interfacing capability. More of the product's specifications can be seen in *Table 18* below.

Feature	EA DIP162	EA DIP203	EA LED5X46
Operating voltage	2.7 V 3.3 V 5 V	2.7 - 3.45 V	3.0 - 3.3 V
Current draw w/ white LED backlight	45 mA	45 mA	40 mA
Backlighting	Yes	Yes	Yes
Display type	Segmented	Segmented	Dot matrix array
Display capability	2x16 characters	4x20 characters	128x64 pixels
Active area dimensions	56x14 mm	56x16 mm	52x32 mm
Interface	4-bit 8-bit parallel	4-bit SPI 8-bit parallel	4-bit SPI
Package	DIP module	DIP module	DIP module
Cost	$27.26	$36.09	$18.78

Table 18: Comparison of LCD Modules

3.6 Buzzer

A buzzer and speaker are acoustic components that can generate sound. Buzzers are typically used for identification and alarm purposes across many major industries for major application categories such as home appliances, automotive electronics, and office automation [2]. Their role in HINT comes into play in the module. Since HINT is aiming to be an interactive system using three of the human senses, the buzzer/speaker will be labeled under the hearing sense. There are certain characteristics to consider for buzzers, which include volume, frequency, voltage, and current consumption [3]. In this section we will elaborate on the two main technologies of buzzers, piezo and magnetic.

At the heart of all piezo-type buzzers is the piezoelectric element. The piezoelectric element is composed of a piezoelectric ceramic and a metal plate held together with adhesive. Both sides of the piezoelectric ceramic plate contain an electrode for electrical conduction. Piezo materials exhibit a specific phenomenon known as the piezoelectric effect and the reverse piezoelectric effect. Exposure to mechanical strain will cause the material to develop an electric field, and vice versa. When an alternating voltage is applied to the piezo ceramic element, the element extends and shrinks diametrically. This characteristic of piezoelectric material is utilized to make the ceramic plate vibrate rapidly to generate sound waves.

There are two types of piezo buzzers - transducers and indicators. Transducers consist of a casing, a piezo ceramic element and a terminal. In order to operate a transducer, the user must send a square wave signal to the buzzer. Indicators consist of a casing, a piezo ceramic element, a circuit board and a terminal. In order to operate an indicator, the user must send the buzzer a specified DC voltage. Some CUI piezo buzzers include a feedback line. Driving circuits for buzzers with feedback tend to be simpler than those circuits without. Feedback is accomplished by dividing the piezo element into two, electrically isolated pieces. When the main piezo element is actuated, it squeezes the feedback portion, creating a voltage on the feedback line. A simple way to use feedback is to have the feedback line connected to the base of a transistor. As the piezo element oscillates, the feedback signal will oscillate and the transistor will alternately block or allow current to flow. The feedback line provides a voltage that is proportional to the strain on the main piezo element. This voltage can be used to create a simple, self-oscillating circuit.

Like piezo technology, magnetic buzzers are available in transducer and indicator configurations. In a magnetic buzzer, the transistor acts as the driving circuit. Indicators include the transistor, creating a tone when a dc voltage is applied. Transducers lack this transistor, requiring a square wave signal to operate properly. The vibrating disk in a magnetic buzzer is attracted to the pole by the magnetic field. When an oscillating signal is moved through the coil, it produces a fluctuating magnetic field which vibrates the disk at a frequency equal to that of the drive signal. *Table 19* shows a brief comparison on the buzzers.

Piezo Buzzer Characteristics	**Magnetic Buzzer Characteristics**
Wide operating voltage (3-250V)	Narrow operating voltage (1-16V)
Lower current consumption (less than 30mA)	Higher current consumption (30-100mA)
Higher rated frequency	Lower rated frequency
Larger footprint	Smaller footprint

Higher sound pressure level	Lower sound pressure level

Table 19: Piezo vs Magnetic Buzzer Characteristics

3.6.1 Buzzer Components

Piezo and magnetic indicators have the driving circuitry built into the design. The disadvantage, however, is that indicators operate on a fixed frequency, reducing the flexibility offered to achieve an alternate frequency as application requirements change. Transducers, on the other hand, do not have the driving circuit built-in, so engineers are offered a greater range of flexibility when designing their circuit. The downside comes in the fact that transducers do require an external driving signal to operate properly, potentially adding complexity and time to the design cycle.[47] A comparison between the two can be seen in *Table 20.*

Indicator Characteristics	Transducer Characteristics
Built-in driving circuit (frequency generator)	External driving circuit required
Simple to design-in	Complex to design-in
Fixed frequency (function)	User-selected frequencies or multiple frequencies

Table 20: Indicator vs Transducer Characteristics

There was an abundant variety of buzzers to pick from so it was determined that the easiest way to select a buzzer was to compare the ones that could be integrated into many other projects or ideas aside from our own. The following *Table 21* references our top picks.

Piezo Buzzers	CEP-2224	CMI-1240-SMT	CPE-224	CEP-2272A
Voltage Range	3 -20 V	3 - 20 V	9 -16 V	3 -20 V
Frequency	3.4 kHz	4.0 kHz	5.0 kHz	3.5 kHz
Operating Mode	Continuous	Continuous	Continuous	Continuous
Sound Pressure level	78 dB @ 12 V, 30 cm	83 dB @ 12 V , 30 cm	80 dB @ 12 V, 30 cm	93 dB @ 12 V, 30 cm
Current Consumption	15 mA	8 mA	35 mA	10 mA
Operating Temperature	(-)30°C - 85°C	(-)30°C - 70°C	(-)30°C - 85°C	(-)30°C - 85°C
Mounting Type	Through Hole	Surface Mount	Through Hole	Through Hole

Size/Dimension	24.0 mm Dia x 9.5 mm H	16.9 mm L x 16.9 mm W x 8.3 mm H	14.0 mm Dia x 10.5 mm H	31.3 mm Dia x 16.5 mm H
Price	$3.05	$3.19	$7.36	$4.23

Table 21: Piezo Buzzer Performance Characteristics Comparison

3.7 Response Button Switch

Push button switches consist of a simple electric switch mechanism which controls some aspect of a machine or a process. Buttons are typically made out of hard material such as plastic or metal. The surface is usually shaped to accommodate the human finger or hand, so the electronic switch can be easily depressed or pushed. Also, most Push Button Switches are also known as biased switches. A biased switch, can be also considered what we call a "momentary switch" where the user will push-for "on" or push-for "off" type. This is also known as a push-to-make (SPST Momentary) or push-to break (SPST Momentary) mechanism. Switches with the "push-to-make" (normally-open or NO) mechanism are a type of push button electrical switch that operates by the switch making contact with the electronic system when the button is pressed and breaks the current process when the button is released.[48] These type of buttons are utilized in calculators, kitchen appliances and various other mechanical and electronic devices, industrial and commercial applications. For HINTS’s purpose an ideal candidate button would be a decent size button that is appealing and visible enough to see from a couple feet away. The following table compares the few buttons that were found.

3.8 Wearable

Wearable technology is a category of electronic devices that can be worn on the body. It has become more popular within the last 3 years and it took an even bigger step forward with the release of the Apple Watch. For our wearable design we wish to implement a low powered notification supplement device with a primary purpose in user proximity detection. The method of the proximity detection selected (Wi-Fi, Bluetooth, ZigBee, or RFID) will impact the design constraints of the wearable because we have to take into account the hardware needed for each possible solution to make it possible, but the possible sensory outputs also need to be taken into consideration. Wearable’s today have a visual, auditory, and haptic notifications. These are what we will try to implement in our design.

3.9 Secure Digital Cards

As part of the system requirements, the central hub is to have a removable local data storage unit. The most feasible unit, for a balance of simple hardware, relatively simple software, and very low cost, is a Secure Digital (SD) Card interface.

SD cards are a variation of Flash memory. It has been standardized to store full files by implementing a file system in the memory. SD cards and their PCB connectors, called readers, come in a few different syles. The two most common types are standard SD cards and microSD. Since our central hub doesn't need to meet tight space requirements, and adapters exist from standard SD to microSD, a standard size card reader will be researched here and implemented in the design. Standard SD cards, which range up to 2 GB of storage, will meet the requirements for the data that we need to store. In addition, the slowest speed class (Class 2) defined by the SD standard will be more than sufficient for our design. Class 2 supports standard-definition video recording. HINT does not have data recording constraints.[49] This interface will be relatively low speed.

3.9.1 Readers

There is a wide variety of SD card readers on the market. They are relatively simple PCB mountable connectors with the nine necessary pins for the SD standard. All nine pins are standard among SD card readers, but can be used for different reasons depending on the mode the SD interface is running. *Table 22* shows the pin definition for the common modes.

Pin Number	SD Mode		SPI Mode	
	Pin Name	Description	Pin Name	Description
1	DAT3	Data Line 3	CS	Chip Select/Slave Select (SS)
2	CMD	Command Line	DI	Master Out/Slave In (MOSI)
3	VSS1	Ground	VSS1	Ground
4	VDD	Power	VDD	Power
5	CLOCK	Clock	CLOCK	Clock (SCK)
6	VSS2	Ground	VSS2	Ground
7	DAT0	Data Line 0	DO	Master In/Slave Out (MISO)
8	DAT1	Data Line 1	IRQ	IRQ/No Connect
9	DAT2	Data Line 2	NC	No Connect

Table 22: Pin Definition for SD Card Readers[50]

Below are a few SD Card reader options that are suitable for the HINT Design.

Farnell SDBMF: This SD card reader is a simple PCB add-on with nothing more than the nine SD pins and three switches. The switches support write locking, unlocking, and card detection.

Yamaichi FPS009: This SD card reader contains options for card detection and write protection (model FPS009-3001-BL). Write protection is a configurable switch.

3.9.2 File System

A file system must be implemented on the SD card to ensure blocks of memory are recognized as actual files. This may be useful if we save HINT logs in the SD card as simple text or comma-separated value (CSV) files. For this reason, and for SD card interfacing with a personal computer (PC), a file allocation table (FAT) file system is preferred. Specifically, a file system called Petit FatFS will be ideal. This sytem was designed for smaller controllers, much like HINT's MCU. This file system also stores data to a single file, which is ideal, as a single HINT system keeps only one log of data. The minimum file size support will be sufficient for the amount of data HINT intends to store. Ranging from 2 KB to 4 KB, the amount of code the file system requires is feasible. This is one of the two main functions of the central hub, so the memory will be safely allocated.

3.10 Host Controller Interface (HCI)

HIC consist of a register-level interface with a Host Controller Driver (HCD) and a Host Controller (HC).[51] Software for the HCD is responsible for posting and maintaining transactions in system memory on a USB, and controlling its traffic. The HC is responsible for moving data within the system memory and to devices on the USB. A HCI is important to our design because we cannot just plug in a USB cable to a port on the PCB and route it to pins on an IC. In other words, we cannot expect to program directly over USB, but rather have to have the date infrastructure to support the communication interface interpretation between USB and the serial interface an IC may use. Specific I/O registers are mapped that allow communication to occur between the controller and the operating system. Standard registers are USB command, USB status, USB IE, Frame Number, Frame List Base Address, Start of Frame Modify, and Port ½ Status and Control.[51]

3.11 Data Conversion

3.11.1 Analog to Digital Converters

An Analog to Digital converter (ADC) is an electronics device that converts a continuous physical electrical quantity to a digital value. There are two parameters to control in doing this conversion, the sampling rate which controls the number of samples taken in a second, and sampling precision which controls the number of quantization levels for the sampling process. The input to an ADC consists of voltage that varies among a theoretically infinite number of values such as different types of waveforms. The output of an ADC has defined values or states such as the simplest digital signals, which are two states and can be defined as binary. Digital signals propagate more efficiently than analog signals, largely because digital impulses which are well defined and orderly, are easier for electronic circuits to distinguish from noise. An analog signal is sampled at a specified rate to get the digital value of the amplitude of the signal. The higher the sampling rate is, the more data points there is per second, thus, a much more accurate representation of the analog signal. However, the higher the sampling rate, the more space it takes to store data. The Nyquist theorem is a good balance between storage and quality, it states that the sampling rate of an ADC must be at least two times the highest frequency wanted to be captured.[52]

3.11.2 Digital to Analog Converters

A Digital to Analog Converter (DAC), is an electronic device that converts a digital code to analog signal such as a voltage, current, or electric charge. Signals can be easily stored and transmitted in digital form, this process is done so that signals can be recognized by human senses or non-digital systems. Converting a signal from digital to analog can degrade the signal, thus, a DAC should be specified that has insignificant errors in terms of the application. Due to their cost, digital to analog converters are mostly manufactured on an integrated circuit (IC). The suitability of a digital to analog converter for a particular application is determined by several attributes such as speed and resolution.

3.12 Antennas

An antenna is a specialized transducer that converts RF fields into AC or vice-versa.[53] When transmitting a current is supplied to the antenna terminals at an oscillating frequency which in turn generates electromagnetic waves. When receiving, the electromagnetic waves are intercepted by the antenna which converts the energy to AC voltage at its terminals.[53] The wireless communication frequencies we would use would either be 2.4 GHz (ZigBee/Bluetooth) or above 860 MHz .

A UHF frequency range antenna would need to be purchased from a vendor as we do not have the resources to fabricate one ourselves. They come with a connector fixed on one end, usually pin/coaxial. Implementing a UHF antenna into our design would require our PCB design to incorporate appropriate a coaxial input to the compatible IC. For frequencies that are below 3 GHz there are many possible antennas that can be used, but the simplest one to implement is a simple wire of certain length. It can also be integrated into the PCB as a simple wire antenna. A PCB antenna is a trace on a circuit board that can either be straight, inverted F-type, meandered, circular, or a curve design. This method of implementing an antenna into our design would be the most cost effective.

3.12.1 Antenna Design

There are a few key design parameters that need to be taken into account when designing a PCB antenna. These parameters include return loss, bandwidth, radiation efficiency, radiation pattern, and gain.[54]

Return Loss: The return loss performance of the antenna indicates how well the transmission line at 50 Ω is matched to the antenna. A standard industry 50 Ω value is used for impedance matching across the industry. If an antenna is perfectly matched then will not reflect any energy ($P_{reflected}$), but radiate it entirely.[54]

An antenna with an infinite return loss is perfectly matched to the transmission line. A general rule is that if the return loss is ≥ 10 dB, then it is considered sufficient. At 10 dB of return loss there is approximately 90% of the incident power ($P_{incident}$) directed into the antenna for radiation. Return loss can be calculated by using the following formula:

$$Return\ Loss\ (dB) = 10\log(\frac{P_{incident}}{P_{reflected}})$$

Bandwidth: The frequency response of an antenna is indicated by bandwidth. Between the 2.40 GHz and 2.48 GHz frequencies, it will signify how well the transmission line is matched to the antenna over the entire band of interest.[54]

Radiation Efficiency: When there is power that is non-reflected it can be dissipated in the form of thermal loss in the antenna, or heat. When all non-reflected power is radiated efficiently into the free space around the antenna it has a radiation efficiency of 100%. With a PCB antenna there is not a concern for heat loss because it is of such a small form factor already.[54]

Radiation Pattern: The direction of how the waves are propagated from the antenna is known as radiation pattern. Orientation of the antenna is important because we need to know how the waves are traveling to be picked up by receiving antennas. Radiation patterns vary depending on the antenna design and in order to determine patterns, adequate design is needed.

Gain: dBi stands for decibels isotropic and it is an indicator of how strong the field of radiation is compared to an ideal scenario. The gain of an antenna provides the radiation in the direction of interest.[54]

3.13 Power

For the realization of our project we need to have a sufficient power supply for all three of our components. Each one may be powered in a different manner and therefore we needed to find the right method of providing power to our project's components. The wearable will need to be powered by some type of battery, while the module and hub may be powered through a standard home electrical socket. The following sections discuss the research of batteries and AC/DC power supplies.

3.13.1 Button Cell – Coin Battery

We are looking at disposable button cell batteries because of the convenience they provide in size and the ability to dispose of them after they have been drained of their charge. Button cells come in various sizes ranging in a diameter from 5 to 25 mm and a height from 1 to 6 mm. The voltages for these types of batteries range from 1.5V to 3.7V which would power most of our communication options.[55] The selection of the battery will depend on the selection of the components for the wearable. Typical cost for coin batteries are less than $2 for an individual battery, but can vary per tray for the different variations that there are.

3.13.2 Rechargeable Batteries

Rechargeable batteries have the advantage of being reused after their charge is depleted. This makes rechargeable batteries a better choice over disposable batteries for the ease of not having to constantly replace batteries when they die. The sizes and capacities they are also available in range vastly, allowing for the selection of a battery that will meet power and design requirements a little easier for a design. Rechargeable batteries can be made in various compositions. These compositions include: Nickel Cadmium (NiCd), Nickel-Metal Hydride (NiMH), Lead Acid, Lithium Ion (Li-ion), Lithium Ion Polymer (Li-ion Polymer).[56] The performance characteristics and differences for each battery type are summarized in *Table 23*: Battery Performance Characteristics Comparison.

Battery	NiCd	NiMH	Lead Acid	Li-ion	Li-ion Polymer
Internal Resistance (mΩ)	100 - 200	200 - 300	<100	150 - 250	200 - 300
Cycle Life (80% Life)	1500	300 - 500	200 - 300	500 - 1000	300 - 500
Fast Charge Time (H)	1	2 - 4	8 - 16	2 - 4	2 - 4
Overcharge Tolerance	moderate	low	high	very low	low
Self-discharge / Month	20%	30%	5%	10%	10%
Cell Voltage (V)	1.25	1.25	200 - 300	3.6	3.6
Load Current [C]	20	5	5	>2	2
Operating Temperature (Celsius)	-40 - 60	-20 - 60	-20 - 60	-20 - 60	0 - 60
Maintenance Required	30 - 60 days	60 - 90 days	3 - 6 months	not required	not required
Battery Cost	$50 (7.2V)	$60 (7.2V)	$25 (6V)	$100 (7.2V)	$100 (7.2V)
Cost per Cycle	$0.04	$0.12	$0.10	$0.14	$0.29

Table 23: Battery Performance Characteristics Comparison
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NiCd – This type of battery is a popular choice for applications like two-way radios, biomedical equipment, power tools, etc. These batteries generally have a low energy density. They are typically best used where a high discharge rate, long life, and low cost are important. These are not environmentally friendly as they contain toxic metals. See *Table 24*: NiCd Advantages vs Disadvantages for brief expansion on advantages and disadvantages.

Advantages	Disadvantages
Increased charging rate	Low energy density provided
Estimated 1000 charge cycles	Subjected to memory effect
Lowest cost battery available for longevity provided	Environmentally unsafe - contains metals that are toxic
Plethora of sizes available	High rate of self-discharge

Table 24: NiCd Advantages vs Disadvantages

NiMH – Compared to NiCd these have a higher energy density and are more durable, at the trade off cost of a reduced life cycle. No toxic metals are present in this battery and some applications include laptops and mobile devices, replacing NiCd batteries. See *Table 25*: NiMH Advantages vs Disadvantages for brief expansion on advantages and disadvantages.

Advantages	Disadvantages
Capacity over NiCd is 30-40% higher	Service life is limited over repeated deep cycling - leads to shorter life
Higher energy density compared to NiCd	High heat generation while charging - trickle charging is critical
Less susceptible to memory effect	50% high self-discharge rate
Environmentally safe - can be recycled	More costly compare to NiCd

Table 25: NiMH Advantages vs Disadvantages

Lead Acid – The most cost effective battery for larger power applications where weight is of little concern. This battery can be found in cars, boats, lighting, hospital equipment, etc. They can be low cost, can deliver high currents, and have low internal impedance. See *Table 26*: Lead Acid Advantages vs Disadvantages for brief expansion on advantages and disadvantages.

Advantages	Disadvantages
Low self-discharge rate - one of the lowest compared to all	Low energy density
Need for maintenance is low	Discharge cycles are limited

Provides durable and dependable service	Environmentally unsafe - lead and electrolyte content can damage the environment
High discharge rates are capable	Susceptible to thermal runaway

Table 26: Lead Acid Advantages vs Disadvantages

Li-ion – Lithium ion batteries have plenty of benefits like a very high power density, high cell voltage, low weight, and long life cycles. Energy density is twice that when compared to a standard NiCd. Capacity varies so it is easier to find one to meet any application. They require a protection circuit though for safety. The circuit limits the peak voltage of each cell while charging and also prevents the voltage from dropping too low when discharging. See *Table 27*: Li-Ion Advantages vs Disadvantages for brief expansion on advantages and disadvantages.

Advantages	Disadvantages
High energy density	Protection circuit required
Self-discharge rate is low	Subjected to aging whether in use or not
Plethora of sizes available	Changing in chemical makeup affect battery

Table 27: Li-Ion Advantages vs Disadvantages

Li-ion Polymer – This battery offers the benefits of the Li-ion battery except in an ultra-slim form with simplified packaging. More stable and less vulnerable to problems caused by overcharging, damage, or abuse. They are most commonly used in mobile phones. See *Table 28*: Li-Ion Polymer Advantages vs Disadvantages for brief expansion on advantages and disadvantages.

Advantages	Disadvantages
Low profile form - comparable to that of a credit card	Low energy density
Light weight	
More resistant to overcharging	

Table 28: Li-Ion Polymer Advantages vs Disadvantages

3.13.2.1 Battery Compare

It has been determined that a rechargeable battery would be best for the wearable to avoid any problems that would be encountered when replacing a coin cell battery. A rechargeable battery can also provide a longer battery life compared to a coin cell. We have narrowed it down to a lithium ion polymer battery from the above possible selections. Two batteries have been selected as candidates to fulfill our power needs for the wearable.

Battery	LP 503035	LP 503562

Capacity	500 mAh	1200 mAh
Nominal Voltage	3.7 V	3.75 V
Charging Voltage	4.2 V	4.2 V
Standard Charge	Constant Current: 0.2 C5A Constant Voltage: 4.2 V Cut-off Current: 0.01 C5A	0.2 C5A
Standard Discharge	Constant Current: 0.2 C5A End Voltage: 3.0 V	0.5 C5A Cut-off Voltage: 2.75 V
Operating Temperature	Charge: 0—45° C Discharge: -20—45° C	Charge: 0—45° C Discharge: -20—45° C
Cycle Life	> 500	> 400
Dimensions	29 x 36 x 4.75 mm	34 x 62 x 5 mm

Table 29: Li-ion Polymer Battery Compare provides the comparison information.

Battery	LP 503035	LP 503562
Capacity	500 mAh	1200 mAh
Nominal Voltage	3.7 V	3.75 V
Charging Voltage	4.2 V	4.2 V
Standard Charge	Constant Current: 0.2 C5A Constant Voltage: 4.2 V Cut-off Current: 0.01 C5A	0.2 C5A
Standard Discharge	Constant Current: 0.2 C5A End Voltage: 3.0 V	0.5 C5A Cut-off Voltage: 2.75 V
Operating Temperature	Charge: 0—45° C Discharge: -20—45° C	Charge: 0—45° C Discharge: -20—45° C
Cycle Life	> 500	> 400
Dimensions	29 x 36 x 4.75 mm	34 x 62 x 5 mm

Table 29: Li-ion Polymer Battery Compare

3.13.3 AC/DC Power Supply

Electrical sockets in the United States supply electricity from 110V to 120V AC. In order to use the power provided by the electrical socket we would need an AC to DC converter. They are designed by using diodes to rectify the signal coming from the socket. A full-wave or bridge rectifier with smoothing capacitor can be utilized to provide the power conversion we need. A bridge rectifier is more efficient in converting the input signal so that is what we would use to design our own converter. In *Figure 4* you can see the setup of the rectifier circuit.

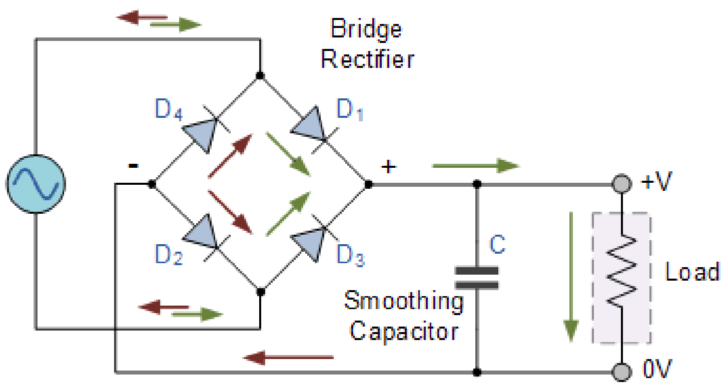

Figure 4: Full-wave Bridge Rectifier Circuit
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The design requires 4 diodes to fully rectify the input signal efficiently. In the circuit there is a ‘smoothing capacitor’. It is there to provide a discharge between peak to peak waves, and in turn this converts the signal to a DC signal. The capacitor value needed varies depending on the input voltage. In *Figure 5* you can view the output waveform of a rectified AC signal.

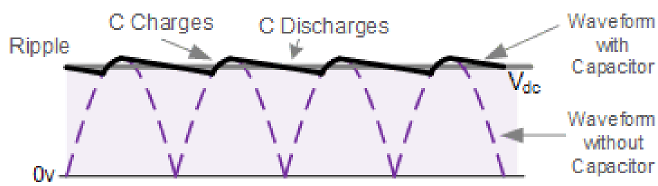

Figure 5: Bridge Rectifier Output Waveform
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If we choose not to design an AC to DC converter to suit our projects needs, we can purchase one off the shelf. Commercial off the shelf converters are readily available and can be purchased anywhere. They are already designed in a wide range of power ratings and some come with end adapters to fit any need. The advantages of an off the shelf adapter include safety, heat reduction, electrical noise reduction, weight, and versatility. In not designing a power supply we gain the advantage of obtaining one that is compliant to the IEEE standard 1823-2015 already. Eliminating the headache of designing one ourselves.

3.13.4 Voltage Regulators

A voltage regulator is a circuit that maintains a constant output voltage, regardless of the load it is driving. Since DC voltage regulators serve as an option to increase, decrease and invert voltage levels, they will be highly needed for different components of our system that require specific voltage levels. There are linear and switching voltage regulators, for our applications we will explore the two and choose which will be more useful with our design.

Switching Voltage Regulators: The switching regulator is increasing in popularity because it offers the advantages of higher power conversion efficiency and increased design flexibility (multiple output voltages of different polarities can be generated from a single input voltage). It uses a switching element to convert an input into time-varying (AC) voltage or current, then transforms it into a differential voltage using elements such as inductors and capacitors and converts it back to a DC voltage. The action of transformer is such that a time-varying voltage or current is transformed to a higher or lower value. The transformer does not add power, so it follows that the power on either side must be constant. That is the reason that the winding with more turns has higher voltage but lower current, while winding with less turns has the opposite

Linear Voltage Regulators: Linear voltage regulators are the simpler regulators of the two and operate by sending a voltage to the output via a current source. Linear regulators can only step down voltage using resistive voltage drops to change the voltage. The voltage drop across a voltage regulator is a loss of power in the form of heat, and if the output voltage is much lower than the input voltage, then too much heat may be dissipated. This can potentially be a problem if the amount of heat released is higher than the operating temperature of the device and connections. The output power is directly proportional to the difference of voltages. Additionally, control of external circuit temperature can be cooled using a small fan or reducing the ambient room temperature. If the temperatures cannot be controlled, heat sinks can be used to help dissipate the excess heat. *Table 30* has the advantages vs disadvantages summary.

Advantages	Disadvantages
Low complexity and low cost	Only operable in a step-down configuration
Small form factor with many integrated options	Low efficiency
Low noise and high ripple rejection	High heat diffusion

Table 30: Linear Voltage Regulator Advantages vs Disadvantages

Measuring Regulator Efficiency: The efficiency of a switching regulator is defined as

$$\eta = P_{LOAD}/P_{TOTAL}$$

In determining converter efficiency, the first thing that must be measured is the total consumed power (P_{TOTAL}). Assuming a DC input voltage, P_{TOTAL} is defined as the total power drawn from the source, which is equal to:

$$P_{TOTAL} = V_{IN} \times I_{IN(AVE)}$$

The input current will not be sinusoidal nor be DC, it must be the average value. Since the total power dissipated must be constant from input to output, $P_{TOTAL}$is also equal to the load power plus the internal regulator power losses.

$$P_{TOTAL} = P_{LOAD} + P_{LOSSES}$$

Switching Regulator Applications: This section will cover information to keeping mind in order to enhance ability to maximize switching regulator performance. Capacitor parasitic affect switching regulator performance. All capacitors contain parasitic elements which make their performance less than ideal. A couple effects of parasitic are the Equivalent Series Resistance (ESR), and the Effective Series Inductance (ESL). The ESR causes internal heating due to power dissipation as the ripple current flows into and out of the capacitor, therefore making the capacitor fail if it exceeds maximum ratings. The ESL limits the high frequency effectiveness of the capacitor. High ESL is the reason electrolytic capacitors need to be bypassed by film or ceramic capacitors to provide good high-frequency performance.

A vast majority of switching converters operate as DC-DC converters that chop a DC input voltage at a very high frequency. As the converter switches, it has to draw current pulses from the input source, thus the source impedance is extremely important because it can cause significant ringing and spiking on the voltage at the input of the converter. To conclude, for input capacitors is always best practice to provide adequate capacitive bypass as near as possible to the switching converter input.

The primary function of the output capacitor in a switching regulator is filtering during operation because current must flow in and out of the output filter capacitor. The ESR of the output capacitor directly affects the performance of the switching regulator. ESR is specified by the manufacturer on good quality capacitors, but we must be certain that it is specified at the frequency of intended operation. Some ESR dependent parameters are the ripple voltage, efficiency, and loop stability.

High-frequency bypass capacitors are always recommended on the supply pins of IC devices, but if the devices are used in assemblies near switching converters bypass capacitors are absolutely required. Proper grounding in a circuit is also absolutely essential. Components which perform high speed switching generate significant EMI that easily radiates into PCB traces and wire leads. To assure proper circuit operation, all IC supply pins must be bypassed to a clean, low inductance ground. *Table 31* has the advantages vs disadvantages summary.

Advantages	Disadvantages
Functional flexibility	Large size and difficult to implement
High efficiency	High cost
Low heat dissipation	Medium to high noise

Table 31: Switching Voltage Regulator Advantages vs Disadvantages

Regulator Decision: A linear voltage regulator designed by us can be seen in *Figure 6*. This is an example of a regulator with output voltage regulated down to 3V. With the circuit below we can manipulate the resistor values to provide any regulated output needed, provided it is lower than the input voltage. To calculate the output voltage, we will use the following formula and our circuit diagram below (Vcc is the positive rail voltage of op amp):

$$Vcc \times \frac{R4 + R5}{R5} \times \frac{R3}{R3 + R4}$$

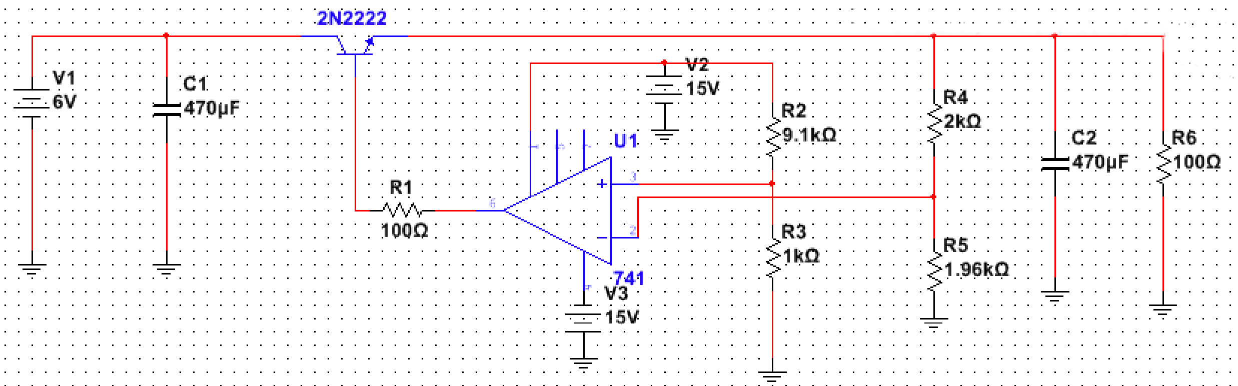


Figure 6: Linear Voltage Regulator Design

If we don't design a regulator, we have the option of purchasing one from a vendor since linear voltage regulators are pretty common in the industry. The IC linear regulator is so easy to use and inexpensive that it is usually one of the cheapest components in an electronic assembly.

3.14 Software

Software will be needed for both designing the system and loading onto the different MCUs of HINT. Software to support system design will include computer aided design (CAD) tools and integrated development environment (IDE) suites. Eagle CAD is the preferred CAD tool for schematic capture and board layout. Depending on the MCUs being used, different IDE's may be required. The two preferred software packages would the Arduino IDE for any ATMega328 MCUs in the design and T.I. Code Composer Studio (CCS) for any T.I. MCUs.

The software being loaded onto the MCUs can be written in the C language or assembly code. Through the MCU research conducted, a part can be picked to fit compiled and assembled C code in it. Assembly code may be reserved for last-resort system optimization or memory reduction.

Research has shown that various code libraries, either supplied or designed, may be needed in the HINT design.

Central Hub

- Wireless Communication Stack
- SD Card Library

Module

- Wireless Communication Stack
- LCD Driver
- Range Detection Library

Wearable Device

- Wireless Communication Stack

3.15 Packaging

Packaging is, by definition, processes and materials employed to contain handle, protect, and/or transport an article. The packaging of a product also includes the design as to make it more appealing to customers. For our purposes we will be aiming to drive down the cost of our packaging by housing the components in the most cost effective method possible. This includes selecting a material with the lowest cost and making the design as small as possible to stay within financial constraints. To design the housing for all components we will be using SOLIDWORKS as it is readily available to all of the group members. There were two methods that came to mind in manufacturing the housing for all the devices, 3D printing and wood manufacturing.

With 3D printing the rendered housing from SOLIDWORKS could be submitted directly to a vendor that could fulfill our order. Depending on the vendor we would have the housings mailed back to us within two weeks. The problem with 3D printing is that it gets expensive very fast. For an object measuring 6.03 x 8.20 x 8.20 cm the average cost is between $50 - $60, depending on the vendor. Our solution to this would be to minimize the sizes of the PCBs, but since they are not designed yet we have no way of knowing what we can do in terms of design. Using the approximate constraints our total for 3D casing for housing rises well about $250.

Wood has the benefit of being readily available from a department store and is usually very cheap. A piece of ¼" thick plywood measuring 4' x 8' cost a $20, and this is the lowest cost available. With this much material it would be possible to fabricate a housing for the module and central hub, but no the wearable because of the design constraints. The negative to doing it this way is that we would have to manually cut the wood with tools and design by hand. There is a large margin of error for our team in doing this as none of us have wood working experience. Estimated cost for going with this decision would be $20 plus an additional amount for the wearable housing.

4 Project Design Details

The following sections contain the design details for the central hub, module, and wearable device. The design can be broken down further into electronic hardware, mechanical PCB design, and software and firmware.

4.1 Electronic Hardware Design

Electronic hardware design refers to the electronic components and any electrical characteristics This accounts for communication interfaces and techniques between such components, even wireless communication. The final design results in board-level schematics.

4.1.1 Central Hub

The central hub consists of a single PCB and is dedicated solely for system control, programming, and data storage.

4.1.1.1 Block Diagram

Below is the technical block diagram for the central hub, including interfaces and the major components on the PCB.

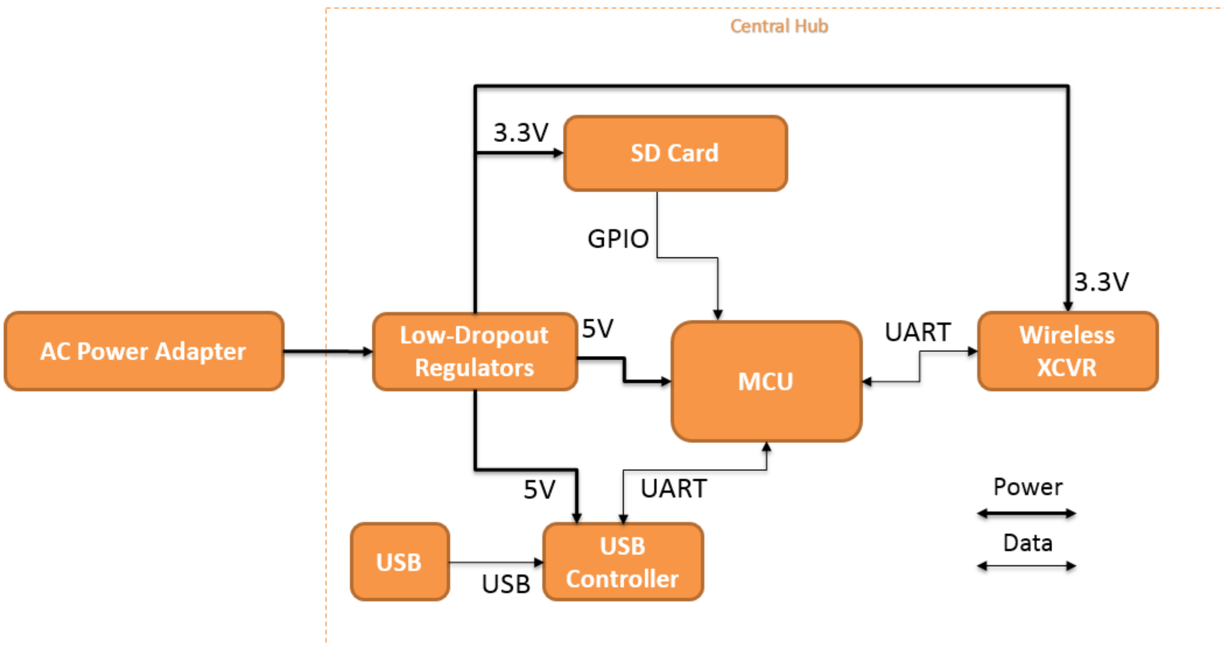


Figure 7: Central Hub Block Diagram

4.1.1.2 Components

The central hub is the simplest PCB in the HINT design. For that reason, half of the component selection is based on a reference design. For example, the USB controller is the current programming and debugging option and is based off of the Arduino Uno open source hardware. Another (even simpler) option is to run a JTAG interface from the MCU to headers on the PCB. This will be the alternate option if the USB controller integration proves to be burdensome. The USB controller design is not described in detail in this section.

Microcontroller: The ATMega328P has been chosen for the original design. It is the lowest cost MCU that can support all the required peripherals with minimal support from supplementary ICs. In addition, the ATMega can be prototyped very easily with its DIP-28 package and the availability and low cost of its development board, the Arduino Uno.

Table 33 below displays the architecture of the ATmega and the embedded peripherals in the device. With all the capability, it is worth the price.

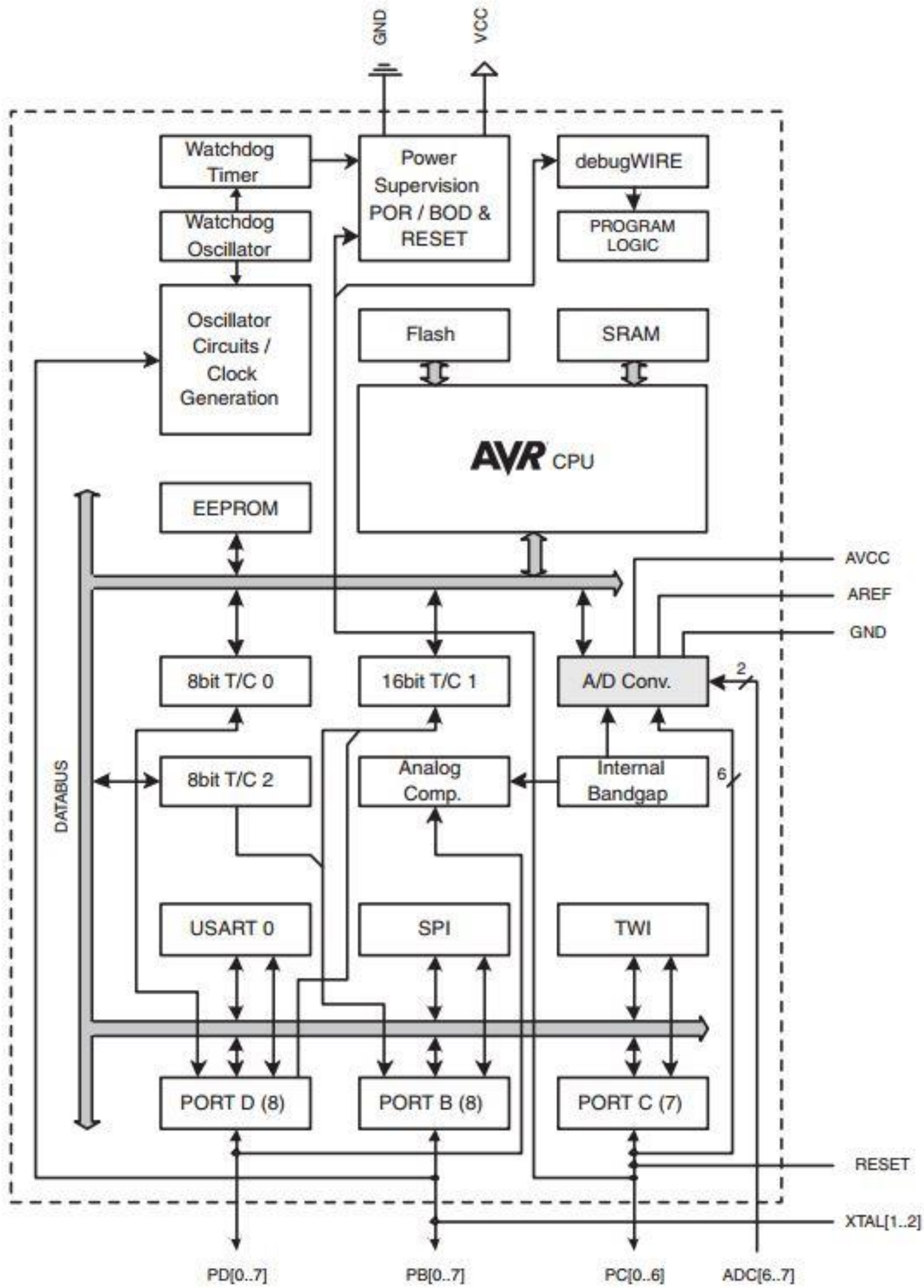


Figure 8: ATmega328P Architecture
Pending permission from Atmel

The heavy load peripherals the ATmega is driving are the SD card reader and the ZigBee transceiver. It is expected that the supporting code to initialize and run these interfaces will fit in the given amount of Flash and run on the given amount of RAM.

Power Supply: For the implementation of the power supply unit, it is necessary to know the total power consumption of all the components in the module in order to select an appropriate part. An AC-DC power supply was selected, since a wall adapter will reduce the amount of space allocated on the PCB, as well as reduction of soldering required for production.

Wireless Transceiver: The 802.15.4 RF Module (RFM) was selected for the module component of this project. This specific part is the Digi International WRL-11215 module. This part was selected because it offered the easiest integration into our design by providing a through-hole solution for ZigBee communication. The functionality of using RSSI to detect user presence provided on this module also aided in its selection. The module will remain in an 'ON' state to continuously monitor RX signal strength of the wearable. Once the RSSI detects a value within a pre-programmed threshold, it will send out a digital signal to the wearable to activate the notification features. There will also communication through this module with the central hub so pre-programmed tasks can be set up through this interface. It will be driven by the ATMega328P since it needs an external controller for functional use. For our functional purpose, we will be using several pins on the RFM. Pin assignments can be seen in *Table 32*. Pins 2 & 3 will be used to communicate with the MCU over the UART communication interface. Pin 6 will be used in the aid of user proximity detection through the RSSI feature. Digital pin 4 will be used in conjunction with pins 12 & 16 to send out wireless communications. *Figure 9* shows a pinout top view of the module.

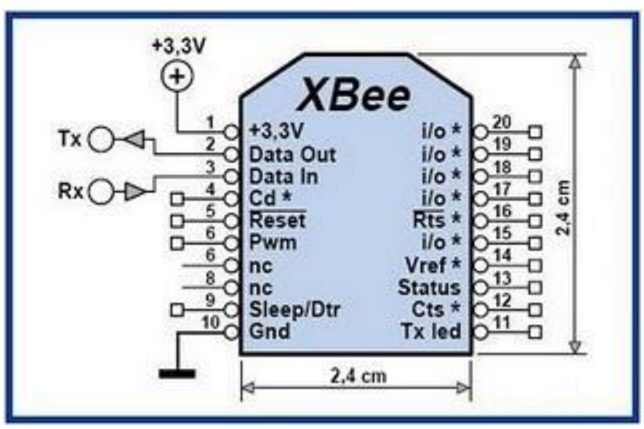


Figure 9: XBEE WRL-11215 Pinout (Top View)
Pending permission from Tech Help Blog

Pin #	Name	Direction	Description
1	VCC	-	Power supply
2	DOUT	Output	UART Data Out
3	DIN / CONFIG	Input	UART Data In
4	DO8*	Output	Digital Output 8
5	RESET	Input	Module Reset (reset pulse must be at least 200 ns)
6	PWM0 / RSSI	Output	PWM Output 0 / RX Signal Strength Indicator
7	PWM1	Output	PWM Output 1
8	[reserved]	-	Do not connect
9	DTR / SLEEP_RQ / DI8	Input	Pin Sleep Control Line or Digital Input 8
10	GND	-	Ground
11	AD4 / DIO4	Either	Analog Input 4 or Digital I/O 4
12	CTS / DIO7	Either	Clear-to-Send Flow Control or Digital I/O 7
13	ON / SLEEP	Output	Module Status Indicator
14	VREF	Input	Voltage Reference for A/D Inputs
15	Associate / AD5 / DIO5	Either	Associated Indicator, Analog Input 5 or Digital I/O 5
16	RTS / AD6 / DIO6	Either	Request-to-Send Flow Control, Analog Input 6 or Digital I/O 6
17	AD3 / DIO3	Either	Analog Input 3 or Digital I/O 3
18	AD2 / DIO2	Either	Analog Input 2 or Digital I/O 2
19	AD1 / DIO1	Either	Analog Input 1 or Digital I/O 1
20	AD0 / DIO0	Either	Analog Input 0 or Digital I/O 0

Table 32: ZigBee RF Module Pin Assignments

Secure Digital Card Reader: The SD Card reader chosen for the initial design was the Yamaichi FPS009-3001-BL. It is a simple interface that can be connected to the MCU via a SPI interface or the SD Standard interface (GPIO). *Figure 10* below shows the current design, using the SD Standard, but open to change.

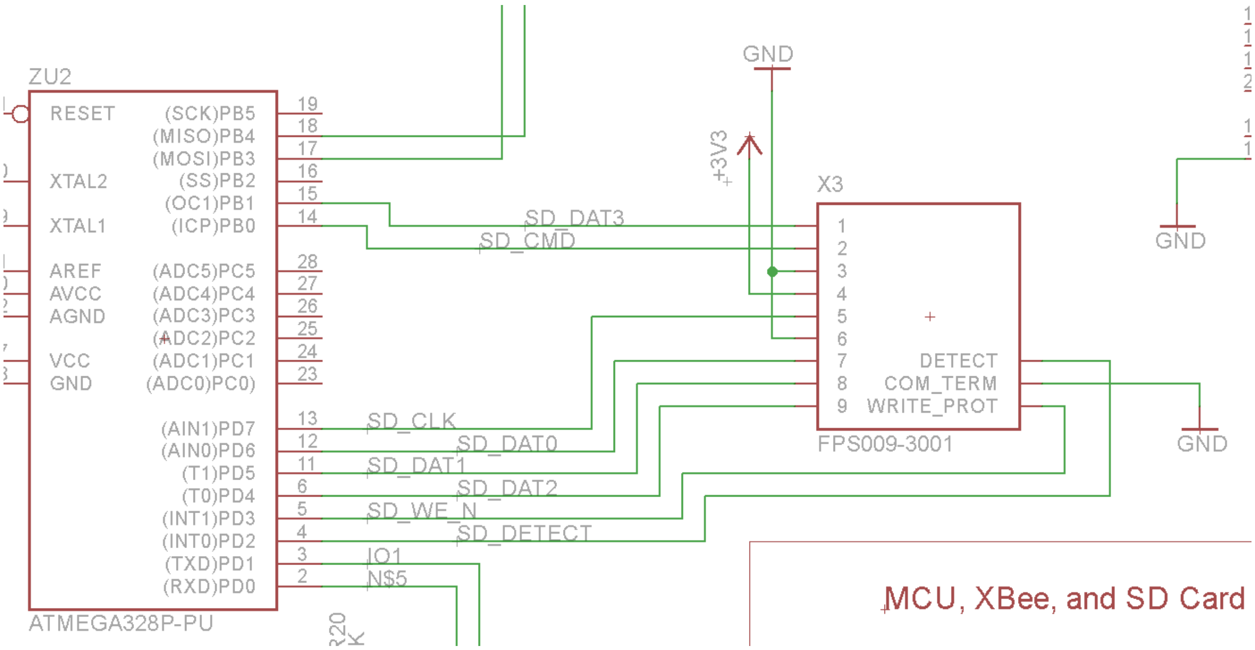


Figure 10: SD Card Reader Interface

The write protection line is driven as an inverted "write-enable" signal from the MCU. The detect signal will alert the MCU if an SD card is present in the reader. The rest of the signals define the SD standard interface, defined in section section 3.9.1.52

4.1.2 Module

For this project, the primary job of the module is to utilize a sensory output notification system when a user is detected. It will work in conjunction with the wearable through a ZigBee communication interface. When a user is detected by the motion sensor, and a predetermined RSSI value is met, there will be an output signal sent to the components on the module. A signal will also be sent to the wearable to enable notification components to initiate their respective functions.

4.1.2.1 Block Diagram

Below is the technical block diagram for the module, including interfaces, and the major components on the PCB.

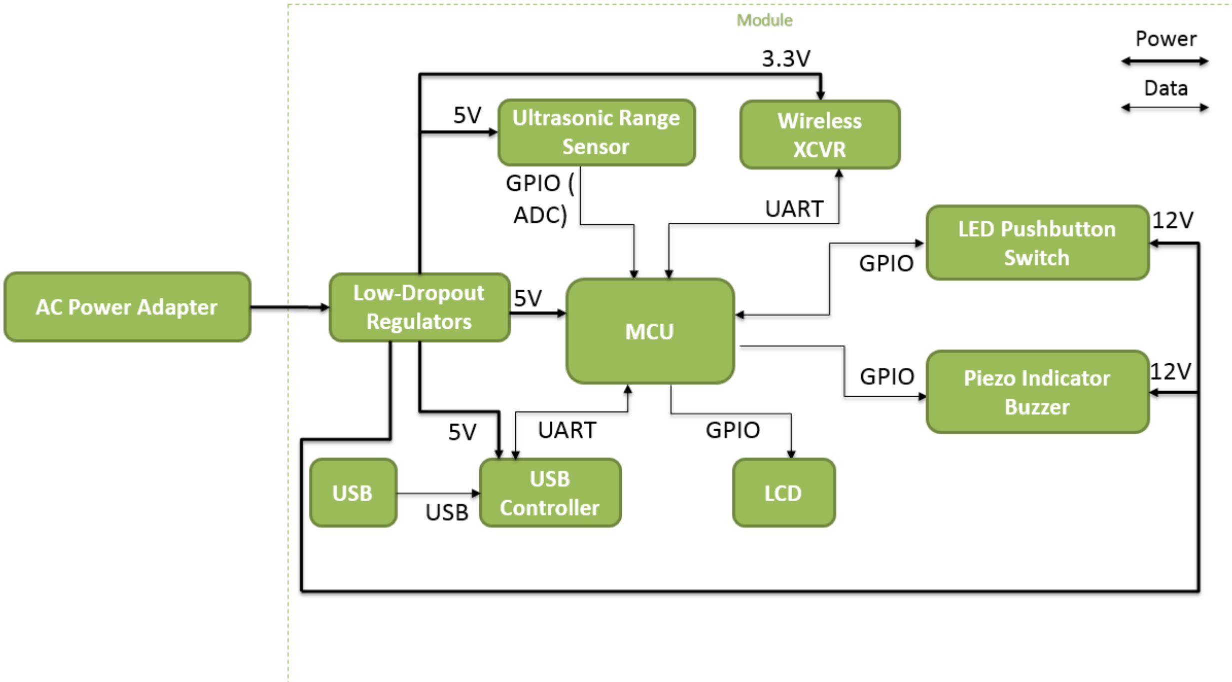


Figure 11: Module Block Diagram

4.1.2.2 Components

This section will specify final components chosen to implement the module portion of this project and their implementation.

Microcontroller: The MCU chosen for the original design of the module is also the Atmel ATmega328p. Please reference the central hub design section for more info on why this is a good option. The MCU in this design has a heavier load, but it is expected to suffice. If there is any memory issues (or other issues for that matter) presented during prototyping, alternate options presented in the research section will be explored.

Wireless Communication: The wireless communication chip and protocol selected for the module is also the ZigBee component Digi WRL-11215. In this design, the module will be running RSSI measurements, so it has a slightly different purpose. This schematic also needs the RSSI output hookup on the schematic, as show in *Figure 12*.

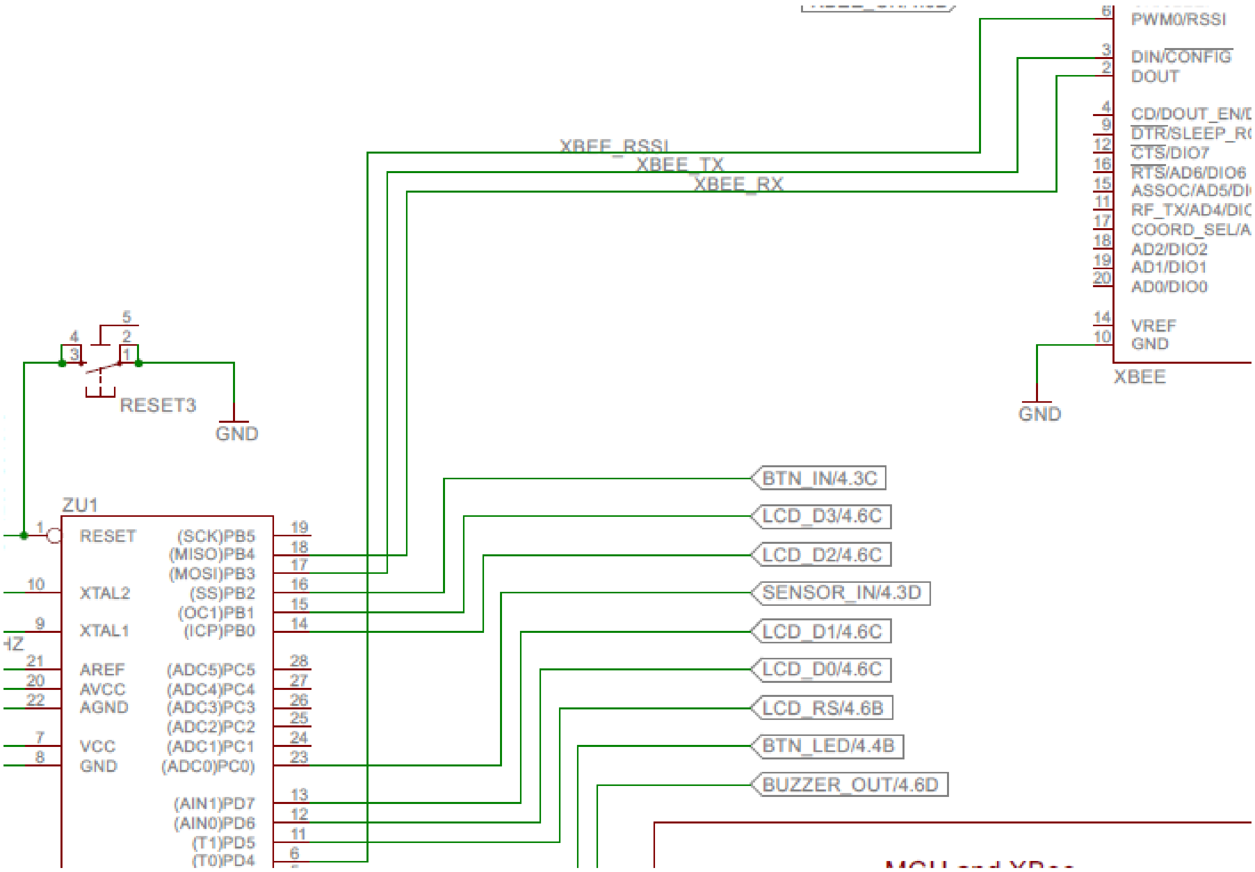


Figure 12: ZigBee RSSI Schematic Hookup

Motion Sensor: The sensor chosen for this project is the MaxBotix LV-EZ0. This sensor was chosen over the Parallax PIR motion sensor mainly due because we need to utilize a sensor for distance calculation over a broad distance detection range. This is so that the group can successfully output tasks on the module's LCD display in a timely manner for the user. This high performance sonar range finder provides very short to long-range detection and ranging in a very small package. It is specifically great for people detection, distance measuring, and proximity zone detection.

A couple benefits of this sensor is that mounting holes are provided on the IC, it is a very low power ranger, it reports the range reading directly freeing up user processor, and we are able to choose either pulse width, analog, and RS232 serial outputs to our convenience. Some of the most significant features include its free run operation that can continually measure and output range information, RoHS compliant, triggered operation provides the range as desired, and it is designed for protected indoor environments, which covers all the functionalities the sensor is intended to be used for. *Figure 13* shows the LV-MaxSonar component we will be utilizing.

Figure 13: LV-MaxSonar-EZ0
Reprinted with permission of MaxBotix

In the design, the sensor signals will be ported through a header to a hole in the module packaging, as shown in *Figure 14*. Note that we are using the analog output pin of the sensor. This requires only a single pin to the MCU. Also note the resistor and capacitor that compose the protection circuit defined by MaxBotix.

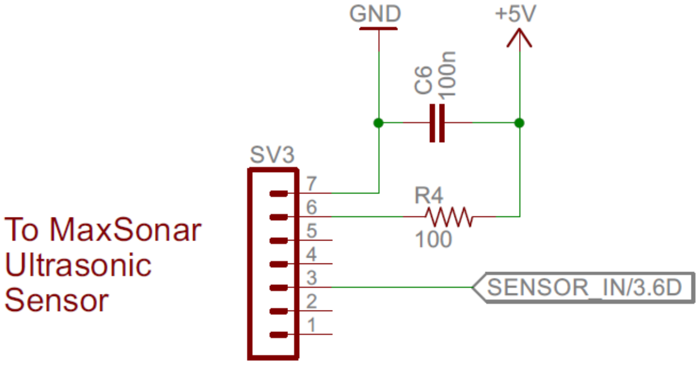


Figure 14: Ultrasonic Sensor Schematic

LCD: The LCD chosen was a simple 2 x 16 character segmented array. Our design doesn't need any heavier duty display. The display is the Electronic Assembly DIP162. The DIP package of the module allows for easy system integration. The four-bit interface allows for low MCU peripheral consumption. *Figure 15* shows the schematic of the LCD, with R18 being a current limiter for the LED backlight display. The LED backlight (between pins A and C) has roughly a 3.0V drop and cannot exceed 45 mA. The 1kΩ resistor was chosen, knowing that it has a good safety net for not exceeding that current rating. With a 1.7V drop onR18, the current through the led backlight pins will be limited to roughly 0.2 mA.

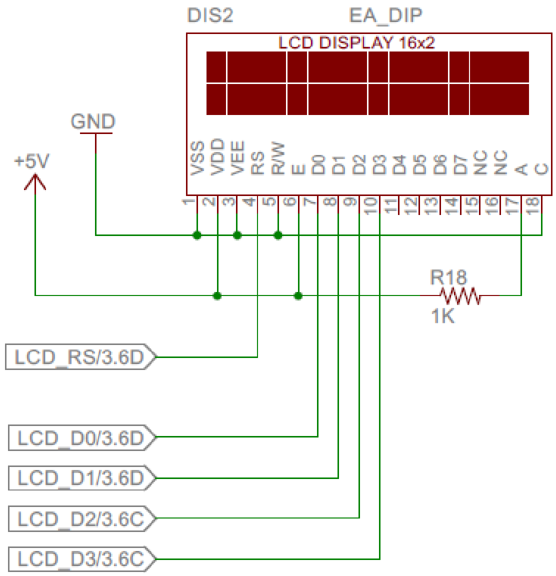


Figure 15: LCD Schematic

Buzzer: The concept of the buzzer as part of the module is for it to go off when the user comes inside the room and the LCD screen displays a notification in a way to warn or remind the user that a task must be completed. Buzzers have two different types of available configurations for the driving circuitry, transducer and indicator. For simplicity of not having an external driving circuit required aside from the buzzer itself, the group decided to go with an indicator also because they have sound effects included in the package. The buzzer chosen for the implementation of the module requirements is the CPE-224. Although a little more expensive than the other buzzers, it will be accomplishing its main task, which is being loud enough to be heard in a regular noisy room so that the user experiences the hearing portion of our five human senses. *Figure 16* shows our selected component.

Figure 16:CPE-244 Piezo Buzzer
Reprinted with permission of CUI INC

The sound pressure level (SPL) is one of the main characteristics that was looked at as the buzzer was chosen, it is a logarithmic measure of the RMS sound pressure of a sound relative to a reference value, and the threshold value of hearing is measured in decibels (dB). This buzzer's SPL is 80 dB, which is equivalent to a dishwasher, garbage disposal or street traffic. Another factor that came in while choosing the right piezo buzzer was that it provides a plug and play solution because it is internally driven and we do not have to worry about building a complex circuit to drive it. The piezo audio transducer's dustproof/waterproof level is IP67, which is compliant with the IEC standard 529.

It states it is totally protected against dust and protected against the effect of immersion between 15 cm and 1 m. Lastly, it is one of the smallest few piezo buzzers found, which will be ideal when soldered onto the PCB since it is also a through hole mounting type.

A custom circuit is required since the MCU cannot drive 12V (required to drive the buzzer) directly from its power rails. The design uses a custom circuit with a bipolar junction transistor (BJT) and a resistor at its base. *Figure 17* shows the schematic. The output from the MCU will close the buzzer's custom circuit and drive an output. Resistor R2 is used to keep the buzzer circuit open when the MCU output is logic low. It keeps the voltage at the base of the BJT below the turn-on voltage.

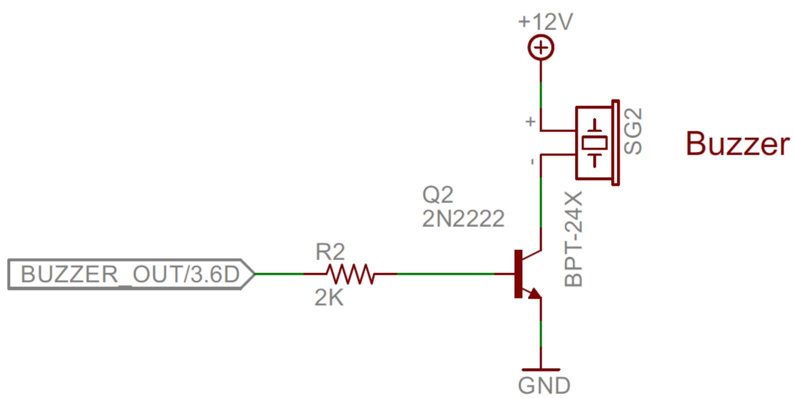


Figure 17: Buzzer Circuit Schematic

Response Button: The concept of the response button with an LED for the module is to turn on in conjunction with the notification on the LCD display so that it is visually easier for the user to identify when a task must be completed. The button is an important interaction part of the module because it utilizes the human sense pertaining to touch. HINTS sole purpose is to be an interactive system, therefore, as the user walks in a room the button will light up to signify a notification is being displayed. The button will stay lit up patiently waiting for user interaction to push it once the task is completed thus turning the LED off.

The selection of the button was mostly guided by its size. The Big Dome Pushbutton has a diameter of about 4 inches which suffices our visibility requirement. It has a polycarbonate lens cap for optical clarity. The button itself looks like an arcade button therefore bringing a fun and appealing interactive environment. The button is reliable for the longevity use it will be undergoing, the 3 terminal button actuator microswitch it has included is reliably tested to 10,000,000 cycles and can easily be replaced. *Figure 18* shows the selected component for our design.

Figure 18: Big Dome Pushbutton
Reprinted with permission of Sparkfun

The circuit driving and reciving the signals from the pushbutton must also be custom, as the device is a custom three-terminal input and output device and the LED inside requires 12V to drive it (this information was provided by the manufacturer). *Figure 19* shows the circuitry. An operational amplifier without a feedback path (essentially a comparator) is used to receive the LED signal from the MCU. The 12V power supply at the positive rail of the comparator drives a logic high output from the MCU to a 12V input into the LED terminal of the pushbutton. The resistors are for current limiting on the switch and for protection.

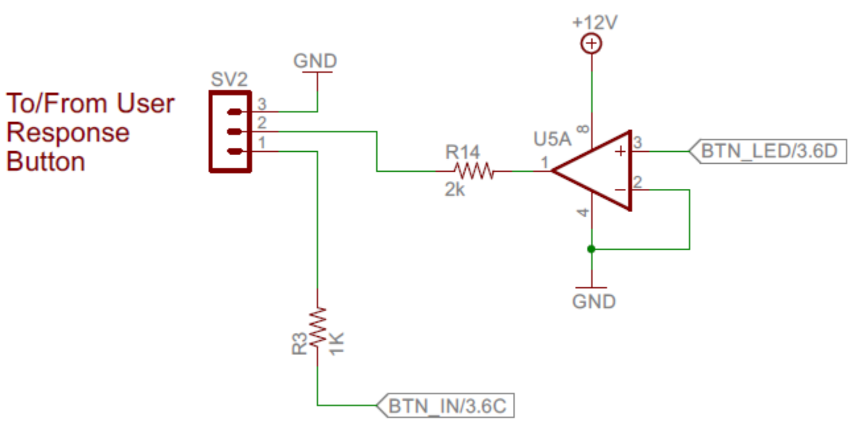


Figure 19: LED Pushbutton Schematic

Power Supply: For the implementation of the power supply unit, it is necessary to know the power consumption of all the components in the module in order to select an appropriate part. An AC-DC power supply was selected, since a wall adapter will reduce the amount of space allocated on the PCB, as well as reduction of soldering required for production. The additional components for a custom power supply would make the PCB more populated, and it could violate our physical requirements and constraints when included with all of the peripheral devices. The huge loads of the MCUs peripheral's also made this a easy solution. With a few 12V components, the board consumes a lot more power than the typical embedded project. The design currently includes a standard PCB mount connector for a wall adapter. As shown in the schematic in *Figure 20*, the power comes in through the connector X2 and is regulated by U2 (one of the board's power rails is 5V).

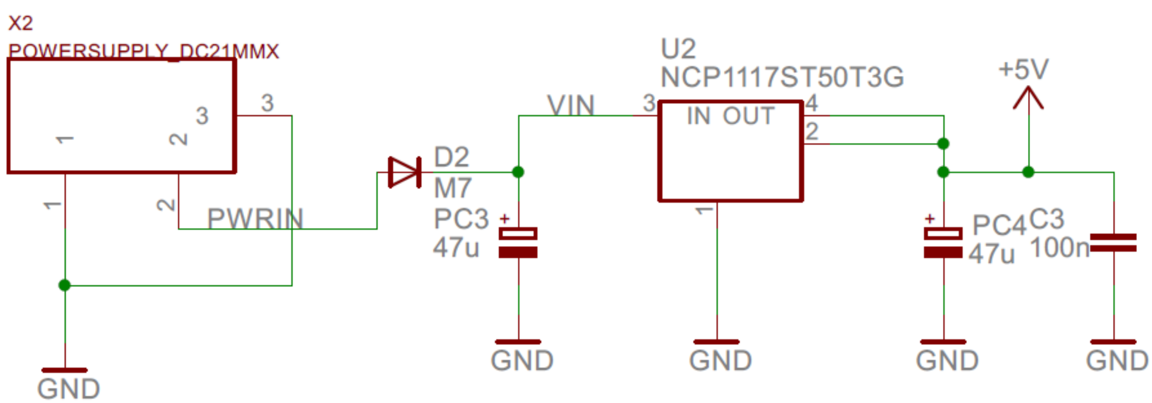


Figure 20: Module Input Power Schematic

4.1.3 Wearable Device

For this project, the wearable is one of the three main components for realization of the home interactive tracking perspective of the group's concept. The primary job of the wearable is to provide a proximity detection aid to the module so the module will set off notifications when needed a user is detected. The secondary function for the wearable will be to emit notifications as well. These notifications will be auditory, visual, and physical that will be achieved by the implementation of a Piezo Speaker, RGB LED, and small vibration motor.

4.1.3.1 Block Diagram

Below is the technical block diagram for the wearable, including interfaces, and the major components on the PCB.

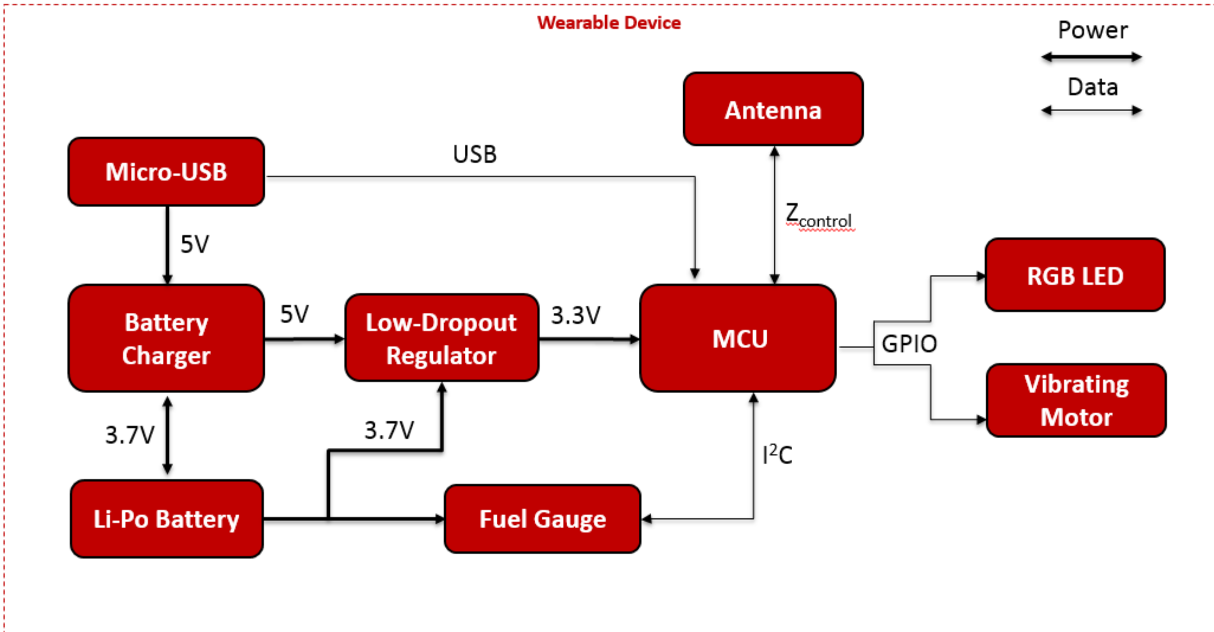


Figure 21: Wearable Block Diagram

4.1.3.2 Components

This section will specify final parts chosen to implement the wearable component of this project and their implementation.

Microcontroller: The CC2530 SoC was selected because of it has an integrated MCU, and it is a small size. It would allow us to design a PCB to meet our specific requirements without the added bulk that a module would provide. A negative in the selection of this part is that we would need to provide an external antenna. This means we would have to find one that can be integrated to this IC that supports a 2.4 GHz frequency, or design one on the PCB as an inlay. The benefit of having multiple timers and power modes also allows us to add or remove features that take advantage of these additional features.

The flash memory will contain the program code and will be programmed through the debug interface. This interface has a two-wire serial interface that will be used to start and stop the execution of the program.

Several of the features on the CPU core and peripherals are controlled through the special function registers (SFR). For example, USART 0 control and status is located at the 8-bit SFR address 0x86. The XREG registers will be programmed for radio configuration and control. They are located in the XDATA memory space and are 16-bit in length. For example, 0x6230 is the XDATA address for I^2C control. There are 18 interrupt sources that can be configured since they each have their own request flag located in the SFR registers. *Figure 22* shows a pinout top view of the CC2530 component.

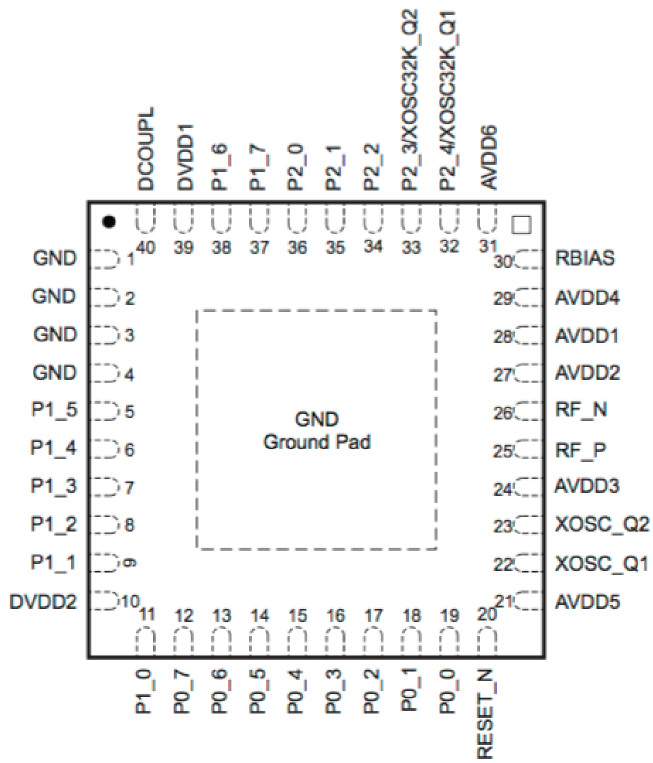


Figure 22: TI CC2530 SoC Pinout (Top View)
Pending Permission from Texas Instruments

CC2530 Schematic: The CC2530 will be configured with 2 peripherals, vibrating motor and LED. Both components are connected in series and biased with a diode to protect the components. P1_0 will drive both these components. The antenna has a 50 Ω impedance matching circuit has that has been included to reduce the return loss.

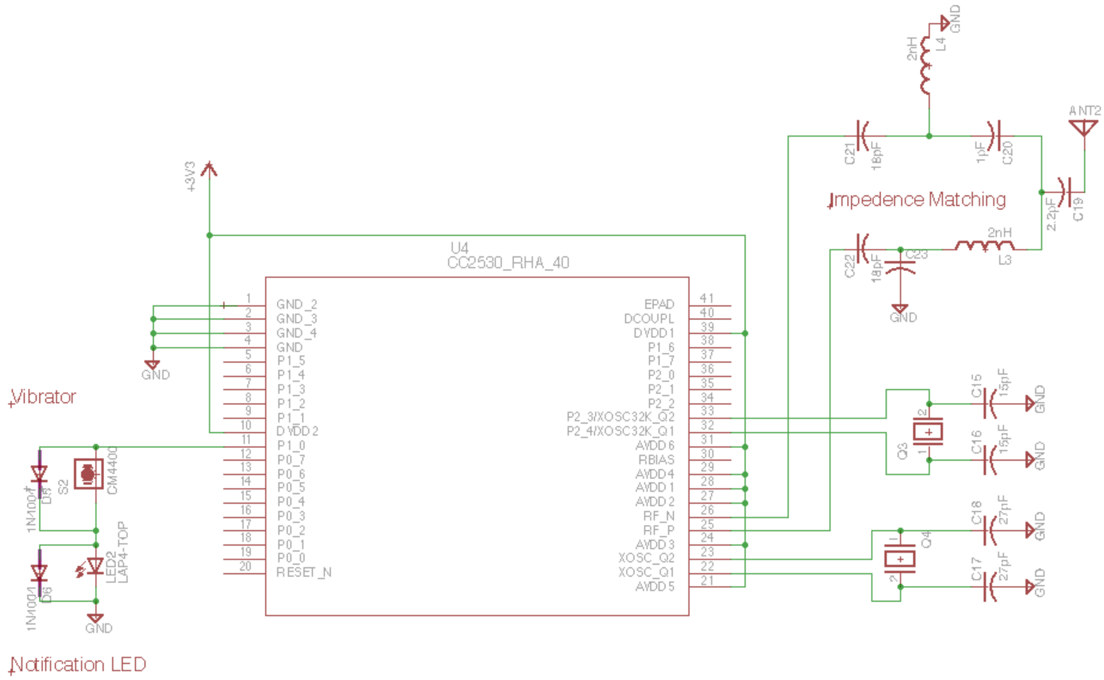


Figure 23: CC2530 Initial Schematic

Battery: Power for the wearable will be provided by the LP 503035 lithium ion polymer battery. This battery was selected over the LP 503562 battery because of its advantage in small size and greater charge cycles provided. It provides an integrated protection circuit for the battery to keep it from over-charging or over-use. The protection of over-charging will allow the wearable to be left charging without the worry of any damage to the battery and the over-use protection will render the battery useless when its' voltage drops below 3.0 V.

Charging: In order to charge this battery a constant-voltage/constant-current charger is required. The rate of the charging needs to be 150 mA or less, or the battery can be damaged. To ensure compliance to these requirements our design will incorporate the TI BQ24072 IC, as shown in *Figure 24.* This IC is a linear charger with 100/500 mA input current selection and system power path management. It operates by either USB port or AC adapter. There is a dynamic power path management (DPPM) feature that charges the battery, while powering the system at the same time and monitoring the charge current. Power will be supplied through the

The battery will be rechargeable over a 4 pin USB-IF certified Micro-USB cable through pins V_{BUS} and GND of the cable. The cable that will also be used to interface with the controller on the wearable through the appropriate communication interface. Interface communication design will be required for our PCB to allow simultaneous charging and reprogramming abilities, as well as appropriate power supply values.

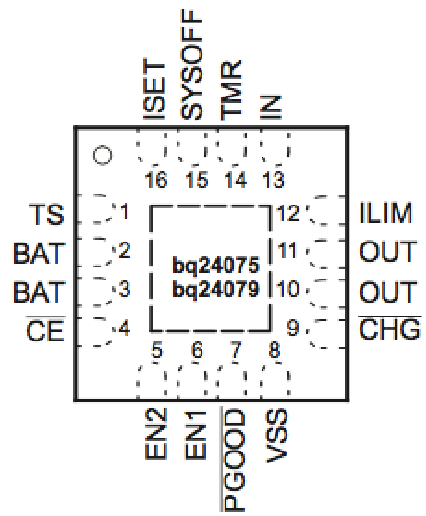


Figure 24: BQ24072 Pinout (Top View)
Pending permission from Texas Instruments

Battery Linear Charger: The battery voltage charger and power-path management IC will be a standalone assembly. It will be powered by a standard Micro-USB upon being plugged in.It will be powered by a standard 5V Micro-USB upon being plugged in. The battery is then charged by the IC given 100mA supply.

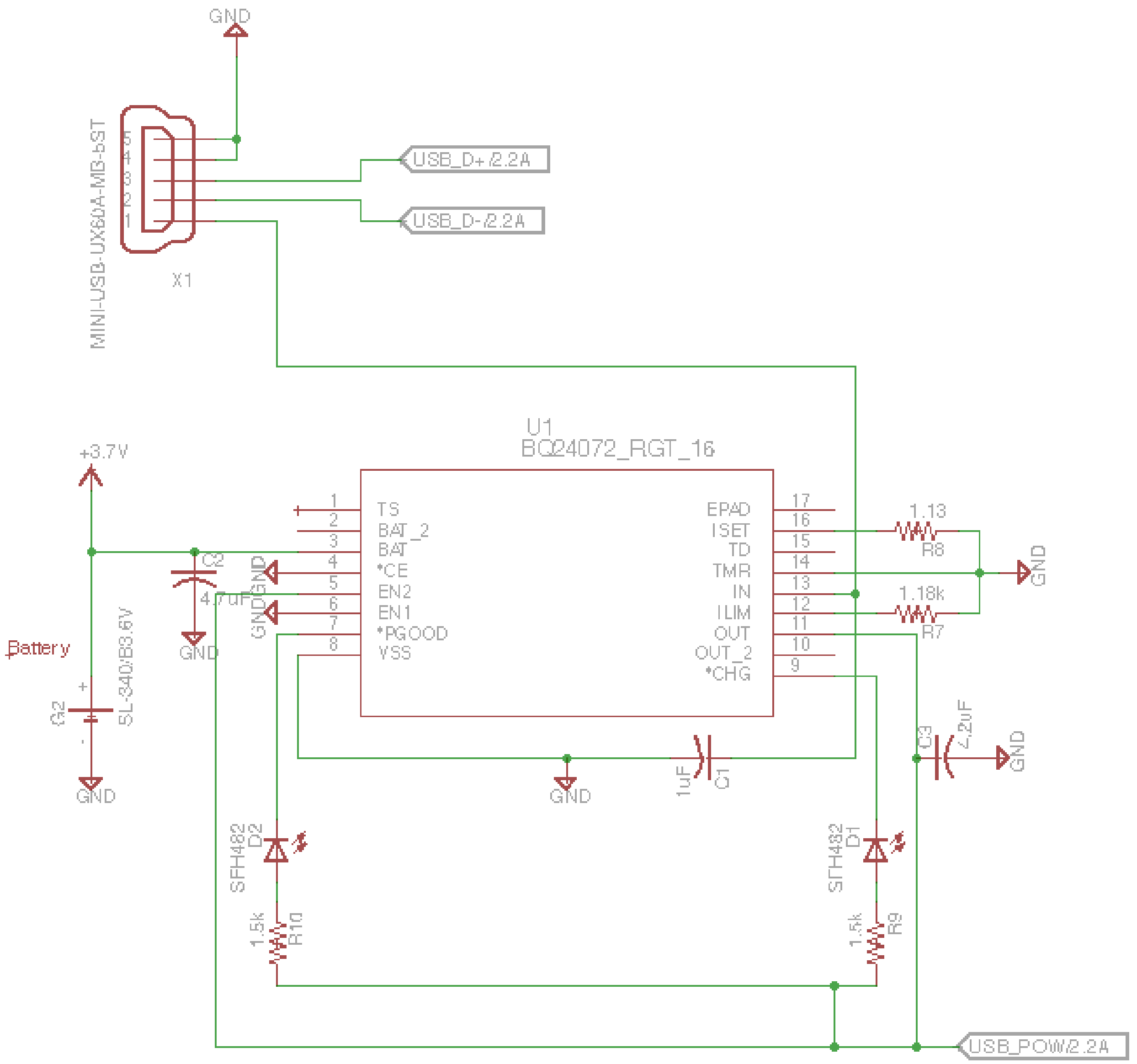


Figure 25: Battery Linear Charger Initial Schematic

Voltage Regulator: We will also institute a linear dropout voltage regulator because the battery supplies a 3.7V output. This voltage is higher than what most of our components are rated for. A TI TPS780 series regulators will be implemented into our design. The regulator will be programmed to provide an output voltage of 3.3V. A voltage of 3.3V is within the parameters of all of the components and can therefore supply power to all components necessary. An internal reference voltage of 1.216V V_{FB} (Feedback voltage) is used to assist in programming the output voltage of this regulator. The range of the output is 1.2 — 5 V. The formula used for the calculation was the following: $V_{out} = V_{FB} \times \left(1 + \frac{R1}{R2}\right)$.

High resistor values had to be avoided because there would be leakage current into or out of the feedback pin from the resistors. This would in turn create an offset voltage that that tampers with the feedback voltage and then it would affect the output voltage. Lower resistors would improve noise performance, but would require more power. Therefore our solution was to select R_2 as a 1MΩ resistor and solve for R_1. It was calculated to be approximately 1.8MΩ. A simplified schematic can be seen in *Figure 26.*

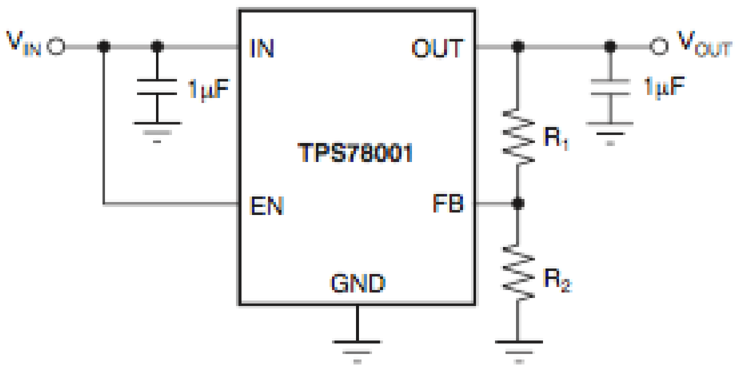


Figure 26: TI TPS780 Series Simplified Schematic
Pending permission from Texas Instruments

Voltage regulator schematic: The voltage regulator was programmed to have an output voltage of 3.3V using the two resistor values calculated in section Figure 27**Error! Reference source not found.**. The 3.3V regulated voltage will power all components within the wearable design.

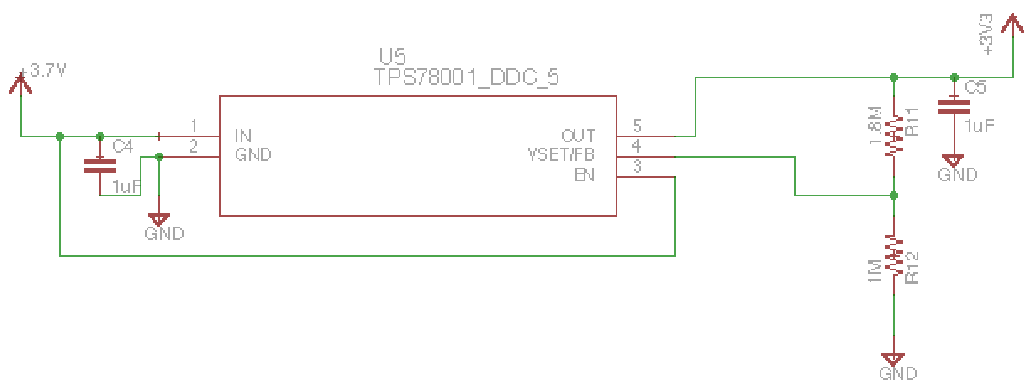


Figure 27: VDC Regulator +3.3V Initial Schematic

Fuel Gauge: The final power related component that will be placed within the wearable will be a fuel gauge. We would like to implement a system to determine when the wearable's battery is 20% or lower. The MAX17047 component provides measurement of current, voltage, and temperature. It will be mounted outside the cell pack that it will be monitoring and by observing the battery's relaxation response it can adjust internal registers to depict accurate battery readings. A top view of the IC can be seen in *Figure 28.*

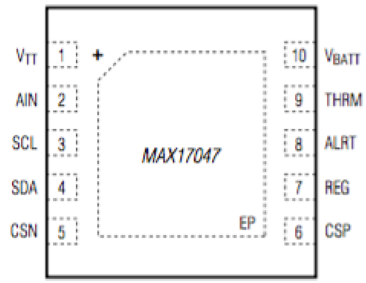


Figure 28: MAX17047 (Top View)
Pending permission from Maxim Integrated

Sensory Outputs: Sensory outputs will be placed in a series configuration on the wearable and biased with a diode. They will be ported out of a common GPIO pin for simultaneous response. This would allow one signal to simultaneously trigger a response from all components. For the realization of the sensory output requirements on our wearable the following sections discuss the hardware selections.

Vibration: For the vibration function the ROB-08449 part was selected. This vibration motor was selected for the wearable because of its small form factor and low power requirements. Its dimensions are 3.4 x10 mm and there is also a 3M adhesive backing that eliminates the need for an applicator like glue. The operating voltage is 2.3 – 3.6 VDC with the rated voltage at 3.0 VDC, and a current draw at a max of 60 mA. It operates at a rated speed of 13000 ±3000 rpm and emitting a 50 dB mechanical noise while doing so. This motor had the lowest power supply requirements when compared to others of the same form factor which made it the ideal selection for a battery powered component.

Visual: The visual component for the wearable has been chosen to be a tri-color RGB LED. We chose this LED because of the capability to associate a different color LED with the possible variations in notifications provided to the user. It also has a small form factor of 5.0 x 5.8 mm. The forward voltage varies for each of the colors, while the current remains the same. Voltages for the red, green, and blue lights are 1.8 – 2.2 V, 3.0 – 3.4 V, and 3.0 – 3.4 V respectively. The forward current for all three colors is 20 mA, with a peak current of 30 mA (at a 10 KHz duty cycle). The LED would only be illuminated when a signal is received by the wearable, from the module, indicating a notification is being triggered. Light degradation for the colors would not impact our design since it will not be illuminated at a constant rate.

4.2 Software Design

Software will be loaded on all three components of HINT. A breakdown of the software designs can be seen below for each board.

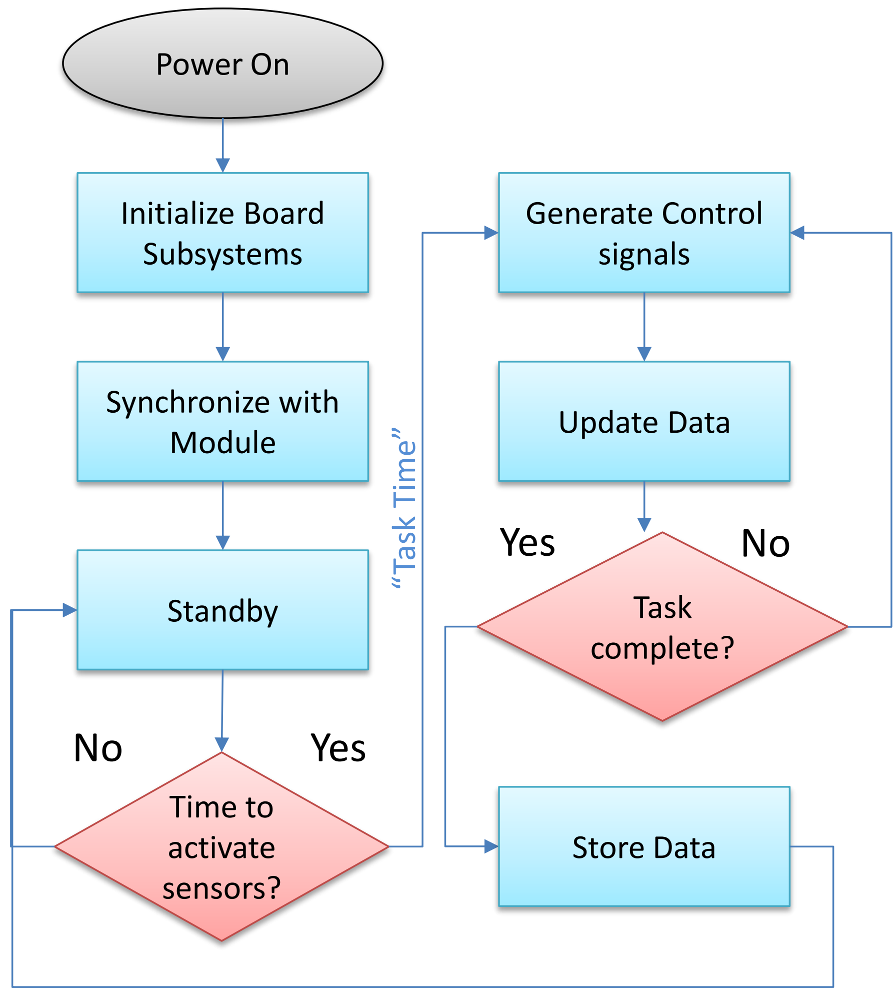


Figure 29: Central Hub Software Flow Diagram

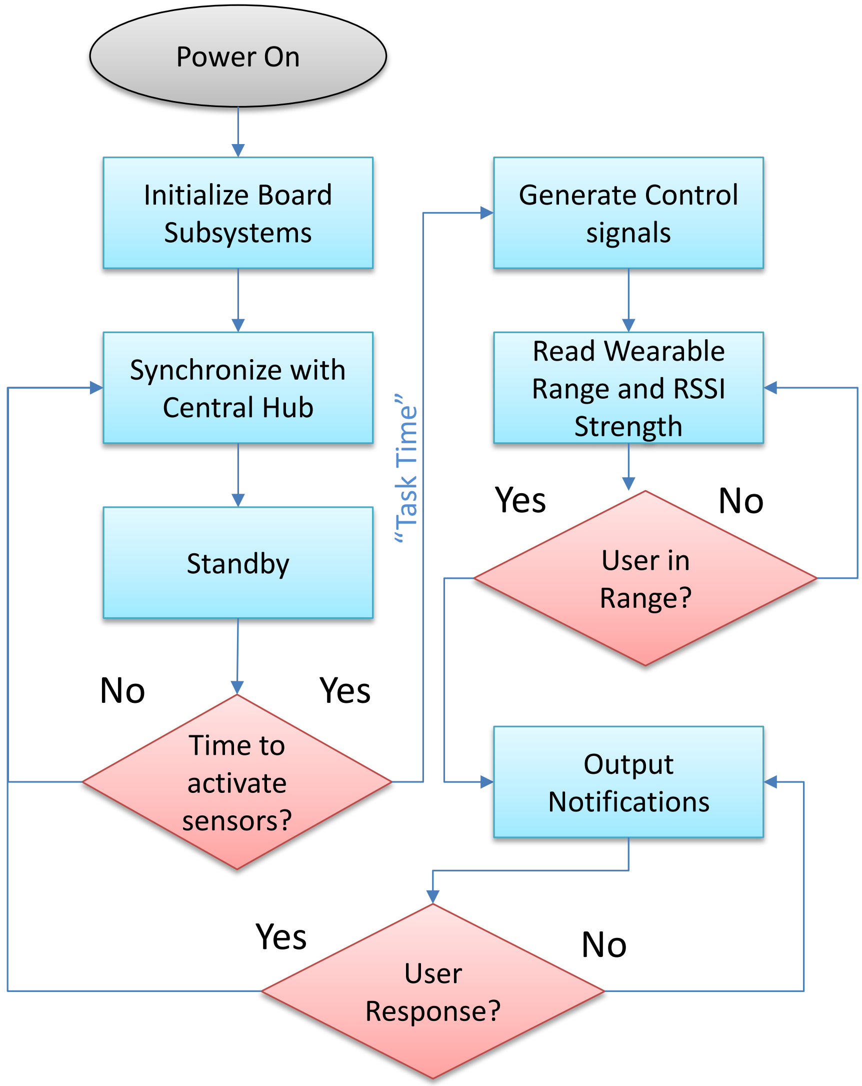


Figure 30: Module Software Flow Diagram

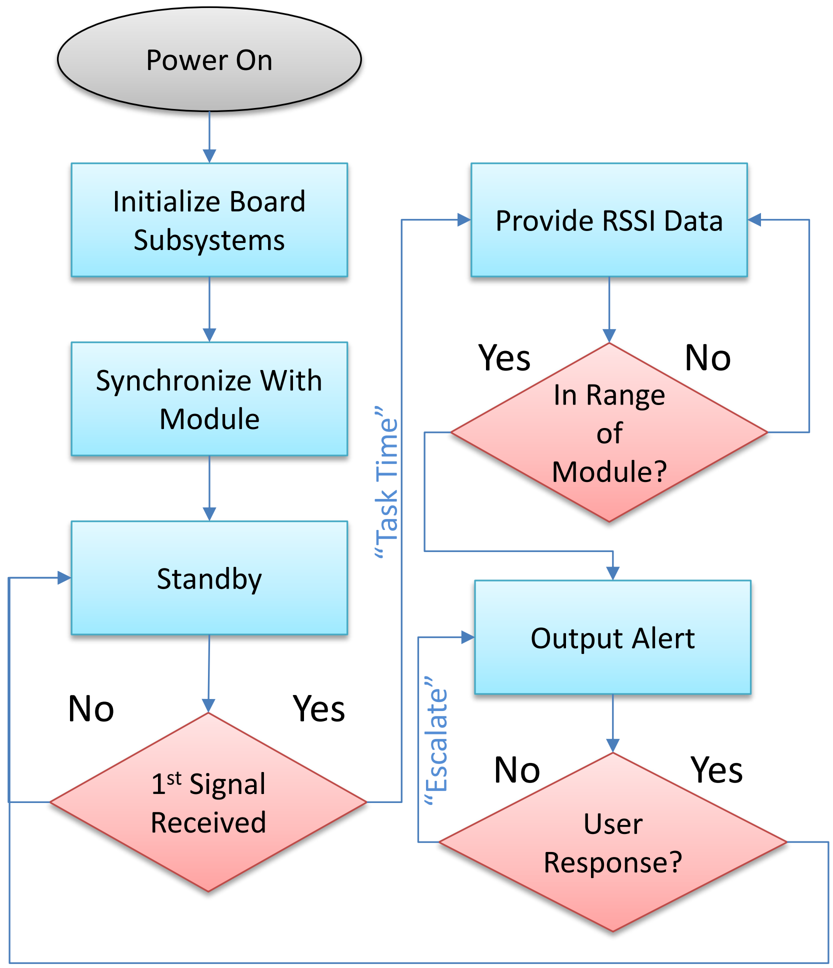


Figure 31: Wearable Device Software Flow Diagram

Development Tools: The C language will be used to develop the code for all devices of HINT, except where there may need to be memory optimization. In that case, assembly code will be explored. Arduino IDE will be used to program the ATmega MCUs, and has ample library support. T.I.'s CCS will be used to program and debug the CC2350 wireless MCU. Texas Instruments also proved a variety of communication, both chip interfacing and wireless, libraries.

4.2.1 Algorithms

HINT proposes a method of user interaction and detection that is not currently offered in the market. Although they are relatively simple, HINT must be the framework of some unique algorithms to implement these proposed functions. The following sections breakdown the projects algorithmic goals.

4.2.1.1 Activity Detection

HINT will implement an "activity detection" algorithm that uses RF communication and ultrasonic sensing to determine if the correct person is in the room. This process will be embedded in the MCU of the module. The ultrasonic sensor will be used to read if there is any activity in it's field of view (FOV). This is one triggering criteria that leads to proper notification and alert delivery. However, that method alone introduces high error. There may be multiple people in the FOV at any given time, for instance. HINT needs a specific way to also determine if the person it "senses" is the person it needs to deliver the alerts to.

That being said, It will also use the RSSI feature of the ZigBee communication protocol to determine if that is the right person. Now, if the person is there, there will be very little failure in proper notification delivery. In addition, if the person is behind the sensor (the sensor must be placed in a corner, and therefore that person is behind the wall), HINT will detect a lossy signal and potentially no motion. The chance of delivery failure is much lower than with either input alone.

4.2.1.2 Task Completion

In addition to finding the correct person, HINT must implement a smart method of determining task completion and influencing this completion if it was for any reason bypassed. To do so, HINT will have multiple levels of alert "escalation". If a mesh of modules existed in one building, this would be an easy task. However, it is harder to implement this with a single module. HINT will escalate notifications by continuing data reading from the RF RSSI feed and the ultrasonic sensor. Notification output will escalate on both the module and the wearable. However, the "smart" aspect of this algorithm would be the transition from the module to the wearable, as the output on the module should not last long when the wearable is out of range.

4.3 Printed Circuit Board Design

HINT will be utilizing the use of 3 PCBs, one for each of our components. Our design goal is to meet our financial goal, and to ensure that each PCB fits within the following design constraints:

- Wearable – 2" x 2" x .6", non negotiable
- Module – 6" x 6" x 6", negotiable
- Central Hub – 5" x 5" x 5", negotiable

All three PCBs will be designed using Cadsoft's EAGLE PCB design software and 3D rendered, for presentation and viewing, in SOLIDWORKS or SKETCHUP Pro.

One of the main requirements for Senior Design is to integrate your own PCBs in the project. CadSoft's Eagle CAD tool will be used to layout the PCBs. Mechanical characteristics must be considered at this stage in the design.

Since the central hub has no constraints it will be the easiest to house, or design around the size of the final PCB design. For the module, there is an ideal design that we would like to meet for ease of use, proper functionality, and portability. The biggest challenge is going to be ensuring that the wearable PCB is as small as it can be. This design constraint comes from the need of it needing to fit on the users' wrist, while still offering full planned functionality. To combat this problem, we have chosen the smallest components possible to implement.

The design for each PCB has June 15, 2016 projected date of completion. There will be three copies of each PCB ordered for testing, prototyping, and construction.

Central Hub: The central hub, not being a crucial board in this system, will be designed as a standard PCB that could have standoffs and sit horizontally on a table. There is no interfacing, other than programming and pulling the memory of the board, between users and the central hub.

Module: The module must have the most critical mechanical design. The most important component that this relates to is the ultrasonic sensor. If mounted flat on a board, the sensor will be facing upwards. The design must account for the fact that the sensor needs to see a 90 degree FOV at the very minimum for HINT to function as proposed. We can accomplish the requirements by designing a custom, vertically standing board or by creating custom mounts. The other components on the module, though not as critical, also need to be treated this way. For example, the buzzer and pushbutton need to be accessible easily to the senses of the user. Improper mechanical design can hinder that feature.

Wearable Device: The wearable device must have mechanical considerations strictly related to size and board height. The PCB should not stick out excessively, as part of the proposal is a user friendliness and ease of wear. For that reason, surface mount components and mechanically designed PCB inlay antenna will be focused on in the initial design.

5 Project Construction

Upon fabrication of the printed circuit board, the individual assemblies must be built up with components. This requires the gathering of all components and the use of proper soldering and mounting techniques.

5.1 Bill of Materials

The completion of schematics lead to the development of a bill of materials (BOM). This bill contains all parts used in the design, as well as additional components added and required by the designers for a successful build. Figure show the BOMs for the central hub, module, and wearable device, respectively.

RefDes	Value	Device	Package	Description
C1	100n	C-EU0603-RND	C0603-ROUND	CAPACITOR, European symbol
C3	100n	C-EU0603-RND	C0603-ROUND	CAPACITOR, European symbol

C4	1u	C-EU0603-RND	C0603-ROUND	CAPACITOR, European symbol
C5	100n	C-EU0603-RND	C0603-ROUND	CAPACITOR, European symbol
C7	100n	C-EU0603-RND	C0603-ROUND	CAPACITOR, European symbol
C8	1u	C-EU0603-RND	C0603-ROUND	CAPACITOR, European symbol
C9	22p	C-EU0603-RND	C0603-ROUND	CAPACITOR, European symbol
C10	100n	C-EU0603-RND	C0603-ROUND	CAPACITOR, European symbol
C11	22p	C-EU0603-RND	C0603-ROUND	CAPACITOR, European symbol
C12	100n	C-EU0603-RND	C0603-ROUND	CAPACITOR, European symbol
D1	CD1206-S01575	DIODE-MINIMELF	MINIMELF	DIODE
D2	M7	DIODE-SMB	SMB	DIODE
D3	CD1206-S01575	DIODE-MINIMELF	MINIMELF	DIODE
F1	MF-MSMF050-2 500mA	L-EUL1812	L1812	INDUCTOR, European symbol
GROUND		SJ	SJ	SMD solder JUMPER
ICSP1	3x2 M	PINHD-2X3	2X03	PIN HEADER
L1	BLM21	WE-CBF_0805	805	SMD EMI Suppression Ferrite Beads
ON3	GREEN	LEDCHIP-LED0805	CHIP-LED0805	LED
ON4	GREEN	LEDCHIP-LED0805	CHIP-LED0805	LED
PC3	47u	CPOL-EUD	PANASONIC_D	POLARIZED CAPACITOR, European symbol
PC4	47u	CPOL-EUD	PANASONIC_D	POLARIZED CAPACITOR, European symbol
R1	1M	R-US_0204/2V	0204V	RESISTOR, American symbol
R2		R-US_0204/2V	0204V	RESISTOR, American symbol
R3	1K	R-US_0204/2V	0204V	RESISTOR, American symbol
R4	1K	R-US_0204/2V	0204V	RESISTOR, American symbol

R6	22	R-US_0204/2V	0204V	RESISTOR, American symbol
R7	22	R-US_0204/2V	0204V	RESISTOR, American symbol
R8	10K	R-US_0204/2V	0204V	RESISTOR, American symbol
R9	1K	R-US_0204/2V	0204V	RESISTOR, American symbol
R10	1K	R-US_0204/2V	0204V	RESISTOR, American symbol
R11	1K	R-US_0204/2V	0204V	RESISTOR, American symbol
R15	10K	R-US_0204/2V	0204V	RESISTOR, American symbol
R16	10K	R-US_0204/2V	0204V	RESISTOR, American symbol
R18	1M	R-US_0204/2V	0204V	RESISTOR, American symbol
R19	10K	R-US_0204/2V	0204V	RESISTOR, American symbol
R20	1K	R-US_0204/2V	0204V	RESISTOR, American symbol
R21	1K	R-US_0204/2V	0204V	RESISTOR, American symbol
RESET-EN		SJ	SJ	SMD solder JUMPER
RESET2	TS42031-160R-TR-7260	TS42	TS42	TS42
RESET3	TS42031-160R-TR-7260	TS42	TS42	TS42
RX	YELLOW	LEDCHIP-LED0805	CHIP-LED0805	LED
T2	FDN340P	PMOSSOT23	SOT-23	MOS FET
TX	YELLOW	LEDCHIP-LED0805	CHIP-LED0805	LED
U2	NCP1117ST50T3G	MC33269ST-3.3T3	SOT223	Adjustable Output Low Dropout Voltage Regulator 800 mA
U3	ATMEGA16U2-MU(R)	ATMEGA16U2-MU	MLF32	
U4	LMV358IDGKR	LMV358MMX	MSOP08	Dual General Purpose, Low Voltage, Rail-to-Rail Output Operational Amplifiers

U7	LP2985-33DBVR	LP2985-XXDBVR33	SOT23-DBV	ULTRALOW-POWER 50-mA LOW-DROPOUT LINEAR REGULATORS
X1	USB-B_TH	PN61729	PN61729	BERG USB connector
X2	POWERSUPPLY_DC21MMX	POWERSUPPLY_DC21MMX	POWERSUPPLY_DC-21MM	
X3	FPS009-3001	FPS009-3001	FPS009-3000	SD Card and MMC Reader (Manual Insertion)
XB2	XBEE	XBEE	XBEE	XBee (TM) /XBee-PRO(TM) OEM RF Modules
Y1	16MHz	XTAL/S	QS	CRYSTAL
Y2	CSTCE16M0V53-R0 16MHZ	RESONATORMU	RESONATOR	
Z1	CG0603MLC-05E	VARISTORCN0603	CT/CN0603	VARISTOR
Z2	CG0603MLC-05E	VARISTORCN0603	CT/CN0603	VARISTOR
ZU2	ATMEGA328P-PU	ATMEGA328P-PU	DIL28-3	MICROCONTROLLER
n/a	TS2GSDC	TS2GSDC	n/a	SD Card

Figure 32: Central Hub Bill of Materials

RefDes	Value	Device	Package	Description
C1	100n	C-EU0603-RND	C0603-ROUND	CAPACITOR, European symbol
C3	100n	C-EU0603-RND	C0603-ROUND	CAPACITOR, European symbol
C4	1u	C-EU0603-RND	C0603-ROUND	CAPACITOR, European symbol
C5	100n	C-EU0603-RND	C0603-ROUND	CAPACITOR, European symbol
C6	100n	C-EU0603-RND	C0603-ROUND	CAPACITOR, European symbol
C7	100n	C-EU0603-RND	C0603-ROUND	CAPACITOR, European symbol
C8	1u	C-EU0603-RND	C0603-ROUND	CAPACITOR, European symbol
C9	22p	C-EU0603-RND	C0603-ROUND	CAPACITOR, European symbol
C10	100n	C-EU0603-RND	C0603-ROUND	CAPACITOR, European symbol
C11	22p	C-EU0603-RND	C0603-ROUND	CAPACITOR,

				European symbol
C13	100n	C-EU0603-RND	C0603-ROUND	CAPACITOR, European symbol
D2	M7	DIODE-SMB	SMB	DIODE
D3	CD1206-S01575	DIODE-MINIMELF	MINIMELF	DIODE
D4	CD1206-S01575	DIODE-MINIMELF	MINIMELF	DIODE
DIS2	EA_DIP	EA_DIP	EA_DIP	LCD-MODUL 2x16 - 6,68mm, INKL. KONTROLLER HD44780
F1	MF-MSMF050-2 500mA	L-EUL1812	L1812	INDUCTOR, European symbol
G2	SL-160AA/PT	SL-160AA/PT	SL-160AA/PT	LI BATTERY Sonnenschein
GROUN D		SJ	SJ	SMD solder JUMPER
ICSP1	3x2 M	PINHD-2X3	2X03	PIN HEADER
L1	BLM21	WE-CBF_0805	805	SMD EMI Suppression Ferrite Beads
ON1	GREEN	LEDCHIP-LED0805	CHIP-LED0805	LED
ON3	GREEN	LEDCHIP-LED0805	CHIP-LED0805	LED
PC3	47u	CPOL-EUD	PANASONIC_D	POLARIZED CAPACITOR, European symbol
PC4	47u	CPOL-EUD	PANASONIC_D	POLARIZED CAPACITOR, European symbol
Q2	2N2222	2N2222	TO18	NPN Transistor
R1	1M	R-US_0204/2V	0204V	RESISTOR, American symbol
R2	2K	R-US_0204/2V	0204V	RESISTOR, American symbol
R3	1K	R-US_0204/2V	0204V	RESISTOR, American symbol
R4	100	R-US_0204/2V	0204V	RESISTOR, American symbol
R5	1M	R-US_0204/2V	0204V	RESISTOR, American symbol
R6	22	R-US_0204/2V	0204V	RESISTOR, American symbol
R7	22	R-US_0204/2V	0204V	RESISTOR, American symbol
R8	10K	R-US_0204/2V	0204V	RESISTOR, American symbol
R9	1K	R-US_0204/2V	0204V	RESISTOR,

				American symbol
R10	1K	R-US_0204/2V	0204V	RESISTOR, American symbol
R11	1K	R-US_0204/2V	0204V	RESISTOR, American symbol
R12		R-US_0204/2V	0204V	RESISTOR, American symbol
R13	1K	R-US_0204/2V	0204V	RESISTOR, American symbol
R14	2k	R-US_0204/2V	0204V	RESISTOR, American symbol
R15	10K	R-US_0204/2V	0204V	RESISTOR, American symbol
R16	10K	R-US_0204/2V	0204V	RESISTOR, American symbol
R18	1K	R-US_0204/2V	0204V	RESISTOR, American symbol
R19	1K	R-US_0204/2V	0204V	RESISTOR, American symbol
R23	10K	R-US_0204/2V	0204V	RESISTOR, American symbol
R24	1K	R-US_0204/2V	0204V	RESISTOR, American symbol
R25	1K	R-US_0204/2V	0204V	RESISTOR, American symbol
RESET-EN		SJ	SJ	SMD solder JUMPER
RESET1	TS42031-160R-TR-7260	TS42	TS42	TS42
RESET3	TS42031-160R-TR-7260	TS42	TS42	TS42
RX	YELLOW	LEDCHIP-LED0805	CHIP-LED0805	LED
SG2	BPT-24X	BPT-24X	BPT-24X	
SV2		MA03-1	MA03-1	PIN HEADER
SV3		MA07-1	MA07-1	PIN HEADER
T2	FDN340P	PMOSSOT23	SOT-23	MOS FET
TX	YELLOW	LEDCHIP-LED0805	CHIP-LED0805	LED
U2	NCP1117ST50T3G	MC33269ST-3.3T3	SOT223	Adjustable Output Low Dropout Voltage Regulator 800 mA
U3	ATMEGA16U2-MU(R)	ATMEGA16U2-MU	MLF32	
U4	LMV358IDGKR	LMV358MMX	MSOP08	Dual General Purpose, Low Voltage, Rail-to-Rail Output Operational

				Amplifiers
U5	LMV358IDGKR	LMV358MMX	MSOP08	Dual General Purpose, Low Voltage, Rail-to-Rail Output Operational Amplifiers
U7	LP2985-33DBVR	LP2985-XXDBVR33	SOT23-DBV	ULTRALOW-POWER 50-mA LOW-DROPOUT LINEAR REGULATORS
X1	USB-B_TH	PN61729	PN61729	BERG USB connector
X2	POWERSUPPLY_DC21MMX	POWERSUPPLY_DC21MMX	POWERSUPPLY_DC-21MM	
XB2	XBEE	XBEE	XBEE	XBee (TM) /XBee-PRO(TM) OEM RF Modules
Y1	16MHz	XTAL/S	QS	CRYSTAL
Y3	CSTCE16M0V53-R0 16MHZ	RESONATORMU	RESONATOR	
Z1	CG0603MLC-05E	VARISTORCN0603	CT/CN0603	VARISTOR
Z2	CG0603MLC-05E	VARISTORCN0603	CT/CN0603	VARISTOR
ZU1	ATMEGA328P-PU	ATMEGA328P-PU	DIL28-3	MICROCONTROLLER
n/a	LV-MaxSonar-EZ0	LV-MaxSonar-EZ0	n/a	Ultrasonic Range Sensor
n/a	CPE - 244	CPE - 244	n/a	Piezo Buzzer
n/a	COM-11274	COM-11274	n/a	Big Dome Pushbutton

Figure 33: Module Bill of Materials

RefDes	Value	Device	Package	Description
ANT2		ANTENNA	PAD-01	Antenna
C1	1uF	C-US025-024X044	C025-024X044	CAPACITOR, American symbol
C2	4.7uF	C-US025-024X044	C025-024X044	CAPACITOR, American symbol
C3	4.2uF	C-US025-024X044	C025-024X044	CAPACITOR, American symbol
C4	1uF	C2,5-3	C2.5-3	CAPACITOR

C5	1uF	C2,5-3	C2.5-3	CAPACITOR
C15	15pF	C-US025-024X044	C025-024X044	CAPACITOR, American symbol
C16	15pF	C-US025-024X044	C025-024X044	CAPACITOR, American symbol
C17	27pF	C-US025-024X044	C025-024X044	CAPACITOR, American symbol
C18	27pF	C-US025-024X044	C025-024X044	CAPACITOR, American symbol
C19	2.2pF	C-US025-024X044	C025-024X044	CAPACITOR, American symbol
C20	1pF	C-US025-024X044	C025-024X044	CAPACITOR, American symbol
C21	18pF	C-US025-024X044	C025-024X044	CAPACITOR, American symbol
C22	18pF	C-US025-024X044	C025-024X044	CAPACITOR, American symbol
C23		C-US025-024X044	C025-024X044	CAPACITOR, American symbol
D1	SFH482	SFH482	SFH482	IR LED
D2	SFH482	SFH482	SFH482	IR LED
D5	1N4004	1N4004	DO41-10	DIODE
D6	1N4004	1N4004	DO41-10	DIODE
G2	SL-340/B3.6V	SL-340/B3.6V	SL-340/B3.6V	LI BATTERY Sonnenschein
L3	2nH	L-US0204/7	0204/7	INDUCTOR, American symbol
L4	2nH	L-US0204/7	0204/7	INDUCTOR, American symbol
LED2	LAP4-TOP	LAP4-TOP	P47F-TOP	PointLED® Enhanced Thinfilm LED TOP & BOTTOM mount
Q3		XTAL	Q	CRYSTAL
Q4		XTAL	Q	CRYSTAL
R7	1.18k	R-US_0204/5	0204/5	RESISTOR, American symbol
R8	1.13	R-US_0204/5	0204/5	RESISTOR, American symbol
R9	1.5k	R-US_0204/5	0204/5	RESISTOR, American symbol
R10	1.5k	R-US_0204/5	0204/5	RESISTOR, American symbol
R11	1.8M	R-US_0204/5	0204/5	RESISTOR, American symbol
R12	1M	R-US_0204/5	0204/5	RESISTOR, American symbol
S2	CM4400	CM4400	CM4400	MOVEMENT / VIBRATION SWITCH - Mercury Contacts
U1	BQ24072_RGT_16	BQ24072_RGT_16	RGT16_1P7X1P7	
U4	CC2530_RHA_40	CC2530_RHA_40	RHA40_4P5X4P5	
U5	TPS78001_DDC_5	TPS78001_DDC_5	DDC5	

X1	MINI-USB-UX60A-MB-5ST	MINI-USB-UX60A-MB-5ST	UX60A-MB-5ST	MINI USB Connector
n/a	LP 503035	LP 503035	n/a	Battery
n/a	MAX17047G+	MAX17047G+	n/a	Fuel Gauge
n/a	LED	LED	n/a	RGB LED
n/a	ROB-08449	ROB-08449	n/a	Vibrating Motor

Figure 34: Wearable Device Bill of Materials

5.2 Printed Circuit Board

The printed circuit board will be fabricated by a manufacturer or vendor. We currently have a few vendors in consideration for the construction of our PCB. They are the following:

- OSH Park
- Gold Phoenix
- Advanced Circuits
- PCBCART

The selection of the vendor will be decided on after completion of the PCB designs. We will need to ensure we send over all the relevant information to the vendors to receive an accurate quote. Since we are doing three PCBs our cost is projected to be moderately high at this step in our project. We will not only take cost into consideration, but also quality and delivery time.

5.3 Mechanical Assembly

The board will then be constructed by the team, using soldering techniques. Proper soldering techniques shall be adhered to, in order to avoid damaging hardware. Any micro-packages, like ball grid arrays (BGAs) or 0402 packaged resistors and capacitors, will be taken to a fabrication house for professional placement. The constructed boards will then be packaged into a “consumer-friendly” casing, as explained in the next sections.

5.3.1 Wearable

The housing for the wearable will be a custom design. It will be designed in SOLIDWORKS and 3D printed at the TI Innovation Lab at the University of Central Florida. Resin for the printing will be black and the dimensions are not to exceed 2” x 2” x .5”. For comparison, our design will aim to resemble the open source design of the F*watch shown in Figure 35: F*watch .

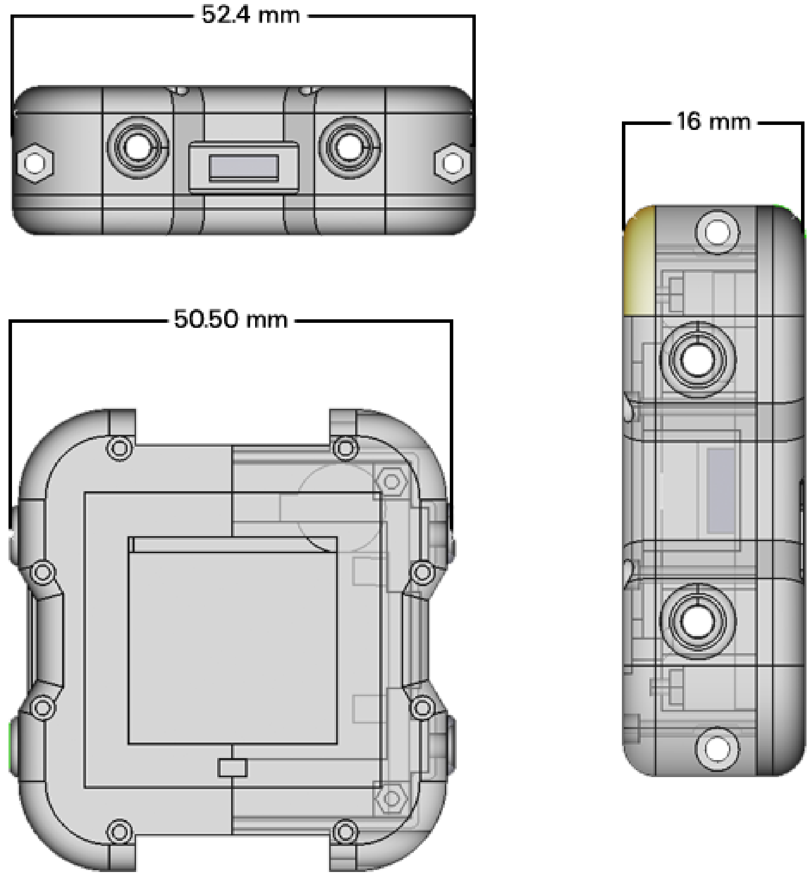


*Figure 35: F*watch Housing Design*
Reprinted with permission from F*watch

5.3.2 Module

The housing for the module will be manufactured out of wood and its initial design will be done in SOLIDWORKS. Its manufacturing will be done by the Innovation Lab at the University of Central Florida by laser cutting the wood. The LCD and motion sensor will be fitted on the front of the housing so the LCD can be read, and for the sensor to detect. A small circular hole created on the rear will be the pathway for the power supply cable to enter for the PCB. Finally, the top of the housing will fit the response button that was selected. Housing design is planned to be 6” x 6” x 6”. The intended design can be seen in Figure 36: Module Proposed Housing Design.

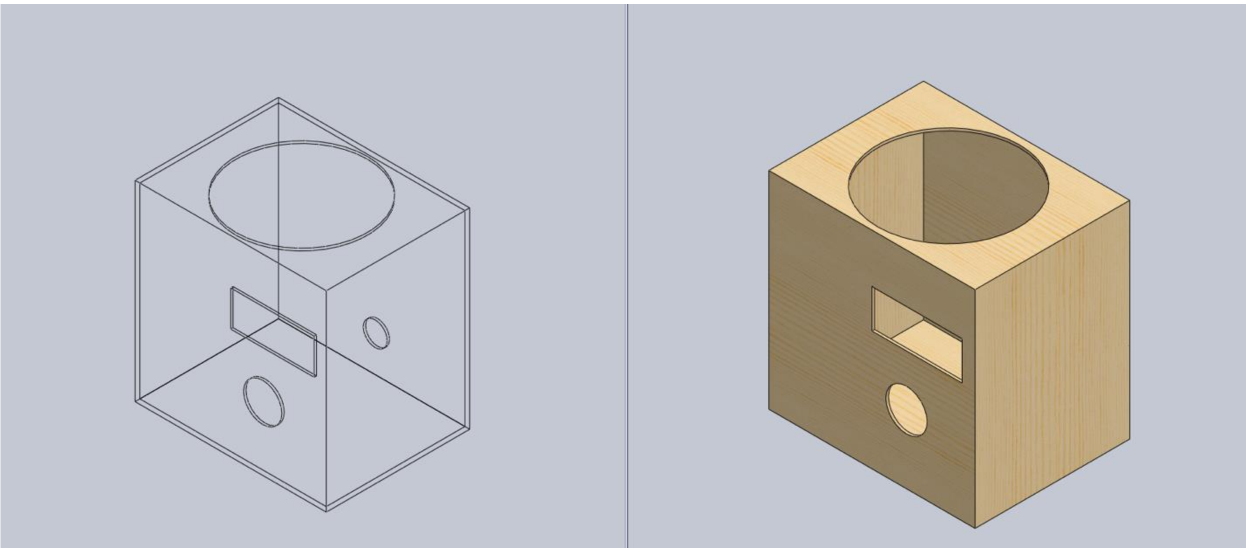


Figure 36: Module Proposed Housing Design

5.3.3 Central Hub

The housing for the central hub will be manufactured out of wood and its initial design will be done in SOLIDWORKS. Its manufacturing will be done by the Innovation Lab at the University of Central Florida by laser cutting the wood. There are no peripherals on the central hub other than the ZigBee module, therefore a simple 5” x 5” x 5” box design will fulfill our needs. A small opening on the rear will be placed for power supply pathway. The intended design can be seen in Figure 37: Central Hub Proposed Housing Design.

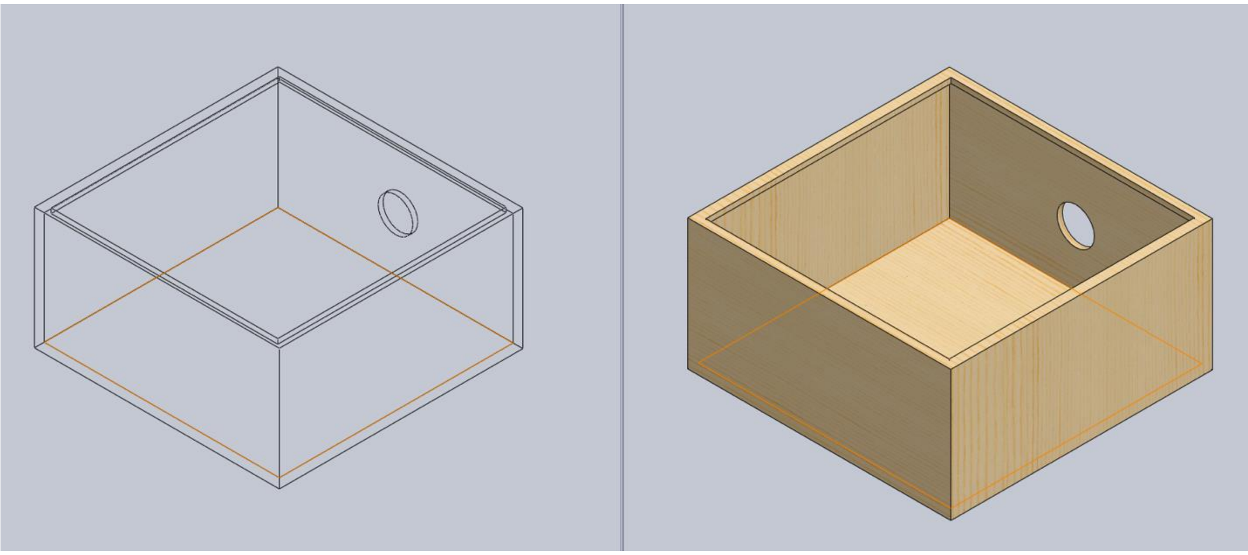


Figure 37: Central Hub Proposed Housing Design

5.4 Quality

All of the design aspects mentioned above shall be inspected for quality. The first step is the inspection of the printed circuit board. Making sure there are no visual defects is important. One important test at this stage is the continuity test, where every point-to-point electrical connection is tested to make sure there is, in fact, a connection. If not discovered at this stage, continuity issues can lead to the some of the most difficult faults to troubleshoot. Once the boards are built, another inspection can be done to check for mounting anomalies, like solder bridges shorting pins together. Quality is essential in a good design, and these steps help verify that quality.

6 Project Testing

The HINT components will be tested in the Senior Design Lab for most of this project lifespan due to the readily available equipment. All components will be tested individually, to ensure proper functionality, and then together. The wearable and module must be tested together first before moving forward to the central hub. Since the wearable and the module are the biggest portion of this project we cannot test any further system integration until the function of these two components are as efficient as needed. After the testing has been completed for the wearable and the module system the central hub will be introduced and tested with the module. The module and central hub must communicate as planned and work efficiently without effecting module to wearable communication. Once this testing is completed a full system test will be done. All test will be scheduled and done cooperatively.

6.1 Hardware Test Environment

The hardware test environment will consist of breadboard prototyping. Three individual breadboards will communicate wirelessly, to simulate the board-to-board interface. Additional on-board functionality will also be verified within the breadboard environment.

6.2 Hardware Test Procedure

Objective: The scope of this test setup is to ensure that all hardware components and designs are acting as they should be.

Test Items: For this test we will require an oscilloscope and a logic analyzer.

Procedure: The following steps shall be taken in order to test the module and wearable's functionalities:

1. Set up all hardware on a breadboard, with connections extending outwards, so as to probe.
2. Verify all hardware powers up. LEDs on voltage rails can help easily show this.
3. Run through the first communication net or bus, using functional test software if needed. Verify that the signals act as they should, per the transmitter and receiver datasheets.

4. Repeat step 3 for each critical net or bus, and for all components transmissing data.

Conclusion: Nets on the PCB can be tweaked if we find that certain hardware connections or configurations don't work.

6.3 Software Test Environment

The software test environment will be hosted by development boards. Both Texas Instruments development boards and Arduinos will be used to verify communication software and algorithms. The development boards are referred to as "emulators" in the test procedure.

6.4 Software Test Procedure

Objective: The scope of this test setup is to ensure that all components are working as needed, after the hardware design is verified. The module needs to monitor the approximate distance of the user with RSSI, and the wearable needs to provide the signal for the RSSI calculation. Upon the module detecting the user both components need to initiate the notification sequence. The module also needs to be updateable through the central hub.

Test Items: For this test we will require a PC connected to the module to review the RSSI measurements and a user to wear the wearable.

Procedure: The following steps shall be taken in order to test the module and wearable's functionalities:

5. Position module emulator in a clear area with no objects obstructing its line of sight and power on
6. Have wearable emulator placed on user and powered on
7. User will walk directly towards the module until notification sequence is initiated by the sensor and preset RSSI value, and then immediately stopped
8. RSSI measurement values will be recorded from module, and the distance to the module will also be recorded
9. Reset module and have user leave area
10. Repeat steps 3 through 5 twenty times to obtain an average RSSI and distance value
11. Initiate central hub reprogramming to change type of notification that the module will give off
12. Repeat steps 3 through 5 while observing if notification behavior has changed
13. Power off all equipment

Conclusion: RSSI values can be fine tuned to enable notifications at a nearer or farther distance as seen fit. If all components work as initially described test is considered successful.

7 Administrative Content

This section of the report will be fully used to extensively portray the management of the project. Its content includes designation roles, important milestones needed to accomplish and to move forward with the project in a prompt manner, and financial details on the parts that make up HINT.

7.1 Project Milestones

For the purpose of organization and group productivity, milestones were created in order to be able to accomplish our goals by a relative time frame. The main goals for HINT is its design, the construction of the project, testing of the project, and final presentation of the project. Those milestones will be completed over the course of two full semesters, and the summer in between. The first semester consists of intensive research of similar projects, their components, and finalizing the initial project document. The summer and second semester will consist of the actual physical construction of the final design. View

Table 33 for milestones dates and list.

Milestone	Due Date
Initial Project Proposal (5-10 pages)	1/29/16
Approval meeting with Dr. Richie/Dr. Lei Wei	2/2/16
Table of Contents due	3/3/16
First document draft due (60-90 pages)	3/31/16
Document review meeting (w/ advisors)	4/5/16

Final Document due (>=90 pages)	4/28/16
Prototype design plan complete	*6/1/16*
Finalize wearable and module PCB	*6/15/16*
Place wearable PCB design order	*7/1/16*
Place module PCB design order	*7/1/16*
Order components	*7/1/16*
Integrate components to boards	*8/1/16*
Critical Design Review (CDR) presentation	*8/30/16*
Design review meeting (w/ advisors)	*9/1/16*
Conference paper due (8 pages)	*9/16/15*
Faculty review committee presentation	*9/20/16*
Middle term demo	*10/18/16*
Final review meeting (w/ advisors)	*10/28/16*
Final presentation and demo	*11/18/16*
Website due	*11/25/16*
Senior Design Day	*12/1/16*
Exit interview	*12/2/16*

Table 33: Milestones

7.2 Group Dynamics

The group consists of three members:

- Ramon Jimenez (EE)
- Maria-Camila Nuñez (EE)
- Mannuel Cortes-Irizarry (EE, CS)

This project was divided into three major hardware component system: a central hub, module, and wearable. In order to maximize the dynamics of the group, each member is responsible for one of the three systems, as well as their respective document content. Collaboration between the group members is needed because all our systems are will continuously communicate wirelessly. Team member role assignments are shown in *Table 34*: Project Role Division.

Design Role	Member(s)
Central Hub	Mannuel Cortes-Irizarry
Module	Maria-Camila Nuñez
Wearable	Ramon Jimenez
Power Supply	Maria-Camila Nuñez
Microcontrollers	Mannuel Cortes-Irizarry
LCD Display	Mannuel Cortes-Irizarry
Wireless Communication	Ramon Jimenez

Table 34: Project Role Division

Ramon Jimenez is responsible for the following:

- Wearable sensory I/O
- Wearable power supply
- Wearable controller
- Wearable hardware design
- Mechanical design (enclosures) for all 3 components
- Communication interfaces for all 3 components
- Testing and implementation of wearable

Maria-Camila Nunez is responsible for the following:

- Module sensory I/O
- Module power supply
- Module hardware design
- Central Hub power supply
- Testing and implementation of Module

Mannuel Cortes-Irizarry is responsible for the following:

- Central Hub sensory I/O
- Central Hub data storage
- Central Hub microcontroller
- Module Microcontroller
- Module display
- Testing and implementation of Central Hub

7.3 Finance

Kaizen Matters is financing the whole project, which means cost efficiency is key and the budget was made so expenses could be kept significantly small. The budget is to not exceed $1000. A planned comprehensive list of all parts for HINT was made, which includes the perspective names, quantities and estimated costs of each part. Some of these items do not have a set price and solely depend on other factors such as size when it comes to the manufacturing of the printed circuit board. The following *Table 35* illustrates our expenses.

Subsystems	Parts and Materials	Quantity	Cost

Hub	Hub Microcontroller	1	$35
	Zigbee Components	1	$30
	SD Card	1	$10
	AC Adapter	1	$25
	Miscellaneous Components	N/A	$50
Module	Module Microcontroller	1	$35
	Zigbee Components	1	$30
	Module LCD Display	1	$15
	Response Button	1	$10
	Range Sensor	1	$30
	Buzzer	1	$10
	Printed Circuit Board	1	$150
	Other PCB Expenditures	N/A	$25
	AC Adapter	1	$25
	Miscellaneous Components	N/A	$75
Wearable	Wearable Controller	1	$25
	Zigbee Components	1	$30
	Beeper	1	$15
	Vibration	1	$15
	Printed Circuit Board	1	$100
	Other PCB Expenditures	N/A	$25
	Batteries	2	$20
	Miscellaneous Components	N/A	$50
		Total Cost:	$835

Table 35: HINT Budget Breakdown

Making a budget that is completely correct covering every possible expense was a group goal. We want to make sure our sponsor knows exactly where all their money is being contributed towards. Complex projects like this one will not always be completely perfect throughout its longevity; having purchases of items being below, above, or not even on our list may be expected but not necessarily a problem since we made sure our finance approximations gave us that extra cushion if needed be. It is also very important that the group keeps track of all the receipts in order to show what exactly we are being reimbursed for and proof that summation of funds are maintained within budget and up to par.

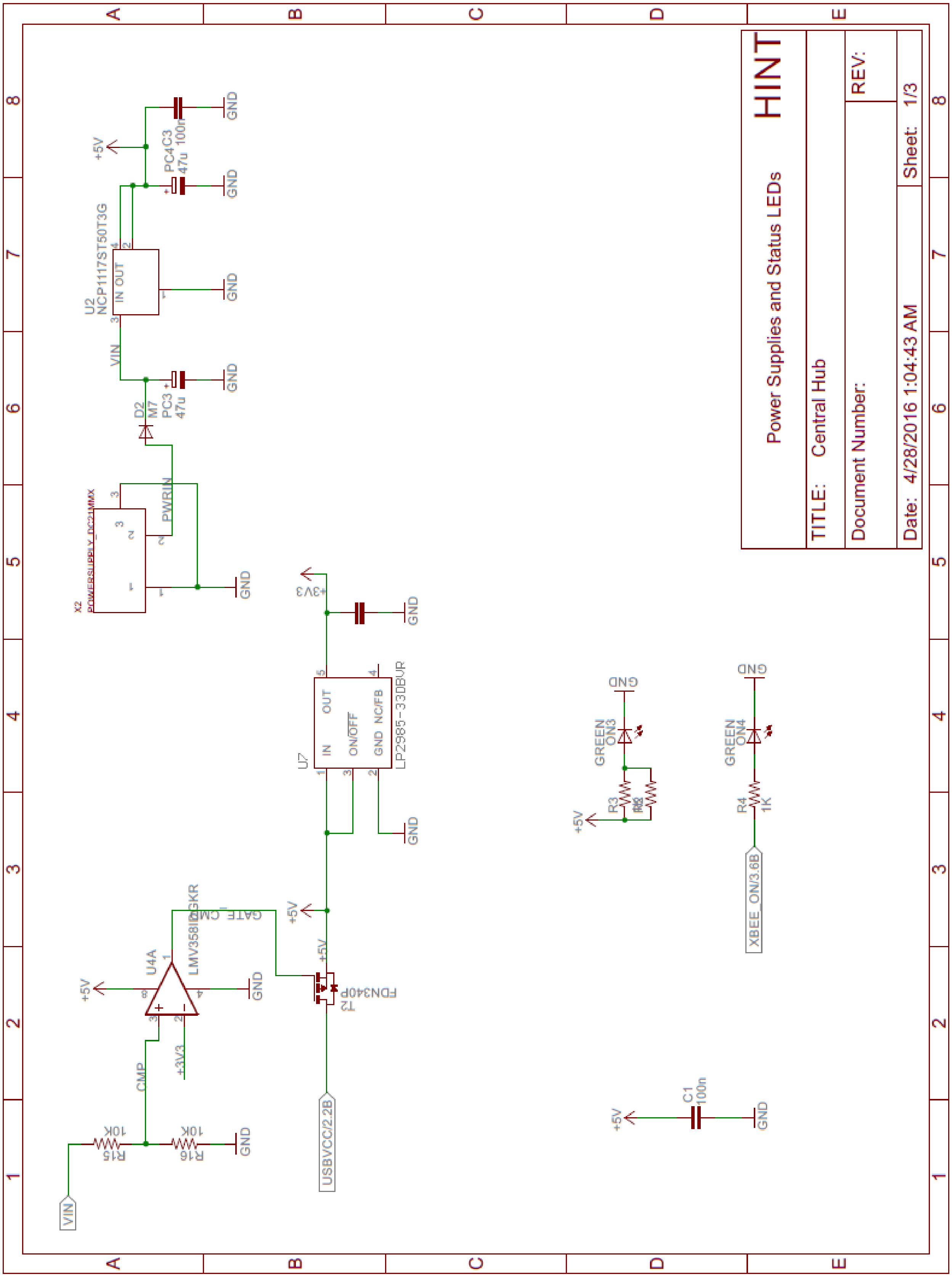
8 Design Summary

The final design of the Home Interactive Notification System (HINT) is based upon inspiration, research, calculations and simulations performed and explained in this document. The prototype of this interactive system will consists of the three main systems and their respective components

9 Appendices

9.1 Appenidx A - HINT Schematics

Central Hub: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Power Supplies and Status LEDs
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PC4
47u
C3
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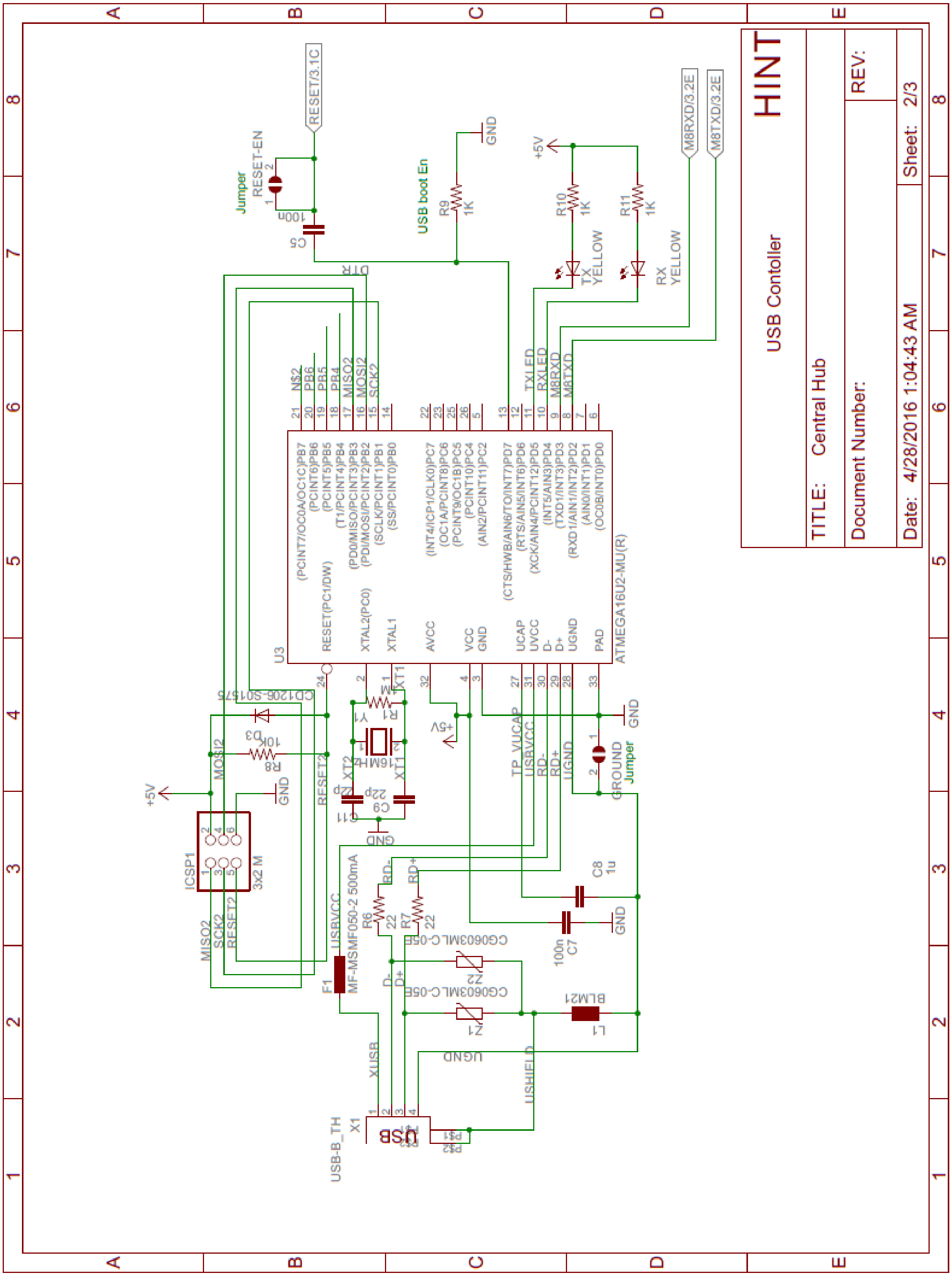
+5V
GND
VIN
D2
M7
PC3
47u
X2
POWERSUPPLY_DC21MMX
PWRIN
U7
LP2985-330DBVR
+3V3
U4A
LMV358IDGKR
CMP
GATE_CMP
R15
10K
R16
10K
FDN340P
USBVCC/2.2B
R3
ON3
GREEN
R4
1K
ON4
GREEN
XBEE_ON/3.6B
C1
100n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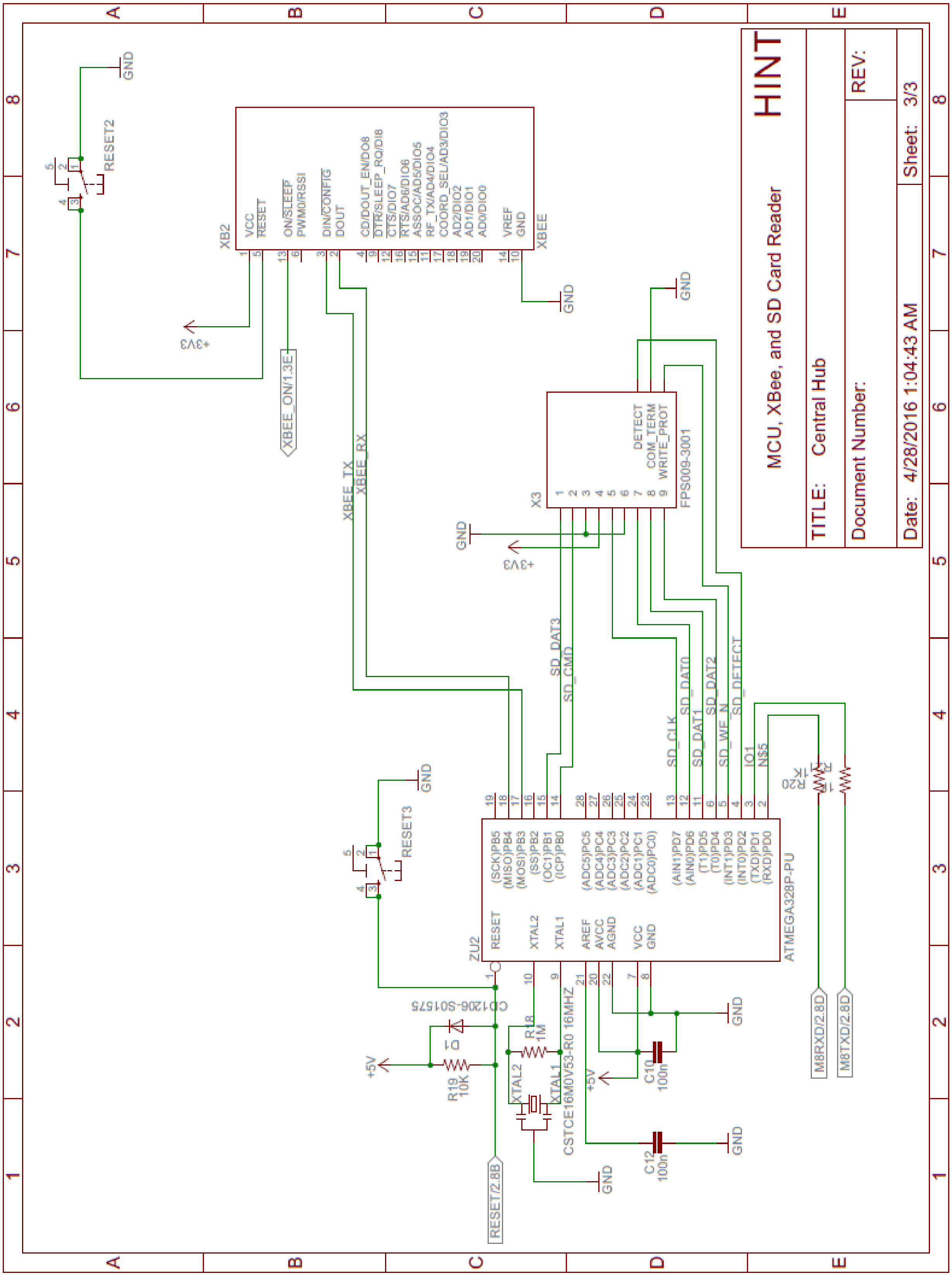
RESET/3.1C
RESET-EN
Jumper
C5
100n
DTR
USB boot En
R9
1K
GND
+5V
R10
1K
R11
1K
TX
YELLOW
RX
YELLOW
M8RXD/3.2E
M8TXD/3.2E
TXLED
RXLED
M8RXD
M8TXD
N$2
PB6
PB5
PB4
MISO2
MOSI2
SCK2
(PCINT7/OC0A/OC1C)PB7
(PCINT6)PB6
(PCINT5)PB5
(T1/PCINT4)PB4
(PD0/MISO/PCINT3)PB3
(PDI/MOSI/PCINT2)PB2
(SCLK/PCINT1)PB1
(SS/PCINT0)PB0
(INT4/ICP1/CLK0)PC7
(OC1A/PCINT8)PC6
(PCINT9/OC1B)PC5
(PCINT10)PC4
(AIN2/PCINT11)PC2
(CTS/HWB/AIN6/TO/INT7)PD7
(RTS/AIN5/INT6)PD6
(XCK/AIN4/PCINT12)PD5
(INT5/AIN3)PD4
(TXD1/INT3)PD3
(RXD1/AIN1/INT2)PD2
(AIN0/INT1)PD1
(OC0B/INT0)PD0
RESET(PC1/DW)
XTAL2(PC0)
XTAL1
AVCC
VCC
GND
UCAP
UVCC
D-
D+
UGND
PAD
CD1206-S01575
D3
R8
10K
R1
1M
Y1
16MHz
XT1
XT2
C9
22p
C11
22p
RESET2
MOSI2
ICSP1
3x2 M
MISO2
SCK2
RESET2
TP_VUCAP
USBVCC
RD-
RD+
UGND
GROUND
Jumper
C8
1u
C7
100n
F1
MF-MSMF050-2 500mA
USBVCC
R6
22
R7
22
CG0603MLC-05E
Z1
Z2
L1
BLM21
XUSB
USHIELD
UGND
USB-B_TH
X1
USB
P$1
P$2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XBEE
X3
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ZU2
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RESET2
RESET3
+3V3
+5V
GND
XBEE_ON/1.3E
XBEE_TX
XBEE_RX
SD_DAT3
SD_CMD
SD_CLK
SD_DAT0
SD_DAT1
SD_DAT2
SD_WE_N
SD_DETECT
RESET/2.8B
M8RXD/2.8D
M8TXD/2.8D
CSTCE16M0V53-R0 16MHZ
CD1206-S01575
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R19 10K
R20 1K
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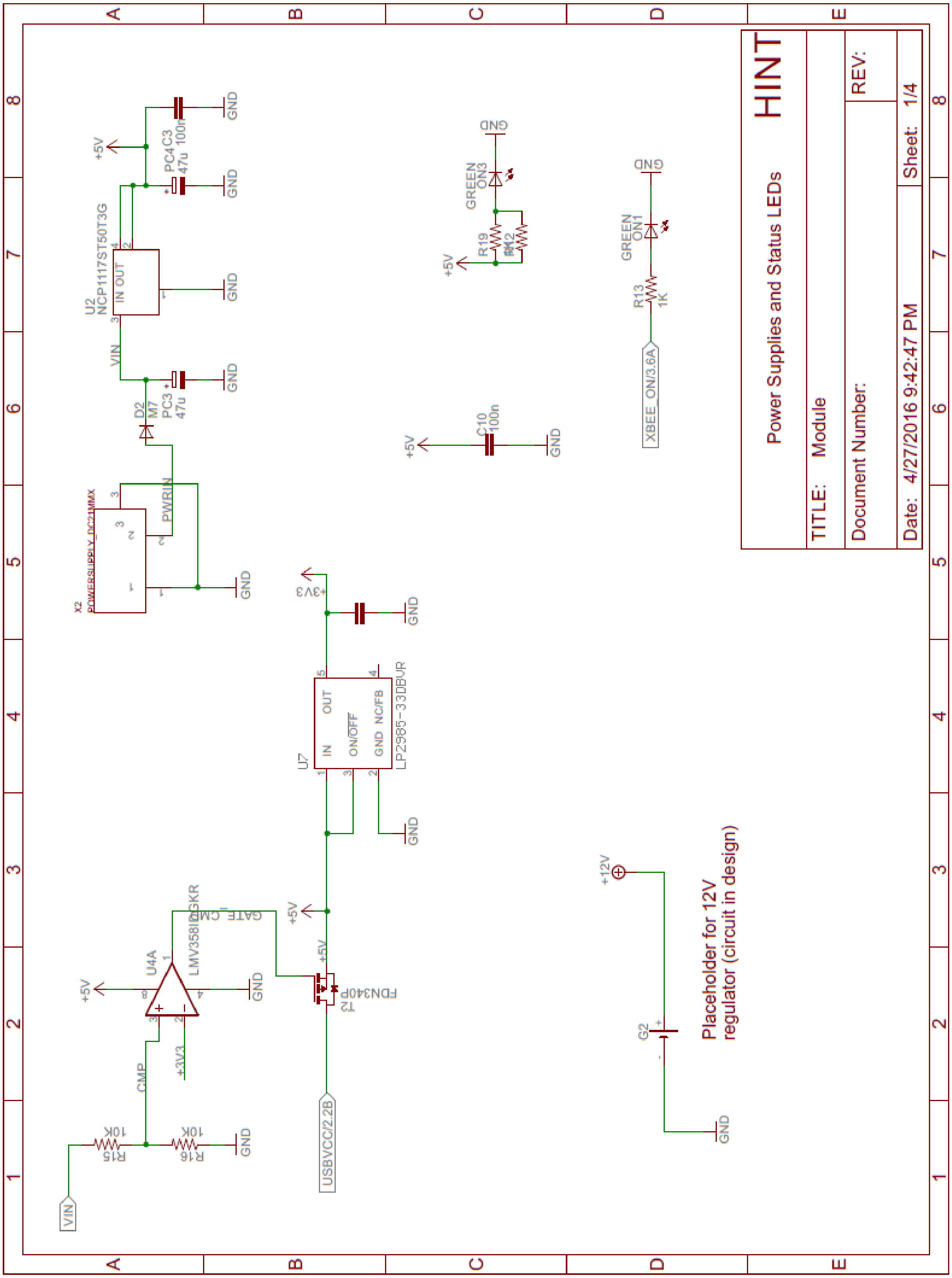
C12 100n

Module: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LP2985-33DBUR
U4A
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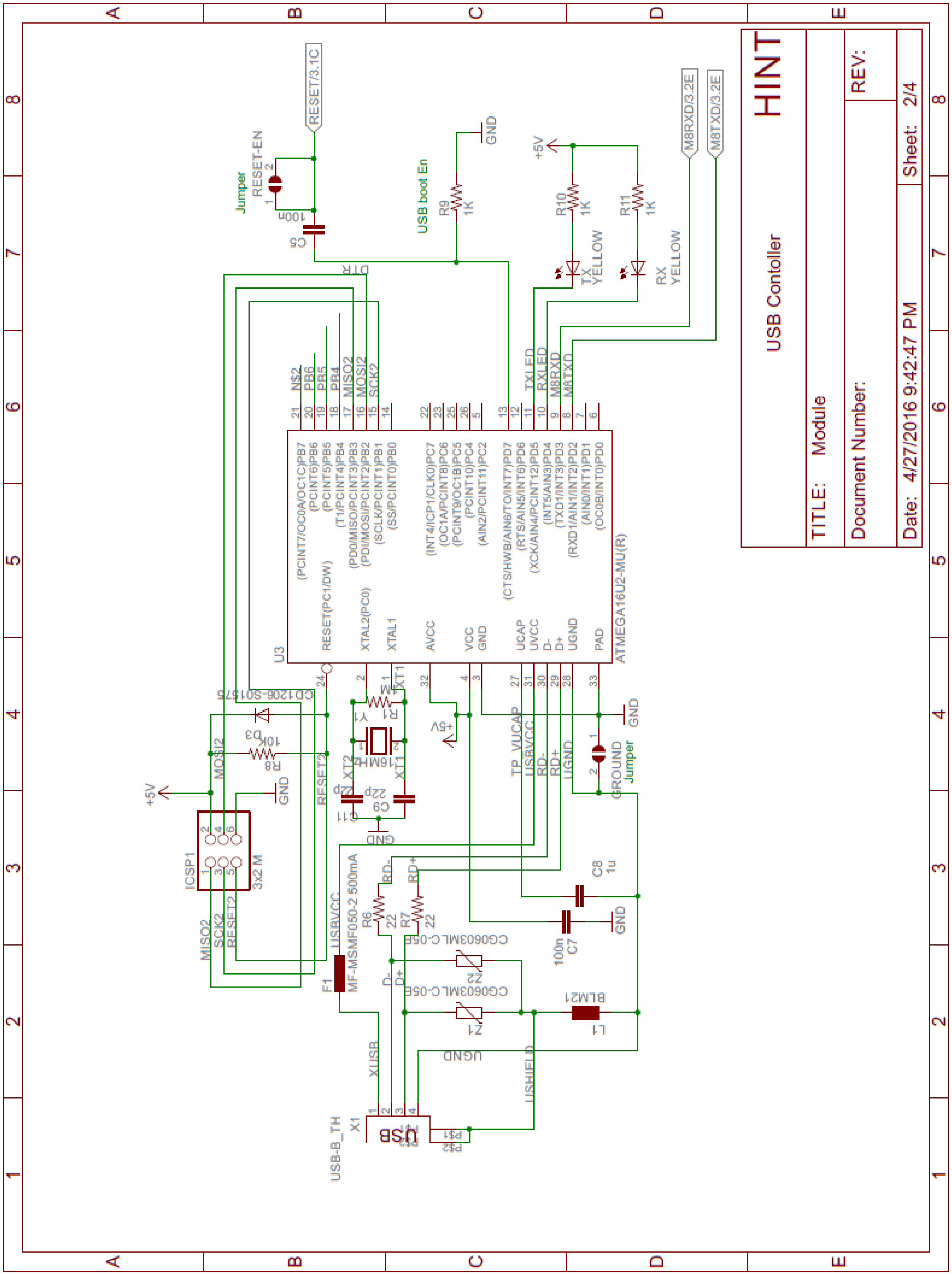
USBVCC/2.2B
VIN
GND
+5V
+3V3
+12V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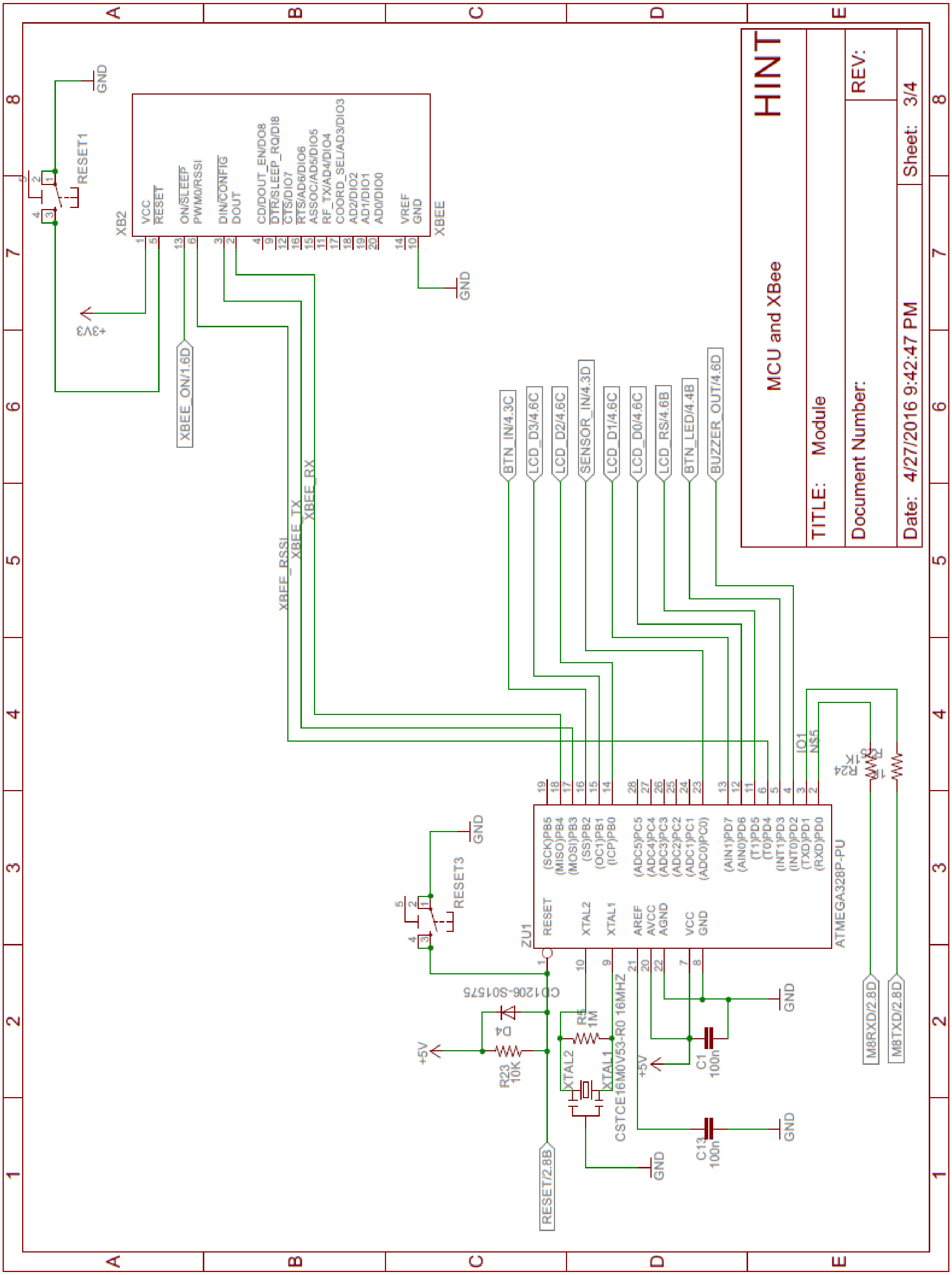
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ON/SLEEP
PWM0/RSSI
DIN/CONFIG
DOUT
CD/DOUT_EN/DO8
DTR/SLEEP_RQ/DI8
CTS/DIO7
RTS/AD6/DIO6
ASSOC/AD5/DIO5
RF_TX/AD4/DIO4
COORD_SEL/AD3/DIO3
AD2/DIO2
AD1/DIO1
AD0/DIO0
VREF
GND
RESET1
RESET3
GND
+3V3
+5V
XBEE_ON/1.6D
XBEE_RSSI
XBEE_TX
XBEE_RX
BTN_IN/4.3C
LCD_D3/4.6C
LCD_D2/4.6C
SENSOR_IN/4.3D
LCD_D1/4.6C
LCD_D0/4.6C
LCD_RS/4.6B
BTN_LED/4.4B
BUZZER_OUT/4.6D
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ATMEGA328P-PU
RESET
XTAL2
XTAL1
AREF
AVCC
AGND
VCC
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(MOSI)PB3
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(OC1)PB1
(ICP)PB0
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(RXD)PD0
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R25 1K
R23 10K
D4
CD1206-S01575
R5 1M
CSTCE16M0V53-R0 16MHZ
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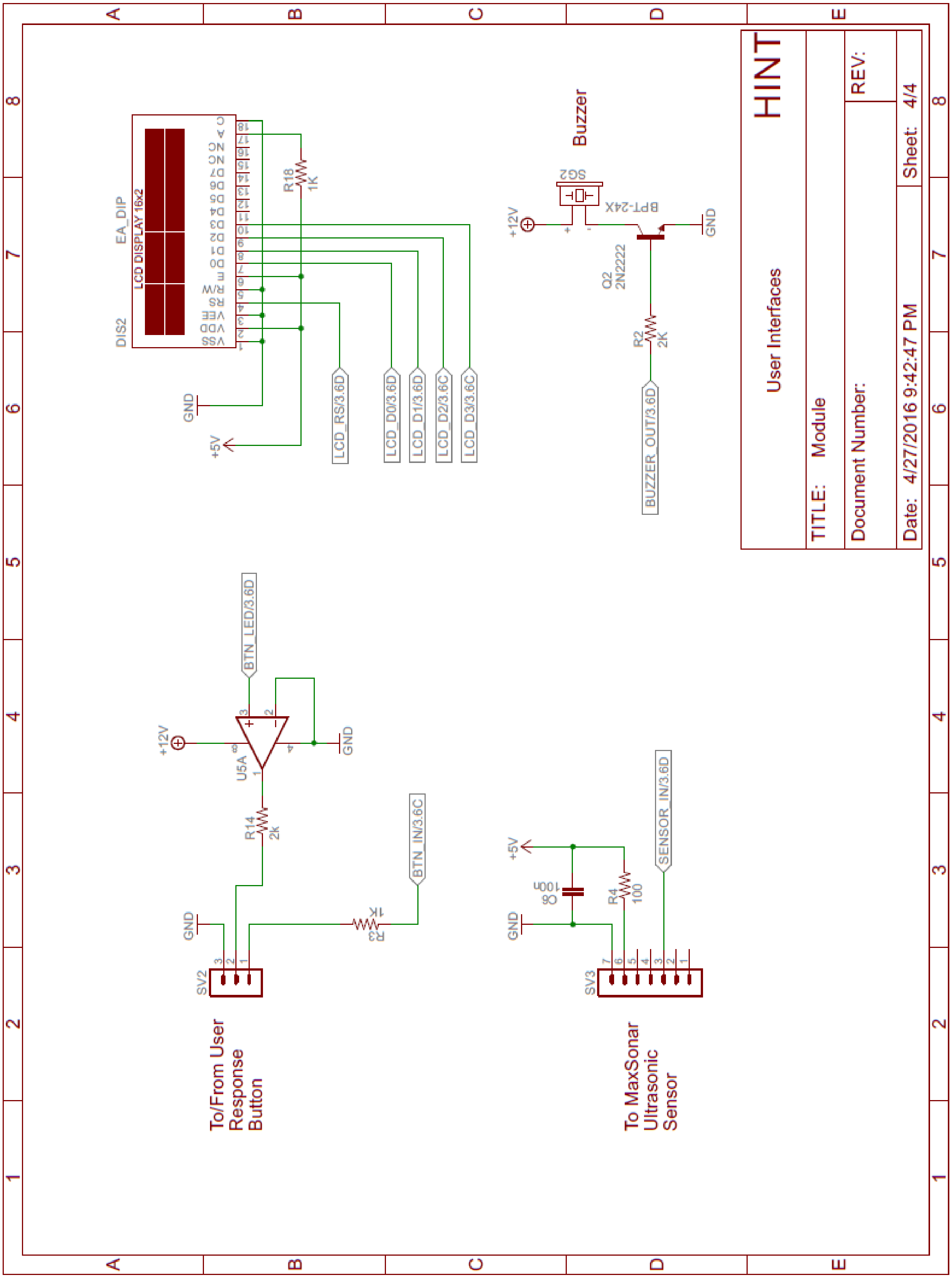
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+5V
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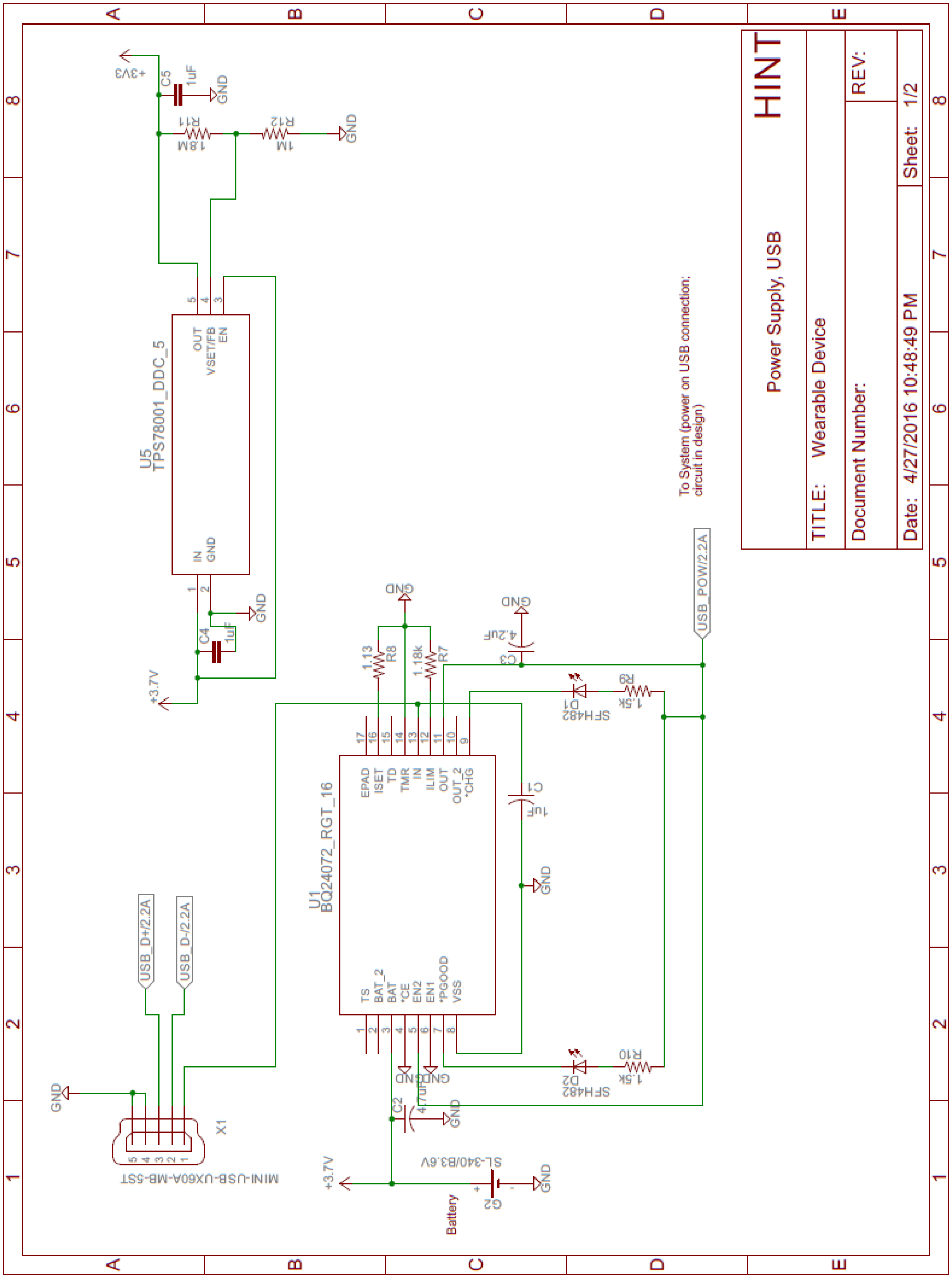
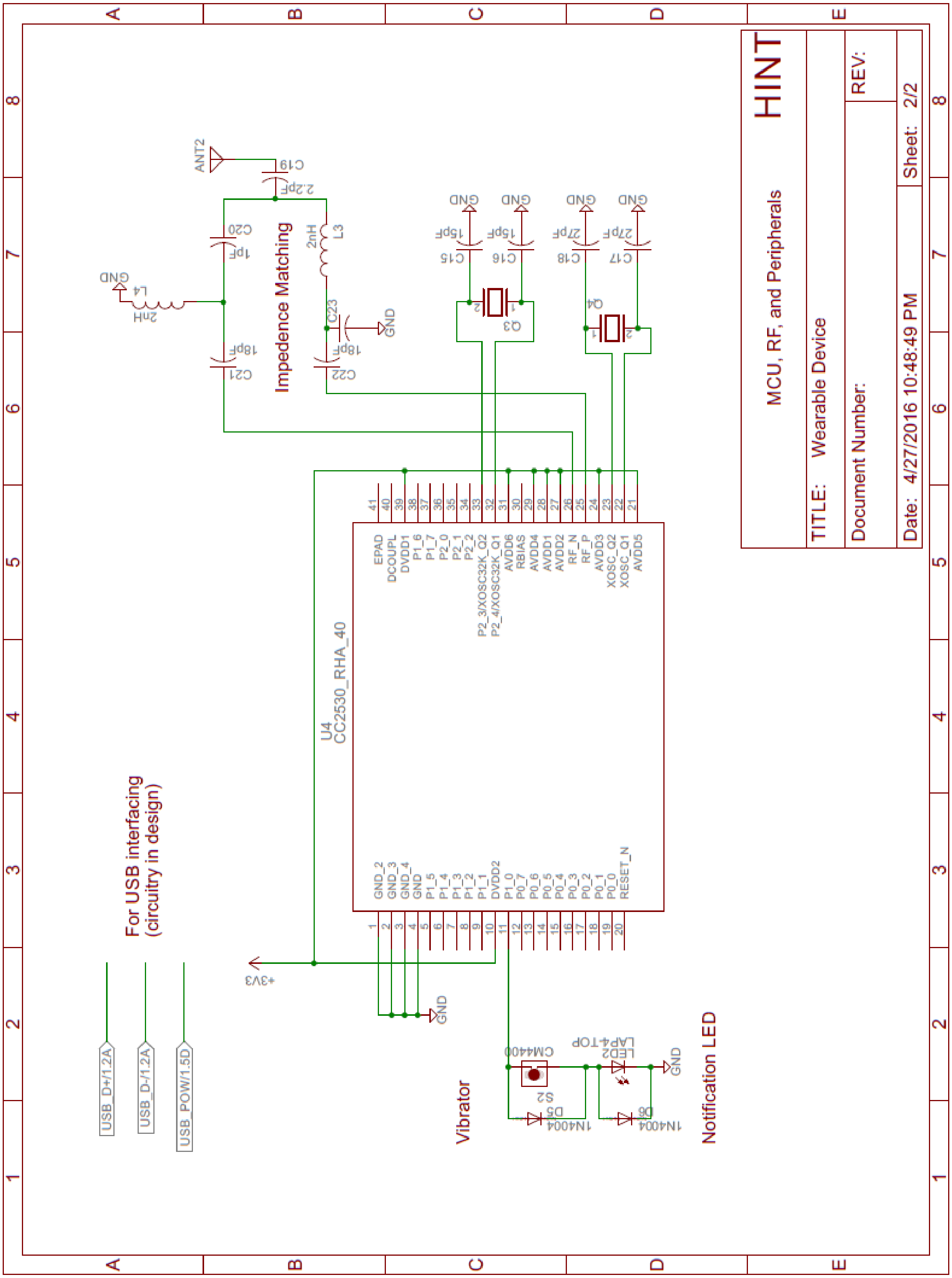
LCD_D0/3.6D
LCD_D1/3.6D
LCD_D2/3.6C
LCD_D3/3.6C
Buzzer
SG2
BPT-24X
+12V
Q2 2N2222
R2 2K
BUZZER_OUT/3.6D
BTN_LED/3.6D
U5A
R14 2k
BTN_IN/3.6C
R3 1K
SV2
To/From User Response Button
+5V
GND
C8 100n
R4 100
SENSOR_IN/3.6D
SV3
To MaxSonar Ultrasonic Sensor

Wearable Device:

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18pF
C22
18pF
C23
L3
2nH
L4
2nH
GND
C15
15pF
C16
15pF
C18
27pF
C17
27pF
Q3
Q4
+3V3
For USB interfacing
(circuitry in design)
USB_D+/1.2A
USB_D-/1.2A
USB_POW/1.5D
Vibrator
S2
CM4400
D5
1N4004
D6
1N4004
LED2
LAP4-TOP
Notification LED
EPAD
DCOUPL
DVDD1
P1_6
P1_7
P2_0
P2_1
P2_2
P2_3/XOSC32K_Q2
P2_4/XOSC32K_Q1
AVDD6
RBIAS
AVDD4
AVDD1
AVDD2
RF_N
RF_P
AVDD3
XOSC_Q2
XOSC_Q1
AVDD5
GND_2
GND_3
GND_4
GND
P1_5
P1_4
P1_3
P1_2
P1_1
DVDD2
P1_0
P0_7
P0_6
P0_5
P0_4
P0_3
P0_2
P0_1
P0_0
RESET_N

9.2 Appendix B – Datasheets

CC2530 - http://www.ti.com/lit/ds/symlink/cc2530.pdf

BQ2407 - http://www.ti.com/lit/ds/symlink/bq24072.pdf

TPS780 - http://www.ti.com/lit/ds/symlink/tps780.pdf

MAX17047 - https://datasheets.maximintegrated.com/en/ds/MAX17047-MAX17050.pdf

WRL-11215 - https://www.sparkfun.com/datasheets/Wireless/Zigbee/XBee-Datasheet.pdf

Atmega328P - http://www.atmel.com/images/atmel-8271-8-bit-avr-microcontroller-atmega48a-48pa-88a-88pa-168a-168pa-328-328p_datasheet_complete.pdf

FPS0009-3001-BL - http://datasheet.octopart.com/FPS009-3003-BL-Yamaichi-datasheet-564453.pdf

MaxBotix LV-EZ0 - http://www.maxbotix.com/documents/LV-MaxSonar-EZ_Datasheet.pdf

CPE-224 - http://www.cui.com/product/resource/cpe-244.pdf

9.3 Appendix D - Copyright Permissions

Nunez,

Thank you for your email. I am glad to assist you with your question. Please see my comments in the text below.

You state the following information: I would like to request permission to use an image and information from this link in my report.http://www.maxbotix.com/Ultrasonic_Sensors/MB1000.htm

Yes, as long as Maxbotix is properly referenced you are more than welcome to use our image.

I hope this information helps, and good luck with your project.

Please let me know if you have any questions.

Best regards,

Dan Alcox
Level 1 Technical Support
of MaxBotix Inc.
Phone: +1(218) 454-0766 ext 2
Direct +1(218)-454-7313
Fax: +1(218) 454-0768

Email: cody@maxbotix.com

Hi Maria-Camila,

CUI would be happy to allow you to utilize our images and product information. Thank you in advanced for properly referencing us. If you have any questions about our product or CUI don't hesitate to ask.

Best of luck on your senior project. I hope all goes well.

Regards,

Kelly Wigginton
Brand Director
CUI Inc

Direct: 503.612.2327
Toll Free: 800.275.4899
www.cui.com

APR 25, 2016 | 10:27AM MDT
Rob R. replied:

Hi Maria-Camila,

Thank you so much for contacting us. All of our images are released under the Creative Commons license, [http://creativecommons.org/licenses/by-nc-sa/3.0/], so you are absolutely free to use the image or images. The license just asks for attribution when using the images – just put somewhere that it came from Sparkfun, the coolest company in the known universe :-). (Okay, that second part is completely optional.)

I hope this helps. Good luck on your Senior Design Project, and have a great day!

Warm regards,

Rob

****
Rob R
Technical Support Rep
Sparkfun Electronics
6333 Dry Creek Parkway
Niwot, CO 80503
303-284-0979

Julian Lewis
To: Ramon Jimenez, f-watch@ohwr.org
Re: Reprint Permission
Today at 5:14 AM

Ok by me, go for it

On Thu, Apr 28, 2016, 10:22 Ramon Jimenez <rjimenezucf@knights.ucf.edu> wrote:

Good Morning,

My name is Ramon Jimenez and I am an Electrical Engineering student at the University of Central Florida. My senior design team and I are doing some research for our project and we came across your design. We wanted to ask permission to re-use the imag below in our research paper for our project. It would be a public publication and you will be receiving the credit for sharing the image with us. We are using your design as a comparison to what we would like to design to since there are not a lot of these independently done.

techsupport@maximintegrated.com
To: rjimenezucf@knights.ucf.edu
Permission for Reprint [ref:_00D306AVj._50040vc3vh:ref]
Today at 4:50 AM

Hello Ramon Jimenez,

Thank you for contacting us.

Below is a link to Maxim's "Authorization for Limited Use of Maxim Material - Copy and Use Restrictions".

Please read and sign the document and return to the address provided at the bottom of that document.

Thank you for coming to us to make this request.

https://www.maximintegrated.com/en/legal/terms/terms-and-conditions-of-use.pdf

Regards,
Javier Monsalve
Applications Engineeirng

ref:_00D306AVj._50040vc3vh:ref

[This Email Sent From: Email Technical Support
http://www.ti.com/general/docs/contact.tsp]

[wfsegen]

[DATE / TIME (UTC): Thu, 28 Apr 2016 08:13:38 GMT]
[CUSTOMER'S REGIONAL LOCAL TIME: April 28, 2016 at 4:13:38 AM EDT]

[Name: Ramon Jimenez]

[Prefix: Mr.]
[First Name: Ramon]
[Last Name: Jimenez]
[Job Title:]
[Company: UCF]
[Email: rjimenezucf@knights.ucf.edu]
[Phone: 3215142469]
[FAX:]
[Country: USA]
[Address1: 11215 pinewood cove lane]
[Address2:]
[City: orlando]
[State: FL]
[Postal Code: 32817]
[Part# or Description: MULTIPLE]
[Category: General Information]
[Application: Other]
[Design Stage: New design]
[Estimated Annual Production: N/A units]
[Production Date: N/A]

[Problem:
Good Morning, My name is Ramon Jimenez and I am an Electrical Engineering student at the University of Central Florida. My senior design team and I are doing some research for our project and we came across the following components: TPS780, BQ24072, CC2530. We wanted to ask permission to re-use the images (specifically the top level view) of the components in our research paper for our project. It would be a public publication and you will be receiving the credit for sharing the image with us. Thank You, Ramon]

[Steps Needed to Recreate Problem:

]

techsupport@maximintegrated.com Today at 4:50 AM T
To: rjimenezucf@knights.ucf.edu
Permission for Reprint [ref:_00D306AVj._50040vc3vh:ref]

Hello Ramon Jimenez,

Thank you for contacting us.

Below is a link to Maxim's "Authorization for Limited Use of Maxim Material - Copy and Use Restrictions".

Please read and sign the document and return to the address provided at the bottom of that document.

Thank you for coming to us to make this request.

https://www.maximintegrated.com/en/legal/terms/terms-and-conditions-of-use.pdf

Regards,
Javier Monsalve
Applications Engineeirng

ref:_00D306AVj._50040vc3vh:ref

Ramon Jimenez Today at 3:45 AM RJ
To: Ramon Jimenez
You emailed Tech Help Blog

Name: Ramon Jimenez

Email: rjimenezucf@knights.ucf.edu

Comments: Good Morning,

My name is Ramon Jimenez and I am an Electrical Engineering student at the University of Central Florida. My senior design team and I are doing some research for our project and we came across the images (XBEE pinout) on your website. We wanted to ask permission to re-use this image in our research paper for our project. It would be a public publication and you will be receiving the credit for sharing the image with us.

http://www.techhelpblog.com/2012/12/05/xbee-s1-802-15-4-guide/ -- original article

-- Thank You

9.4 Appendix E - Requirements Verification Methods

9.5 Appendix F – Acronyms and Abbreviations

9.6 Appendix C - References

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