

**Project Proposal and Feasibility Study**

**Team 5 – Com 1 Com All**

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## 1.0 Introduction

This section will introduce the reader to the context in which this project will be completed including: the class, the team, the project, and what will be found in the remainder of this report.

## 1.1 Senior Design

Calvin College is a small liberal arts college in Grand Rapids, MI which offers an Accreditation Board for Engineering and Technology (ABET) accredited engineering degree in chemical, civil, electrical, and mechanical concentrations. As the core capstone of this major Engineering 339/340 Senior Design requires students to form a team to research and design a solution to a problem or fill a need.

## 1.2 Team Description

Com 1 Com All is a design team made up of three senior electrical engineers: Joe Gluvers, Justin Slocum and Josh Velthouse. Members of the team can be seen below in Figure 1.



**Figure 1: Team Photo**

### 1.2.1 Joe Gluvers

Joe is a senior engineer in the electrical concentration, and has a broad taste within the field of electrical engineering. This summer he worked for Twisthink LLC in Holland, MI as an intern

and developed his skills in test development and reporting. Joe is originally from Sacramento, CA where he attended Rocklin High School before coming to Calvin College. He is also a four year varsity swimmer for Calvin and a team captain this year. He recently celebrated his first anniversary and will be working mostly on the overall visual design and human interface of the device.

### *1.2.2 Justin Slocum*

Justin is focused on hardware design and board layouts for digital and analog electrical systems; he is working on an engineering degree of electrical concentration and a math minor. While working at Dorner Works Imbedded Systems Engineering in Grand Rapids, MI this summer and through this year Justin worked on development and testing of imbedded hardware systems as well as gained experience in reverse engineering. He hails from suburban Detroit where he attended Oscar A. Carlson High School before coming to Calvin College. When not engineering, Justin is also a member of the Calvin College Capella. He will be working on the board layout, RF communication, and other various support tasks.

### *1.2.3 Josh Velthouse*

Josh is a programming focused electrical engineer and will receive an additional math minor. He worked as an intern at Gentex Corporation in Holland, MI where he gained valuable experience in a manufacturing environment. Josh is originally from Holland and attended Holland Christian High School prior to attending Calvin College. He also enjoys singing, reading, and creating. It is likely he will be working on much of the programming and related functionality of the design.

## **1.3 Our Project**

Intercoms allow a person to communicate with another person or all persons within earshot of an intercom module when circumstances prohibit face to face communication. Unfortunately, installation of a wired intercom system is an arduous task because it involves running communications wires between all points that require communication. These wires can be a major eyesore if great care is not taken to run them through walls, ceilings and floors, so the obvious solution is to do away with the new communication wires. Two main solutions exist for this, power line communication, and wireless radio frequency (RF) transmission. Com 1 Com All has decided to design a wireless RF intercom solution called t<sub>COM</sub>.

## **1.4 This Document**

This document details the engineering design and feasibility analysis the team has completed this semester as well as provides a road map for work to be done next semester.

## **2.0 Problem Statement**

In the home intercom market there are three prevalent solutions: low cost systems that transmit through the house's power lines, low quality wireless radio frequency intercom systems that

offer little more than simple communication similar to walkie-talkies, and advanced wired intercoms that mesh with home security systems, offering video communication and surveillance, home control features, and costing upwards of a thousand dollars per module. Our goal is to provide reliable and feature rich wireless communication to both do-it-yourself home improvers and new home builders to fit in the niche between the represented extremes.

### **3.0 Project Objectives**

This section will outline the major objectives which Com 1 Com All hopes to accomplish in the design and testing of the  $t_{COM}$  intercom system. Project objectives include: affordability, simplicity and transparency, AC (alternating current) power fluctuation insensitivity, and Manufacturability.

#### **3.1 Affordability**

At the core  $t_{COM}$  is a commercial product and therefore must turn a profit when sold, however, in a competitive market if the product is not worth the asking price customers will ignore it and it will never turn a profit. Therefore, the  $t_{COM}$  system must be affordable to manufacture, so that it can be affordable to own, in that it does not have an exorbitant initial cost, nor unrealistic maintenance and operating costs.

#### **3.2 Simplicity (Transparency)**

Each  $t_{COM}$  station needs to be extremely easy to use so that the entire family including children and disabled persons whom might need the system the most can benefit from the installation of a home intercom system. Device setup and programming also should be easy, so it will appeal to all people not just the tech savvy. With these two objectives complete  $t_{COM}$  will appeal to the widest possible user base, directly impacting the number of units sold.

#### **3.3 Insensitive to AC Power Fluctuations**

Fluctuations in the AC line voltage can cause damage to a system's components if the voltage is not properly regulated. In addition to component damage the talk over the power lines intercom systems, fluctuations in the AC line voltage cause pops and buzzes in the communication line. This would cause the users to turn off the intercom and forget to turn it back on. An intercom is not useful when it cannot transmit and receive data, so our device will have communications isolated from the AC line, thus lowering the noisy interference, and protecting sensitive components.

#### **3.4 Easily Manufacturable**

To improve production cost and compete commercially  $t_{COM}$  must be able to make the transition from prototype single board builds to mass manufacture. Mass production procedures such as automated board fabrication, automated testing, and automated final assembly and packaging bring down the per-unit cost.

## 4.0 Christian Perspective

Since we are all Christian engineers, our faith undoubtedly will have a significant impact on both our final system design in addition to how we go about our design process. Although this project at first glance may not seem to have specific applications for “Christian life” or “outreach”, the final product would impact everyday living which is itself an offering to God. Also, community and relationships are central to human life for people of all religious perspectives and an intercom system is one way to further enable communication between friends, families, and coworkers. What could be seen as a somewhat insignificant gadget could have significant impact on how people live with each other in worship to their creator.

### 4.1 Product’s Purpose

The overall aim of the  $t_{COM}$  is to enable communication within a home or business. This is done by enabling verbal contact between areas/rooms which were previously physically separated by walls or physical distance. Although not a necessity, having an intercom system offers a simple way to save time and physical energy communicating between different locations in a building. In addition, the intercom system would also provide added safety to the home environment. Extra features like a “Listen Mode” (baby monitor type feature) would allow parents to monitor young children who are sleeping or playing in another room. We see our intercom system as a very useful addition for many homes and businesses.

### 4.2 Specific Design Norms

Design norms are a collection of ethical principles which engineers or other professionals can use as a framework to base the design of a product or process. They can be used effectively to remind the engineer what is needed by the end user and thus help to provide a better serve their client. In addition to affecting the end design, many of these design norms also apply directly to the design process itself and how the engineer carries out their work. Throughout our design process, we have and will continue to use design norms as a way of guiding choices for  $t_{COM}$ ’s final system design. These will be explained in the context of our project in the following sections.

#### 4.2.1 Transparency

It is essential for the intercom system to be intuitive for the user and easy to program and use. If the customer has difficulty learning how to use the system, it will be little more than a dust collector that will not at all be useful. Additionally, young children may potentially have to use the intercom in the home setting. This means that small children must be able to easily learn and use the intercom as well as adults.

This will affect our design most noticeably in the area of the user interface. We want to provide the robust system features (“Com 1/Com All”, module naming, automatic network setup and upkeep, hot button communication, synchronized system clock, alarms) using only as many buttons as is absolutely necessary. Extra buttons would cause a cluttered and confusing exterior for the user.

#### *4.2.2 Integrity*

In addition to providing a product that is easy to use, we feel it is also extremely important that we provide the customer with a product that works well and respects their privacy concerns when using the intercom. Because of this the audio quality delivered to the end user should be of sufficient both in possible volume and audio quality with reduction of electrical noise. Other systems became functionally useless due to the problem of noise on the signal. So, it will be of key importance in the final integrity of our product. Also, the system should provide reliable functionality for the end user, secure communication kept within the home network, and not become quickly obsolete due to other technology changes. All of these are expectations of potential customers that must be met if our product is to serve them well.

Integrity also covers the area of how we work on the project and develop our designs. We are called to honesty in the amount and source of our ideas and eventual designs and should always give credit to those who have given us their valuable input.

#### *4.2.3 Stewardship*

Finally, we believe that it is extremely important to provide a high quality final product while making good use of our and the consumers resources. Solid technical functionality and low cost to the consumer should take precedent over flashy features that would drive up the final system cost. Many of the existing products on the market have a large financial cost for an intercom with robust functionality and wireless or dedicated wired audio transmission. It is our hope to be able to dramatically lower the final cost of our intercom while still providing robust features the consumer will find desirable. This will make it a more easily accessible product for those who may have ignored the product due to the high prices in the past.

#### *4.2.4 Cultural Appropriateness*

The fact that  $t_{COM}$  may be used in commercial/business environments in addition to the residential environment adds another layer of complexity to the design tasks. Usage in a small business would be very different from in a home and thus requires a slightly different or more flexible design to account for these differences. For example, a monitor or listening mode may be a critical feature for a couple with a new baby but would probably be looked upon negatively in the work environment. As a result, our design must take into account the fact that the user may wish to prevent other intercoms from listening in on them by making some sort of blocking feature available.

Also, the possibility of this product being used in other countries must be considered in the final production design. This may not change the technical functionality offered by the  $t_{COM}$ , but it would have a major impact on how the product would be packaged and marketed in those countries. It would be extremely short sighted to think that someone who only spoke or read French for example would be quick to buy a product which only used English. Exterior packaging should have varying markings based on the native language of the country in which it is being sold. In addition, the interactive menus displayed should have the option of changing the language to the user's language of choice. Finally, each country will most likely have a

slightly different view of the product in the marketplace and would require varying strategies in marketing and distribution.

#### *4.2.5 Trust*

The consumer being able to find the  $t_{COM}$  as a reliable and useful product will be critical to it finding a permanent place within the intercom market. In the past, many consumers were completely disappointed with the functionality of inexpensive systems which claimed wireless capability while the functionality depended completely on the wires within the building. Some of these consumers may have had their thoughts of purchasing an intercom greatly reduced and the  $t_{COM}$  will have to work at rebuilding the sense of trust in these products. As designers, we must be open and honest about the capabilities and functionality of the final design and portray it as such to the customer. If this is not done, the customer will feel betrayed and would be unlikely to look to our products in the future because of such a deception.

#### *4.2.6 Caring*

All things considered, we want to design this product in such a way that we serve the customer's needs by creating a product that will improve their everyday life. Every aspect of the design should look to improve the way it serves the end user's immediate community. Caring for the customer encompasses all of the other design norms and is at the core of the design and design process.

## **5.0 Alternative Solutions**

In order to deliver basic intercom functionality, the designer must, at minimum, be able to transmit the audio from one intercom to another. There are three basic means of audio transmission used in intercom systems: sending the signal through the building AC power lines, additional wires between the intercom stations, or an RF (radio frequency) connection between intercom stations. These each have their own strengths and weaknesses that should be considered when implementing an intercom system or any other audio link.

### **5.1 “Wireless” Wired System**

In this implementation, the audio signal is sent over the building's AC power lines by impressing a low frequency, frequency modulated carrier signal which carries the audio. The carrier signal also must have a small amplitude so it will not significantly change the existing 120 V<sub>AC</sub> power signal. This is a functionally low cost option since the transmission medium is already implemented within the building. All the intercom system would have to do is to create the modulated carrier and demodulate and the receiver side to recover the original audio. The savings on additional wiring or RF connections would be significant thus dramatically reducing the cost of the intercom system.

Unfortunately, some fairly serious problems for audio transfer come with the power lines within your home. IEEE (Institute of Electrical and Electronics Engineers, Inc.) member Luis Montoya, in an article about power line communication protocols, points to several problems with

implementing communication over power lines. First, power lines were only meant to be used for transmission of power at a frequency of at most 400 Hz. Additionally, it is difficult to produce dependable results since power lines are extremely “electronically contaminated” and signal attenuation is high at the frequencies used. The results of these problems could be heard in many people who have used these systems. Many complained of noise demodulated from the wiring when audio was not being transmitted causing unacceptable audible noise being produced at the intercom speaker. Others also criticized these systems for having unreliable behavior in which configurations which worked one day would not on another. Finally, these systems can only transmit data between intercoms which are connected to the same physical circuit within the house. Otherwise the receiving intercom wouldn’t even see the audio signal being sent making the pair useless.

## **5.2 Wired System**

These audio transmission systems use additional dedicated wiring to transmit audio and other data between a number of intercoms. Twisted pair, coaxial, and Ethernet wires are the most commonly used for intercom systems. Ethernet is more prevalent among the newest systems. After the initial cost of implementing all the wiring and setup within the home, these systems can provide extremely fast data transmission with very few concerns for noise tainting the audio signal. Because of the additional bandwidth, these systems have much more flexibility to add additional features in addition to the basic intercom functionality. Many include the option of inputting and making available audio from another device which could then be listened to on any of the intercom systems. The increased bandwidth is often dedicated towards video transmission as well in intercoms implemented as part of a security system.

Cost is the obvious drawback for choosing a dedicated wiring system. As well as the installation and materials cost for the wiring, there is also the additional cost of implementing a high speed transmission protocol like Ethernet or otherwise. The task of determining where all of these signals need to be sent as well sending these large amounts of data is extremely daunting. If done well though, improvements in system quality would be obvious.

## **5.3 RF Wireless System**

RF or true wireless systems would implement the audio transmission through the means of RF communication between a transmitter and receiver. In RF communication a base frequency is selected and that signal is then modulated to include the data that is to be transmitted. How this is done varies based on the given RF protocol being used. Wireless data transmission is desirable first of all because it is wireless and would require no installation of additional wires jus the like “wireless” wired systems. Unlike those systems though, RF intercoms would not be dependent on a physical system and less likely to have data corrupted by noise.

There are of course drawbacks to the wireless implementation. While there isn’t a physical wire which would encounter noise on, additional RF signals may be present at the frequency of choice making it difficult or impossible to transmit the data signals. Bandwidth is also significantly reduced by going to a wireless connection. Additionally, RF communication is also contingent upon the receiver being within the physical range of the transmitter. The signal loses power as it

travels further from the transmitter and becomes harder for the receiver to successfully receive the signal. Range is a function of the transmitter output power, receiver sensitivity, and any signal gain on the antennas used. So, range of a given system can be improved by using a more powerful antenna. If the two RF intercoms are in range and are not encountering significant signal on the frequency, a wireless connection should be able to provide effective and dependable data transmission.

## **6.0 Patent Concerns**

All projects must keep patent infringement and opportunities in mind. With wireless technology at the forefront of today's market, there are many patents to be aware of and look over. Patents are also a source of information and ideas to help projects get on the right track.

### **6.1 Wireless Patents**

There were two wireless intercom patents of interest found regarding tCOM's design. The first patent, US 7,103,392 B2, describes a wireless microphone of the sort that might be used in a restaurant. It mentions other units which include a headset model and a unit with a remote switch. This patent references patents as late as 1969. No detailed circuitry is provided since the patent is primarily for the housing. Because the circuitry needed for the design is patented over 20 years before the patents 2002 date, there was no infringement for the design. Likewise tCOM's design will incorporate only circuitry such as filters that no longer are covered by patents.

The second patent describes a wireless hub for attaching multiple wired intercoms to a wireless headset device. This patent shows a fairly complicated analog circuit that is used to implement the wireless transmission. Because tCOM's design does not use extensive analog circuitry, there is no real opportunity for patenting. No patents were found that patented an arrangement of patented IC's.

### **6.2 Component Patents**

While most of the components in tCOM's design are integrated circuits available for purchase, there was no manufacture that sold scroll wheels like the ones used in mice. It is possible that each mouse manufacturer has their own patents for individual use or that some unknown manufacturer is providing them behind the scenes. More research and inquiry will be needed to determine whether or not its incorporation will infringe on patent holdings.

## **7.0 Market Study**

Prior to the development of our product, thorough knowledge of the existing intercom market was necessary. This information would be used to help determine desired features, final product target cost, technology usage, and marketing strategies. An adequate sampling of the products currently available were compiled and compared to determine the market status. In addition to product offerings, data was also collected on annual home construction in the United States.

This along with general commercial sales would make up the majority of possible sales for the tCOM.

## 7.1 Overview of Options

A brief compilation of information on a variety of intercoms available online is shown in Table 1 below. The full table of intercom data from our market study is available in Appendix B. These intercoms show the wide range of technology, quality, and price available to consumers on the market today. Each of the options represented will be explained in the sections to follow.

Table 1 - Available Intercom Examples

Name	Transmission Type	Range	Size	Price (1)
Radio Shack	200 - 270 kHz (FM)	-	-	20
Reporter Wirefree Intercom	900 MHz	1000 ft	4"x5.5"x2"	89
Flush Reporter Wirefree Intercom	900 MHz	1000 ft	6"x7"	99
Outdoor Reporter Wirefree Intercom	900 MHz	1000 ft	6"x3.5"x2"	79
Westinghouse WHI-4CUPG	FM	500 ft	-	62.5
Westinghouse WHI-2C	FM	1500 ft	5.5"x5.5"x1.75"	20
Westinghouse WHI-3C	FM	1500 ft	6.75"x5"x1.75"	27
Westinghouse WHI-4C	FM	1500 ft	6.25"x5.5"x1.25"	35
Nutone IMA110	200 - 290 kHz (FM)	500 ft	7"x5.75"x1.875"	43
GE/Jasco TL97600	Home Wiring	Same Circuit	-	20
GE SmartCom	Wired (Ethernet)	Cable Length	-	2200 (four module system)
M&S DMC1	Wired (Ethernet)	Cable Length	-	500 (master only)

### 7.1.1 Home Power Circuit Intercom Systems

This type of intercom system, represented by the GE/Jasco TL97600 in Table 1 and Figure 2 below, was the source of the problem which created this project idea. While these intercom systems are extremely inexpensive, they are functionally restrictive due to their means of audio transfer. Intercom modules in one of these systems send their audio data through the home's wiring system by modulating the standard AC signal. Unfortunately, this requires that two intercoms which hope to communicate must be plugged into the same circuit within the building. Otherwise they will be unable to communicate and the intercom will be completely useless. Additionally, the audio signal is sensitive to fluctuations in the AC power signals which can cause noise on the audio output. These systems still are bought due to their low prices but are disappointing for those unaware of their wiring requirements.



Figure 2 - GE/Jasco TL97600

### 7.1.2 High-end Wired Intercom Systems

Another type of wired intercom system does not use the building's power circuits but additional wires connecting each of the intercom modules. The GE SmartCom and M&S DMC1 are two examples of this type of system. GE's SmartCom module is shown in Figure 3 below. These intercoms provide much greater reliability in data transfer and include additional features like home audio distribution from traditional audio devices (i.e. cd players, radios, etc). Along with the superior functionality and features of these systems comes the overwhelming cost of implementing them in a home or office. In addition to at least a hundred dollars for each module and more for master or hub modules, there is the additional material and installation cost for wiring these systems. There are extremely impractical for existing homes but are a viable option for new construction or renovation projects.



Figure 3 - GE SmartCom Module

### 7.1.3 Wireless Intercom Systems

The remaining intercoms, those listed first in **Table 1**, represent systems technically similar to the proposed  $t_{COM}$ . All of these use RF data transmission to send audio between intercom modules. All of the systems we found made use of transmission on either the 200 kHz or 900 MHz frequency ranges. This does not seem to be the only indicator of final system cost even though the 900 MHz systems are the most expensive systems listed. Additionally the number of channels available for communication seems to have a direct relationship with the intercom cost. The Westinghouse intercoms show this as each intercom increases in cost due to the addition of another channel for communication between intercoms. The most expensive version, the WHI-4CUPG shown in Figure 4 below, includes five channels the user can set for a module's communication. Two intercoms hoping to communicate must be placed on the same channel for transmission to take place. Additional channels provide flexibility for the user but also force the modules to be manually placed into the correct channel to communicate with a specific module. Westinghouse's least expensive model provides only two channels for communication. None of these systems provided additional features available on the higher end wired systems like a graphical interface to provide clock, alarms, or other information to the user.



Figure 4 - Westinghouse WHI-4CUPG

## 7.2 $T_{COM}$ 's Place in the Market

Due to  $t_{COM}$  proposed RF transmission, we believe the  $t_{COM}$  will fit into the market as a mid-priced but fully featured wireless intercom system. The presence of its LCD screen will allow it to offer additional features not offered on most wireless intercom systems. In addition, the automatic frequency or channel setup for talking modules will make the system much simpler for the user. The  $t_{COM}$  will be more expensive than the cheaper intercom systems but should provide superior functionality to even those systems more expensive than our projected selling costs. Because of this, it should be a successful product within the existing intercom market.

## 7.3 Sales Prospects

While data on yearly sales of comparable intercom systems seem to be relatively difficult to procure, there are still other methods to determine a possible sales market for the  $t_{COM}$ . Our device will be most useful in the home market and to a lesser extent the smaller office environment. Because of the  $t_{COM}$ 's ability to be wall mounted or even placed into a wall, an

excellent target market would be for new home construction. According to the National Association of Home Builders (NAHB), there were just over 1.8 million new homes started in 2006. Some percentage of these, assumedly the more expensive homes, probably included intercom/home audio systems comparable to the GE SmartCom. The  $t_{COM}$  would provide a low cost alternative, both in system and installation cost, compared to expensive wired systems which could be offered to new home construction companies and contractors. Additionally, the lower system cost would make it a more feasible option for less expensive homes. Making a conservative estimate,  $t_{COM}$  could prospectively be used in about half a million new homes in America each year alone. In addition, the  $t_{COM}$  could be marketed to retailers as a higher quality alternative to less expensive systems like the one found at Radio Shack. Retail sales in addition to possible direct online sales would further increase possible sales.

## **8.0 Detailed Requirements**

The final intercom system should adhere to the requirements as listed below. Section 4.1 details the requirements for our final prototype design which will be tested on actual prototypes next semester. Requirements for the full scale production design are given in Section 4.2 as additions to the prototype requirements which will already have been met.

### **8.1 Prototype Requirements**

As a means of solidifying the high level system design and focusing the design process, the requirements for the prototype system in terms of functionality, power usage, size, environmental concerns, and final cost.

#### *8.1.1 Functionality*

The final prototype design for the  $t_{COM}$  will:

1. Network up to 255 intercom modules.

One byte of data will be used to indicate the intended intercom to receive and carry out a given system instruction. Eight bits would allow for a maximum of 256 modules to be addressed. One of these addresses will allow for a message to be intended for all intercoms on the network. This makes the maximum number of intercoms 255 on a given network.

2. Provide and keep track of separate data transmission frequency channels dedicated to or being used for networking tasks, calling other modules and network detail updates, and direct audio transmission.

Having a consistent knowledge of which frequency channels are being used by the  $t_{COM}$  network will be crucial to the final functionality. There will a dedicated RF (radio frequency) channel for all  $t_{COM}$  intercoms used for initial network setup and later intercom additions to the network. Another dedicated but changeable channel should be used to facilitate communication requests and updates of intercom station and network

information. This information would include new intercoms on the network, updated intercom names, system clock changes, and channels and intercoms being used in audio transmission. Any number of additional channels can then be used for audio transmission between intercom stations once the requests are facilitated.

3. Have a range up to 300 m (1000 ft).

In our market study, available range from wireless intercom systems was one of our main areas of interest. Most wireless systems claimed a range of either 150 m (500 ft) or 300 m (1000 ft). Designing for a range of 1000 ft would keep us on the same level as existing competition and also make the  $t_{COM}$  much more flexible for physical network configurations.

4. Provide RF (radio frequency) audio transmission from one intercom to one or more other intercom stations.

The transmission should send audio in one direction at a time but the audio signal should be receivable by multiple stations within range of the output signal.

5. Provide the user a button to initiate conversation with a single module or group of intercom stations.

This will be called the “Com One” button and will be the general call button for conversation with any set of intercoms smaller than the whole network. After indicating which intercom(s) will receive the audio, pressing this button will allow the user to begin talking directly to the other intercoms.

6. Provide an audible busy signal when requesting another intercom already in conversation.

The user should not be able to initiate conversation and send audio to another station already in conversation. This would corrupt the signal being sent for the preceding audio transmission.

7. Provide the user a button to request conversation and transmit audio with all other modules.

The “Com All” button will be used as a general purpose call to all the network intercoms. When pressed, the user can begin talking with all the other intercoms.

8. Provide transition from initial “Com All” request to continued audio response from another intercom to all network intercoms or just the original “Com All” requester.

After initial audio is sent from the original requester, another user could press the “Com All” button on their intercom to send audio back to the entire network. Pressing the “Com One” button would end the entire network audio transmission and initiate a single conversation with the original requester.

9. Provide the user a button to end an intercom call.

Pressing this button would transmit a message to the other intercom(s) indicating that the current call has ended. Then the intercoms should return to the frequency channel dedicated to facilitating com requests.

10. Provide a monitor function which will receive and play audio from another intercom station.

This must also be subject to the end call button. The audio transmission must therefore provide gaps to allow the monitoring intercom to send the end call message to the intercom sending the audio. This is equivalent to a baby monitor.

11. Provide automatic network initialization upon initial startup.

When a  $t_{COM}$  is first opened and plugged in, it will be configured to receive data on the dedicated channel for network setup. If it does not receive a message from another intercom already on a network, it will then begin the process of initializing a network. This entails creating a network address, producing an encryption key, determine the network frequency channel used for facilitating com requests and network information updates, and then send this data to any other intercom that powers up within at most 5 minutes of its initial power up. All of these intercoms will be assigned an initial name to distinguish them on the network and address for network instructions.

12. Provide 128 bit data encryption for secure data transmission.

An exclusive-or operation will be done to all data sent over the transceiver with the encryption key produced during the automatic network initialization. This can be undone on the receiver side by an additional exclusive-or operation with the same network key which will be saved in each intercom.

13. Provide a process to add additional intercom units after the initial automatic network initialization process has completed.

There may be the need to add additional intercoms to a network after its initialization. This process should provide that new intercom with all the required network information from requirement (11) above and inform the intercoms on the network of the new intercom details (address and initial name).

14. Provide for module naming and renaming after initial network setup.

The naming feature will allow the users to easily determine which intercom they wish to communicate with due to a descriptive name.

15. Provide programmable hot buttons for one or more intercoms.

These buttons will be used to quickly select which intercoms will be used under an upcoming “Com One” call. They should be able to be reprogrammed by adding or removing an intercom from the button list.

16. Provide a system clock showing the time and date and also allows for synchronous updates among the entire network.

The clock should be set by the user and then be kept through the use of a real time clock or software routine. Any changes in the clock from any intercom station should be sent to the other stations which will update their own time based on that information.

17. Provide alarm options based on the system clock.

These alarms should cover single intercoms only and not to the entire network.

18. Provide a graphical (visual) interface to display an interactive menu system used to help the user control the intercom.

This menu will provide access to clock updates, setting alarms, programming hot buttons, adding additional intercom units, volume control, backlight control, monitor function, accessing network information on intercom names, and selecting a custom list of intercoms to call.

19. Provide a physical interface (buttons) to allow control of the module and system.

These will include the “Com One”, “Com All”, end call, four “hot buttons”, and the control for the interactive menu.

20. Provide a means of volume adjustment within existing buttons.

Volume must be able to be adjusted without adding additional buttons to the system. It should be controlled through the menu system when not transmitting audio and through the menu control buttons during audio transmission.

21. Have programmable backlight feature on the display for nighttime use based on the system clock.

The user must be able to turn the backlight off and adjust the brightness. Additionally they can program the time during the day in which the backlight will be used at all.

### *8.1.2 Power*

For power supply and requirements the t<sub>COM</sub> prototype will:

1. Provide a nominal DC voltage above 5V using an AC to DC converter to convert standard outlet power.

The requirement of a voltage above 5V is due to the fact that we will need to regulate supply voltages at a 5V maximum for some integrated circuits. If the provided voltage is not adequate we will not be able to provide the required voltages.

2. Provide nominal voltages of 5V and 3V for integrated circuits in the design.

This should be done through integrated voltage regulators if possible. 5V and 3V were selected because they are the two commonly used supply voltages for almost all integrated circuits.

3. Use less than 5.324 W in total power.

For an estimated ten year life, the cost of the power used if permanently receiving audio should remain less than the cost of purchasing the system.

### *8.1.3 Size*

The prototype board should fit within the following size restraints:

1. Total dimensions – 5” by 8”

Based on the market study, this dimension will make the prototype board only a few inches in each direction larger than most available intercom packages. Assuming the final production design will be able to be made a few inches smaller in each direction, this should be a good requirement for the prototype.

### *8.1.4 Environmental*

The prototype should adhere to the following environmental requirements:

1. All parts should be RoHS (reduction of hazardous substances) compliant.

t<sub>COM</sub> modules will comply with reduction of hazardous substances (RoHS) standards, this includes a lead free components and soldering in the prototyping and production stages. The product must comply with these regulations in order to be marketed in Europe, and it will add to the safety of the product for the end user and community.

### *8.1.5 Cost*

The final cost for an assembled prototype design shall:

1. Not exceed \$100.

For adequate testing of the system, a minimum of three prototypes will be necessary. With the current project budget of three hundred dollars, each prototype will have to be assembled for a total cost to the team of less than \$100.

## **8.2 Production Requirements**

The production design must adhere to the requirements of the prototype design above and any additional requirements listed in this section.

### *8.2.1 Functionality*

In addition to the prototype functionality, the production design must also:

1. Provide the option of changing the displayed language of the interactive menu system.

In order to make the product marketable in other countries and non-English speakers, the options of additional display languages must be included.

### *8.2.2 Power*

The power system of the production design must:

1. Convert AC power from the outlet with an on board AC to DC conversion circuit.

The further regulation should be implemented on board as in the prototype design. This requirement helps to make the product more marketable due to the lack of an external power converter that will be used for prototyping.

### *8.2.3 Packaging*

Intercom packaging for the production design must:

1. Have a maximum allowable size of 5" by 8" by 1.5".

This was determined based on comparisons to available wireless intercoms in the market study.

2. Have a maximum allowable circuit board size of 4.5" by 7.5" by 1.25".

This is based on the maximum size of the product packaging. The circuit board must be able to fit inside the exterior packaging.

3. Provide the capability to be wall mountable, flush mountable, and free-standing within the same package design.

These options would further improve the marketability and flexibility of the  $t_{COM}$  for the end user. Wall mountable entails the intercom being hung from a nail like a picture frame. Flush mountable entails the package being embedded within the wall so the face is roughly even with the wall. Free standing entails standing on a desk or counter with some sort of support system to the intercom easier to use.

4. Provide rounded corners and edges

This will add to the safety of the final design for small children in the homes.

5. Provide durability to retain system functionality after a ten foot drop onto a hard surface.

This will be essential to the final marketing and distribution of the product. If it breaks easily, then there will be significant cost in replacing or fixing this problem.

6. Provide easy cleaning without harming the interior electronics.

Users should be able to clean their systems without worry of breaking the product.

#### *8.2.4 Environmental*

The production design must adhere to the following environmental requirements:

1. Any additions in the product packaging or on board power supply must comply with RoHS standards.

This follows the reasoning explained in the prototype environmental requirements section.

#### *8.2.5 Cost*

Manufacture the production design must:

1. Be able to produce a single intercom unit for under \$20.

To sell for a preliminary target market price of around \$80 per unit, the manufacturing cost must come in under \$20. This is assuming that the price per unit will double for each link in the distribution chain until the product is brought to the end user. That would bring the wholesale cost to \$40 and the consumer cost to \$80 per unit.

#### *8.2.6 FCC Compliance*

The final production design must:

1. Be able to pass FCC compliance testing.

Commercially available products to be marketed in the United States must comply with FCC (Federal Communications Commission) regulations part 15 for intentional and unintentional radio frequency radiators. Since our product will operate in the unlicensed industrial, scientific and medical (ISM) radio frequency bands at the 950 megahertz, 2.4 gigahertz, or 5.8 gigahertz frequency range. The FCC has set maximum output power in these frequency ranges is one watt or thirty decibels referenced to one milliwatt and defined the exact frequency range available in each area, our product must comply with those regulations. In other countries similar organizations control the use of the radio frequency spectrum with similar rules. Worldwide the 2.4 gigahertz band is available for unlicensed communication, however, the specifically allowed frequencies vary slightly, so our system will have to be flexible if it is to be marketed worldwide.

## **9.0 Preliminary Design**

Our preliminary design shows how the  $t_{COM}$  is to be implemented and will fulfill the requirements for the system. The system level, hardware, software, and any additional system protocol designs will each be explained along with any internal components or subroutines used to fulfill the higher level design. Decision criteria for each component will be explained along with the eventual selection and any key information about that component or subroutine.

### **9.1 System Design**

This section will describe the top level system design for the  $t_{COM}$ . The intention is to show the various areas of the entire system design and how they are connected and work together to provide the intercom functionality.

#### *9.1.1 Modular Unit Network Implementation*

One of the first decisions made was to design the intercom system using several identical modular units. This design choice would simplify the design and manufacturing process and also allow for a more consistent experience for the end user. Instead of having several different unit types for the user to understand, each intercom module would provide identical functionality to be mastered. This would also allow for network setup and other system functions to be carried out from any location rather than at a central hub or mother intercom which would most likely control all setup and most of the audio transmission as well. Most wireless intercom systems similar to our design employ a similar design but also provide a simpler module version for outdoor locations like the front door. This would be another addition to possibly consider after the main module design is complete.

#### *9.1.2 Modular System Design*

The block diagram in Figure 5 below shows the five main systems of the  $t_{COM}$  module design. Along with the various connections between each system, the general features supplied by each are also listed. Further description of each system is provided in the sections to follow.

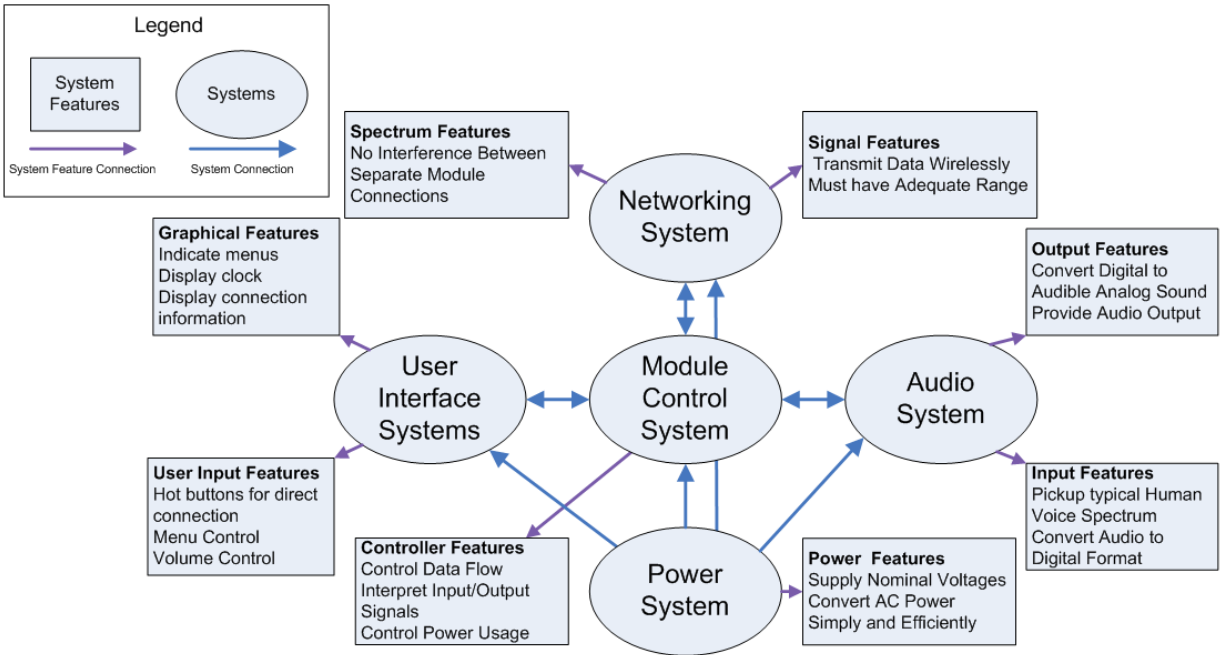


Figure 5 - System Level Functionality

### 9.1.2.1 Module Control System

The control system is the brain of the intercom module. From this point all data from the other systems will be processed and additional messages sent out to implement the various system functionalities. Upon initial power up, the control system will have to configure all of the other system components and initialize the network connections between modules through the network system. It will also store a variety of network information in every module that will be used to keep track of network activity and ensure successful communication and functionality between the various modules.

### 9.1.2.2 Networking System

In order to connect and transfer data between the various modules, a networking system had to be implemented. Because of our choice to use wireless RF data transmission this system will consist of only our transceiver integrated circuit and additional external hardware necessary including an antenna. Such an integrated circuit would implement an RF transmission and receiving protocol to consistently send data between the modules over the required range of 300 m (1000 ft). The controller will have to configure this circuit through data messages and also upload and download the data messages being sent and received on the intercom network.

### 9.1.2.3 Audio System

This system will implement the audio input and output functionality. For audio input, it will take an audio input from a microphone, provide this analog signal at the proper amplitude to be converted to a digital signal, and then transmit the digital audio data to the control system to be transmitted over the network. On audio output, it will receive digital audio data from the control

system, convert this back into an analog audio signal which will be amplified so that it can be used to drive a speaker and provide audible sound back to the user. This system will consist of some means of conversion between the analog and digital audio formats and addition analog hardware to provide changes amplification and output power to the speaker.

#### 9.1.2.4 User Interface System

The user interface system is the tool that allows the user to interact with the intercom module and network as a whole. A graphical display will be used to show the system clock and interactive menu used control some of the intercom functionality. User input will be provided through a series of buttons which will control the menu and thus also the functions of the intercom. Buttons for the “Com 1 Com All” functionality will be independent of the graphical display menu and will automatically begin conversation with the other modules. The volume will be controlled through the menu control buttons if the module is talking with another module. Otherwise it will be changed through the settings under the displayed menu.

#### 9.1.2.5 Power System

The power system provides the necessary voltages to all of the components within the  $t_{COM}$  module. It will have to convert standard power from a electrical outlet to a DC (direct current) voltage. From this point the system will use voltage regulators to reduce the initial DC values to those required by any integrated circuits and other components in our design.

#### 9.1.2.6 Design Conceptualization

Early in the design process  $t_{COM}$  required an initial visual design concept, this early concept can be seen below in Figure 6. The design has since been refined to include a two like LCD display, scroll wheel interface and different sized audio components.



**Figure 6 - Initial Design Concept**

## 9.2 Hardware Design

A large portion of the functionality for the  $t_{COM}$  will be provided using hardware which will then be controlled through software control. Due to their low power consumption and ease of use for prototyping, integrated circuits (ICs) were used wherever possible for our hardware design. This choice would significantly simplify the design process as large portions of required functionality could be covered by a single IC.

### 9.2.1 Preliminary Block Diagram

The first conceptualization for the hardware required for the  $t_{COM}$  is shown in **Figure 7** below. Based on the system level design of the most previous section, the following components were selected: a microcontroller ( $\mu C$ ), transceiver (TX/RX), digital to analog converter (DAC), analog to digital converter (ADC), LCD (liquid crystal display), external buttons, power supply unit (PSU), external memory, microphone, speaker, antenna, and line in/out.

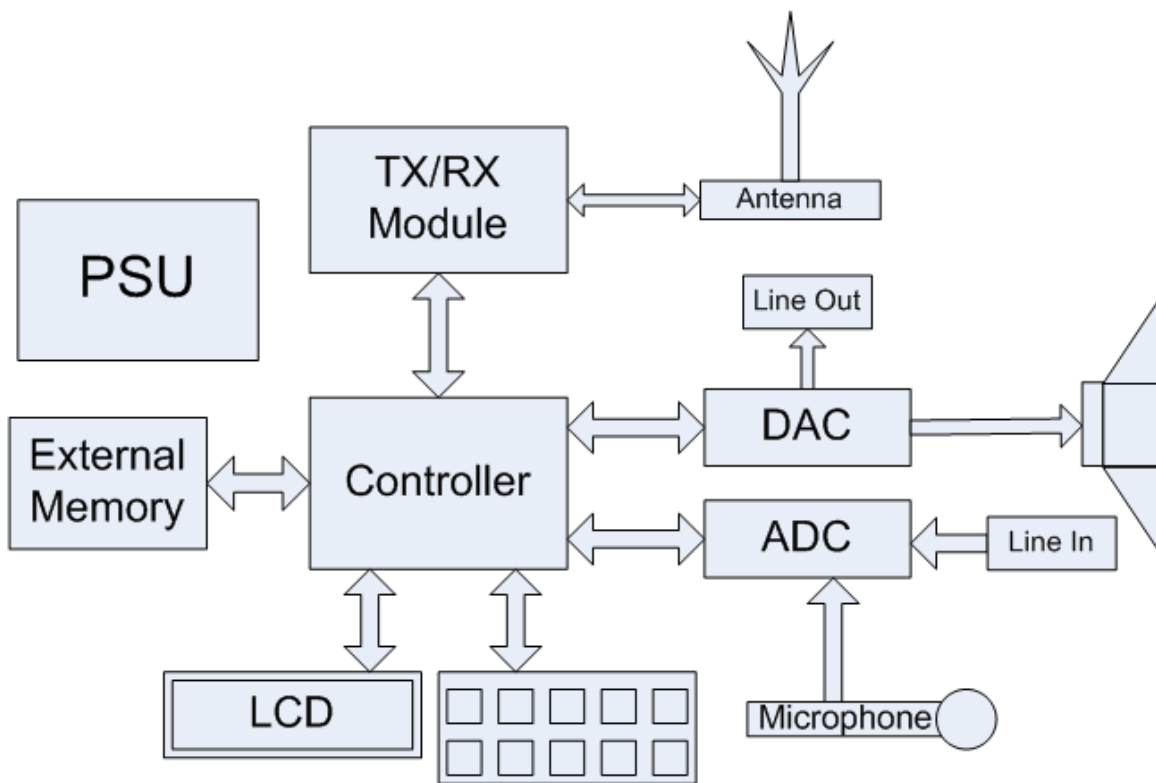


Figure 7 - Initial Hardware Block Diagram

From this point we began the task of selecting components for the intercom system.

### 9.2.2 Wireless Transmission Technology

The wireless transmission technology is arguably the most essential component to the basic functionality of a wireless intercom system. If the transceiver is unable to provide the necessary data rate, range, or cost effectiveness then the system will not be able to meet its requirements. When selecting this device, the first task was to decide on an RF protocol which the transceiver would use to transmit the data. For this decision, we compared six major wireless protocols in the areas of available data rates, range or transceiver sensitivity, price for implementation, and overall practicality. In addition to general 2.4 GHz and 900 MHz transceivers, ZigBee, Wi-Fi, Bluetooth, and Wireless USB were considered for this application. Our decision matrix in Table 2 below shows the ratings for each protocol type and the total score to determine the eventual choice.

Table 2 - Decision Matrix for Wireless Protocol

Criteria	Weight	Protocol Type											
		2.4 GHz RF		900 MHz RF		ZigBee		Wi-Fi		Bluetooth		Wireless USB	
		Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score
Data Rate	4	3	12	2	8	2	8	5	20	3	12	5	20
Range/Sensitivity	4	3	12	4	16	2	8	3	12	2	8	1	4
Price	5	5	25	5	25	4	20	2	10	4	20	1	5
Practicality	4	5	20	4	16	4	16	3	12	2	8	1	4
<b>Total</b>		<b>16</b>	<b>69</b>	<b>15</b>	<b>65</b>	<b>12</b>	<b>52</b>	<b>13</b>	<b>54</b>	<b>11</b>	<b>48</b>	<b>8</b>	<b>33</b>

A general 2.4 GHz transceiver was our choice for the type of wireless transmission protocol. Although they provide a slightly slower over air data rate than some of the specific protocols, they were much less expensive to implement and more practical for our specific project. This was due mostly to the cost of individual ICs which are much more expensive for ZigBee, Bluetooth, and especially Wireless USB transceivers. Range further eliminated Wireless USB and Bluetooth from being a viable option for the  $t_{COM}$ .

With 2.4 GHz transceivers selected as the general wireless protocol, a decision still had to be made as to the specific transceiver to use in the  $t_{COM}$ . The main criteria for this decision were data transfer rate, transceiver sensitivity and output power, and the amount of available frequency channels. Without adequate data transfer rates to cover the task of streaming the audio, a transceiver would be functionally worthless. Preliminary data transfer analysis in Appendix C showed that to transfer the audio data without any associated protocol overhead would take a transfer rate of 576 kbps. This showed that the actual data rate would have to be at least 1 Mbps or perhaps even more to be considered. Transceiver sensitivity and output power are the main components to calculating possible data transmission range. A larger range of output power to receiver sensitivity would provide a larger transmission range. The use of our expected transceiver design also required that it use a wide range of transmission frequencies for the various types of communication taking place between modules. This can be seen in our frequency usage diagram in Figure 8 below.

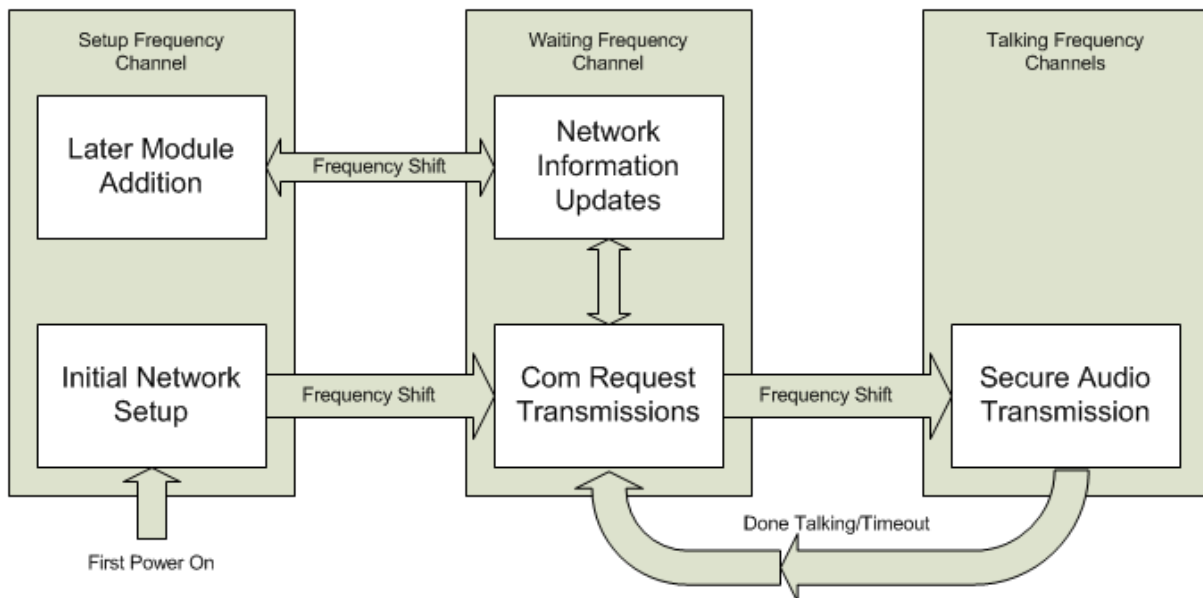


Figure 8 - Designed Usage of Set Frequency Channels

The intercom software will be designed so that specific frequencies will be allocated for specific types of network tasks such as the initial network setup and additional module additions, network updating, matching of requested intercoms for communication, and the actual audio transmissions during secure talking. Every  $t_{COM}$  module will be programmed with the same network setup frequency where network information will be dispersed to the various modules before they can work as a viable network. From this point, the modules will shift transmission frequency to a “waiting channel” in which the modules will share updated network information and send requests to talk with specific modules. Finally any number of the remaining channels can be used for connections between talking modules which need to stream audio data. Additional channels would allow for the transceiver and/or microcontroller to find a clear channel within the operating frequency range. So, the transceiver must be able to allow easy changes to the operating frequencies for data transmission.

After a thorough search of available 2.4 GHz transceivers, five possibilities, each from a different manufacturer, were compared to determine which would provide the best functionality for our project. Four of the options were available in individual parts while the RFW3M from Vishay was a module only product. Module designs could be soldered onto the existing circuit board design greatly simplifying the eventual board layout unfortunately they are also much more expensive than implementing the full design on the board with the rest of the design.

Table 3 - Decision Matrix for Transceiver Selection

Criteria	Weight	Transceiver Type															
		ATMEL		Nordic		Analog Devices		Texas Instruments		Vishay							
		ATR2406	Rating	Score	nRF24L01	Rating	Score	ADF7020	Rating	Score	CC2400	Rating	Score	RFW3M	Rating	Score	
Data Rate	5	4	20	5	25	1	5	4	20	5	25	1	5	4	20	5	25
Range/Sensitivity	4	4	16	3	12	5	20	3	12	3	12	5	20	3	12	3	12
Price	3	5	15	4	12	5	15	4	12	4	12	5	15	4	12	1	3
Packaging/Size	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	5	5
Available Channels	4	4	16	5	20	4	16	5	20	5	20	4	16	5	20	1	4
<b>Total</b>		19	69	19	71	17	58	18	66	15	49						

The choice for the transceiver to be implemented, the nRF24L01 from Nordic Semiconductors, provided all of the necessary features and capabilities for the  $t_{COM}$  technical requirements. Its top data rate of 2 Mbps was double that of the initial 1Mbps estimated requirement. Available channels will not be an issue as it allows 126 different transmission frequencies. The only slight drawback was a slightly lower sensitivity than the other options when operating at the highest data rate. In addition to the main design criteria, it also provided a standard Serial Peripheral Interface (SPI) for transmission of data to and from the microcontroller. This will decrease the burden on microcontroller software for transmitting data to the transceiver. Although more expensive than some of the other options, the transceivers were only \$2.05 each and provided excellent functionality to implement in the  $t_{COM}$  system.

### 9.2.3 Microcontroller

There are a multitude of different microprocessors available on the market. Not only do they come with a verity of costs, features, and speeds, but also offer a variety of development kits and support software. Com 1 Com All considered a number of popular low cost microprocessors to potentially use for  $t_{COM}$ 's controller. The microprocessor's decision matrix can be found below in Table 4.

Table 4 - Microcontroller Decision Matrix

Categories	Weight	PIC	AVR	SX	Freescala
RAM	2	1	1	0	5
Cost	3	5	4	4	1
Flash	2	5	5	1	2
Speed	2	1	1	5	4
Features	3	5	3	1	4
Prototyping	5	5	1	3	1
Weighted Total		67	37	42	42

The most important category for the choice of microcontroller ended up being the cost and ease of prototyping. This is primarily because of the limited funds available for spending on development kits which were as high as 300\$. The two second most important categories were the production cost of each microprocessor and their functionality. The cost was important to keep  $t_{COM}$ 's pricing in its desired market and the functionality was necessary for communicating with the peripherals. The last three categories were important for performance, but all possible microcontrollers were chosen to have at least as much flash, RAM, and speed as was necessary for functionality of the final design. The relative scoring was based on a scale of ten where 10

was given to the most favorable of the possible microcontrollers and the others were given proportional scores based on their proportional performance. The PIC processor ended up with the highest score.

With a PIC selected as the microprocessor of choice, there were two possible choices which maximize necessary features and minimize cost. The PIC18F45J10, which was the cheapest PIC available with two Serial Peripheral Interface ports necessary for communicating with the transceiver and audio codec, is only just capable of fulfilling the controller needs. It has the advantage of coming in a plastic dual inline package for easy prototyping. Should the microcontroller need additional peripheral interfaces, a second microcontroller the PIC24FJ16GA004 can provide an additional two Inter-Integrated Circuit ports for possibly communicating with the LCD and real time clock. The PIC24FJ16GA004 only is available in surface mount parts.

#### *9.2.4 Signal Processing Solution*

Because the speaker and microphone are analog and the transceiver requires digital transmission, some signal processing must take place. To keep cost down, the pulse wave modulation capabilities of the PIC processor could approximate the digital to analog conversion and use its own 10 bit analog to digital converter for the conversion of analog into a digital signal. Unfortunately this conversion was too computationally intensive to allow for the other features desired for  $t_{COM}$  and limited the bit depth of the audio to only slightly better than that of the tradition telephone. In addition, using pulse wave modulation to emulate a digital to analog converter is clumsy and causes unacceptable distortion. Instead, a relatively cheap codec was found that provided the same functionality but allowed for a much higher bit depth. The AD74111 codec supports 16-24bit signal processing. Using the AD74111 also allows for digital control of the volume along with a lower signal to noise ratio than the PIC. 16 and 20 bit codecs available for purchase did not provide significant cost reduction.

#### *9.2.5 LCD Display*

For the LCD display Com 1 Com All decided to use the Crystalfontz CFAH1602O-YYH-ET sixteen character, double line, yellow/green, transfective, backlit, super-twisted nematic (STN), LCD display that will display the time, desired calling address, and menu structure. The  $t_{COM}$  system requires a sixteen character field because module names can be up to sixteen characters long, and Com 1 Com All felt that horizontal scrolling must be avoided. It also became apparent during research that single line LCDs are actually more expensive than double line modules. Another requirement that became apparent was that the LCD display must be backlit for the  $t_{COM}$  system to be useful in the dark.

Alternate solutions included modules from Lumex Opto. These units seemed very similar to offerings from Crystalfontz, however, Lumex modules were available via digikey and mauser, so the single price was much better than Crystalfontz's, but the bulk discounts were not as deep. Lumex also does not supply good documentation for their product, and while it could be inferred that they operated similarly to the Crystalfontz the designers would not know. Details of the design criteria and results of each option are displayed below in Table 5. As you can see bulk

pricing and documentation were the most important criteria, with single or prototype pricing also having a large effect on the outcome.

**Table 5 - LCD Decision Matrix**

Criteria	Weight	LCD Type									
		crystalfontz		crystalfontz		crystalfontz		Lumex Opto			
		CFAH1602O-YYH-ET	Rating	Score	CFAH1602O-TFH-ET	Rating	Score	CFAH1602D-TMI-ET	Rating	Score	LCM-S01602DSF/C
Documentation	4	4	16	4	16	4	16	1	4		
Color/Image*	2	3	6	5	10	4	8	3	6		
Price (Single)	3	1	3	1	3	1	3	3	9		
Price (Bulk)	5	4	20	2	10	3	15	1	5		
Packaging/Size	2	3	6	3	6	3	6	3	6		
<b>Total</b>		<b>15</b>	<b>51</b>	<b>15</b>	<b>45</b>	<b>15</b>	<b>48</b>	<b>11</b>	<b>30</b>		

Originally there was some resistance to a yellow/green display, however, the more attractive color arrangements held too much of a cost penalty to warrant the upgrade. The same happened to the film compensated super-twisted nematic (FSTN) display; the added crispness was not worth the added cost.

#### 9.2.6 User Keypad and Scroll Wheel Control

The graphical user interface of the  $t_{COM}$  system will be menu driven system which needs to be navigated. This navigation can be accomplished using arrow keys and an enter button, however, arrow keys are not very well suited to navigating long lists of menu options. A more elegant solution to menu navigation would be to use a scroll wheel such as found in any modern mouse device. This scroll wheel could incorporate all three previous buttons into a single intuitive feature. Module programming will also be controlled via the scroll wheel interface.  $t_{COM}$  will also feature a small number of “Com 1” buttons which when programmed by the user call a specified module on the network. Finally, there will be a “Com All” button which will call all modules currently connected to the network.

#### 9.2.7 Real Time Clock

In order to relieve the micro controller of the burden of counting out time,  $t_{COM}$  will include a real time clock chip that will count the seconds, minutes, hours, days, months and years to be displayed on the LCD display when the system is not actively communicating, the singular design criterion for this device was price, however the component needed to be compatible with the rest of the system. To this end the Phillips PCF8563 Real time clock/calendar was chosen because it provided: year, month, day, weekday, hours, minutes and seconds based on 32.768 kilohertz quartz crystal and communicates with a 400 kilohertz two-wire I2C-bus interface, for a price that fell inside the budget.

#### 9.2.8 Microphone

Initially a member the team purchased a small board mounted condenser microphone element from a local Radio Shack so that the team could have the equipment immediately for testing and demonstration purposes. For the final prototype and production model a bulk purchasing solution

was investigated. On Digikey.com there were two manufactures of omni-directional condenser microphones in the frequencies that matched the response of the speaker. Details of the design criteria and results of each option are displayed below in Table 6. The most important design criterion was the bulk pricing since all microphone options met minimum required quality standards. Secondary considerations were single pricing and audio quality considerations.

Table 6 - Microphone Decision Matrix

Criteria	Weight	Microphone Type					
		Horn EM9765P-42		Horn EM1050-38-LF		Panasonic WM-64PNT	
		Rating	Score	Rating	Score	Rating	Score
Response Range	3	3	9	4	12	4	12
Sensitivity	3	4	12	3	9	4	12
Price (Single)	3	3	9	4	12	2	6
Price (Bulk)	5	5	25	4	20	3	15
Packaging/Size	2	3	6	2	4	4	8
	<b>Total</b>	<b>18</b>	<b>61</b>	<b>17</b>	<b>57</b>	<b>17</b>	<b>53</b>

The Horn EM9765P-42 was the cheapest unit when bought in bulk, coming down below \$ 0.15 when purchased in quantities greater than 10,000 units, and while its response range was less than the other options the sensitivity was just as good as the more expensive Panasonic model.

### 9.2.9 Speaker

Initially a member of the team purchased a small .1 watt (W) speaker from a local Radio Shack so that the team could have the equipment immediately for testing and demonstration purposes. In testing this circuit element the team discovered that the speaker did not have enough power to output a clear and audible signal when in a crowded and busy room. Com 1 Com All decided that a louder speaker with a broader response range was needed, after some research a 1W solution was found from CUI Inc. The GF0771 speaker covers a range of 180 hertz to 10 kilohertz at a sound pressure level of 92 decibels per watt. The speaker also fits within the space constraints of a  $t_{COM}$  module.

### 9.2.10 Antenna

Based on our range requirement feasibility study the antenna gain, transceiver output power, and transceiver sensitivity dictate that a  $t_{COM}$  module will need an antenna gain if between two and three decibels of gain. The antenna module chosen is a Pulse Engineering W1027 high gain antenna that provides 3.2 decibels of amplification on the transmit power and receive sensitivity. The W1027 utilizes a one-quarter wavelength dipole configuration to provide a uniform radiation pattern in the horizontal plane with the only meaning full nulls on its south and north poles. This radiation pattern means that the modules will have maximum range across a vertical plane and will only have trouble when two modules are situated directly above one another; however, the distance between levels in a home is considerably lower than our maximum transmission distance requirement of 105 meters.

### *9.2.11 Additional Analog Circuitry*

Additional circuitry will be required to maximize the utility of components, including tuning networks for the transceiver, capacitors to mitigate pin capacitances, and filters and amplification for analog audio. These components are not projected to have a large impact on the final cost of  $t_{COM}$  modules, and the total scope of the required additional circuitry is still an unknown and will be fleshed out during the prototyping stage of the design.

### *9.2.12 Power Supply*

Some intercoms run on expensive but convenient batteries,  $t_{COM}$  runs on the cheap power available from home power lines. There are two versions of this power supply. One is intended for prototyping and the other is for production. This separation will allow Com 1 Com All to focus more on digital system design and less on analog design.

#### *9.2.12.1 Prototype Supply*

The prototype design uses a power adapter to handle most of the power regulation. The use of the adapter allows for minimal on-board components to regulate the remaining direct current voltage. The power adapter also reduces the heat of internal components. It is quite likely that the end user desires the flexibility of plugging the  $t_{COM}$  into a wall outlet, so this functionality is also available on the production supply as well. This setup does not integrate well with a wall mountable design which encouraged a change for the final production design.

#### *9.2.12.2 Final Production Supply*

The final production supply incorporates the power adapter's functionality into on-board circuitry. This incorporation is far more practical in production because the use of surface mount parts makes less expensive and space intensive. The on-board transformer still requires significant space, but the other components reduction from using surface mount equivalents should help offset the space. The advantage of an on-board adapter is that the units would become wall mountable for a superior integration in homes. A plug would still be provided for the option of plugging into an electrical outlet.

### *9.2.13 Circuit board layout*

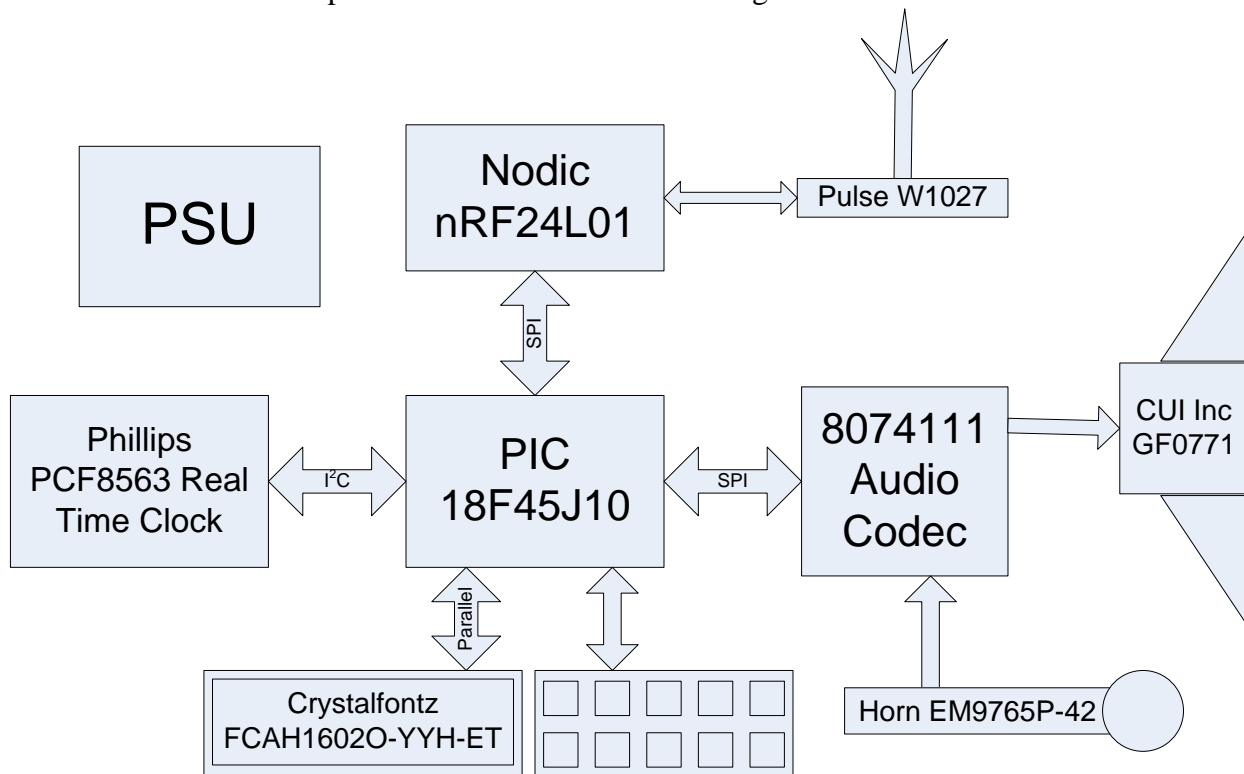
During the preliminary stages of our design, there is no need for a full circuit board design until all parts have been selected and preliminary testing on individual system components is completed. Until that point, there is still some preliminary board design work for testing purposes of individual components. For testing of the audio codec and transceiver control with our PIC microcontroller development kit, it will be necessary to create a daughter boards for each of these surface mount chips to interface with the breadboard on the microcontroller development board. Although relatively small designs, these will be important initial steps towards a final board design as well as a necessary addition for initial testing of the components. These designs will be completed over the Christmas break and ready to be used for testing at beginning of January.

### *9.2.14 Product packaging*

Prototype versions of the  $t_{COM}$  system will not include a packaging solution however for the production model the packaging will likely be constructed of a polymer or resin for ease of mass manufacture and their lesser effect on RF transmissions than a metal case. RF interference properties of the selected material will have to be taken into account when tuning the antenna. Polymers and resins can also be made in several colors at creation, rather than having to paint the final product. Initially  $t_{COM}$  will be available in a range of colors suitable for interior use, including: white, beige, and black. Special attention will be paid to the texture of the plastic, as it will have an effect on the perceived quality of the product as well as the ease of cleaning.

### 9.2.15 Current Block Diagram

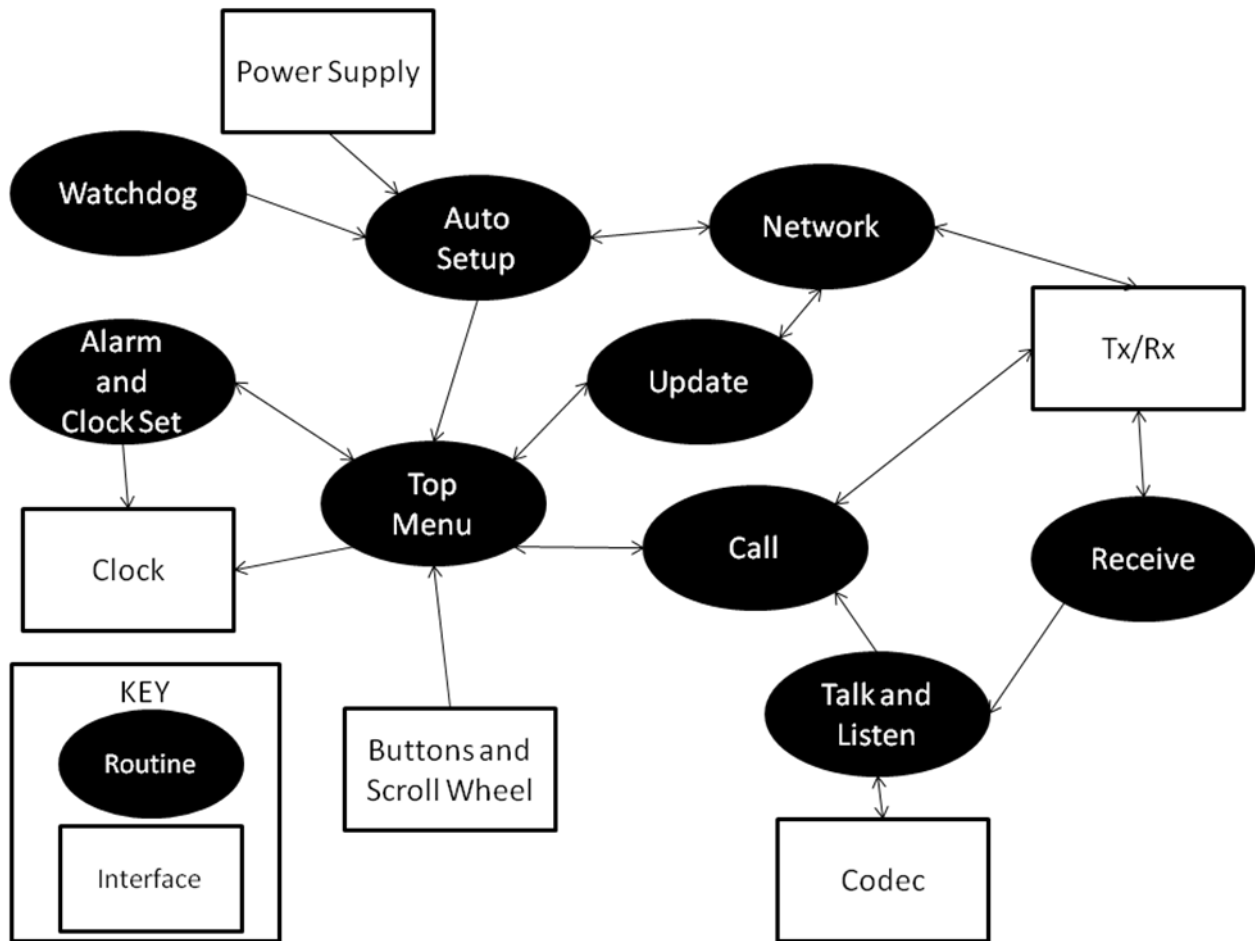
Below in Figure 9 is the current hardware block diagram displaying our hardware design choices and the communications protocols between communicating blocks.



**Figure 9 - Current Hardware Block Diagram**

### 10.3 Software Design

The preliminary design's software is best represented in sections or routines that focus on certain aspects of the Intercom's functionality. These routines frequently incorporate other the other devices controlled by the microprocessor. The preliminary design's routines and their interfaces can be seen below in Figure 10.



**Figure 10 - Software Block Diagram**

### 10.3.1 Auto Setup

A key feature of t<sub>COM</sub> is its ability to automatically detect and set up a wireless network without any user programming. This feature will be implemented in the Auto Setup routine with the help of the Network routine. The Auto Setup will look for an existing open network to connect to. If detected, the routine will obtain network information including addressing, module names, and the encryption key. If no open network is available, the routine will assume a preprogrammed encryption key. A generic module name will be assigned if none exists in the memory. The Auto Setup directly interfaces with the power supply in that upon powering up, the Auto Setup is initiated. The watchdog routine may also restart the software by calling Auto Setup. The Auto Setup is also responsible for reestablishing the network in the case of a power failure.

### 10.3.2 Network

The network routine directly interfaces with the transceiver. It sends data and network info requests to and from other routines and implements the data protocol. The network routine must

establish a network frequency when communicating with other modules in order to avoid collisions with other module requests.

### *10.3.3 Update*

The Update routine is a relatively simple routine that updates key network information such as module name changes, new module connections, and clock updates. This routine is intended to synchronize information on the network and provide features like timeSYNC and nameSYNC.

### *10.3.4 Top Menu*

The Top Menu routine is the interface control center. It updates the clock by directly interfacing with the LCD and allows for user interaction by interfacing with the buttons and scroll wheel. The Top Menu runs most of the other routines allowing access of the many features of t<sub>COM</sub> to the end user. As its name implies, Top Menu is menu based to facilitate use. Menu options include call, clock, change name, and hot buttons. Hot button changes are stored in memory and in registers. Other selections run their respective routines. This is the default routine after periods of disuse.

### *10.3.5 Call and Receive*

The Call and Receive routines directly interface with the transceiver to control the flow of data during module communication. Like the Network routine, they implement the data protocol and work in conjunction with the Talk and Listen routine to transfer audio. It is extremely important to make these sections as efficient as possible as they will be the most processing intensive and poorly written code could reduce audio quality.

### *10.3.6 Talk and Listen*

The Talk and Listen routine directly interfaces with the audio codec. It will be able to control the volume settings as well as any of the other features available through the codec. Should the Talk and Listen routine when combined with the Call and Receive routines become too processor intensive, a second microprocessor dedicated to interfacing the codec will be added to separate these tasks.

### *10.3.7 Alarm and Clock Set*

The Alarm and Clock Set routine directly interfaces with the Real Time Clock to change clock settings and also sets control registers for the alarm. Changes to the clock can be sent across the network through the update routine.

### 10.3.8 Watchdog

While much of the watchdog is in fact separate hardware on the microprocessor, the control of this automated function will be set with the Watchdog routine. This routine will reset a watchdog timer to indicate that the entire program is functioning correctly. If the program should freeze for some reason, the watchdog will reset the program and initiate the Auto Setup routine. The Watchdog routine will also be used to periodically send the program to sleep during periods of inactivity in order to conserve power.

## 10.4 Network Protocol

Network protocols are extremely important for wireless systems. They provide the means for communication and transmission validation between wireless transceivers. In the case of a  $t_{COM}$  network, the network protocol enables important feature such as updating the network, adding new modules, and making calls. The protocol is 32 bytes long and includes a section for instruction, address, and data. While many protocols include handshaking within the instruction set,  $t_{COM}$ 's transceiver can automatically be set to acknowledge transmissions. Because of this automatic handshaking, there is no need for a separate handshaking instruction. The complete instruction set for  $t_{COM}$ 's network protocol can be seen below in Table 7.

**Table 7 – Network Protocol Instruction Set**

Instruction(1B)	Addr(1B)	Data(29B)						END(1B)	
Call Request	0hXX	Frequency(1B)	Empty(28B)						End(1B)
Monitor Request	0hXX	Frequency(1B)	Empty(28B)						End(1B)
Talk Start	0hXX	Empty(29B)						End(1B)	
Talk End	0hXX	Empty(29B)						End(1B)	
Call End	0hXX	Empty(29B)						End(1B)	
New Module Request	0hFF	Addr(1B)	Empty(28B)						End(1B)
New Module Return	0hFF	0	Network Frequency(1B)	Network Addr(3B)	Encryption Key(16B)	Clock(8B)	Empty(1B)	End(1B)	
	0hFF	1	Addr(1B)	Name(16B)	Empty(12B)			End(1B)	
Update	0hXX	0	Network Frequency(1B)	Clock(8B)	Empty(22B)			End(1B)	
	0hXX	1	Addr(1B)	Name(16B)	Empty(12B)			End(1B)	

#### 10.4.1 Call Request and Monitor

Perhaps the most important instructions in  $t_{COM}$ 's instruction set are the Call Request and Monitor instructions. These instructions tell other modules when to expect audio data packets and where to expect them. The Call Request instruction sends information to all of the other modules on the network. The address portion communicates to each module if they are the intended recipient of the request. The frequency portion tells each module on which frequency the audio data will be transmitted. Similarly, the Monitor Request also communicates which module is being monitored and on which frequency the module should send its audio data. The Monitor Request instruction must be resent after every second to continue audio reception from the destination module.

#### 10.4.1 Talk Start, Talk End, and Call End

Because the audio data sent from module to module is usually continuous and for undefined lengths of time, it is necessary for each module to communicate when they would like to talk and when they are done talking. The Talk Start and Talk End instructions achieve this goal.

Likewise, the Call End instruction alerts the other module that the entire conversation is over and that the module should return to the network frequency. If for some reason an instruction or data packet is not received by the module for an appropriate length of time, the module assumes that the transmission has been terminated and returns to the network frequency automatically.

#### *10.4.2 New Module Request and New Module Return*

The New Module Request instruction is only used during the Auto Setup routine for a module that has not already been networked. After the New Module Request has been sent, a New Module Return is sent back to the requesting module if a module already on the network has been set to accept new modules by the user. If no New Module Return is received after 15 requests, the module assumes that there is no network available and sets up its own network based on preprogrammed randomized values. The Network Module Return sends key network information including the network frequency, network address, 128 bit encryption key, and network clock. The Network Module Return can also send the addresses and names of the other modules on the network after which it can indicate the end of transmission. Both instructions use the 0xff address for speaking to all modules because neither module knows the other's address.

#### *10.4.3 Update*

The Update instruction allows a module to make changes to the network clock, frequency, and the modules own name. The instigating module sends this instruction to each module on the network and must try again if the some of the modules are unavailable.

## **11.0 Feasibility study**

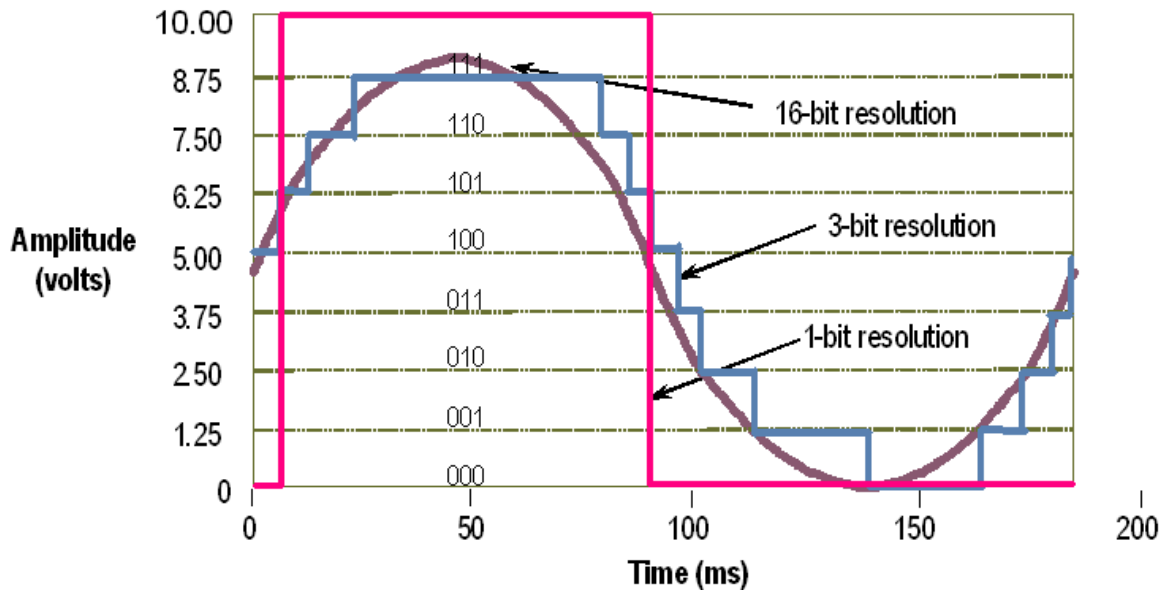
### **11.1 Audio Quality Study**

While some of the competition may incorporate minimal quality audio systems in order to reduce cost, because  $t_{COM}$  is targeting upper middle class and commercial markets that desire increase in functionality, audio quality will be a significant factor for sales and design. Other similar devices have very poor audio quality to the point of user annoyance or even information loss. Such devices include walkie-talkies, phones, and low quality toys. On the opposite spectrum DVD's and CD's are known for their excellent audio quality. For these reasons, the goal of the  $t_{COM}$ 's audio quality is to exceed that of a phone and approach that of a CD.

#### *11.1.1 Bit Depth*

Audio quality is a difficult thing to define even though it is very apparent to the sensitive human ear. One measure of the quality is the bit depth of the signal. Bit depth refers to the divisions of sound levels in the signal. For instance, a signal with a bit depth of one would have  $2^1$  sound levels. This signal would only be able to produce square waves at one volume. A signal with a bit depth of three would have  $2^3 = 8$  different sound levels and one with sixteen would have  $2^{16}=65536$ . Since natural occurring signals are produced by vibrations in the air, desired signals

have a sine wave shape. This shape is far better approximated by the sixteen bit signal than by the three or one bit as seen below in Figure 11 below.



**Figure 11 - Signal Approximation with Bit Resolution (zone.ni.com)**

This differentiation becomes more important and noticeable with smaller signals and with approximating complex frequencies like voices that have many frequencies present at the same time. The necessity of having more than 16 bits or even just 8 bits of depth for a signal may seem excessive, but even moving from 16 to 24 bit signals can improve overtones and nuances (extremetech.com). The bit depth of a common telephone is 8 bits and a CD frequently has 24 bits.

### 11.1.2 Frequency Range

A second measure of audio quality is the frequency range of a signal. The human ear can differentiate frequencies from 20-20,000Hz. To perfectly replicate audible sounds, these frequencies must be covered and sometimes sub-audible signals are included to feel sounds like those of a jet engine. When converting an analog signal into digital, the frequency range of the result is determined by the sample rate. This sample rate is exactly twice as fast as the fastest frequency in the desired range. This is why CD's which cover the entire audible spectrum must sample at a rate of 44.1 kHz. The telephone's frequency range of 180-3.2 kHz is a clear indicator of its far lower quality. In general, frequency range is far more noticeable than bit depth and is a far greater factor in total audio quality. Unfortunately, increasing the frequency range of an audio system is far more expensive than increasing its bit depth. It is especially expensive for small sized systems, because larger speakers are needed for producing lower frequencies and space is sometimes too limited for multiple speakers.

### 11.1.3 Noise

Even more apparent than a reduced frequency range is the introduction of noise to a signal. Noise often is heard as a crackling or whining sound. Noise can occur from a multitude of

different sources including the supply lines to speaker, microphone, or codec, crosstalk between lines, electromagnetic pollution, and poor data transmission. In fact, it is noise induced from home power lines that inspired the conception for the  $t_{COM}$ . In terms of noise, a digital system has significant advantages over analog. However, any audio system will need to incorporate at least some analog circuitry. Because  $t_{COM}$ 's data will be transmitted over RF, poor signal reception may cause intermittent connections. This makes the transceiver the most crucial component effecting audio quality.

#### *11.1.4 Audio Quality of Design*

$t_{COM}$  incorporates all of the audio quality issues mentioned above to provide for affordable but high quality sound. By using slightly more expensive parts,  $t_{COM}$  is designed to have a bit depth of 24, a frequency range of 180-12,000Hz, and as little noise as possible especially when the speaker is not being used during listen mode. Bottlenecks for  $t_{COM}$ 's designed bit rate are the transceiver and microprocessor. These components must be able to handle the 576kb/s required to move a 12kHz signal with a bit depth of 24. Any further range extension will only increase the bit rate and subsequently the transceiver's and microprocessor's necessary performance. The chosen components account for the desired bit rate to ensure the desired audio quality. This expected quality is far better than a telephone's 180-3.2kHz 8b signal but not quite as good as that of a CD's 20-20kHz 24b sound.

### **11.2 Data Transfer Analysis**

To achieve the desired audio quality mentioned in the Audio Quality Study section above, all of the components must be able to transfer at the necessary data rate. A failure of a component to comply with this rate would lower the quality of sound and if unaccounted for, cause unacceptable distortion. These data rates must be carefully calculated because data rates given in data sheets can be very misleading. The needed transfer calculations can be found in Appendix C and result in a rate of 576,000 bps (bits per second).

#### *11.2.1 Transceiver*

According to the transceiver data sheet, the nRF24L01 transmits at 2 Mbps or 1Mbps. Allowing for some packaging inefficiencies expected to add up to 50% of the data transmitted, it initially appears to more than cover the desired bit rate even at low speed. A more careful analysis of the data sheet showed that this assumption was not true. As seen in the calculation found in Appendix C, the actual maximum rates are closer to 584 kbps and 906 kbps. These results make using the lower transmission rate too risky and leave no room at the higher rate for acknowledgement of individual packets.

#### *11.2.2 Codec*

The codec is designed to convert analog and digital signals at sample rates of 48 kHz and up to 24 bits of depth. Thus the theoretical bit rate for the codec is 1.1152 Mbps. Not only is this well above the needed rate, but also indicates that the device will not reduce quality to keep up.

### 11.2.3 Microprocessor

The microprocessor has two areas with possible transmission rates. Using only the general input-output ports, the processor can transfer raw data at a rate over 1MHz. However,  $t_{COM}$ 's other features make using the processor's computing power inefficient and undesirable. The SPI (serial peripheral interface) capabilities of the PIC18F45J10 allow for up to 10 Mbps transfer rates that do not use software or PIC computing power. Both codec and processor were chosen to coordinate in their peripheral support of SPI to facilitate the requirements of data transfer and ease of programming.

### 11.3 Power Consumption Analysis

Because  $t_{COM}$  is designed for quality and functionality, the power supply must provide adequate power to all of the components without overheating. Partially for this reason, IC's were the most common choice for components reducing the total need for power. A list of the components used in  $t_{COM}$ 's design can be found below in Table 8.

Table 8 - Component Power Requirements

Device/Component	Max Power(mW)	Sleep(mW)	Active (mW)
PIC Processor	1000.0	0.7	568
Audio Codec	35.0	1.9	35.0
Microphone	5.0	2.3	2.3
Speaker	1000.0	0.0	500
Transceiver	60.0	0.1	36.9
LCD	826.5	7.5	7.5
Real Time Clock	4.4	0.0	4.4
Additional Circuitry	200	1	100
Total	3130.9	13.3	1254.1

While over three watts of power is far beyond the expected power requirements for an intercom, it is a value that will likely never be needed. To max out all of the components, the end user must be receiving a transmission with the backlight on at a constant full volume. The PIC's maximum assumes that the output pins are providing their max total output current of 200mA. This will never happen because  $t_{COM}$  does not require the PIC to drive any of the surrounding circuitry. A more accurate estimation, the active power, is a better indicator of  $t_{COM}$ 's power needs until prototypes can be built and tested for consumption rates. A max power usage of 1.25 W is below our 5.324W requirement.

### 11.4 Economic analysis

Cost estimates are important for determining the marketability and the budget of a design. As already mentioned in the Detailed Design Requirements,  $t_{COM}$  needs to cost 20\$ or less to manufacture to reach its goals. This requirement is extremely tight and a small amount of overshoot may be deemed acceptable for additional features. In terms of budgeting, Com 1 Com All has only \$300 to spend on resources. Therefore \$300 is the desired total spending unless

additional funding from other senior design allotments can be redistributed to t<sub>COM</sub>'s development.

#### 11.4.1 Parts List and Bill of Material

The total amount of money expected to be spent on t<sub>COM</sub> including projected bulk pricing can be found below in Table 9.

**Table 9 - Cost For Purchased and Needed Parts**

Item	Description	Sing. Cost(\$)	Multi Cost(\$)	Qty Needed	Qty Bought	Sing. Sub Tot	Multi Sub Tot
DV164120	DEV KIT	50	0	0	1	50	0
PIC16F685-I/P	PIC	3	1.14	0	1	3	1.14
PIC18F45J10	PIC	0	1.79	3	0	0	1.79
PIC24FJ16GA004	PIC	0	1.84	3	0	0	1.84
AD74111YRUZ	Codec	5	2.66	1	2	15	2.66
EM9765P-42	Microphone	0.98	0.147	3	0	2.94	0.147
GF0771	Speaker	3.6	1.92	3	0	10.8	1.92
nRF24L01	Transciever	2.05	1	0	4	8.2	1
w1027	Antenna	4.65	1.97	3	0	13.95	1.97
PCF8563	Real Time Clock	1.33	0.6625	3	0	3.99	0.6625
CFAH16020-YYH-ET	LCD	19.24	3.3	3	0	57.72	3.3
Human Interface Devices	Buttons and Scroll	5	1.5	3	0	15	1.5
Boards	Final Boards	25	1	3	0	75	1
Packaging	Packaging	0	1	3	0	0	1
Contingency	Contingency	50	0	1	0	50	0
PSU	Power Supply	10	1	0	0	0	1
Shipping	Shipping	25	0.1	0.72	0.28	25	0.1
<b>Total</b>					78.2	<b>330.6</b>	<b>18.0495</b>

Table 4 clearly shows that t<sub>COM</sub>'s total cost with a \$50 contingency is \$330.6 which is more than the goal. While goal can be reached if the contingency is unneeded, it is far more likely that Com 1 Com All will require additional funding. The total under the multi subtotal calculates the cost of a single module's materials using only the PIC18F45J10. This total is very close to the goal of \$20 per module, but costs are based on actual bulk rates available online and it may be possible to negotiate better deals in an actual business setting. Bulk pricing was unavailable for the transceiver so a conservative half pricing was assumed.

#### 11.4.2 Manufacturing Costs

Additional cost such as labor, shipping, and machine maintenance make the actual cost of production higher than merely the cost of materials. These rough estimates and assumptions can be found in Appendix D. Added to the estimated cost of materials, the total production cost comes out to \$19.8915. This is below our goal of \$20 and is conservative because of the lack of availability of certain bulk prices and production costs.

## 12.0 Test Plans

To ensure that our designs are meeting the functional requirements of the t<sub>COM</sub>, thorough testing of key requirements must take place during and after the prototyping stages.

## **12.1 Prototype Testing Method**

We plan on implementing much of our testing to individual blocks of the design while they are being prototyped. After the block has shown it meets the requirements we have set, it will then be saved until further implementation on the system level. Final functionality tests will be undertaken once the system has been completely implemented. The following sections indicate design areas which will require testing during the prototype stage.

### *12.1.1 Audio Quality*

This test will check the audio codec's ability to tack input audio from a microphone and pass it out to a speaker after converting it to digital form and passing it through the microcontroller. When this can be done effectively and provide clear sound from the speaker, the testing will be complete.

### *12.1.2 Data Transmission*

The transceiver must first be able to transmit any data over the wireless connection before we can move to audio transmission. Using the microcontroller to configure and control two transceivers, we will transmit a previously determined data packet over multiple frequency channels. This will show we are able to change frequencies and successfully transmit data.

### *12.1.3 Transmission of Audio*

This test will show that the microprocessor is able to handle both the tasks of transferring audio data to and from the codec and the transceivers in a manner which will allow for audio transmission. Only with proper hardware and software configurations will the transmission be able to take place. Completing this test will be essential to making working prototypes. Success will be defined as wirelessly transmitting an input audio signal and hearing it at the output speaker of the other intercom prototype.

### *12.1.4 Networking*

Networking testing will show that the microcontroller with the help of the transceiver will be able to set up a network, and complete additional networking tasks. This testing is far less intensive on precise coding and will probably take place before audio transmission.

### *12.1.5 LCD Control*

The microcontroller must be able to initialize and update the LCD screen based on software design. Completion of this test will allow the LCD to be used in other test areas.

### *12.1.6 Clock and Alarms*

These tests will show that the coding for clock and alarm routines work as required. This will also include clock change synchronization over a network of two intercoms. The alarm test will

show that the microprocessor can properly keep track of the time based on signals from the real time clock.

### *12.1.7 Power Usage*

This test will be to check the on board voltage regulation and ensure that they provide the necessary voltages for our integrated circuits. It will also need to be completed again when the power system is connected to the full system.

## **12.2 Final Test Method**

We will have two main types of testing once the entire system prototypes are built and are functioning properly. They are described in the sections below.

### *12.2.1 User Functionality Testing*

This will be the equivalent of a full user testing of all the functionality required of the system. Three prototypes will be involved in testing audio transmission in all com connection variations. Also all networking tasks will be carried out multiple times to confirm their functionality. Any problems in the functionality will be addressed through software debugging and hardware debugging if necessary. The hope is that earlier testing will resolve most if not all of the major issues in system block designs.

### *12.2.2 System Endurance Testing*

Due to the possible use of the  $t_{COM}$  as a baby monitor, it will also be necessary to show that the system will be able to work properly while transmitting audio for a long continuous period of time. We will do this under constant supervision in case the system happened to fail during the testing process. Checks of all the power requirements should also be done near the end of the test due to the continual load placed on the power supply unit during a long period of transmitting, receiving, and outputting audio. This test will show the robust nature of the components selected for our design and the system design as a whole.

### *12.2.3 Range Testing*

Two intercom modules will be used to transmit audio in an open outdoor area and will be moved further away until the maximum system range is determined. This will be defined as the distance at which the wireless audio transmission ceases to provide adequate audio on the output.

## **13.0 Task breakdown and time schedule**

The overall Project has been broken down into several categories of work including: hardware, software, analysis, prototyping, documentation and prototyping. In Figure 12 the hardware, analysis, and documentation tabs have been expanded to show the areas that have received the greatest amount of attention this semester. The figure also displays the projected schedule for

work to be done during the following semester. For a more detailed breakdown of the schedule and tasks please refer to Appendix A

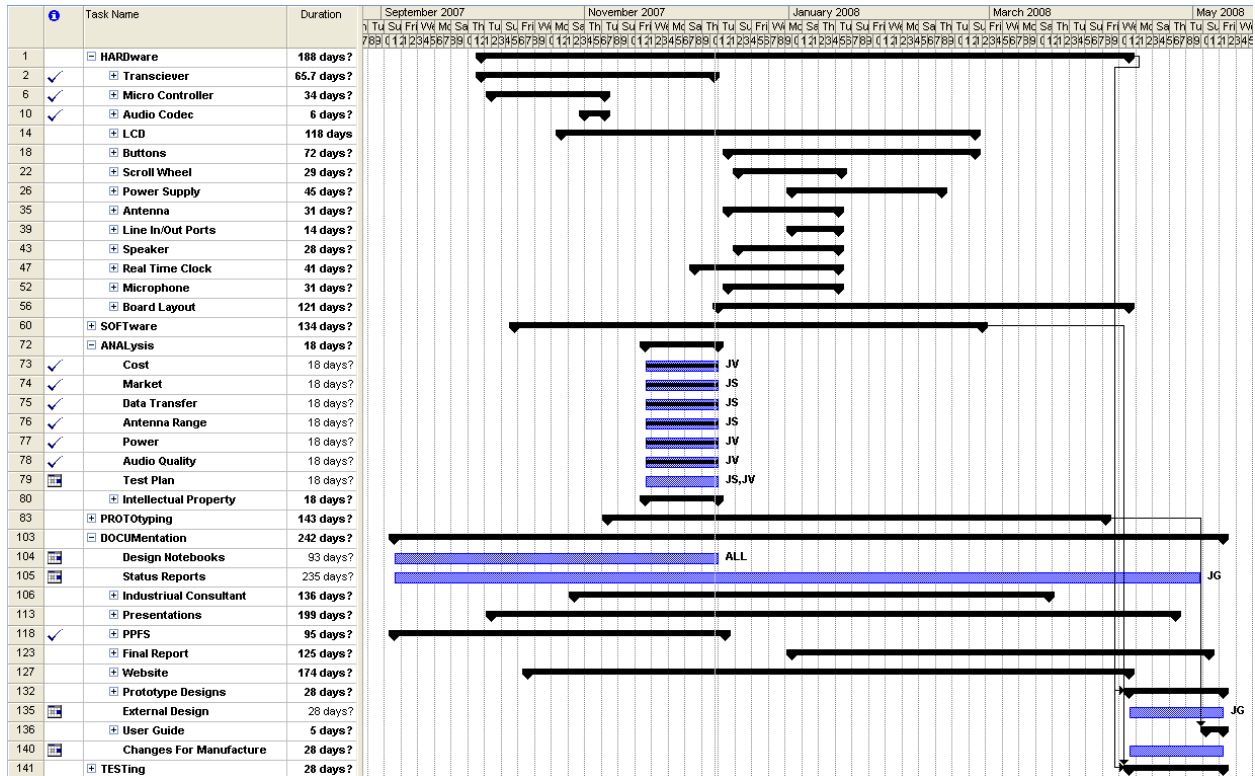


Figure 12 - Task Breakdown and Time Schedule

## 14.0 Full scale production plan (further updates to come)

The full scale production plan is currently incomplete because the product has not even entered the prototyping stage and as such the team does not have a firm grasp on exactly all facets of the design which must be considered when moving from the single build prototype stage to the mass manufacture phase.

### 14.1 Large Scale Bill of Materials

In creating a large scale bill of materials an effort would be made to make component values as uniform as possible to take advantage of bulk pricing discounts on large orders of unique or more expensive parts such as inductors capacitors, regulators, and transformers.

### 14.2 Parts Provider

In a large scale production environment a company develops relationships with parts manufacturers, distributors, or manufacturer’s representatives. These relationships provide steeper discounts on bulk orders which reduce the production cost of  $t_{COM}$  modules. Such relationships also enable just in time delivery of parts and bulk orders with interval deliveries.

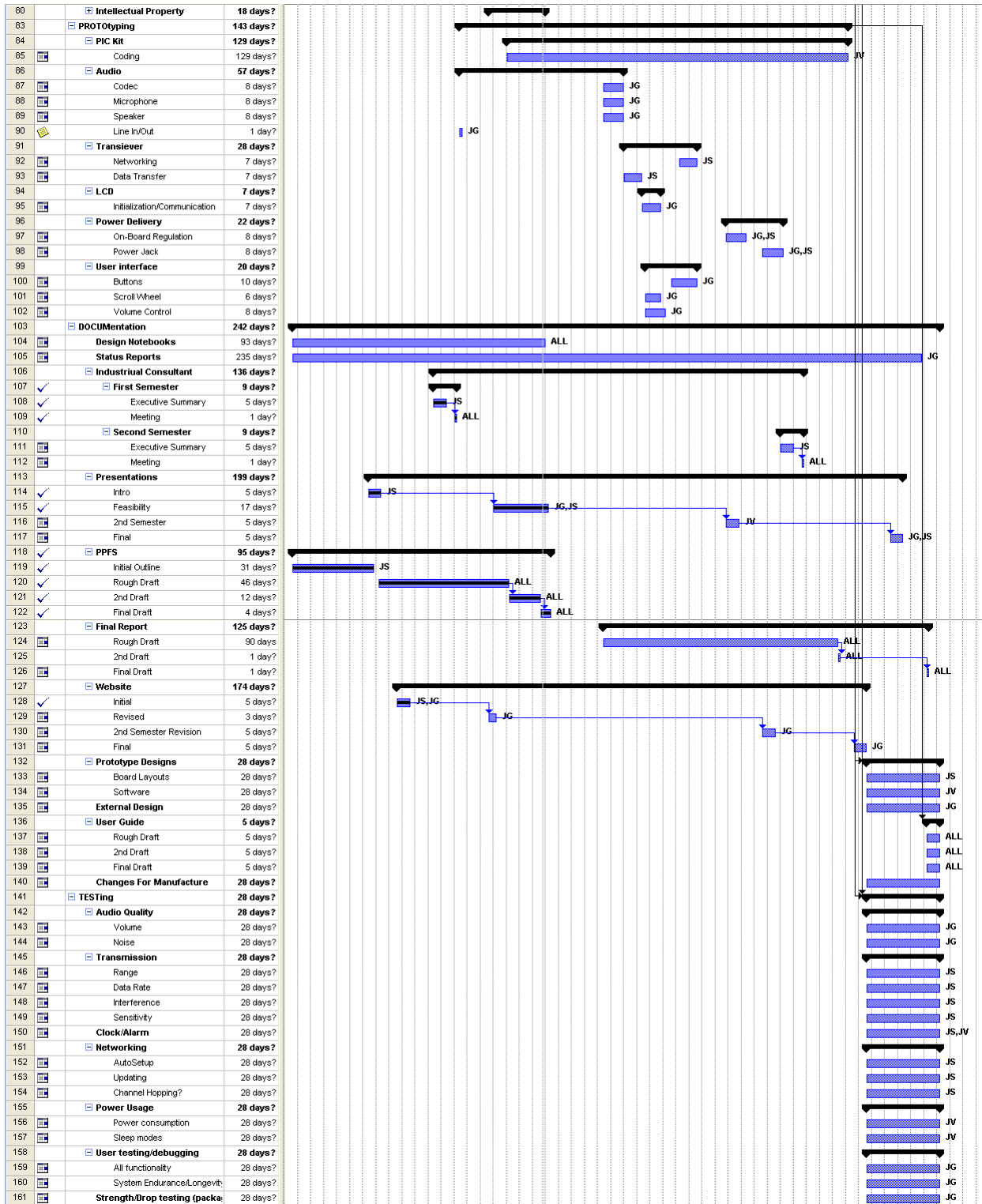
### **14.3 Product Assembler**

To achieve the desired economies of scale, printed circuit board assembly must be completed by an automated part placement and testing suite. This approach to assembly limits the number of people required to produce each board, directly reducing the cost to manufacture each board since labor accounts for roughly eighty percent of projected non-material production cost.

### **14.4 Compliance Testing**

The final product must pass FCC (Federal Communication Commission) regulations to be marketed in the United States, and other regulating bodies for sale abroad. An outside testing firm is required to certify that the product meets all regulations; therefore the  $t_{COM}$  system modules would have to be submitted to one such testing firm. Underwriters Laboratories (UL) is the oldest and most widely known testing company in the United States; however there are several more testing firms, which will certify a product in compliance with FCC regulation.





## Appendix B: Market Study

Name	Frequency Range	Channels	Max Network Number	Batteries/AC Power
Radio Shack	200 - 270 kHz (FM)	3	?	N/Y
Reporter Wirefree Intercom	900 MHz	4	Unlimited	4 AA (12 months)/ Y
Flush " " "	900 MHz	4	Unlimited	4 C (3 years)/ Y
Outdoor " " "	900 MHz	4	Unlimited	4 AA (12 months)/ N
Westinghouse WHI-4CUPG	FM	5	Unlimited	N/Y
Westinghouse WHI-2C	FM	2		N/Y
Westinghouse WHI-3C	FM	3		N/Y
Westinghouse WHI-4C	FM	4		N/Y
Nutone IMA110	200 - 290 kHz (FM)	4	8	N/Y
GE/Jasco TL97600	home wiring	3		N/Y
GE SmartCom	Wired (Ethernet)		16	N/Y
M&S DMC1	Wired (Ethernet)			
Name	Monitor Mode	Wall Mountable	Volume Control	Size
Radio Shack	N	N	Y	
Reporter Wirefree Intercom	Y	Y	Y	4"x5.5"x2"
Flush " " "	Y	Y	Y	6"x7"
Outdoor " " "	Y	Y	Y	6"x3.5"x2"
Westinghouse WHI-4CUPG	?	Y	Y	
Westinghouse WHI-2C	?	Y	Y	5.5"x5.5"x1.75"
Westinghouse WHI-3C	?	Y	Y	6.75"x5"x1.75"
Westinghouse WHI-4C	?	Y	Y	6.25"x5.5"x1.25"
Nutone IMA110	Y	N	Y	7"x5.75"x1.875"
GE/Jasco TL97600		N	Y	
GE SmartCom	Y	Y	Y	
M&S DMC1	Y	Y	Y	
Name	Two Way Comm?	Transmission Range	Audio In/Out	Price (1)
Radio Shack	N	?	N/N	20
Reporter Wirefree Intercom	Y	1000 ft	N/N	89
Flush " " "	Y	1000 ft	N/N	99
Outdoor " " "	Y	1000 ft	N/N	79
Westinghouse WHI-4CUPG	N	500 ft	N/N	62.5
Westinghouse WHI-2C	N	1500 ft	N/N	20
Westinghouse WHI-3C	N	1500 ft	N/N	27
Westinghouse WHI-4C	N	1500 ft	N/N	35
Nutone IMA110	N	500 ft	N/N	43/62.50
GE/Jasco TL97600		same circuit	N/N	20
GE SmartCom	N	Cable Length	Audio/Intercom	2200 (full system)
M&S DMC1		Cable Length	Audio/Intercom	500 (master only)
Name	Hyperlink			
Radio Shack	<a href="http://www.radioshack.com/sm-advanced-3-station-3-channel-fm-wireless-intercom--pi-2036287.html">http://www.radioshack.com/sm-advanced-3-station-3-channel-fm-wireless-intercom--pi-2036287.html</a>			
Reporter Wirefree Intercom	<a href="http://www.gadgetshack.com/wireless-home-intercom-system.html">http://www.gadgetshack.com/wireless-home-intercom-system.html</a>			
Flush " " "	<a href="http://www.gadgetshack.com/waflmowiin.html">http://www.gadgetshack.com/waflmowiin.html</a>			
Outdoor " " "	<a href="http://www.gadgetshack.com/ouwiinad.html">http://www.gadgetshack.com/ouwiinad.html</a>			
Westinghouse WHI-4CUPG	<a href="http://www.home-technology-store.com/intercom/W-WHDBI-5C-KIT.aspx">http://www.home-technology-store.com/intercom/W-WHDBI-5C-KIT.aspx</a>			
Westinghouse WHI-2C	<a href="http://www.westinghouse-home.com/wireless-intercoms-2ch.htm">http://www.westinghouse-home.com/wireless-intercoms-2ch.htm</a>			
Westinghouse WHI-3C	<a href="http://www.westinghouse-home.com/wireless-intercoms-3ch.htm">http://www.westinghouse-home.com/wireless-intercoms-3ch.htm</a>			
Westinghouse WHI-4C	<a href="http://www.westinghouse-home.com/wireless-intercoms-4ch.htm">http://www.westinghouse-home.com/wireless-intercoms-4ch.htm</a>			
Nutone IMA110	<a href="https://www.centralvacuumstores.com/intercom/nutone_ima110.php">https://www.centralvacuumstores.com/intercom/nutone_ima110.php</a>			
	<a href="http://www.nutone.com/product-detail.asp?ProductID=3042">http://www.nutone.com/product-detail.asp?ProductID=3042</a>			
GE/Jasco TL97600	<a href="http://www.stores9.com/product-info/electronics/B000069J9C">http://www.stores9.com/product-info/electronics/B000069J9C</a>			
	<a href="http://www.amazon.com/Jasco-TL97600-Channel-Wireless-Intercom/dp/B000069J9C">http://www.amazon.com/Jasco-TL97600-Channel-Wireless-Intercom/dp/B000069J9C</a>			
GE SmartCom	<a href="https://www.centralvacuumstores.com/intercom/ge_smartcom.php">https://www.centralvacuumstores.com/intercom/ge_smartcom.php</a>			4 rooms
M&S DMC1	<a href="https://www.centralvacuumstores.com/intercom/dmc1.php">https://www.centralvacuumstores.com/intercom/dmc1.php</a>			

## Appendix C: Data Transfer Analysis

### Transceiver Data Transfer Calculations

bitdepth := 24 bits

maxSpeaker := 12·kHz samplerate := 2·maxSpeaker

samplerate = 24kHz minimum sample rate is double maximum audio frequency

DataTransfer := bitdepth · samplerate · 1s **DataTransfer = 576000 bps** just for audio data

#### nRF24L01 Packet Overhead

- using 3 byte address, 24 byte payload, and 2 byte CRC

Preamble := 8 Address := 24 PacketControl := 9 Payload := 32·8 will transfer 8 24 bit audio words at a time

CRC := 16 Payload = 256

$$\text{Payload\%} := \frac{\text{Payload}}{\text{Preamble} + \text{Address} + \text{PacketControl} + \text{Payload} + \text{CRC}}$$

**Payload% = 81.789%**

nRFDataRate2 := 200000 bps

nRFDataRate1 := 100000 bps

AudioTrans2 := Payload% · nRFDataRate2 **AudioTrans2 = 1635782.748 bps**

AudioTrans1 := Payload% · nRFDataRate1 **AudioTrans1 = 817891.374 bps**

### Data Range Calculations

desiredRange := 1000ft desiredRange = 304.8 m

$$\text{PathLoss} := 40 + 20 \cdot \log\left(\frac{\text{desiredRange}}{\text{m}}\right) \quad \text{PathLoss} = 89.68 \text{ dBm}$$

PowerOut := 0 SenseIn := -82 from nRF24L01 AntGain := 3.2 proposed gain

RFLinkBudget := PowerOut - SenseIn + 2·AntGain RFLinkBudget = 88.4 dBm

$$\text{TheoreticalRange} := 10^{\frac{\text{RFLinkBudget} - 40}{20}} \quad \text{TheoreticalRange} = 263.027 \text{ m}$$

## Microcontroller Calculations

$$\text{clkMAX} := 8\text{MHz}$$

Maximum internal clock speed

$$\text{instcycle} := \frac{4}{\text{clkMAX}}$$

Instruction cycle is four clock periods

$$\text{instcycle} = 0.5\mu\text{s} \quad \text{Time for each instruction}$$

## Need bit rates for transfer here

$$\frac{1\cdot\text{s}}{\text{instcycle}} = 2000000 \quad \text{Instructions per second}$$

## Codec Timing Calculations

$$\text{CodSamFreq} := \text{samplerate}$$

$$\text{CodSamFreq} = 24\text{kHz}$$

Can handle up to 48 kHz at up to 24 bit depth

$$\text{sampleRate} := 24000\text{Hz} \quad \text{bitDepth} := 24 \quad \text{maxTxRate1} := 1000\text{kHz}$$

$$\text{bitrate} := \text{sampleRate} \cdot \text{bitDepth} \quad \text{maxTxRate2} := 2000\text{kHz}$$

$$\text{dataBitPackage} := \text{payloadSize} \cdot 8 \quad \text{payloadSize} := 32$$

$$\text{totalPacketBit} := 57 + \text{payloadSize} \cdot 8$$

$$\text{bitWaitTillNextTx1} := 130\mu\text{s} \cdot \text{maxTxRate1}$$

$$\text{dataTxTime\%1} := \frac{\text{dataBitPackage}}{\text{bitWaitTillNextTx1} + \text{totalPacketBit}}$$

$$\text{usedBandWidth\%1} := \frac{\text{bitrate}}{\text{dataTxTime\%1} \cdot \text{maxTxRate1}}$$

$$\text{usedBandWidth\%1} = 0.997$$

$$\text{bitWaitTillNextTx2} := 130\mu\text{s} \cdot \text{maxTxRate2}$$

$$\text{dataTxTime\%2} := \frac{\text{dataBitPackage}}{\text{bitWaitTillNextTx2} + \text{totalPacketBit}}$$

$$\text{usedBandWidth\%2} := \frac{\text{bitrate}}{\text{dataTxTime\%2} \cdot \text{maxTxRate2}}$$

$$\text{usedBandWidth\%2} = 0.645$$

## Appendix D: Production Cost

$$\text{numberOfBoardsPerWorkDay} := \frac{2000}{8\text{hr}}$$

$$\text{costOfLabor} := \frac{25}{\text{hr}}$$

$$\text{costOfMachineMaintenance} := \frac{500000}{\text{yr}}$$

$$\text{workersMachineOperators} := 2$$

$$\text{percentOverchangeForProfitAndManagement} := 1.5$$

$$\text{workersFinalAssembly} := 5$$

$$\text{workersTestingAndPackaging} := 3$$

$$\text{totalWorkers} := \text{workersTestingAndPackaging} + \text{workersFinalAssembly} + \text{workersMachineOperators}$$

$$\text{productionCostOfLabor} := \frac{(\text{totalWorkers} \cdot \text{costOfLabor}) \cdot \text{percentOverchangeForProfitAndManagement}}{\text{numberOfBoardsPerWorkDay}}$$

$$\text{productionCostOfMaintenance} := \frac{\text{costOfMachineMaintenance} \cdot \text{percentOverchangeForProfitAndManagement}}{\text{numberOfBoardsPerWorkDay}}$$

$$\text{ProductionCostPerBoard} := \text{productionCostOfMaintenance} + \text{productionCostOfLabor}$$

$$\text{Maintenance\%} := \frac{\text{productionCostOfMaintenance}}{\text{ProductionCostPerBoard}}$$

$$\text{Maintenance\%} = 18.577\%$$

$$\text{Labor\%} := \frac{\text{productionCostOfLabor}}{\text{ProductionCostPerBoard}}$$

$$\text{Labor\%} = 81.423\%$$

$$\text{ProductionCostPerBoard} = 1.842$$

Assumption: These assumptions were primarily based on actual production data and experience at Gentex, a auto-dimming mirror manufacturing company. The cost of labor is assumed to be no more than 18\$/hr plus an additional 7\$/hr for benefits and liability coverage. The cost of machine maintenance is intentionally high because it shows how little it contributes to the final cost and to add extra wiggle room since actual cost is less available than the cost of labor. The extra 50% charge is added for covering manament costs, fixed costs like machines, and leave enough left over for an acceptable profit.