Department of Electrical Engineering and Computer Engineering (EECE)

Smart-Phone Based Snoring Analysis System

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Bachelor of Science in

Electrical /Computer Engineering

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Technical Advisor: Dr. Chong Ahn_______________________________________ Date:________

Dedication

A special thanks to Dr. Ahn and his help and throughout the past year. Your guidance drove our interest and pushed us to work to our full potential.

Thank you to Dr. Purdy for the work she put into teaching the senior design course, and her frequent guidance throughout the semester.

Thank you to the EECE Department and all its faculty for their work in guiding us through the past five years. We have all grown immensely over our time as undergraduates, and our lives will forever be better for attending this University.

We also want to thank our friends and family for helping support us not only through the senior design process but throughout our whole college career.

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Abstract

Although there have been many improvements in medical testing, there is still a high cost and often complex time commitment associated with testing. Many medical conditions go undiagnosed because precautionary tests cost too much money for the average consumer. These precautionary tests are completed at most once a year, which isn't frequent enough to accurately test someone's day-to-day health. With an aging general population, the need for in-home care is also increasing greatly.

The computation power and overall use of smart-phones offers a unique solution to this issue. We propose smart-phones could be used to collect intermittent data and even substitute basic medical tests. There are already many devices and apps that currently track health statistics, like your heart rate, daily step counters, and daily nutrition intake. Right now, each of these sources work independently of each other. Creating a total all-in-one system that works together would allow patients to better track their daily health. Doctors could then use this data to better diagnose their patients, or maybe suggest further tests to be completed.

Having accurate, powerful, and mobile medical testing would allow for a major change in the current medical community. In-home care would be cheaper and easier for both patients and physicians. Being able to customize these systems to fit specific needs would allow for groups like Doctors Without Borders to test/diagnose in remote locations with just a cell phone. Combining all the previously mentioned issues with the creation of faster/cheaper IOT devices the need for smart-phone based biomedical testing couldn't be greater.

Introduction

Problem Statement

We chose to pick a single and generally easily testable condition to focus on for this senior design project. Our advisor, Dr. Chong H. Ahn, suggested that we focus on sleep due to the current sleeping issues facing the general population. There are many possible traits of someone's sleep that one could measure; the total time spent each night, the amount of times someone wakes up, or the amount of time in each sleep cycle. There are many devices (smart watches, Fit Bits, etc.) that currently do this to good accuracy. The one trait that Dr. Ahn suggested we try and measure was snoring. People sometimes are unaware that they snore, or only snore when they are sick. Although snoring isn't necessarily a disease, it is often a condition/symptom of something worse.

Snoring patterns are not very complicated to measure objectively provided you possess the appropriate equipment. When participating in sleep studies in a lab, there are typically a myriad of sensors connected to you while you sleep which provides a good amount of data but can be very uncomfortable potentially disrupting sleep and requires that you sleep in a lab. You are able to diagnose snoring at home using a sleep apnea test kit, however this requires a bulky mask that keeps you tethered to a device while sleeping. Not to mention these solutions are designed for diagnosing snoring in general and are not practical for long term snoring pattern analysis. A better solution could be found if we considered the functionality of mobile devices.

Although tracking someone's snoring patterns can be helpful when looking into other diseases, we decided to expand further on the diagnostic aspect of our solution. **Sleep apnea** is a condition when the patient has short pauses in breathing or abnormally low breathing while asleep (Hansen). *Hansen* says most patients that have sleep apnea suffer from snoring, grunting, or gasping for air. Figure 1 shows how often sleep apnea occurs along-side other condition/diseases (ResMed). Although not directly related, snoring is often a symptom of sleep apnea, which we can use to our advantage. Since it is simple to measure and record one's snoring pattern, tracking any interruptions in this snoring pattern would also be a simple implementation.

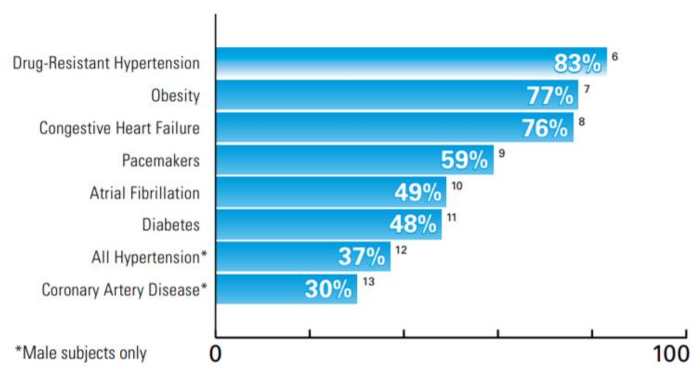


Figure 1: Sleep Apnea in Comorbidities

Advancements in smartphones and embedded technology has allowed for the emergence of the mHealth market. mHealth describes the use of mobile and wireless devices to improve health outcomes, healthcare services and health research. It already has numerous applications such as heart rate monitoring, water testing and cataract detection. However, sleep monitoring, more specifically snoring pattern monitoring, has yet to be explored in depth as an mHealth application. There are a few applications that utilize the mobile device's microphone to detect snoring patterns, but the quality of the data is limited by the capability of the device. It also requires that you have the device within close proximity during measurement which can be impractical if you charge your phone at night. Figure 2 shows sample snoring waveforms.

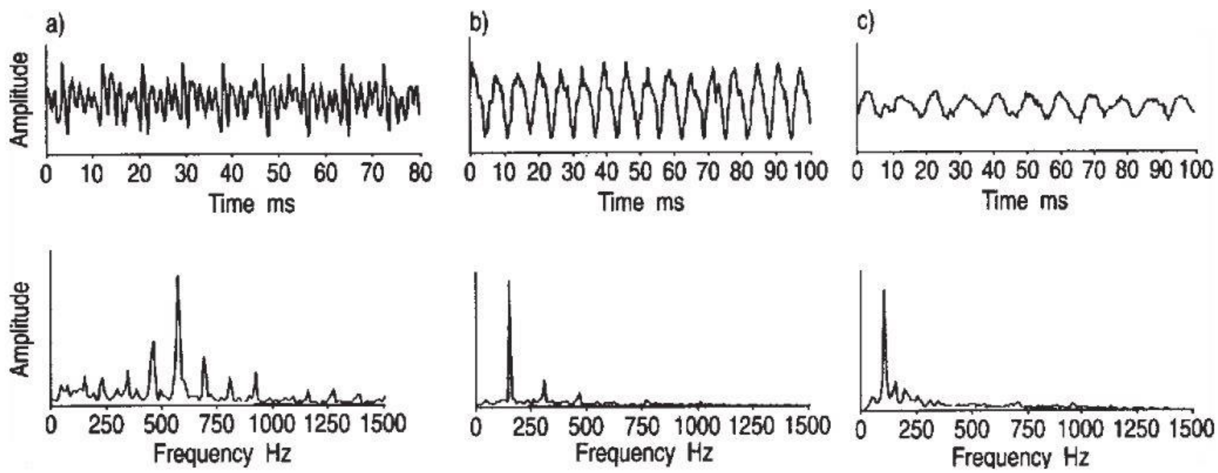


Figure 2: Sample Snoring Waveforms

Current Solutions

Figure 3: Common Sleep Apnea Test

Sleep Studies

Sleep studies are currently the main way to accurately test if someone has sleep apnea. The tests are expensive, with the cheapest tests being $600+ after an insurance deductible. The benefits of this solution are that they are the most accurate solution and that the data from the test goes directly back to the physicians that ordered them. The cons are that you have to sleep in a foreign environment with all of those wires/sensors hooked up to you, and of course the price. Insurance is different for each person meaning that the cost can possibility be high enough that those that need the test can not afford to have it

Test Kits

Figure 4: Sleep Apnea Test Kit

An alternative to the in-lab test are sleep apnea test kits. They are also expensive, with the cheapest coming in around $250. The benefit over an in-lab test is that you can sleep in your normal bed, but this comes with other cons. Although you are in your bed, you have to still hook-up lots sensors or wires that disturb your normal sleeping pattern. These devices are often also less accurate than an in-lab test.

Smart-Phone Applications

A third alternative that we found was using a smart-phone application to record your sleeping pattern. The application then determines your snoring statistics and plots them for you. The benefits are that some apps are free or relatively cheap. But the cons are that it is often very inefficient and heavily relies on the accuracy of the cell phone's microphone. Also this greatly lowers the battery life of the cell phone, and would require you to keep it plugged in all night.

Figure 5: Smart-Phone Test Kit

Our Solution

We found pros/cons of each of the three previous solutions and wanted to implement parts of each. The major things that we decided upon were that our solution had to be

- Wearable
- Non-intrusive
- Inexpensive
- Low power
- Rechargeable
- Accurate
- Adaptive
- User friendly

The solution we propose is to design a small dedicated sensor, which can be adhered to the user's face, that can record the sound waveform produced while snoring and transmit the data wirelessly to the user's mobile device via Bluetooth. A mobile application will also be developed to allow users to record and store their snoring patterns so that we can then try and diagnose sleep apnea. We believe that this system will allow users to gain a better understanding of the quality of their sleep, and if they should seek further help.

Credibility

All three students assigned to this project are senior students in the Electrical and Computer Engineering College at the University of Cincinnati. The team consists of two Electrical Engineers and one Computer Engineer. The group has many unique qualities between themselves, but they also have lots of overlap in knowledge. This allows us to each focus on a specific aspect of the project but still be able to consult each other with any issues that we could have.

Corey Butts (Computer Engineer)

- Mobile Application Development
    - Android Studio
- Embedded System Development
    - PIC, MSP430, AVR and ARM chipsets
    - Embedded Linux
    - MQX RTOS
- Applicable Software Languages
    - C, Python, Java
- Database Management (InfluxDB)
- Analog/Digital Circuit Design
- Soldering
- 3D Printing (Solidworks)

Bayley King (Electrical Engineer)

- Software Languages
    - C, VBA, Python, MATLAB, R
- Data Processing / Management
- VLSI Design
    - VHDL, HSpice, IRSim, Magic
- Analog Circuit / Filter Design
- Power Systems
- Project Management Processes
- CAD Design
- Embedded System Design

Dallas Phillips (Electrical Engineer)

- Hardware
- Filter Design
- PCB Design
- Software Languages
    - C++, VBA, MATLAB
- Analog/Digital Circuit Design
- Embedded System Design

Project Goals

Our original goals involved creating a fully adaptive sensor hub to be used with a mobile device. Our main final goal was to make an all-in-one mHealth system that utilized our own set

	Ergonomic Design	Data Accuracy	Data Transmission	Data Visualization	Data Management	Ease of Use	Battery Life	Rechargeable	Expandability	Total Score
Ergonomic Design		0	0	0	0	0	0	0	0	0
Data Accuracy	1		1	1	1	1	0	0	0	5
Data Transmission	1	0		1	1	1	0	0	0	4
Data Visualization	1	0	0		1	0	0	0	0	2
Data Management	1	0	0	0		0	0	0	0	1
Ease of Use	1	0	0	1	1		0	0	0	3
Battery Life	1	1	1	1	1	1		0	0	6
Rechargeable	1	1	1	1	1	1	1		0	7
Expandability	1	1	1	1	1	1	1	1		8

Figure 6: Original Pairwise Comparison Chart

communication protocol that could allow future expansions to a variety of sensors that followed our protocol. After discussion with our advisor Dr. Ahn, we focused on one specific application of mHealth to show the possibilities of this field. We then had to re-layout our project goals, since the final product of the project had changed. Our original pairwise comparisons chart can be seen in the figure 6 above.

The first new goal that we set for our project involved the implementing the bullet points laid out in the *Our Solution* section of the report. Even though the specific preliminary designs for our system changed over the course of the past two semesters, we made sure that we stuck to these key points. We felt that these points are what would set our device above and beyond the other options on the market. Our new pairwise comparisons chart can be seen in figure 7 at the top of the next page.

	Wearable Design	Non-intrusive	Inexpensive	Low Power	Rechargable	Accuracy	Adaptive	User Friendly	Total Score
Wearable Design		0	1	0	1	0	1	1	4
Non-intrusive	1		1	1	1	1	1	1	7
Inexpensive	0	0		1	1	0	1	1	4
Low Power	1	0	0		1	0	1	1	4
Rechargable	0	0	0	0		0	0	1	1
Accuracy	1	0	1	1	1		1	1	6
Adaptive	0	0	0	0	1	0		1	2
User Friendly	0	0	0	0	0	0	0		0

Figure 7: New Pairwise Comparison Chart

The original chart states that we thought expandable, rechargeability and battery life were the three most important aspects. After we changed our final project goals our chart changed greatly. First off, we changed the overall goals of our project, so we updated these in our graph. Our new chart states that we think that non-intrusiveness, data accuracy, wear-ability, low-power and cost are the most important aspects of our system. This shows the main cons of the current solutions that we found were the main focuses of our final product.

Discussion

Project Concept

Our project is designed to be a primary example of why the field mHealth is so important and has lots of room for improvements. This is a large problem that would take more time/resources that are available to us for a senior design project to fully prove. We then chose to try and implement one specific medical test with our system, just to show the strengths of mHealth. Our system is designed to help someone who snores track if they exhibit sleep apnea conditions. We can take advantage of the fact that snoring is a periodic signal that is normally consistent for a user throughout the night.

We researched the current solutions to test for sleep apnea and found that they had many flaws. Mostly we found that other options were too expensive and impaired the user's normal sleep pattern to a point where the test was measuring "bad" data. If you are hooked up to wires/sensors or in a different bed, your sleep pattern will be different than a normal night at home in your own bed. We want to implement a wearable, low cost, and non-intrusive device that connects to a mobile application so that any user could use the system at home in their own bed.

We designed this project to be more of proof-of-concept for mHealth, to showcase the possibilities of this field. If we can design a cost-effective, accurate and wearable solution to monitor one's sleep, future work could be completed to further improve this idea. There will of course be further optimizations in regards to system performance, but there also could be more additions in regards to data analysis. If the aforementioned total mHealth system could be created, machine learning could be implemented to help try and find abnormalities in user data to help further diagnostic medicine.

Design Objectives

- Wearable
    - We want the device to be wearable because modularity, size, and efficiency are a major aspect of mHealth devices. Our system needs to be wireless and have some connection to a mobile application, we chose a cell phone
    - We chose to use an Android application and to send data over Bluetooth from an Arduino.
- Non-intrusive
    - One of the major cons of the current solutions to sleep apnea testing was that the tests are in a different sleeping environment then you are used to sleep every night. You are in a different bed while wearing wired sensors, where we believe that you are not getting a normal night's sleep.

  - We wanted our solution to intrude upon the user's sleep as little as possible so that the recorded data could be as close to their normal sleeping patterns as possible.
- Inexpensive
  - All the current solutions are very expensive costing over $250 for an at home testing kit or at least $600 for an in-lab test after help from insurance.
  - We want our solution to be affordable for any consumer who wants to better track their sleeping patterns without having insurance cover the costs of the device.
- Low power
  - We want this device to be battery powered and then rechargeable, which would require one less wire to be included with the system. Our plan was to then make the system as low powered as possible, to better increase battery life. We also need to design the system to last for at least one full night of sleep (8 hours).
- Rechargeable
  - We wanted to make the device as simple as possible, so we chose to use a rechargeable lithium ion battery which a charging protection circuit instead of using replaceable batteries.
- Accurate
  - Our system had to be accurate, otherwise our software would output incorrect results. Since we are using a microphone to record the user's snoring patterns, there are many ways for the signals to get distorted. We needed to account for ambient noise levels and filter out anything that wasn't snoring patterns.
- Adaptive
  - We want the system to be adaptive and work on any smart-phone. We decided to create an android application for the project due to the developer license and complexity of Apple development, but we want to still design the system with future expansion in mind.
- User friendly
  - We want the application and the device itself to be simple to set-up and use. The device should be simple to turn on and charge, while the application should be easy to navigate.

Figure 8 on the next page is the objective tree that we created to let us better account for these design objectives.

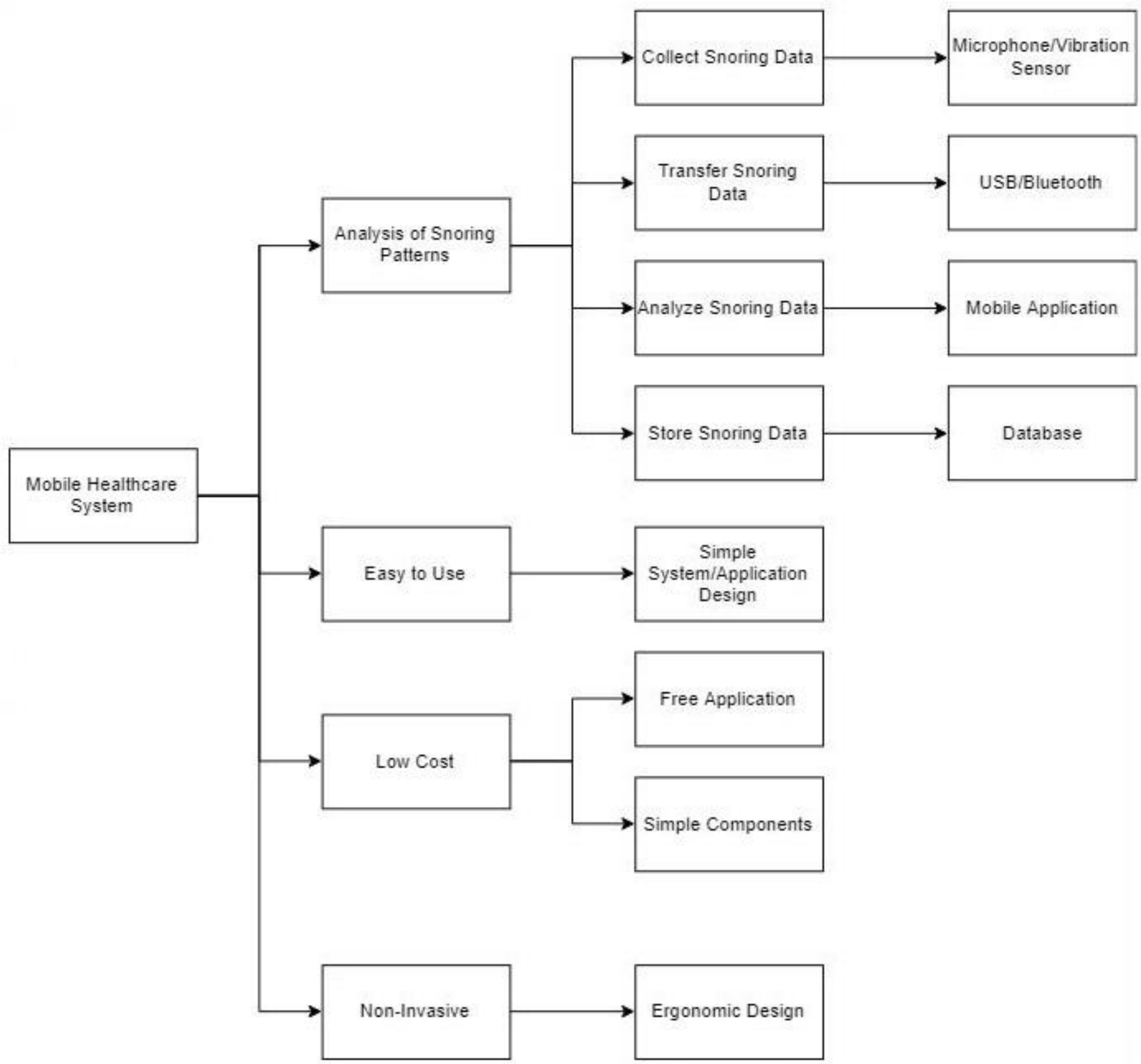


Figure 8: Objective Tree

Technical Approach

Initially, after considering our design objectives and wanting to create a project that the consumer could wear while sleeping that would provide reliable data that also would not disrupt their natural sleep patterns, and is inexpensive, which is not the case with most sleep studies on the market currently. We categorized each function of our system with several options and selected the most appropriate function fulfillment according to our design objectives and goals. These choices are summarized in our morphological chart (next page).

Function	Means			
	1	2	3	4
Data Collection	Microphone	Vibration Sensor	Air/Wind Sensor	***
Data Transmission	USB	Bluetooth	Wi-Fi	***
Database Design	SQL/SQLite	InfluxDB	***	***
Application	Mobile Application (Android Studio)	Mobile Application (Visual Studio)	Web Application (HTML/CSS/JavaScript)	***
Sensor Power	Phone USB	5V Battery Pack	1F Supercapacitor	3.3V Coin Cell
Sensor Design	Microphone Stand	Facemask	Adhesive Facial Strip	***

Figure 9: Morphological Means Chart

- A microphone was selected because this sensor was the easiest to implement for the initial prototype, as well as the cheapest option (considering the oxygen sensor is $100+).
- Bluetooth was the best choice for our project because this requires zero extra wires (wires could disturb natural sleep patterns). Wi-Fi was not chosen because it's not guaranteed that everyone has a strong Wi-Fi signal, and can be unreliable at sometimes.
- SQLite was selected because this seemed like the easiest database to implement with Bluetooth, and there was documentation readily available to access and reference.
- Android Studio was selected because it is the easiest to implement on Android smartphones. Visual Studio can not be directly implemented on Android systems, and we strictly stuck to Android devices because developing apps on Apple would require a license.
- A 3.3V Coin Cell Battery was the option that offered the lowest power of all our means, as well as being wireless, offered rechargeability options, and was relatively small to incorporate into the overall system.
- The initial prototype was designed on a facemask, and because of time constraints an adhesive facial strip was not developed, but facial strips are the best option because they offer the closest proximity to better detect breathing, as well as the least disruptive of all our means.

After selecting the best means in which to fulfill each functional requirement of our system, individual components were selected to accomplish each function. The white box diagram and the specific decisions to select individual components are summarized below:

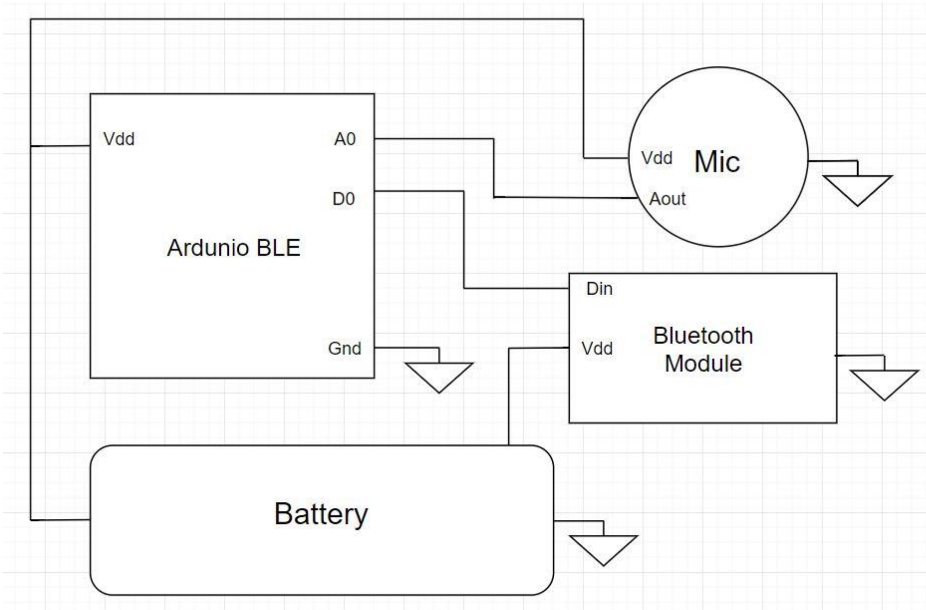


Figure 10: Sensor White Box Diagram

- *Arduino BLE*
    - The microprocessor we selected for the initial prototype was the Beetle Bluno BLE. This is the smallest Arduino currently available on the market, which was ideal for our project since we needed components that would fit inside a facemask. This microprocessor also offers Bluetooth compatibility, which also aligns with our project function means.
- *Battery*
    - A Lithium 3.3V Coin Cell from *Illinois Capacitor* was selected as our battery of choice. The compactness of this battery allows for ample space to fit inside of the facemask, as well as offers rechargeability, which means no extra wires.
- *Battery Protection Circuit*
    - The battery protection circuit was originally adapted and design from samples online from previous projects (**See FIGURE 11**). This allowed for the battery to reliably be recharged without over-charging and over-discharging, which ultimately protects the other components within our system. However, for our initial prototype, we adapted the protection circuit board from a mobile battery pack.

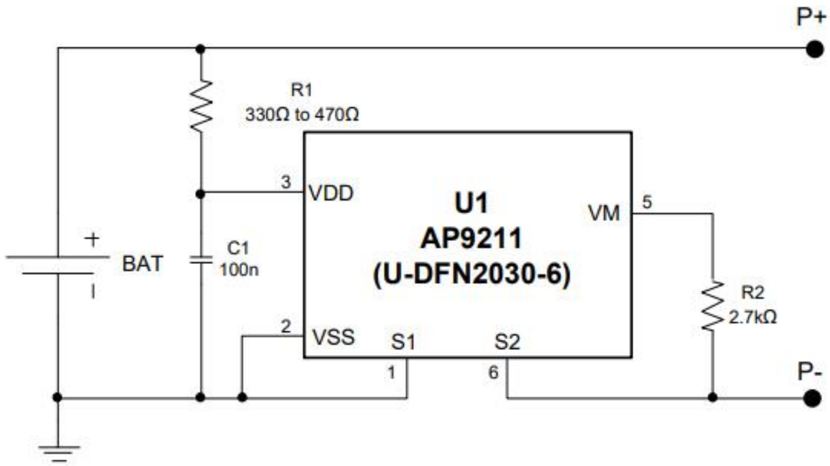
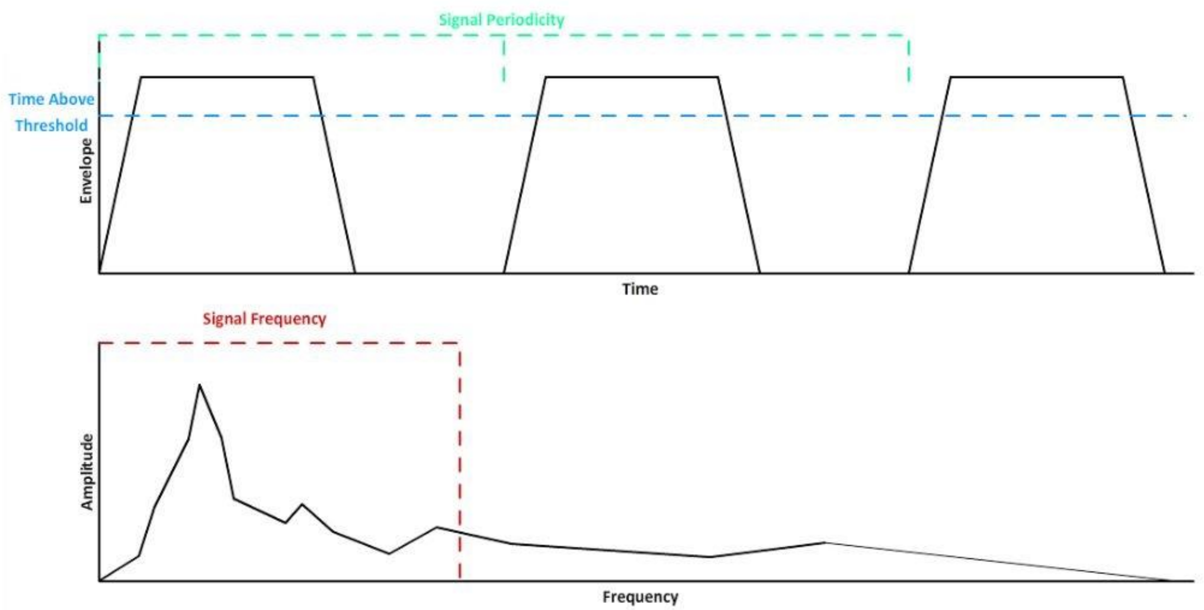


Figure 11: Battery Protection Circuit

- *Microphone*
  - Our initial choice of microphone had to be replaced because it was a surface mount component and was too small to be able to work with for the initial prototype. Instead, it was replaced with the SparkFun Sound Detector Board which has a built-in microphone and amplifier circuit on a circuit board. This was selected as our microphone of choice because we had this sensor from a previously purchased sensor kit.
- *Microphone Amplifier*
  - A bandpass filter and amplifier were designed for our microphone, based on examples from similar utilizations of microphones. The bandpass filter was designed for the range of 10Hz – 3kHz. These values were chosen because snoring frequencies are frequently in the range of 50Hz – 2kHz. Since the SparkFun Sound Detector Board already has a built-in amplifier, we decided to utilize that for our initial prototype (**See FIGURE 18**).

- *Algorithm*
    - Our algorithm uses three different factors from a user's snoring pattern.
        - Period of the signal
        - Frequency (taken from a DFT of the signal)
        - Time signal is above a certain threshold



Algorithm(Signal Frequency, Time Above Threshold, Signal Periodicity) = Snore Score (%)

Periodicity(Snore Score) = Apnea Score (%)

Figure 12: Snoring Algorithm

- These three factors are used to calculate the snoring score of the individual. If a snoring score of 80% is achieved, then the application is confident that the user is snoring. This score is constantly being updated every second by new data, and points are averaged over time, meaning that its takes time for someone's snore score to increase to a high percentage. This is used so that random spikes in noise, like a TV or a fan, will not be considered snoring by the algorithm because they will be averaged out from more measurements.
- If the user currently has a snore score above 80%, then the application starts checking to see if there are any interruptions in the user's sleeping pattern, thus signifying sleep apnea. A user's sleep apnea score will increase throughout the night if they exhibit more interruptions in their snoring pattern, but only when their snore score is set above 80%. All of this is plotted in real time on the mobile application and is stored after the user wakes up in a SQL database.
- On the next page, we show two plots that we have of two user's results from using the application overnight. Figure 13 shows Corey's sleeping patterns from one night, which he learned that he actually snores.

- The application started plotting data once he had a snoring score above 80% which was around 4 am, and then the application started looking for interruptions in his snoring, which rarely happened. The snoring score is the blue/purple dots while the sleep apnea score is the red dot. Although the application detected some lapses in his snoring, which spiked his apnea score, it then normalized his score very soon after showing that although he snored, he didn't show signs of sleep apnea.

Figure 13: Results of a User Snoring (Corey)

- Figure 14 is results of one of our roommates who we knew did not snore. This user's snore score never went above 80%, it actually stayed below 20%, so it never increased their sleep apnea score.

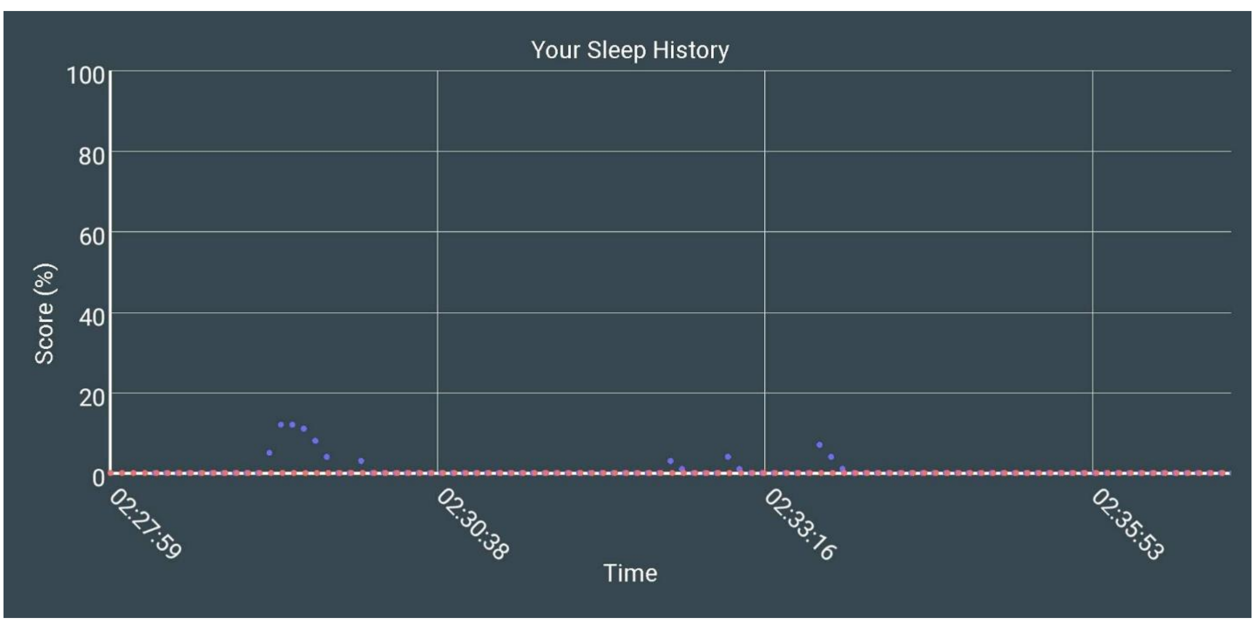


Figure 14: Results of a User Not Snoring

- We would love to test this on more subjects, specifically someone who has sleep apnea, but this project was designed to be a human testing project when we would have needed to apply for the appropriate licenses in the Fall semester. This will be covered more in the future recommendations section.

Standards

The only standard that we applied to our project was **IEEE 802.15-1-2002**. It is IEEE's Standard for Telecommunications and Information Exchange Between Systems - LAN/MAN - Specific Requirements - Part 15: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Wireless Personal Area Networks (WPANs).

We used Bluetooth to communicate between our device and the mobile application.

Budget

- Microphone $5
  - SparkFun Sound Detector (Prototype Only) - $5
- Microprocessor $20
  - Beetle BLE - The smallest Arduino Bluetooth 4.0 $20
- Power $40
  - Illinois Capacitor RJD3555ST1 Lithium 3.7V Coin 35.0mm $35
  - TP4056 board: $5
- Other circuit components $5

Total $70

As we can see, our solution only cost us $70 for a prototyped device, compared to the other solutions which are all over $250. One of our future recommendations is to create this device on a single flexible PCB. This would lower the overall size and cost of the device which would make it more accessible to everyone.

Timeline

Our timeline changed throughout the semester, mostly because our overall design changed. We originally planned on doing all of our data analysis on an outside source/server and then send that data to the cell phone, but we changed this to have our mobile application do all of this for us. This changed our whole section regarding our database and added complexity to our application.

WBS	Tasks	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
1	**Reasearch**	10/1/18	10/31/18	31	100%	23	31	0
1.1	Sleep Studies	10/1/18	10/14/18	14	100%	10	14	0
1.1.1	Snoring	10/1/18	10/14/18	14	100%	10	14	0
1.1.2	OSA	10/1/18	10/14/18	14	100%	10	14	0
1.1.3	Weight, Gender, Race, etc...	10/1/18	10/14/18	14	100%	10	14	0
1.2	Sensor/Harmonics	10/7/18	10/27/18	21	100%	15	21	0
1.2.1	Microphone	10/7/18	10/27/18	21	100%	15	21	0
1.2.2	Vibration	10/7/18	10/27/18	21	100%	15	21	0
1.3	Software	10/11/18	10/31/18	21	100%	15	21	0
1.3.1	App dev	10/11/18	10/31/18	21	100%	15	21	0
1.3.2	Database/python	10/11/18	10/31/18	21	100%	15	21	0
1.3.3	Circuit design/embedded	10/11/18	10/31/18	21	100%	15	21	0
2	**Database/python**	1/1/19	4/30/19	120	27%	86	32	88
1.2	Store user profile	1/1/19	3/1/19	60	100%	44	60	0
1.2.1	Store user measured data	1/1/19	3/1/19	60	50%	44	30	30
1.2.2	Comparison tool	1/1/19	3/1/19	60	50%	44	30	30
3	**App Dev**	1/1/19	4/30/19	120	0%	86	0	120
3.1	UI interface	1/1/19	4/30/19	120	50%	86	60	60
3.2	Functional Expansion	1/1/19	4/30/19	120	33%	86	39	81
4	**Schematics / Data Transmissi**	10/1/18	3/29/19	180	95%	130	171	9
4.1	Sensor Layout	10/1/18	10/30/18	30	100%	22	30	0
4.2	Filter	10/1/18	10/30/18	30	75%	22	22	8
4.3	Power	10/1/18	10/30/18	30	100%	22	30	0
4.4	Data transmission	1/29/19	3/29/19	60	100%	44	60	0
5	**Build**	2/1/19	4/1/19	60	0%	42	0	60
5.1	Combine database and app	2/1/19	4/1/19	60	75%	42	45	15
5.2	Intergrate sensor with app	2/1/19	4/1/19	60	50%	42	30	30
5.3	Circuit Prototype	2/1/19	4/1/19	60	50%	42	30	30
6	**Test/Debug**	3/14/19	4/3/19	21	0%	15	0	21
6.1	Power Circuit Test	3/14/19	4/3/19	21	80%	15	16	5
6.2	Processing Circuit Test	3/14/19	4/3/19	21	0%	15	0	21
6.3	Load Cell Integration Test	3/14/19	4/3/19	21	0%	15	0	21
6.4	Top Level Integration Test	3/14/19	4/3/19	21	0%	15	0	21
7	**Documentation**	4/1/19	4/14/19	14	0%	10	0	14
7.1	Test Results	4/1/19	4/14/19	14	0%	10	0	14
7.2	Report	4/1/19	4/14/19	14	0%	10	0	14

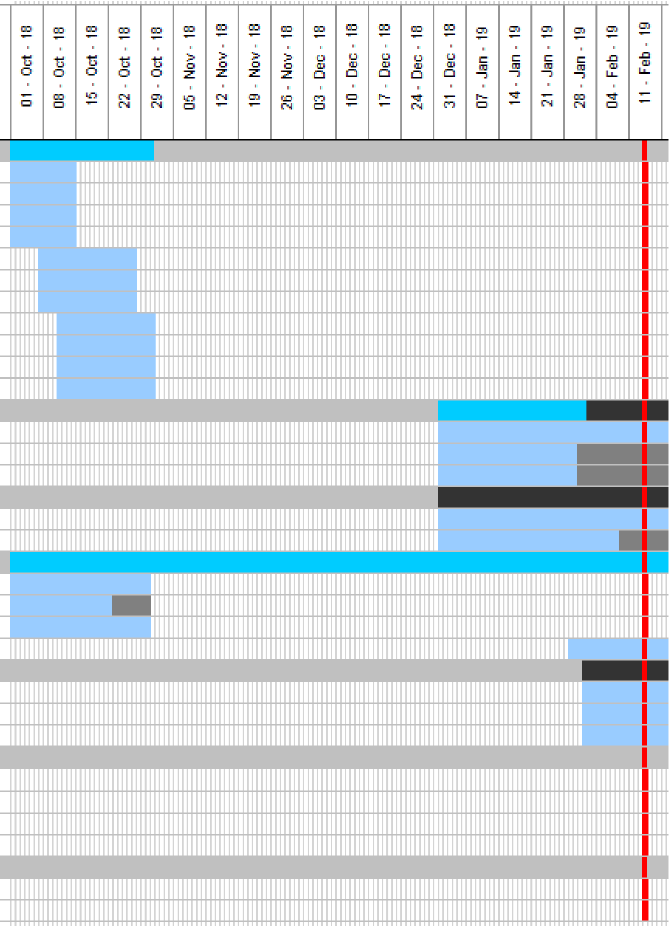
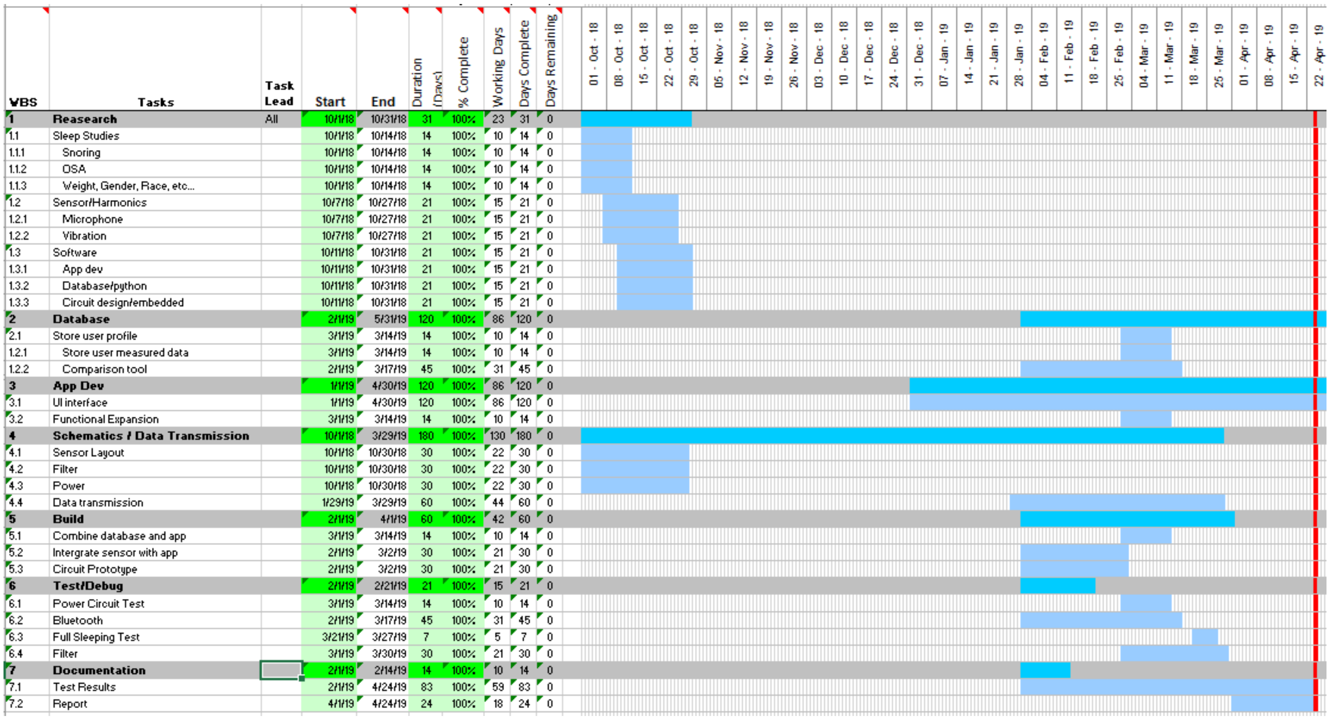


Figure 15: Original Gantt Chart 10-1-2018

As shown in the final Gantt chart, on the top of the next page, most of our work was focused around the second semester of senior design. We were able to complete all our original hardware design and research in the first semester and did all of our building in the second semester. Our database greatly simplified while our application increased in complexity and size which is reflected in the changes between our Gantt charts.



WBS	Tasks	Task Lead	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
1	**Reasearch**	All	10/1/18	10/31/18	31	100%	23	31	0
1.1	Sleep Studies		10/1/18	10/14/18	14	100%	10	14	0
1.1.1	Snoring		10/1/18	10/14/18	14	100%	10	14	0
1.1.2	OSA		10/1/18	10/14/18	14	100%	10	14	0
1.1.3	Weight, Gender, Race, etc...		10/1/18	10/14/18	14	100%	10	14	0
1.2	Sensor/Harmonics		10/7/18	10/27/18	21	100%	15	21	0
1.2.1	Microphone		10/7/18	10/27/18	21	100%	15	21	0
1.2.2	Vibration		10/7/18	10/27/18	21	100%	15	21	0
1.3	Software		10/11/18	10/31/18	21	100%	15	21	0
1.3.1	App dev		10/11/18	10/31/18	21	100%	15	21	0
1.3.2	Database/python		10/11/18	10/31/18	21	100%	15	21	0
1.3.3	Circuit design/embedded		10/11/18	10/31/18	21	100%	15	21	0
2	**Database**		2/1/19	5/31/19	120	100%	86	120	0
2.1	Store user profile		3/1/19	3/14/19	14	100%	10	14	0
1.2.1	Store user measured data		3/1/19	3/14/19	14	100%	10	14	0
1.2.2	Comparison tool		2/1/19	3/17/19	45	100%	31	45	0
3	**App Dev**		1/1/19	4/30/19	120	100%	86	120	0
3.1	UI interface		1/1/19	4/30/19	120	100%	86	120	0
3.2	Functional Expansion		3/1/19	3/14/19	14	100%	10	14	0
4	**Schematics / Data Transmission**		10/1/18	3/29/19	180	100%	130	180	0
4.1	Sensor Layout		10/1/18	10/30/18	30	100%	22	30	0
4.2	Filter		10/1/18	10/30/18	30	100%	22	30	0
4.3	Power		10/1/18	10/30/18	30	100%	22	30	0
4.4	Data transmission		1/29/19	3/29/19	60	100%	44	60	0
5	**Build**		2/1/19	4/1/19	60	100%	42	60	0
5.1	Combine database and app		3/1/19	3/14/19	14	100%	10	14	0
5.2	Intergrate sensor with app		2/1/19	3/2/19	30	100%	21	30	0
5.3	Circuit Prototype		2/1/19	3/2/19	30	100%	21	30	0
6	**Test/Debug**		2/1/19	2/21/19	21	100%	15	21	0
6.1	Power Circuit Test		3/1/19	3/14/19	14	100%	10	14	0
6.2	Bluetooth		2/1/19	3/17/19	45	100%	31	45	0
6.3	Full Sleeping Test		3/21/19	3/27/19	7	100%	5	7	0
6.4	Filter		3/1/19	3/30/19	30	100%	21	30	0
7	**Documentation**		2/1/19	2/14/19	14	100%	10	14	0
7.1	Test Results		2/1/19	4/24/19	83	100%	59	83	0
7.2	Report		4/1/19	4/24/19	24	100%	18	24	0

Figure 16: Final Gantt Chart 4-23-2019

Testing Approach

Testing for this project was approached as a consecutive integration process. This means we would test one process to ensure its functionality was working properly, then move on to the next test and integrate that into the system to ensure that, in the case something went wrong, we wouldn't spend hours (or days) on trying to debug what part of our project was causing the issue. The project started with simple tests regarding getting the Bluetooth (BT) signal connected and sending data to the phone application. Once a good connection was established and the data was accurately and precisely being sent over BT, we were able to move on to testing the battery and output voltage to ensure our sensors, microphone and overall system was both receiving not only a safe level of voltage but the predicted voltage at we designed our system to operate. The voltage levels are crucial to test because a higher level of voltage could result in damage to components, and the system would not function as intended. Once voltages were confirmed at operating levels, a prototype could be developed and tested. The algorithm was changed several times in order to fine tune the precision of our sensor's data by implementing different function libraries, mathematical techniques, and deleting seemingly useless snippets of code. Once the algorithm was at a reasonable level, through testing, we figured out quickly that background noise could be an issue based on the environment in which user is testing. Due to this, a calibration feature was added to our application which takes in the background noise in the environment, so that this data can be subtracted out of the data that enters the algorithm. Thus, ensuring only snoring signals are entering the algorithm. Within the final month of senior design, we focused on implementing and testing a battery protection circuit. This is to ensure the battery does not over charge/discharge. This was then tested by fully discharging the battery then charging it back to full. Finally, we tested the full system through an entire night, the result of this test was successful because there were no unreasonable spikes in the data, and data itself seemed to follow a natural sleeping pattern. For more detail, our timeline is shown below:

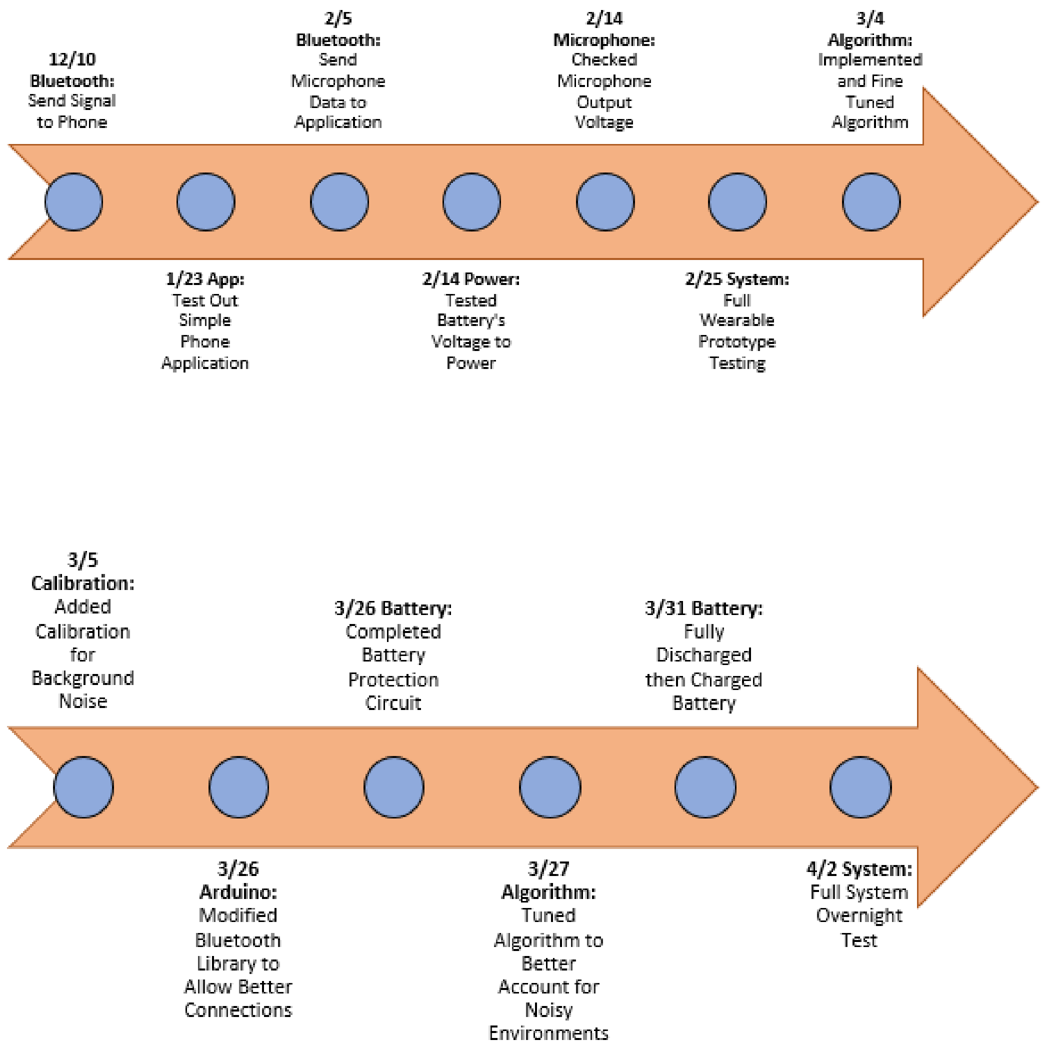


Figure 17: Testing Plan Timeline

Encountered Problems

Audio Noise Interference

One thing that was noticed relatively early in the prototype stage was the relative levels of data being sent over BT to the application. This was reflected most noticeably in our “Snore Score” and “Apnea Score” values. When testing on campus, these values were significantly higher than when tested in a bedroom environment. This was due to the differences in background noise. On campus, there are HVAC, Machinery, Electronics, Other students, etc.

that all contribute to the overall noise levels in that environment. To combat this, we implemented an initial calibration of the system to listen to the background noise levels so that these could be subtracted out of the data that is sent into the algorithm. This ensures that the only data that gets processed is pure snoring (or lack of) signals.

Bluetooth

Bluetooth was for sure one of the biggest issues involved with this project. Although it was the best system for us to use, Bluetooth often had errors sending signal to the application. At first, this stopped all long-term data collection, which was fixed right away. The Bluetooth library that we used had to be modified to superficially work with our project to fix this issue. We tried may different ways to send our signals over Bluetooth, mostly with how often we sent information and what that information was. We found it quite inefficient to send the whole outputted signal from the sensor over Bluetooth, mainly because it was a waste of resources, so we instead sent the three conditions previously mentioned in the technical approach section. We also had issue connecting to our sensor, but modifying the Bluetooth library helped fix this issue.

Microphone Amplifier

From initial integration testing with the microphone into our system, we found that the gain for the microphone was set too low and was not accurately picking up the frequencies for which we had designed. We were able to design our own bandpass filter, keeping in mind that typical snoring frequencies are beneath 1-2kHz, as well as changed the gain of the microphone by referring to the datasheet and populating R17 (**SEE BELOW)** based on the gain we had calculated and designed.

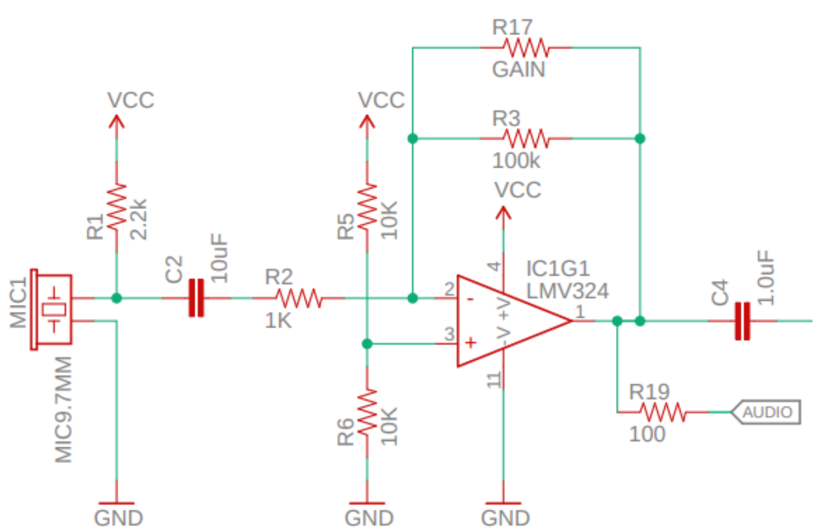


Figure 18: Microphone Amplifier Circuit

Battery Protection Circuit

Initially, we were most worried about being able to implement our system with a battery that is rechargeable, with the reason being that we wanted our system to be wireless in order to get a non-disruptive sleep test. It's very common to have a charging circuit (**See FIGURE #**) hooked up to a battery, such as in a mobile rechargeable battery pack. This not only recharges the battery, but it can help protect against over-charging, over-discharging, or large current draws from the battery which could result in other components in the system to get damaged. Even though a protection circuit was designed specifically for our system, we were able to take a battery circuit from an existing battery pack to implement in our prototype. This protection worked perfectly, being able to charge/discharge our battery throughout overnight cycles without any issues.

Data Plotting

Originally, our application would store all the data, and then plot it all at the end, which sometimes caused some odd-looking graphs, we think from data corruption. We then plotted all our data immediately on the plot, but then the plots became very difficult to read and it often crashed the application. This issue was fixed by us adding the snoring score, and the sleep apnea score, which then required less data to be sent/plotted. This made the graphs easier to read and simplified the complexity of the Bluetooth transmission.

Future Recommendations

<u>iOS Implementation</u>

This prototype is implemented only as an Android Application in its current form. This is due to us having some previous experience with Android Studios, and no experience with iOS implementation. We designed the system to be easily adaptable to iOS, in regard to the used hardware, it would just take some time to create the new application. If this was to be created into a sellable product, we would want any user to be able to use it regardless of their phone type.

<u>PCB Design</u>

Our design is currently just on a sleeping mask, because it places the microphone as close to the nose as possible. Although a face mask worked great for a prototype, we don't like forcing the user to wear something while they sleep, again referencing our initial design objective of being un-intrusive. Our idea is to then create a singular PCB design placed on a flexible PCB placed on the nose. One would need to change the layout of the Arduino, and re-place it on the flexible PCB but our original amplifier and filter design would be implemented in this design. The Arduino could also be removed in this case and a cheaper Bluetooth transmission option could be implemented on the new board. The presentation of the product would also look much better compared to the prototype.

This would take lots of more research into a company that could produce these chips for us, along with changes in the power system. Our current battery system would not work, due to the size of the battery, but changing the Bluetooth transmission system could greatly decrease the power consumption of the system thus reducing the needed battery capacity. More on this will be covered in the next section of the future recommendations.

Improved Battery Life

We designed our system to work for a single night's sleep, 8 hours, but through testing our system was able to work for over 10 hours on a full charge. We would like to improve the system to let it run for a few nights on a single charge without increasing the capacity of the battery. The largest current draw of our system is by far the Arduino, followed by the microphone and its amplification circuitry. Like mentioned in the last section of the recommendations, if we changed the Bluetooth transmission to a simpler component, we could decrease the total power draw. Our current battery offers 500 mAh of capacity, which is great, but our battery is a little large for a wearable sensor.

It would take lots of testing and design to find the perfect balance between lowering power consumption while also decrease the physical size of the battery. One could also change how often our system sends data to our application. We couldn't accurately measure if it drew less current to constantly send the output of the microphone to the application, or have the Arduino do some basic calculations and then send the data in chunks over time. We went with the first solution, thinking that keeping the Arduino doing a basic and consistent task would limit the total power consumption, but there could be more research and testing into this.

Signal Filtering

Our system in its current form will take around 10 measurements right after starting the application from the smart-phone that it considers 'ambient noise'. Everyone sleeps in different conditions, and they often change throughout the year, so we measure this at the start of every night. We then use that to filter out the ambient noise from the transmitted signal, so that we are theoretically getting just the snoring waveform. This worked very well for our prototype and allowed us to test this even in loud environments, so we would for sure keep this feature.

With that being said, of course there can be improvements. Our system in its current form would have trouble telling the differences between two people snoring in the same room/bed. For example, if your partner also snored, the system might have issues distinguishing between the two of you. This is a unique problem, where we would think that software would be the major solution. Making sure that the system is placed close to the user's mouth/noise should make sure that the user's snoring patterns are the dominate factor of the signal, but it is always possible that your partner's snoring overpowers your own signal. We will touch on a possible software solution in the next section.

Machine Learning

The natural progression of any project involving data is to include a machine learning aspect. We have many ideas for this, most of which we came up with near the end of our project after seeing some results. As discussed in our technical approach, our software reads three main factors of someone's snoring; signal period, signal frequency, and the time the signal is above a threshold value. These values are measured and transmitted over time, giving us four total variables. Instead of using these in our current snoring algorithm, one could create a four-dimension vector space for data analysis. Analysis of the changes in the vector space would allow for a different way to analyze someone' sleeping patterns and could open up a whole new way to analyze sleep.

We also suggest using machine learning to help solve the issue mentioned in the previous section, multiple people snoring in the same room. Unless your partner's snoring is so loud that it overpowers your pattern, your pattern should still be the dominating aspect of the signal. The application could then save these characteristics, and then machine learning could then be implemented to check these characteristics compared to the current input. If the application was able to accurately distinguish your snoring from other noise, we could get a cleaner signal to use for data analysis.

Another pathway involving machine learning is searching for patterns in your saved data and checking to see the minor changes overtime. One would need to continue sleep analysis research and/or talk to a medical professional that focuses on sleep analysis to see what conditions that software should look for. If the app notices that your sleeping patterns now distinguish certain qualities, the app could possibly suggest further help for the user.

Other sensors

We decided to just use a microphone to record the snoring waveform and use our algorithm to verify if someone is snoring, but we could use additional sensors/hardware to also do this. We investigated using an oxygen sensor to analyze breathing patterns to verify that an individual is snoring, but the sensors we found were quite expensive and would have driven the cost of the system higher than we wanted.

We suggest more research into possible hardware solutions to better measure and verify if a person is snoring. One could try and measure the vibrations of the system, possibly verifying if a user's nose was moving along with the snoring waveform. This could also help distinguish the noise between two people snoring, because the system could verify if the user was snoring at that given moment.

mHealth

This whole project is supposed to be a look into using mHealth practices to simple healthcare diagnostic needs, which we believe it did. We want more projects/research to be put into this field, because it serves the future needs of an aging population by using current technology. Future work could continue improving sleep analysis, but we suggest people look even further into other diagnostic tests, like blood test, nutrition, sweat analysis, or blood pressure readings. All of these tests use current sensors that exist on the market which if used in unison could act as an at-home diagnostic tool for the average user. Of course, accuracy will always be less than going to have a full medical workup completed in a hospital setting, but mHealth still has its benefits.

With the ever-improving state of technology, these mHealth tests will get more and more accurate along side more testing. Our original project idea of a full health-testing system could use the previously mentioned idea of machine learning to help analyze a user's current health and possibly suggest further test to be done by a medical professional. This would also let medical professionals further practice at-home medical testing using just mobile equipment from their smart-phone. Needless to say, this topic can be greatly continued upon by anyone interested in future work.

Future Testing

We were unable to fully test our system with someone that is known to have sleep apnea, we were only able to test on ourselves. When we first planned this project there was no human testing planned, so we never got the associated licenses that were needed to do a human study. If someone wanted to continue working on this, they should plan to do full human tests with control subjects, and known subjects of sleep apnea.

Conclusion

References

[1] B. Wirsing. "Sending and Receiving Data via Bluetooth with an Android Device," March, 2014. [Online Document]. Accessed 20 November 2018. Available: https://www.egr.msu.edu/classes/ece480/capstone/spring14/group01/docs/appnote/Wirsing-SendingAndReceivingDataViaBluetoothWithAnAndroidDevice.pdf.

This article provides instructions on how to communicate to an Arduino with a Bluetooth module and an Android application. Our project required wireless communication between the sensor and the user's smartphone. Therefore this document showed us exactly how to implement this communication in Android Studio.

[2] Beck, R., Odeh, M., Oliven, A., & Gavriely, N. (1995). The acoustic properties of snores. The European respiratory journal, 8 12, 2120-8 .

We used this paper to assist with our research for snoring patterns, especially when constructing our detection algorithm. We also used some of their figures in our papers, and on our poster.

[3] Dafna E, Tarasiuk A, Zigel Y (2013) Automatic Detection of Whole Night Snoring Events Using Non-Contact Microphone. PLoS ONE 8(12): e84139. Accessed 12 September 2018. https://doi.org/10.1371/journal.pone.0084139

This article also served as a starting point in our research for the project. We used some of their statistics to as justification for our project, and frequently referred to their figures in other instances.

[4] H. Shin and J. Cho. "Unconstrained snoring detection using a smartphone during ordinary sleep," *Biomed Eng Online*, vol. 13, no. 116, August, 2014. [Online Serial]. Accessed 12 September 2018. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4148548/.

This article demonstrates the viability of a snoring sound classifier. They tested an algorithm that was developed by testing against a database of snoring and non-snoring sounds and implemented using a smartphone application and microphone. Within the article they mention the relative frequencies that are associated with typical snoring sounds. This gave us the idea to not only check the sound amplitude but also the frequency peaks when determining if the user is snoring.

[5] Hansen, Kathy. "The Difference Between Snoring and Sleep Apnea Explained." Simple Sleep Services. 22 Mar. 2017. Accessed 5 September 2018. https://www.simplesleepservices.com/snoring-and-sleep-apnea/.

This article contains information into sleep apnea that we used in creating our algorithm for detection. It also served as one of primary sources in the beginning of our research. We looked at their sources and read through their articles as well.

[6] J.A. Pinto, D.K. Ribeiro, A.F. Cavallini, C. Duarte, and G.S. Freitas. "Comorbidities Associated with Obstructive Sleep Apnea: a Retrospective Study," *Int Arch Otorhinolaryngol*, vol. 20, no. 2, March, 2016. [Online Serial]. Accessed 16 February 2019. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4835326/.

This article is about a study whose goal was to determine a correlation between major commodities and obstructive sleep apnea. The conclusion of this article gave us more insight into the disorder and some data on the relationship between age groups and sleep apnea.

[7] J.H. Choi, M. Sun, U.G. Kang, and B.M. Lee. "SMART DETECTION ALGORITHM FOR SNORING AND APNEA," February, 2017. [Online Serial]. Accessed 16 February 2019. Available: https://pdfs.semanticscholar.org/f2c0/6a1b32e77710bc256a7c838c2c6383510f69.pdf.

This article is about the implementation of a snoring detection algorithm into an embedded system. The system was made up of a Raspberry Pi connected to a myriad of sensors, one of which being a microphone, that would monitor the user while they slept. This was very integral in the creation of our snoring and apnea detection algorithm due to the fact that they were using the same microphone module that we were. It gave us insight as to what kind of signal could indicate snoring as well as how to get more resolution out of the data obtained by the microphone module.

[8] Lee, Li-Ang et al. "Energy types of snoring sounds in patients with obstructive sleep apnea syndrome: a preliminary observation," *PloS one*, vol. 7, no. 12, December, 2012. [Online Serial]. Accessed 14 September 2018. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534069/.

This article investigates the energies of soundwaves generated by people diagnosed with obstructive sleep apnea while snoring. They outline the specific frequencies that on average showed more peaks throughout a night of testing that are associated with snoring sounds. We used these frequencies in our own algorithm to help distinguish snoring sounds from non-snoring sounds.

[9] Sparkfun, "Sound Detector Hookup Guide", learn.sparkfun.com, [Online]. Accessed 20 February 2019. Available: https://learn.sparkfun.com/tutorials/sound-detector-hookup-guide/all.

This is a tutorial on how the sparkfun sound detector module works and how to modify it. There was an issue of data amplitude being too low to get any resolution from the FFT. This showed us how to increase the gain of the first stage of the microphone amplifier in order to get more resolution. It also helped us to understand the purpose of each of the output pins.

[10] T. Young, L. Finn, P.E. Peppard, M. Szklo-Coxe, D. Austin, F.J. Nieto, R. Stubbs, and K.M. Hila. "Sleep disordered breathing and mortality: eighteen-year follow-up of the wisconsin sleep cohort," *SLEEP*, vol. 31, no. 8, August, 2008. [Online Serial]. Accessed 12 September 2018. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2542952/.
This article contains information about the symptoms of sleep-disordered breathing, its causes and the risk of mortality in patients diagnosed with it. The content in this document was one of the primary issues touched upon in our problem statement and is a justification of why our project was necessary.

Appendices

Full List of Tests

Date	Type	Test Explanation	Results	Comments
12/10	Bluetooth	Send Bluetooth signal to phone	We were able to send a simple Bluetooth signal from our Arduino to our cell phone app	This was the first step for us in regards to app and system integration, which now allows us to separately developed each part before full integration.
1/23	App	Test out simple phone application features	No issues with our application.	This was more of a test of our knowledge of android studios, since it is new to us.
2/5	Bluetooth	Send microphone data to application then plot it.	We are able to send data, but our app will freeze up after long plots.	We code right now replots the graph every time new data is received, which will greatly slow down the speed. This was mostly for us to just make sure the app can properly plot data in general, we can still clean up the code for the future.
2/14	Power	Tested our battery's voltage to power prototype circuit	Our battery could fully run our Arduino and microphone at 3.3V	This will let us greatly increase battery life since it is a lower voltage than the standard 5V. We also can use our smaller physical battery design which will decrease physical layout.
2/14	Microphone	Checked microphones output voltage	Output signal is too low to work with	We need to increase the gain of our amplifier. We also need to get more microphones, because they are too small for our usage, and we believe they will have trouble picking up the sound levels we expect to hear.
2/25	System	Full wearable prototype testing.	The device collects and transmits data to our application as expected. We used an outside power source for this test, not our battery.	This is very promising, because now we can just fine tune the accuracy and power management of our system. Although we had to use a separate power source for this test, we have already tested our battery and verified that it works. We did not want to fully connect our battery to our system until we had the proper charging circuit created first.
3/4	Algorithm and Circuit	Implemented and fine-tuned our algorithm to better detect OBS	Our system is now more accurate.	We modified out amplification circuit to further increase the output from our microphone. With this now higher output signal, we modified our algorithm to better detect OBS.
3/5	Calibration	A new feature allowing the user to specify the environment they are using the system. When	This further increased the accuracy of the read data.	Although we expect the user to wear this sleeping mask, we would rather not alter the user's sleep to a point where the system is not monitoring

		we tested the circuit in a 'new' environment, it greatly affected the data.		their normal sleeping pattern. This allows the user to not wear the mask, but still let the system work as intended.
3/26	Arduino	Modified the Bluetooth library for the Arduino to allow better connections	Bluetooth connections are now more consistent between the device and a cell phone.	This was a quality of life test for our system, and hopefully nothing else needs to be modified in this regard.
3/26	Battery	Completed our new overcharge circuit alongside our battery	The battery is able to charge.	We still need to test this circuit fully, making sure the battery stops charging whenever it reaches max capacity. We plan to let the battery full discharge, and then charge it back up to full.
3/27	Algorithm	Tuned the detection algorithm to better account for noisy environments	Accuracy was greatly increased	This was a major concern of ours going into the project, and although the algorithm isn't perfect, we believe that we have a more than viable solution for the scope of this project. We suggest that this gets fine-tuned more in the future.
3/31	Battery	Fully discharge then fully charge the circuit	Working as intended.	Our overcharge circuity worked as intended, and our system is able to be fully discharged and then fully charge
4/2	System	First full system test on overnight sleeping data collection.	The system functioned as intended	The system actually worked longer than we expected, going for over 10 hours, and it tracked Corey's sleeping patterns overnight. He actually found out that he snores.

End of Semester One Final Presentation

Smartphone-Based Snoring Analysis System

CE13 Senior Design Project

Team Members:
Corey Butts
Bayley King
Dallas Phillips

Advisor:
Dr. Chong Ahn

University of CINCINNATI

Team Introduction

Name	Corey Butts	Bayley King	Dallas Phillips
Major	Computer Engineering	Electrical Engineering	Electrical Engineering
Relevant Skills	- Mobile Application Development - Android Studio - Embedded System Development - PIC, MSP430, AVR and ARM chipsets - Embedded Linux - MQX RTOS - Applicable Software Languages - C, Python, Java - Database Management (InfluxDB) - Analog/Digital Circuit Design - Soldering - 3D Printing (Solidworks)	- Software Languages - C/C++, VBA, Python, MATLAB, R - Data Processing / Management - Filter Design - Power Systems - Project Management Processes - CAD Design (AutoCAD and Revit) - Embedded System Design	- Hardware - Filter Design - PCB Design - Software Languages - C++, VBA, MATLAB - Analog/Digital Circuit Design - Embedded System Design

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Problem Statement

- Snoring isn't inherently a problem
- It can be a symptom of more serious issues

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Problem Statement

- Sleep Apnea
  - A sleep disorder in which breathing repeatedly stops and starts
  - Sleep-disordered breathing (SDB) is a common cause and snoring is a common symptom
  - 75% of cases of severe SDB remain undiagnosed[1]

[1] Source - Sleep Disordered Breathing and Mortality: Eighteen-Year Follow-up of the Wisconsin Sleep Cohort. (2008). *Sleep*. doi:10.5665/sleep/31.8.1071

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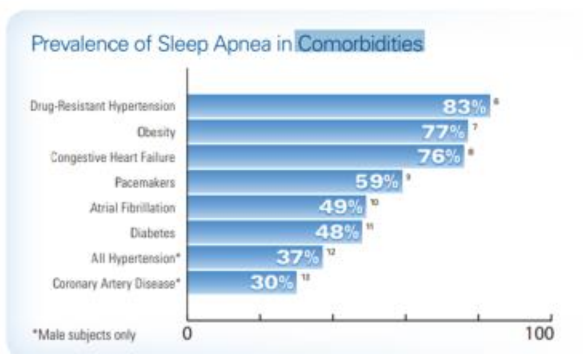

Source - ResMed. (2014, May). Sleep Apnea Facts and Figures https://www.resmed.com/us/dam/documents/products/dental/Narval-CC/facts-and-figures/1015527r4_Narval_MRD_FactsandFigures_web.pdf

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Problem Statement

- Other complications related to sleep apnea:
  - Metabolic syndrome
  - Complications with medications and surgery
  - Liver problems
  - Sleep depravation
  - Sleep-deprived partners

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Available Solutions

- Sleep studies
  - Sleep in a lab
  - Disruptive measuring equipment
  - Expensive (~$200 - 600)
- Sleep apnea test kit (HST)
  - Disruptive tethered sensor
  - Expensive (~$250)
- Smart Phone Applications (IOS/Android)
  - Ease of use with mobile device
  - Microphone inaccuracy
  - High power consumption for phone

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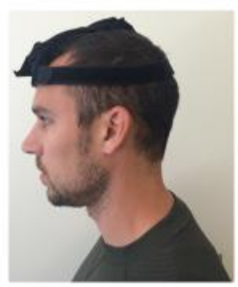
  - Microphone inaccuracy
  - High power consumption for phone

Other Related Products

- Phillips SmartSleep – ($400)
  - Head Band offers minimal sleep interference
  - No snoring tracking
- Smart " Pillows" (~$100)
  - Short device lifetime (~5 weeks)
  - Snoring is not the "main" feature

Our Solution

- Wearable Bluetooth Device
  - Prototype: Headband
  - Product: Adhesive device placed near nose
- Android Application
  - Visualize sleep results
  - Stores results into database



Our Solution

- Ergonomic
  - Face mounted, non-disruptive
- Accurate
  - Dedicated sensor
- Inexpensive
  - Cheap parts
- Convenient
  - Can be used anywhere

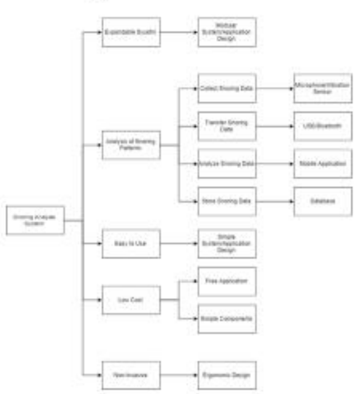
Objectives and Constraints

Objective	Description
Ergonomic Design	The sensor must attach to the user's face comfortably
Data Accuracy	The data being collected must be accurate enough to make a conclusion on the user's snoring patterns
Data Transmission	The data must be transmitted consistently over a wireless connection
Data Visualization	The data and analysis of the data must be visualized through a mobile application
Data Management	Collected data must be stored in a database for future review
Ease of Use	The system must be simple enough for a person that has little experience with technology to be able to use
Battery Life	The battery must be able to deliver power to the sensor for an entire night (~8 hours)
Rechargeable	The sensor must be rechargeable
Expandable	The system must allow for future incorporation of other biosensors

Objectives and Constraints

Constraint	Description
Power Delivery	The sensor will require consistent and stable power throughout an entire night while maintaining a small size
Data Noise	The sensor should be able to distinguish between actual snoring patterns and noise
Low Cost	The system should be functional while maintaining a low manufacturing cost
Requires Smartphone	The system is dependent on the user possessing a smartphone

Objective Tree



Pairwise Comparison Chart

	Ergonomic Design	Data Accuracy	Data Transmission	Data Visualization	Data Management	Ease of Use	Battery Life	Rechargeable	Expandability	Total Score
Ergonomic Design		0	0	0	0	0	0	0	0	0
Data Accuracy	1		1	1	1	1	0	0	0	5
Data Transmission	1	0		1	1	1	0	0	0	4
Data Visualization	1	0	0		1	0	0	0	0	2
Data Management	1	0	0	0		0	0	0	0	1
Ease of Use	1	0	0	1	1		0	0	0	3
Battery Life	1	1	1	1	1	1		0	0	6
Rechargeable	1	1	1	1	1	1	1		0	7
Expandability	1	1	1	1	1	1	1	1		8

Performance Specifications

- Snoring Sensor
  - Adhere to face and not interrupt normal sleep patterns
  - Monitor snoring and block other sounds
  - Wireless data communication
  - Stay powered throughout the night
  - Rechargeable power source

Performance Specifications

- Mobile Application
  - Receive data wirelessly
  - Store data into a database
  - Analyze data against other stored data
  - Visualize data to user
  - Manage multiple user accounts

Morph Chart

Solutions/ Subfunctions	Ideas 1	2	3
Measure Snoring Data	Microphone	Vibration Sensor	Oxygen Sensor
Filtering	Digital Filtering	Band Pass Filter	Low Pass Filter
Transmit Data	Beetle BLE	Atmea/MSP	PIC
Receive Snoring Data	Galaxy S8	Iphone	PC application
Process Data	Android Studio (Java)	Xcode (Swift)	PyCharm (Python)
Store Data	My SQL	SQL Lite	InFluxDB
Display Data	Android Studio	Swift	Python Application
Board Power	Power from Phone	3.3V Coin Cells	Wall Plug In

Design Decisions

Part/Software	Design Decision
1. Knowles 10kHz Analog Microphone Omnidirectional	1. Low power, range between expected snoring frequencies.
2. Beetle BLE Arduino	2. Compact, and has built in Bluetooth 4.0 module. Can function on same voltage as battery.
3. Illinois Capacitor Lithium 3.7V Coin Battery	3. Low power (3.7V), covers well overnight usage. Rechargable.
4. Android Studio	4. Experience with Java and Android development.

Knowles 10 kHz Analog Microphone

- Frequency: 100Hz ~ 10kHz
- S/N Ratio: 65dB
- Impedance: 400 Ohms
- Voltage: 1.5V ~ 3.6V
- Current: 165 µA
- Output: Analog

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Beetle BLE Arduino

- Bluetooth 4.0 (CC2540)
- Size: 28.8mm X 33.1mm (1.13" x 1.30")
- Sensitivity: -93dBm
- Weight: 10g
- Clock Freq: 16MHz
- Operating Voltage: 5V DC
- Digital Pins: 4
- Analog Pins: 4
- I2C Interface x1
- UART Interface x1
- PWM Output x2
- Micro USB Interface x1
- Microcontroller: ATmega328
- Operating Temperature: -10°C ~ 85°C

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Illinois Capacitor Lithium 3.7V Coin Battery

- Nominal Voltage: 3.7 VDC
- Operating Temperature: -20°C ~ 60°C
- Storage Temperature: -20°C ~ 60°C (one month)
- Charging
  - Voltage: 4.2 VDC
  - Current: 0.5 CA
  - Time: < 3.0 hours
- Rechargeable

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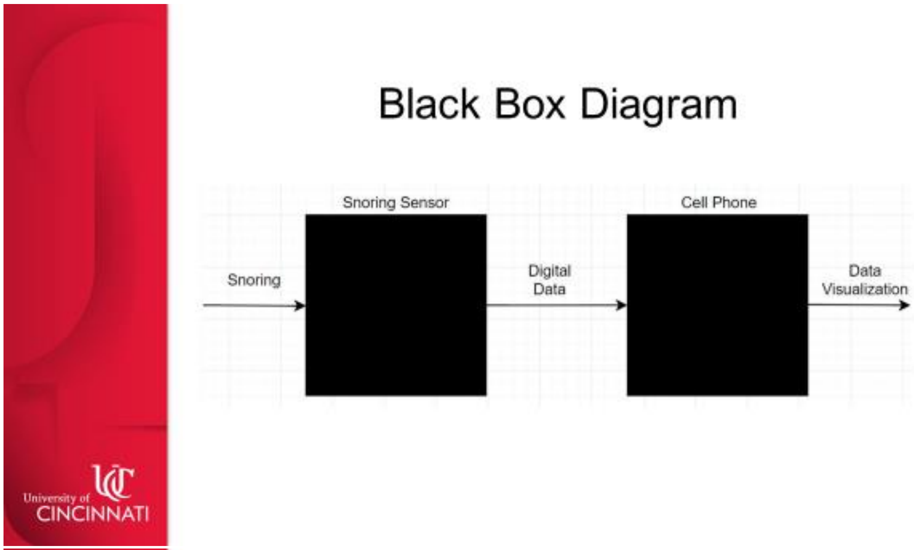
Black Box Diagram
Snoring Sensor
Cell Phone
Snoring
Digital Data
Data Visualization
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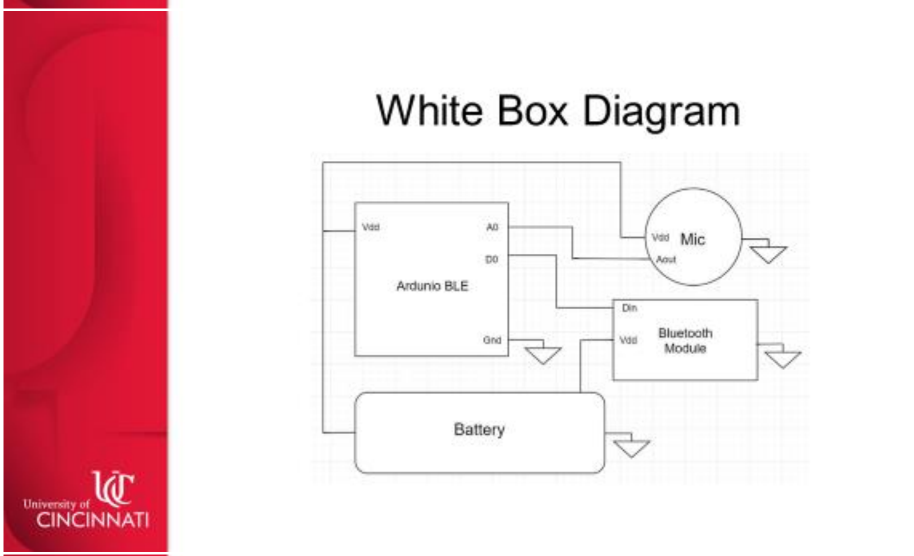
White Box Diagram
Vdd
A0
D0
Ardunio BLE
Gnd
Vdd
Mic
Aout
Din
Vdd
Bluetooth Module
Battery
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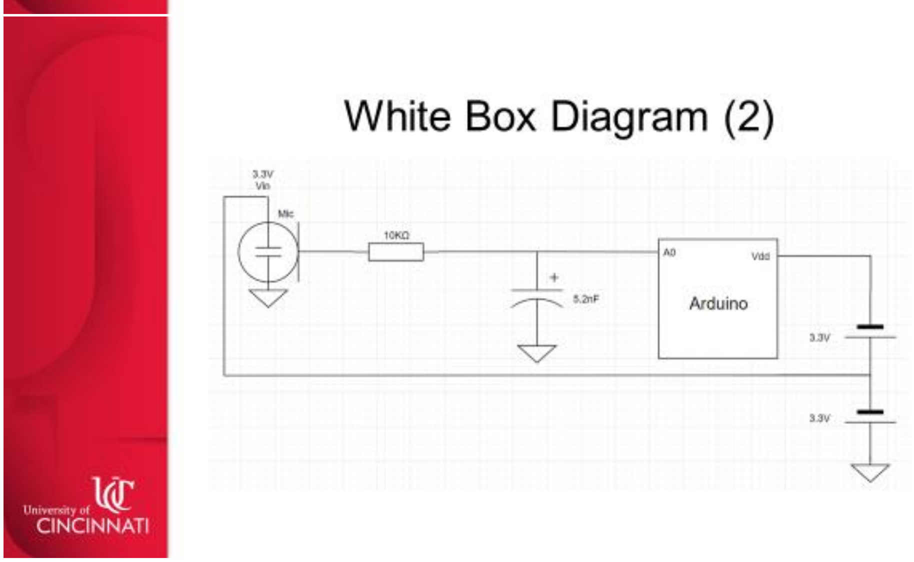
White Box Diagram (2)
3.3V Vin
Mic
10KΩ
+
5.2nF
A0
Vdd
Arduino
3.3V
3.3V
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Proposed Prototype Budget

- Microphone
  - Knowles 10Hz to 10kHz Analog Microphone Omnidirectional . $1/unit
- Microprocessor
  - Beetle BLE - The smallest Arduino Bluetooth 4.0 $20
- Power
  - Illinois Capacitor RJD3555ST1 Lithium 3.7V Coin 35.0mm $35
- Design Equipment
  - All supplied through Dr. Ahn's lab or through ourselves $0
- **Total** - $56

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Time Spent this Semester

- Roughly 2-3 hours a week per person
  - All work was completed in a group setting
  - 30 to 45 total hours per student over the whole semester
- Snoring research ~ 10-15 hours
- System design ~ 18-23 hours
- Testing ~ 2 hours

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Estimated Time to Competition

- App development – 3 months
  - Majority of the semester
  - Lead: Corey
- Database management – 2 months
  - Early next semester
  - Lead: Bayley
- Headband prototype
  - Over winter break (already own the components)
- Flexible PCB layout – 3 months+
  - Lead: Dallas
  - Majority of the semester

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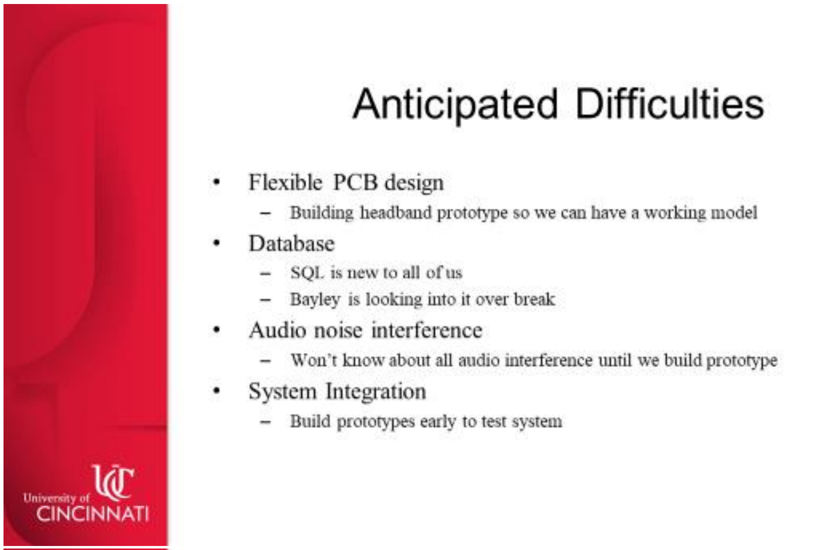
Anticipated Difficulties
• Flexible PCB design
– Building headband prototype so we can have a working model
• Database
– SQL is new to all of us
– Bayley is looking into it over break
• Audio noise interference
– Won't know about all audio interference until we build prototype
• System Integration
– Build prototypes early to test system
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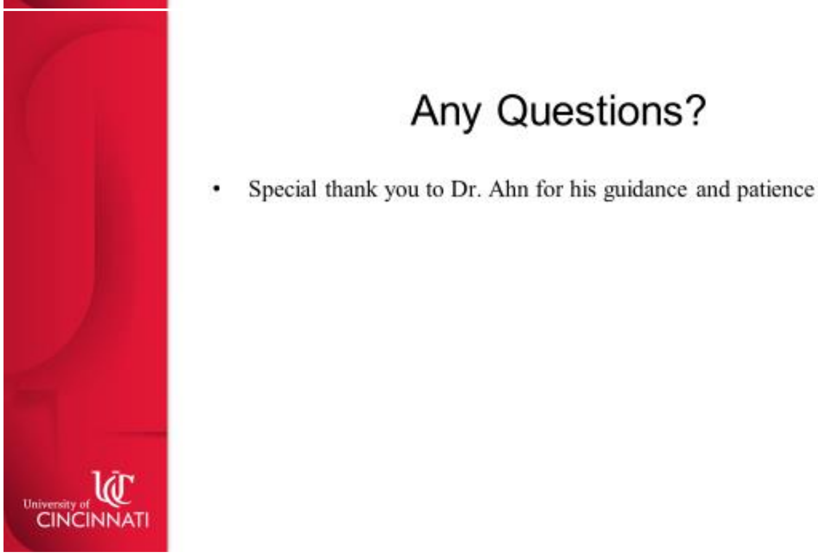
Any Questions?
• Special thank you to Dr. Ahn for his guidance and patience
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Final Poster for the Senior Design Expo

Performance Specification Chart

SNORING SENSOR

Functions	**Performance Specifications**
Adhere to face	Must stay adhered to the user's face comfortably without disrupting sleep. Should be able to readhere to the user's face after removal
Monitor snoring	Must be able to measure snoring through some means (sound, vibration etc.)
Wireless communication	Must be able to communicate with the mobile device wirelessly
Stay powered	If the user has charged the sensor's battery to maximum capacity the sensor should be able to collect and transmit data throughout an entire night
Rechargable	Must be able to recharge the battery to full capacity

MOBILE APPLICATION

Functions	**Performance Specifications**
Receive data	Must be able to receive data wirelessly from the snoring sensor when in use
Store data	Must be able to store the received data into a database which can be accesed by the user who recorded the data
Analyze data	Once data from multiple users within the database, the application will compare the user's data against multiple others in order to give an assessment on their snoring patterns
Visualize data	The application should include a screen dedicated to a visualization of the user's data analysis summary
Manage user accounts	Must be able to add and delete user accounts. User's should be able to login to their accounts to store and view their snoring data

Morphological Chart

Solutions/ Subfunctions	Ideas 1	2	3
Measure Snoring Data	Microphone	Vibration Sensor	Oxygen Sensor
Filtering	Digital Filtering	Band Pass Filter	Low Pass Filter
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Store Data	My SQL	SQL Lite	InFluxDB
Display Data	Android Studio	Swift	Python Application
Board Power	Power from Phone	3.3V Coin Cells	Wall Plug In

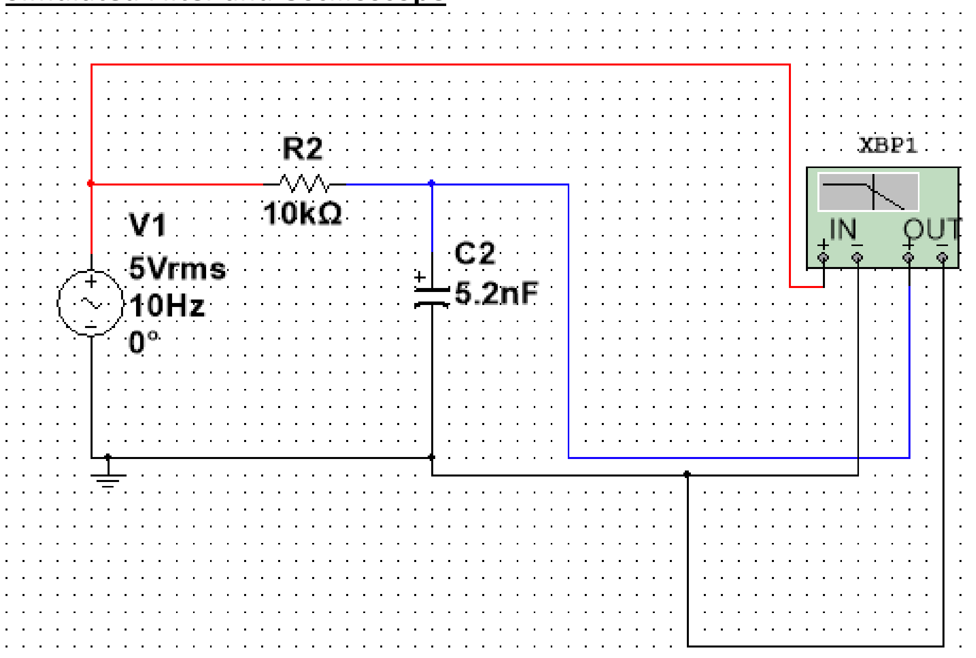
Design Constraints (C) and Objectives (O)	1	2	3
C: Power	1	2	3
C: Smartphone type	1	3	2
C: Accuracy	1	3	2
O: Low Cost	2	3	1
O: Ergonomics	1	2	3

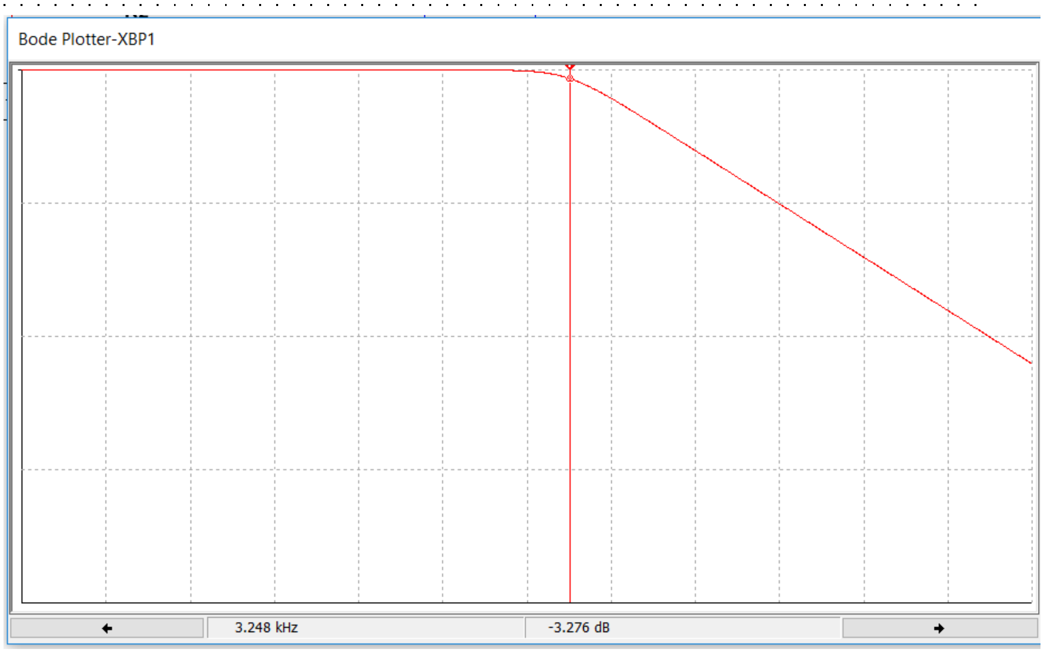
Code

Our code can be found on the following GitHub link. It is far to large and extensive to include in this report.

https://github.com/boreycutts/snore

Simulated Filter and Oscilloscope



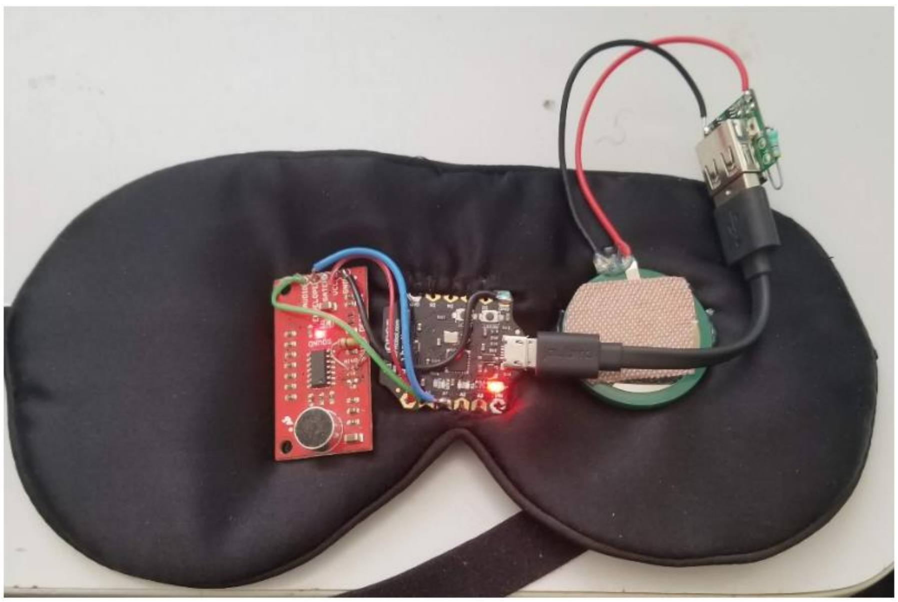


Power Analysis

Here are the power calculations that we did to determine the size of our battery.

Component	Voltage and Current Draw	Estimated Power Consumption for 8 Hour Usage
Arduino	5V ~35mA. Assume 50mA draw.	400mAH
Microphone	3.3V ~185µA.	~1mAH
	Total	401mAH

Image of Prototyped System



Data Sheets

Arduino

Bluno Beetle SKU:DFR0339

Contents

Introduction

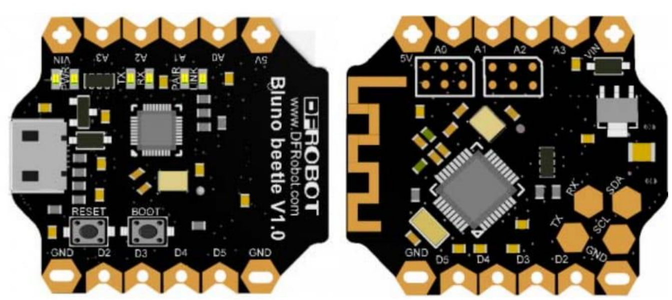
Bluno Beetle is another milestone in wearable electronics device area, which makes DIY users have more options in the project design. It is fully compatible with Bluno in instructions and procedures, supporting Bluetooth HID and ibeacon modes.
And it not only supports USB programming, but also wireless programming method. With the V shaped gilded I/O interface, it is convenient to screw conductor wire on it, which could a good choice in the wearable market.

More instruction about Bluno Beetle can refer to **DFRobot Bluno**。

Specification

Bluetooth Chip	CC2540
Sensitivity	(-93dBm)
Working Temperature：	(-10 ℃ ~ +85 ℃)
Maximun Distance	50m(Open field)
Microcontroller:	ATmega328P
Clock frequency:	16 MHz
Working voltage:	5V DC
Digital Pin	x4
Analog Pin	x4
PWM Output	x2
UART interface	x1
I2C interface	x1
Micro USB interface	x1
Power port	x2

Pinout Diagram



- Pin Mapping

Silkscreen	Digital Pin	PWM Channel	Analog Channel	UART	I2C
RX	0			Serial1	
TX	1				
SDA	A4				SDA
SCL	A5				SCL
D2	2				
D3	3	3			
D4	4				
D5	5	5			
A0	A0		A0		
A1	A1		A1		
A2	A2		A2		
A3	A3		A3		

- Power interface description：

Silkscreen	Description
VIN	external power supply<8V
5V	5V positive supply
GND	GND

Power Supply

- USB cable or external power supply: 5V
- External power supply <8V

Bluno Beetle Basic Demo

In this section, you can use the BLUNO Beetle to connect with the Android phone or iPhone .The Step by Step tutorial of the BLUNO Beetle is almost the same with the Bluno.

Wireless Programming via BLE

In this section, we will learn how to Upload the sketch on air via BLE. It is really amazing that you can do uploading process without a line.The Step by Step tutorial of

the Bluno Beetle is almost the same with the Bluno.

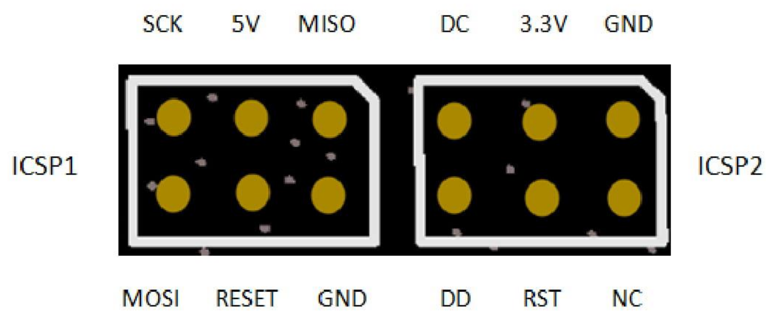
Configure the BLE through AT command

There are three revolutionary BLE firmware versions now, maybe it will be more. For the reason of unified management, we will put all BLE AT command on the BLUNO wiki page Configure the BLE through AT command.

Update BLE Firmware

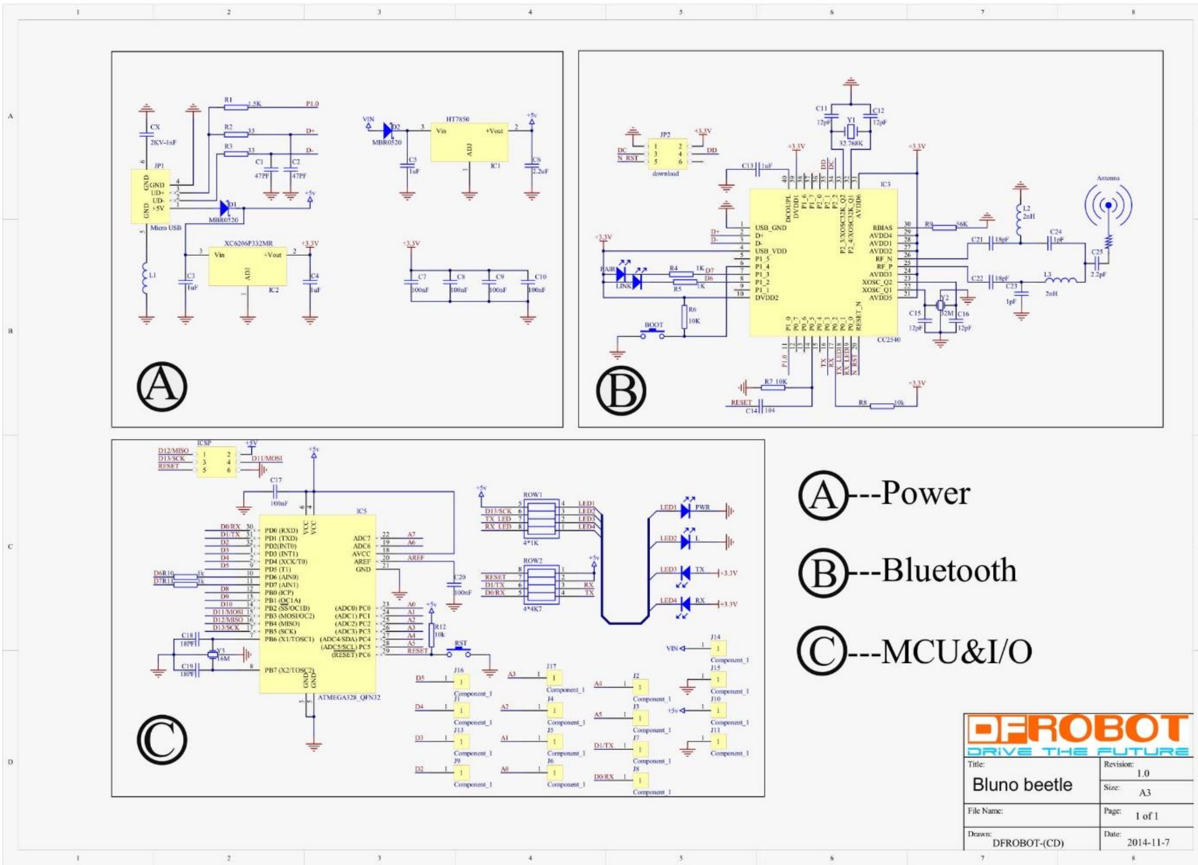
It is better to update the newest firmware for the better experience. As Bluno Beetle is using CC2540 chip, the method of the updating is very close to BLUNO. Please choose "Bluno" firmware. Or it won't work.

ICSP interface



- ICSP1: Atmega 328P
- ICSP2: CC2540

Arduino Board Layout



Battery

RJD

Rechargeable LI-ION Batteries

FEATURES	Highest power rating with long life – Standard parts stocked*
APPLICATIONS	**Wearable electronic & IoT devices – Memory backup circuits**

Nominal Voltage		3.7VDC (4.2VDC to 3.0VDC)
Operating Temperature Range		**-20°C to +60°C**
Storage Temperature Range		-20°C to +60°C (one month) -20°C to +40°C (up to 3 months) -20°C to +25°C (up to 1 year)
Storage Capacity	**Nominal**	See part listing 0.2C rate, 3.0V cut-off
	Minimum	See part listing 0.2C rate, 3.0V cut-off
Charging Voltage		4.2VDC ± 0.03V
Charging current		0.5CA
Charging Time		< 3.0 hours
Charging method		Constant Current/ Constant Voltage (CCCV)
Discharge Current	**Standard**	0.2CA
	Maximum	2CA
Discharge Cut-off Voltage		3.0V
Anode		Graphite
Cathode		Lithium nickel manganese cobalt oxide

Standard Part Listing

IC Part Number	Capacity (mAh)		Charging Current (mA)	Discharge Current (mA)		Maximum Internal Resistance (mΩ)	Weight (G)	Maximum Diameter (mm)	Height (mm)
	Nom.	Min.		STD	MAX				
RJD2032C1	85	80	40	16	160	600	3.4	20	3.5
RJD2048	120	110	60	24	240	700	4.2	20.	5.0
RJD2430C1	110	104	55	22	220	500	4.5	24.5	3.15
RJD2440	150	140	75	30	300	700	5.4	24.5	4.3
RJD2450	200	190	100	40	400	500	6.5	24.5	5.4
RJD3032*	200	190	100	40	400	600	7.2	30	3.4
RJD3048*	300	290	150	60	600	400	9.3	30	4.8
RJD3555*	500	490	250	100	1000	200	14	35.2	5.7

* Additional stocked standard cells with PCM (protection circuit module) & connector
RJD3032HPPV30M
RJD3048HPPV30M
D3555HPPV30M

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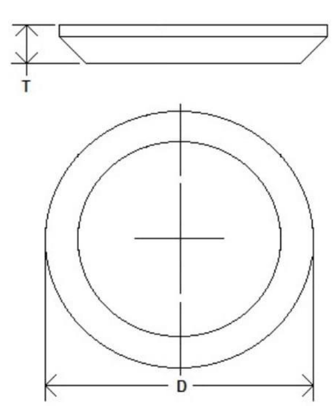
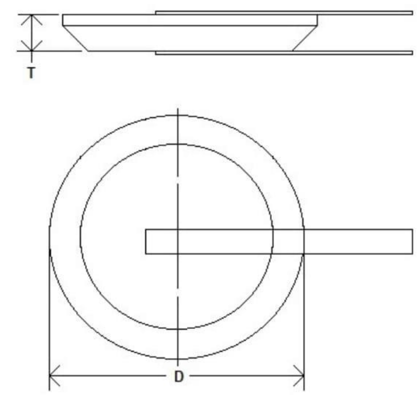
Termination Styles

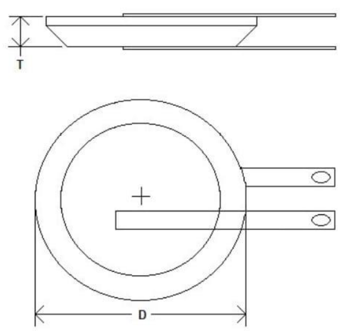
Bare Cell - (Standard)



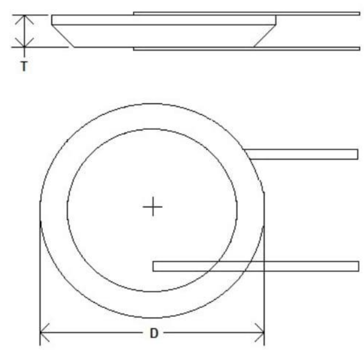
Style - T0



Style - ST1



Style - T1



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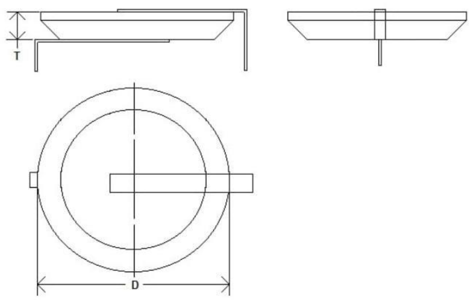
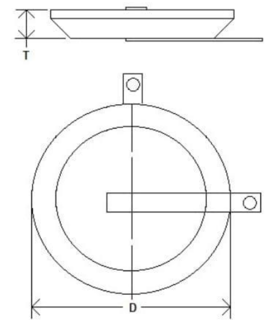
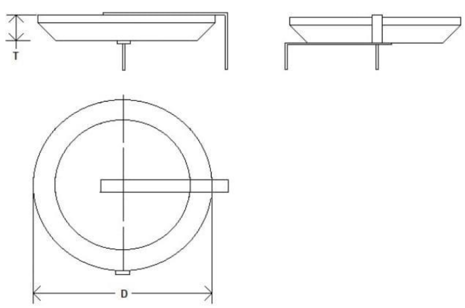
Style - SP8



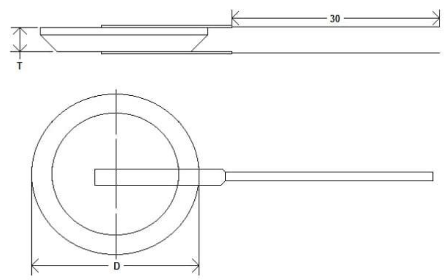
Style - ST9



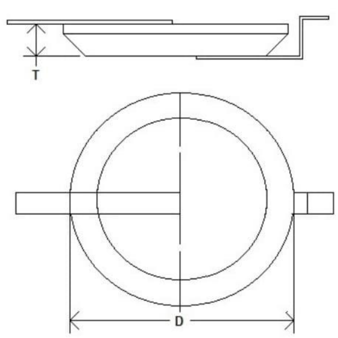
Style - SP9



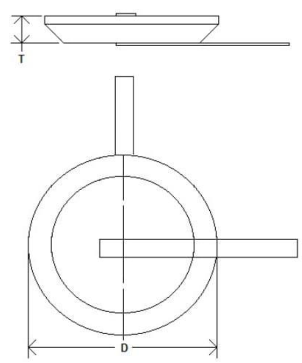
Style - WL



Style - ST8



Style - T9



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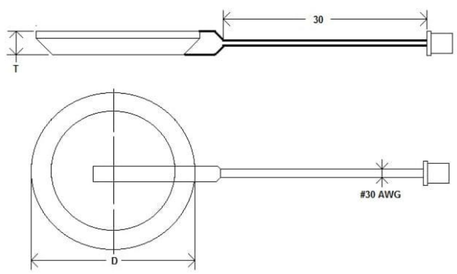
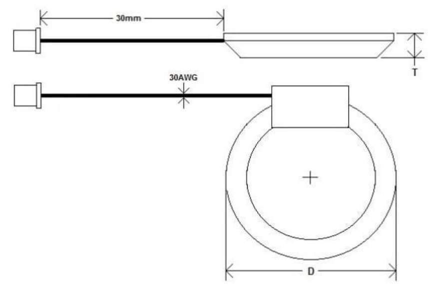
Style – SW	**Style - HP**
	

Contact IC if other termination type is preferred

Part Numbering

RJD 2032C1	AAA	BBB	CCC	D
Section 1	Section 2	Section 3	Section 4	Section 5

Section 1 – IC standard part number (Bare cell)

Section 2 – Optional lead style (see above options)

HP lead style can be supplied with a PCM (Protection Circuit Module).PCM is recommended.
PCM Type: Powerlogics part # RJD9901 (see Protection Circuit Module section for complete specifications).

PCM	Included with Connector	Connector without PCM
	P	N

Section 3 - Wire gauge if other than #30AWG (Standard)

AWG	Code	AWG	Code	AWG	Code	AWG	Code	AWG	Code	AWG	Code
12	A	16	E	20	J	24	N	28	T	32	X
13	B	17	F	21	K	25	P	29	U	33	Y
14	C	18	G	22	L	26	Q	30	V	34	Z
15	D	19	H	23	M	27	R	31	W	35	O

Contact IC if other wire gauge is desired.

Section 4 – Lead Length. Specify lead length in mm.

Section 5 – Connector option (types SW and HP)

IC Code	Connector Manufacturer	Connector Part Number
M	Molex	51021-0200
J	JST	ACHR-02V-S

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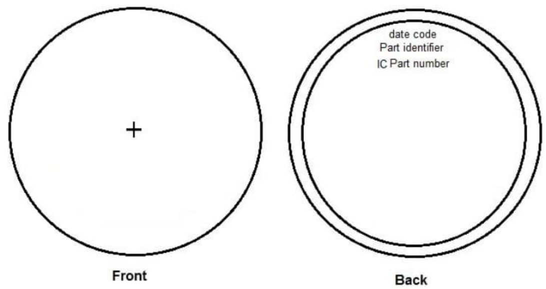
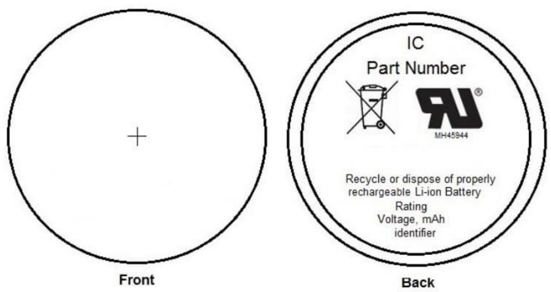
Markings

Standard (bare cells)



Non-Standard Terminations



Cell Dimensions

IC Part Number	Fresh Cell				Cycled cell (after 500 cycles)	
	Shipping (Charged)		Full Charge		Full Charge	
	Maximum Diameter (mm)	Maximum Height (mm)	Maximum Diameter (mm)	Maximum Height (mm)	Maximum Diameter (mm)	Maximum Height (mm)
RJD2032C1	20	3.5	20	3.6	20	3.7
RJD2048	20	5	20	5.2	20	5.3
RJD2430C1	24.5	3.15	24.5	3.25	24.5	3.3
RJD2440	24.5	4.3	24.5	4.4	24.5	4.5
RJD2450	24.5	5.4	24.5	5.5	24.5	5.6
RJD3032	30	3.4	30	3.5	30	3.6
RJD3048	30	4.8	30	4.9	30	5.2
RJD3555	35.2	5.7	35.2	5.8	35.2	5.9

Protection Circuit Module

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RJD
Rechargeable LI-ION Batteries

(RJD 9901)
(Optional for HP lead style)

Specification	RJD 9901	Specification	RJD 9901
Main IC	SP31ABE	Over-Discharge Detection Voltage	2.242V~2.358V
PCB	SALTEK, APEX	Over-Discharge Detection Delay Time	14.0mSec~26.0mSec
FET	X	Over-Discharge Current Detection	1.2 ~ 4.0A
PTC	MicroSMD175F-2 (TE)	Overcharge Current Detection	0.9A ~ 4.4A
L terminal	X	Over-Discharge Current Protection Delay Time	8.0mSec ~ 16.0mSec
Capacitor	2Point	Short Detection Delay Time	100μs ~ 500μs
Resistor	2Point	PCM Impedance	< 220mΩ
Dimension(L*W*T)	16.9*3.9*2.0mm	Operation Current Consumption	Max 6.0μA(TYP 4.0μA)
Wake-up Function	NO	Power-Down Mode Current Consumption	Max 0.1μA
Overcharge Detection Voltage	4.275V ± 25mV	Distance Between B+, B- Tab	13.93mm
Overcharge Detection Delay Time	700.0mSec ~ 1300mSec		

Battery Operation Instruction:

Charging

a. Charge the battery in a temperature range of 0℃ to + 45℃.
b. Charge the battery at a constant current of 0.5C until 4.20VDC±0.03VDC per cell is attained. Charge rates greater than 1C are NOT recommended. (C: Rated Capacity of Battery)
c. Maintain charge voltage at 4.20VDC per cell for 3.0 hours (recommended for maximum capacity).
** Use a constant current, constant voltage (CC/CV) lithium-ion (Li+) battery charge controller.*
** Do not continue to charge battery over specified time.*

Discharging

a. Recommended cut-off voltage to 3.0VDC. Recommended maximum discharge rate is 2C at constant current.
b. For maximum performance, discharge the battery in a temperature range of –20℃ to + 45℃.

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Protection Circuit

Protection circuit can be provided upon request. However, protection circuit may be omitted for most applications without damaging performance and safety. Please consult our engineering staff for technical advice.

Storage Recommendations

a. Storage Temperature and Humidity
Storage the battery at temperature range of –20 ~ +45℃, low humidity and no corrosive gas atmosphere
No condensation on the battery.

b. Long Period Storage

In case of long period storage (more than 3 months), storage the battery at temperature range of –20 ~ +25℃, low humidity, no corrosive gas atmosphere.

Standard Test Conditions

Unless otherwise specified, all tests are conducted at 25°C ± 3°C and relative humidity of 65% ± 20%.

Electrical Characteristics

Standard Charge and Discharge Conditions

A. The "Standard Charge" means charging the Cell with initial charge current (0.5C) and with a constant voltage of 4.2VDC (± 0.03VDC) and the specified cut-off current (see table 1) at 25°C for 3 hours.
B. Standard discharge means discharging cell with constant discharge current (0.2C)(see table 1) and with 3.0VDC cut-off voltage at 25°C
C. Initial Discharge Capacity
D. The initial capacity measured under the standard test conditions
E. Initial Discharge Capacity: See standard part listing
F. Initial Internal Impedance: see standard part listing
G. Internal resistance measured at 1 kHz after Standard Charge.
H. Initial internal impedance: See standard part listing
I. Cycle Life (500 cycles): See table 1
J. Temperature dependence of discharge capacity. See discharge table.
K. Relative capacity at each temperature measured with a constant discharge current (0.2C) with 3.0VDC cutoff after the standard charge shown below

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Discharge Table

IC Part Number	Discharge Temperature			
	-20°C	-10°C	25°C	60°C
RJD2032C1	>60 %	>80%	100 %	>95%
RJD2048	>60 %	>80%	100 %	>80%
RJD2430C1	>60 %	>80%	100 %	>95%
RJD2440	>60 %	>80%	100 %	>80%
RJD2450	>60 %	>80%	100 %	>80%
RJD3032	>60 %	>80%	100 %	>80%
RJD3048	>60 %	>80%	100 %	>80%
RJD3555	>60 %	>80%	100 %	>80%

Table 1

IC Part Number	Charging Current (0.5C) (mA)	Constant Discharge Current (0.2C) (mA)	Charging end condition (at CV mode) (mA)	Capacity after 500 cycles (mAh)
RJD2032C1	40	16	2.4	56
RJD2048	60	24	3.6	77
RJD2430C1	55	22	3.3	72.8
RJD2440	75	30	4.5	98
RJD2450	100	40	6	133
RJD3032	100	40	6	133
RJD3048	150	60	9	203
RJD3555	250	100	15	350

Discharge Characteristics on Current Load (C-Rate)

Relative capacity at each load, measured with constant discharge current 0.2C, 0.5C, 1.0C, 2C with 3.0VDC cut-off after Standard Charge shown below.

Charge Current	Discharge Current			
Standard Charge	0.2 CA	0.5 CA	1 CA	2.0 CA
	100 %	> 95 %	> 90 %	> 50%

Shipment

The Cell shall be shipped with 30% of the nominal voltage. (Nominal Cell voltage range: 3.7 ~ 3.8 V). 30% SOC is only for air transport.

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Storage Characteristics

After storage at the conditions listed below, the battery is measured at the standard charge and discharge condition stated above.

Storage Condition	Charge State	Capacity Retention	Capacity Recovery
20 days at 60°C	Shipping charge	-	> 85%
20 days at 60°C	Full charge	> 70%	> 85%
60 days at 60°C	Full charge	> 40%	> 60%
30 days at 60°C, 90%RH	Full charge	> 40%	> 70%

Safety Test

Test	Test Method	Criteria
High Temperature	Storing a cell at 90°C for 4 hours after being charged to 4.2VDC	No leakage
High Temperature and High Humidity	Storing a cell at 60°C for 1 week after being charged to 4.2VDC	No leakage
Thermal Shock Test	Store a fully charged cell (4.2VDC) at 60°C for 2 hours then at -20°C for 2 hours. 10 cycles with a maximum transition time of 5 minutes.	No leakage
Hot Box Test	A cell is to be heated in a gravity convection oven. The temperature of the oven is to be raised 5°C+/- 2°C per minute to a temperature of 130°C and remain at that temperature for 10 minutes	No explosion, No fire
Overcharge Test	Charge the test samples with constant current (3C) and voltage 4.5VDC. Test samples remain on test for 2.5 hours	No explosion, No fire
Impact Test	A test cell is to be placed on a flat surface. The bar of 9.1 kg weight and 15.8 mm diameter is dropped from a height of 610 mm onto the cell.	No explosion, No fire
Short-Circuit Test	A cell is to be short-circuited by connecting the positive and negative terminals of the battery with copper wire having a maximum resistance load of 100mΩ.	No fire or explosion, until battery is completely discharged
Nail Test	A stainless steel nail having a diameter of 4.0 mm is punched through the cell until the nail has passed through the opposite side of the cell.	No explosion, No fire
Applying Pressure	Placing pressure on entire surface of a fully charged cell with 7kg for 72 hours	No leakage, No weight decrease

Precautions and Safety Instructions

Lithium-Ion rechargeable batteries subjected to abusive conditions can become damaged and/or cause personal injury. Please read and observe the standard battery precautions below before using.

Note 1. The customer is required to contact Illinois Capacitor in advance, if and when the customer needs other applications or operating conditions other than those described in this document.

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Note 2. Illinois Capacitor will take no responsibility for any accident where the cell is used under other conditions than those described in this document.

Precautions and Safety Instructions:

a. Do not expose the battery to extreme heat or flame.
b. Do not short circuit, over-charge or over-discharge the battery.
c. Do not subject the battery to strong mechanical shocks.
d. Do not immerse the battery in water or sea water, or get it wet.
e. Do not reverse the polarity of the battery for any reason.
f. Do not disassemble or modify the battery.
g. Do not remove charge/discharge protection circuitry.
h. Do not handle or store with metallic objects like necklaces, coins or hairpins, etc.
i. Do not use the battery with possible damage or deformation.
j. Do not connect battery to the plug socket or car-cigarette-plug.
k. Do not make the direct soldering onto a battery. Spot weld lead plate onto a battery. Soldering iron temperature should be limited to 350°C with a soldering time of <5 seconds.
l. Do not place batteries in a solder bath.
m. Do not touch a leaked battery directly.
n. D o not use for other equipment.
o. Do not use Lithium-ion battery in mixture.
p. Do not use or leave the battery under direct sunlight (or in heated car by sunshine).
q. Keep battery away from children.
r. Do use the specified charger and observe charging requirement
s. Do not drive a nail into battery or strike battery with a battery or insert a screw into the battery
t. Do not smash or throw battery.
u. Recharge the battery every 6 months.
v. Follow recommended charging conditions when charging battery.

Warnings:

a. Do not swallow. Keep out of reach of infants and children. If swallowed call physician immediately.
b. Do not put battery in microwave or pressure cooker.
c. Do not use battery together with a primary battery, such as dry battery types or batteries with different capacities.
d. Do not replace battery with a different type or model.
e. Discontinue use of battery if an unusual odor, discoloration, deformation, internal heating or other unusual characteristic changes are detected.
f. Do not have any leaked electrolyte come in contact with eyes. If contact occurs flush eyes immediately with water and consult a doctor.
g. If charging does not stop after expected charging time, stop charging battery.

Requirement for Safety Assurance

For the sake of safety assurance, please discuss the equipment design, its system and protection circuit of Lithium-ion battery with Illinois capacitor in advance.

And consult about the high rate current, rapid charge and special application in the same way.

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Microphone (Prototype)

FAIRCHILD SEMICONDUCTOR®

www.fairchildsemi.com

LMV321, LMV358, LMV324

General Purpose, Low Voltage, Rail-to-Rail Output Amplifiers

Features at +2.7V

- 80µA supply current per channel
- 1.2MHz gain bandwidth product
- Output voltage range: 0.01V to 2.69V
- Input voltage range: -0.25V to +1.5V
- 1.5V/µs slew rate
- LMV321 directly replaces other industry standard LMV321 amplifiers; available in SC70-5 and SOT23-5 packages
- LMV358 directly replaces other industry standard LMV358 amplifiers; available in MSOP-8 and SOIC-8 packages
- LMV324 directly replaces other industry standard LMV324 amplifiers; available in SOIC-14 package
- Fully specified at +2.7V and +5V supplies
- Operating temperature range: -40°C to +125°C

Applications

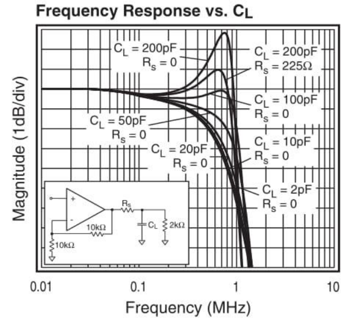
- Low cost general purpose applications
- Cellular phones
- Personal data assistants
- A/D buffer
- DSP interface
- Smart card readers
- Portable test instruments
- Keyless entry
- Infrared receivers for remote controls
- Telephone systems
- Audio applications
- Digital still cameras
- Hard disk drives
- MP3 players

Description

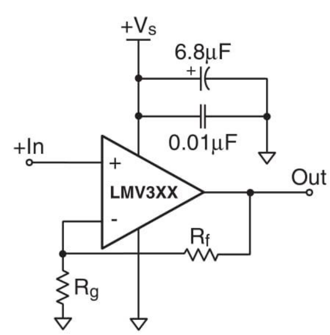
The LMV321 (single), LMV358 (dual), and LMV324 (quad) are a low cost, voltage feedback amplifiers that consume only 80µA of supply current per amplifier. The LMV3XX family is designed to operate from 2.7V (±1.35V) to 5.5V (±2.75V) supplies. The common mode voltage range extends below the negative rail and the output provides rail-to-rail performance.

The LMV3XX family is designed on a CMOS process and provides 1.2MHz of bandwidth and 1.5V/µs of slew rate at a low supply voltage of 2.7V. The combination of low power, rail-to-rail performance, low voltage operation, and tiny package options make the LMV3XX family well suited for use in personal electronics equipment such as cellular handsets, pagers, PDAs, and other battery powered applications.

Frequency Response vs. C_L



Typical Application

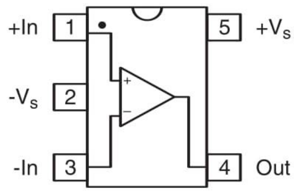


REV. 1D. Feb. 2012

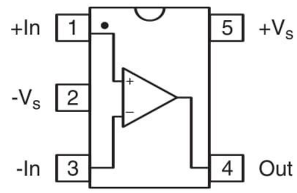
Pin Assignments

LMV321

SOT23-5

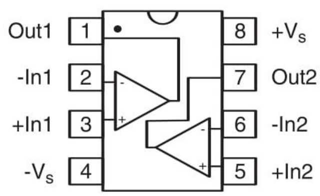


SC70-5

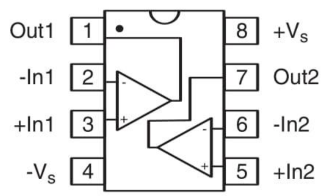


LMV358

SOIC-8

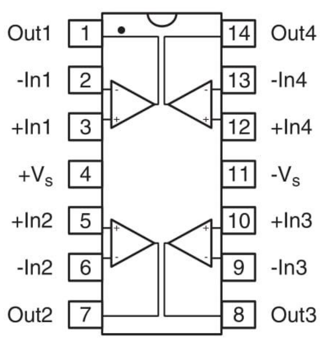


MSOP-8

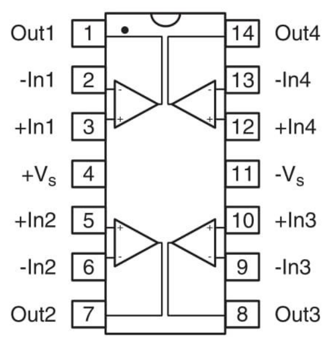


LMV324

TSSOP-14



SOIC-14



Absolute Maximum Ratings

Parameter	Min.	Max.	Unit
Supply Voltages	0	+6	V
Maximum Junction Temperature	–	+175	°C
Storage Temperature Range	-65	+150	°C
Lead Temperature, 10 seconds	–	+260	°C
Input Voltage Range	$-V_S$ -0.5	$+V_S$ +0.5	V

Recommended Operating Conditions

Parameter	Min.	Max.	Unit
Operating Temperature Range	-40	+125	°C
Power Supply Operating Range	2.5	5.5	V

Electrical Specifications

(T_C = 25°C, V_S = +2.7V, G = 2, R_L = 10kΩ to $V_S/2$, R_f = 10kΩ, $V_{o\ (DC)}$ = $V_{CC}/2$; unless otherwise noted)

Parameter	Conditions	Min.	Typ.	Max.	Unit
AC Performance					
Gain Bandwidth Product	C_L = 50pF, R_L = 2kΩ to $V_S/2$		1.2		MHz
Phase Margin			52		deg
Gain Margin			17		dB
Slew Rate	V_o = 1V_{pp}		1.5		V/µs
Input Voltage Noise	>50kHz		36		nV/√Hz
Crosstalk: LMV358	100kHz		91		dB
LMV324	100kHz		80		dB
DC Performance					
Input Offset Voltage[1]			1.7	7	mV
Average Drift			8		µV/°C
Input Bias Current[2]			<1		nA
Input Offset Current[2]			<1		nA
Power Supply Rejection Ratio[1]	DC	50	65		dB
Supply Current (Per Channel)[1]			80	120	µA
Input Characteristics					
Input Common Mode Voltage Range[1]	LO	0	-0.25		V
	HI		1.5	1.3	V
Common Mode Rejection Ratio[1]		50	70		dB
Output Characteristics					
Output Voltage Swing	R_L = 10kΩ to $V_S/2$; LO[1]	0.1	0.01		V
	R_L = 10kΩ to $V_S/2$; HI[1]		2.69	2.6	V

Min/max ratings are based on product characterization and simulation. Individual parameters are tested as noted. Outgoing quality levels are determined from tested parameters.

Notes:
1. Guaranteed by testing or statistical analysis at +25°C.
2. +IN and -IN are gates to CMOS transistors with typical input bias current of <1nA. CMOS leakage is too small to practically measure.

Electrical Specifications

(T_C = 25°C, V_S = +5V, G = 2, R_L = 10kΩ to V_S/2, R_f = 10kΩ, $V_{O\ (DC)}$ = V_{CC}/2; unless otherwise noted)

Parameter	Conditions	Min.	Typ.	Max.	Unit
AC Performance					
Gain Bandwidth Product	C_L = 50pF, R_L = 2kΩ to V_S/2		1.4		MHz
Phase Margin			73		deg
Gain Margin			12		dB
Slew Rate			1.5		V/µs
Input Voltage Noise	>50kHz		33		nV/√Hz
Crosstalk: LMV358	100kHz		91		dB
LMV324	100kHz		80		dB
DC Performance					
Input Offset Voltage[1]			1	7	mV
Average Drift			6		µV/°C
Input Bias Current[2]			<1		nA
Input Offset Current[2]			<1		nA
Power Supply Rejection Ratio[1]	DC	50	65		dB
Open Loop Gain[1]		50	70		dB
Supply Current (Per Channel)[1]			100	150	µA
Input Characteristics					
Input Common Mode Voltage Range[1]	LO	0	-0.4		V
	HI		3.8	3.6	V
Common Mode Rejection Ratio[1]		50	75		dB
Output Characteristics					
Output Voltage Swing	R_L = 2kΩ to V_S/2; LO/HI		0.036 to 4.95		V
	R_L = 10kΩ to V_S/2; LO[1]	0.1	0.013		V
	R_L = 10kΩ to V_S/2; HI[1]		4.98	4.9	V
Short Circuit Output Current[1]	sourcing; V_O = 0V	5	+34		mA
	sinking; V_O = 5V	10	-23		mA

Min/max ratings are based on product characterization and simulation. Individual parameters are tested as noted. Outgoing quality levels are determined from tested parameters.

Notes:
1. Guaranteed by testing or statistical analysis at +25°C.
2. +IN and -IN are gates to CMOS transistors with typical input bias current of <1nA. CMOS leakage is too small to practically measure.

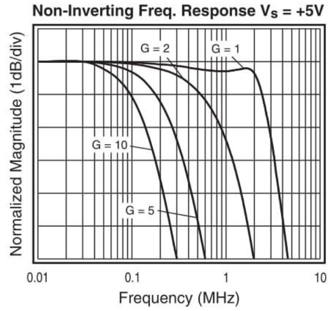
Package Thermal Resistance

Package	θ_{JA}
5 lead SC70	331.4°C/W
5 lead SOT23	256°C/W
8 lead SOIC	152°C/W
8 lead MSOP	206°C/W
14 lead SOIC	88°C/W

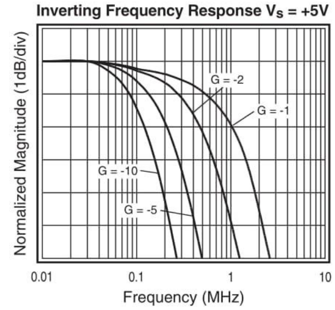
Typical Operating Characteristics

(T_C = 25°C, V_S = +5V, G = 2, R_L = 10kΩ to V_S/2, R_f = 10kΩ, $V_{O\ (DC)}$ = V_{CC}/2; unless otherwise noted)

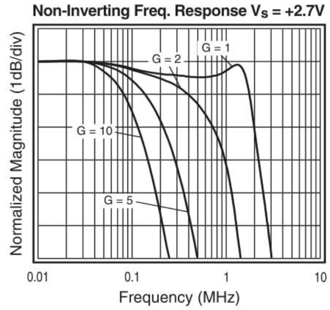
Non-Inverting Freq. Response V_S = +5V



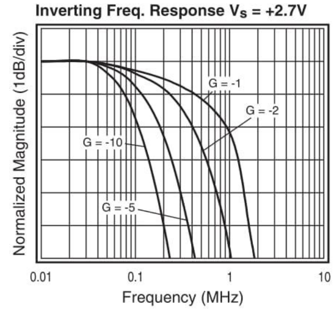
Inverting Frequency Response V_S = +5V



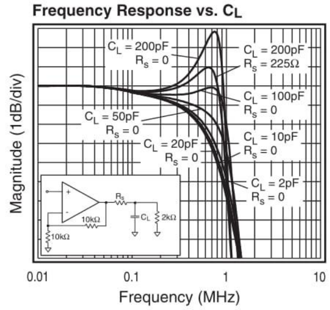
Non-Inverting Freq. Response V_S = +2.7V



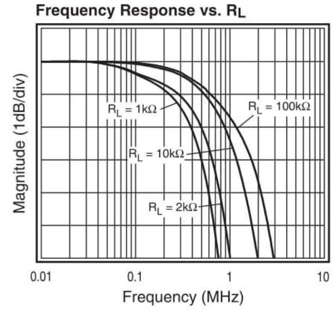
Inverting Freq. Response V_S = +2.7V



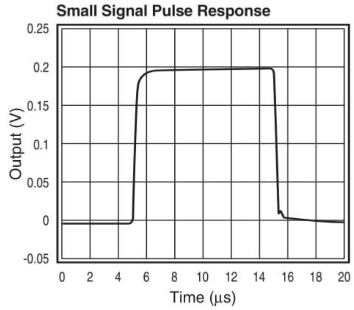
Frequency Response vs. C_L



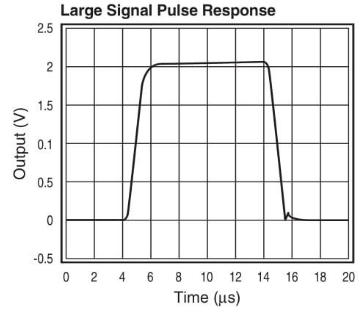
Frequency Response vs. R_L



Small Signal Pulse Response

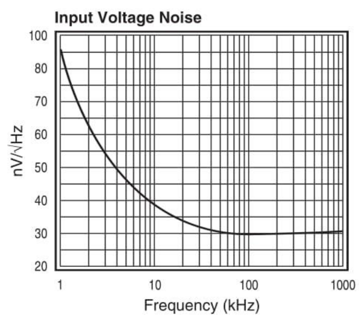


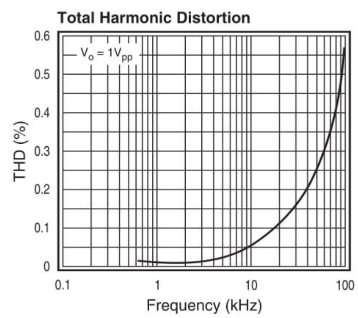
Large Signal Pulse Response

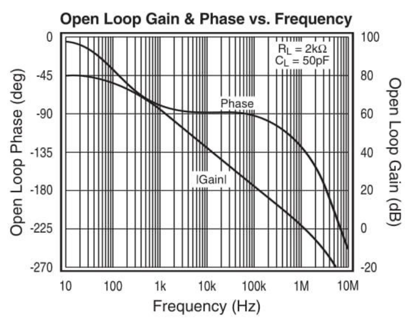


Typical Operating Characteristics

(T_C = 25°C, V_S = +5V, G = 2, R_L = 10kΩ to V_S/2, R_f = 10kΩ, $V_{O\ (DC)}$ = V_{CC}/2; unless otherwise noted)





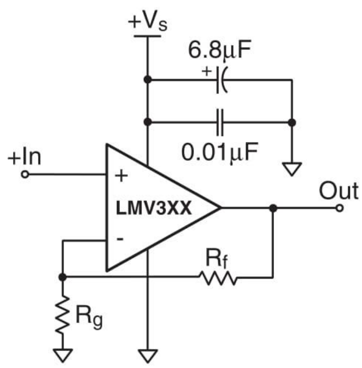


Application Information

General Description

The LMV3XX family are dual supply, general purpose, voltage-feedback amplifiers that are pin-for-pin compatible and drop in replacements with other industry standard LMV321, LMV358, and LMV324 amplifiers. The LMV3XX family is fabricated on a CMOS process, features a rail-to-rail output, and is unity gain stable.

The typical non-inverting circuit schematic is shown in Figure



1.

Figure 1: Typical Non-inverting configuration

Power Dissipation

The maximum internal power dissipation allowed is directly related to the maximum junction temperature. If the maximum junction temperature exceeds 150°C, some performance degradation will occur. If the maximum junction temperature exceeds 175°C for an extended time, device failure may occur.

Driving Capacitive Loads

The ***Frequency Response vs C_L*** plot on page 4, illustrates the response of the LMV3XX family. A small series resistance (R_s) at the output of the amplifier, illustrated in Figure 2, will improve stability and settling performance. R_s values in the ***Frequency Response vs C_L*** plot were chosen to achieve maximum bandwidth with less than 1dB of peaking. For maximum flatness, use a larger R_s. As the plot indicates, the LMV3XX family can easily drive a 200pF capacitive load without a series resistance. For comparison, the plot also shows the LMV321 driving a 200pF load with a 225Ω series resistance.

Driving a capacitive load introduces phase-lag into the output signal, which reduces phase margin in the amplifier. The unity gain follower is the most sensitive configuration. In a unity gain follower configuration, the LMV3XX family requires a 450Ω series resistor to drive a 200pF load. The response is illustrated in Figure 3.

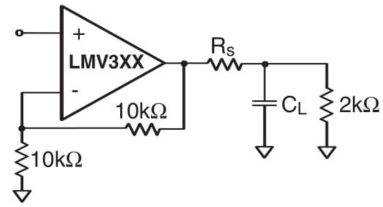


Figure 2: Typical Topology for driving a capacitive load

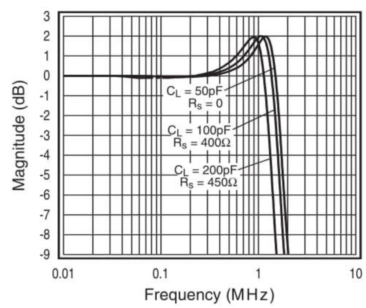


Figure 3: Frequency Response vs C_L for unity gain configuration

Layout Considerations

General layout and supply bypassing play major roles in high frequency performance. Fairchild has evaluation boards to use as a guide for high frequency layout and as aid in device testing and characterization. Follow the steps below as a basis for high frequency layout:

- Include 6.8μF and 0.01μF ceramic capacitors
- Place the 6.8μF capacitor within 0.75 inches of the power pin
- Place the 0.01μF capacitor within 0.1 inches of the power pin
- Remove the ground plane under and around the part, especially near the input and output pins to reduce parasitic capacitance
- Minimize all trace lengths to reduce series inductances

Refer to the evaluation board layouts shown in Figure 5 on page 8 for more information.

Evaluation Board Information

The following evaluation boards are available to aid in the testing and layout of this device:

Eval Bd	Description	Products
KEB013	Single Channel, Dual Supply, SOT23-5 for buffer-style pinout	LMV321AS5X
KEB014	Single Channel, Dual Supply, SC70-5 for buffer-style pinout	LMV321AP5X
KEB006	Dual Channel, Dual Supply, 8 lead SOIC	LMV358AM8X
KEB010	Dual Channel, Dual Supply, 8 lead MSOP	LMV358AMU8X
KEB018	Quad Channel, Dual Supply, 14 lead SOIC	LMV324AM14X

Evaluation board schematics and layouts are shown in Figures 4 and 5.

Evaluation Board Schematic Diagrams

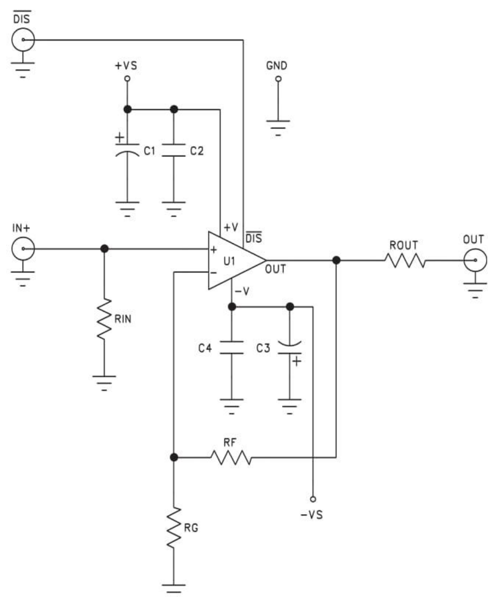


Figure 4a: LMV321 KEB013 schematic

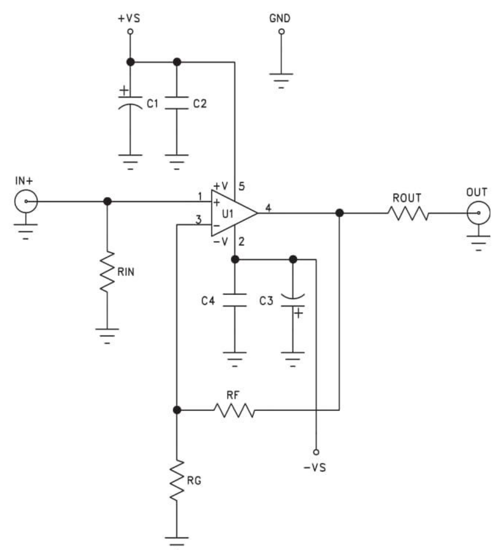


Figure 4b: LMV321 KEB014 schematic

Evaluation Board Schematic Diagrams (Continued)

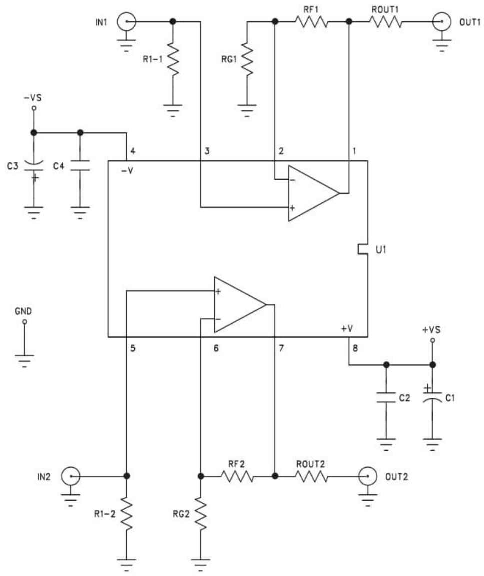


Figure 4c: LMV358 KEB006/KEB010 schematic

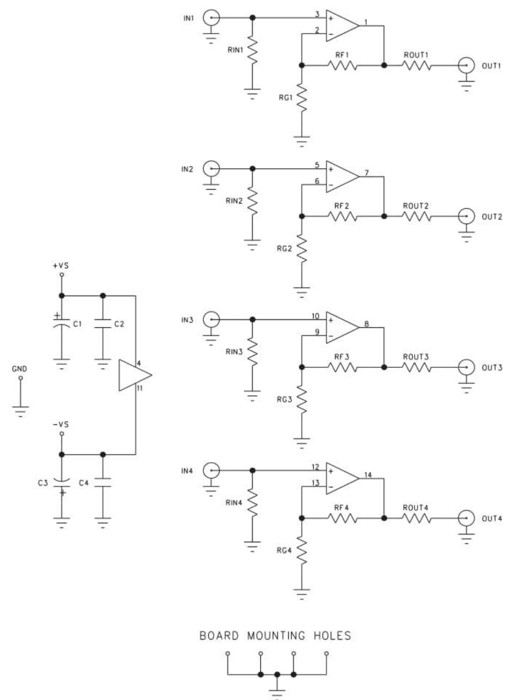


Figure 4d: LMV324 KEB012/KEB018 schematic

LMV321 Evaluation Board Layout

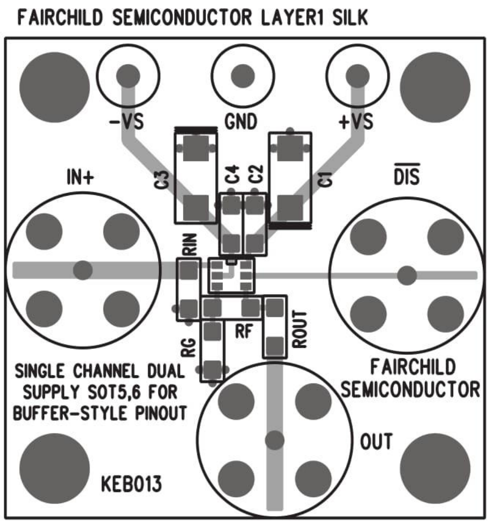


Figure 5a: KEB013 (top side)

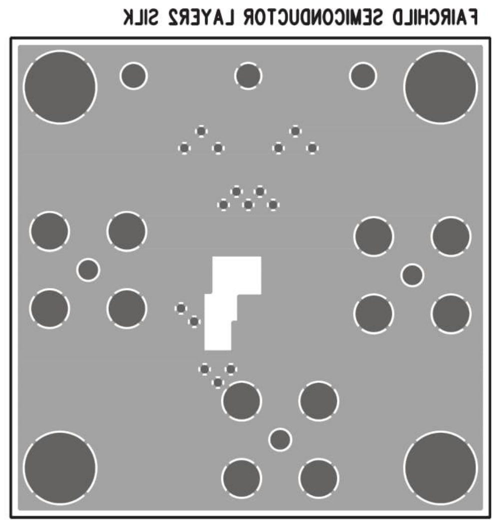


Figure 5b: KEB013 (bottom side)

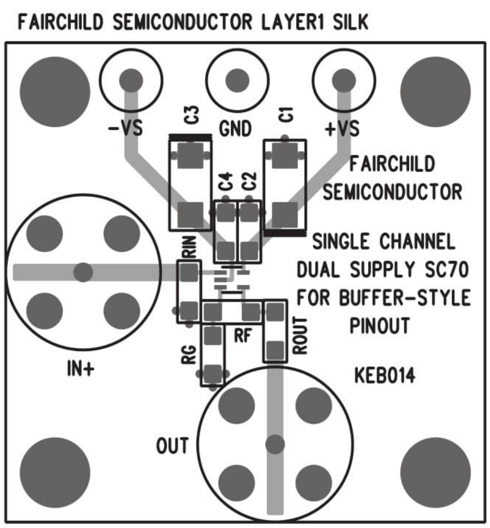


Figure 5c: KEB014 (top side)

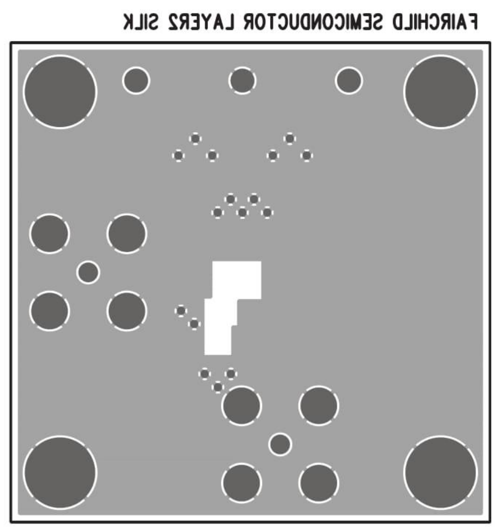


Figure 5d: KEB014 (bottom side)

LMV358 Evaluation Board Layout

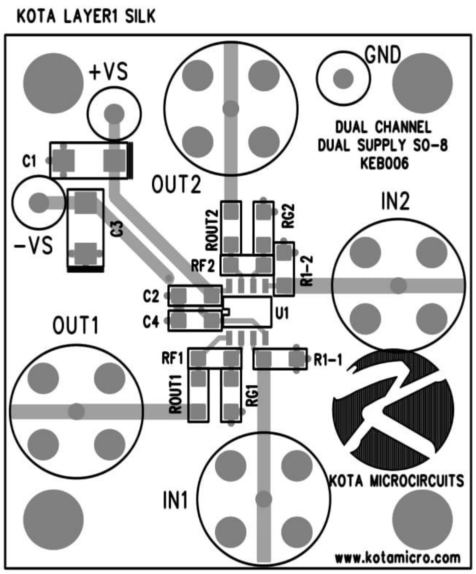


Figure 5e: KEB006 (top side)

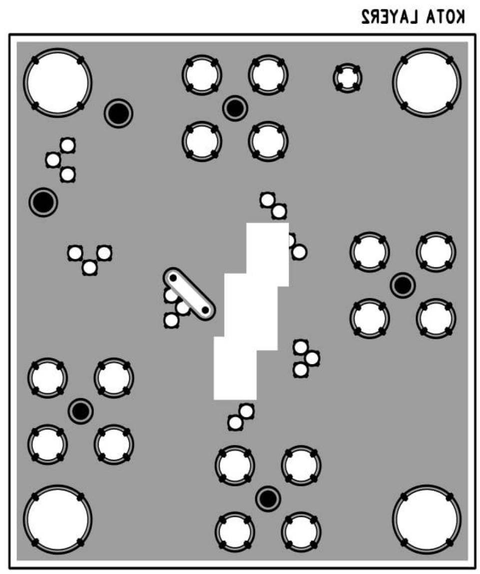


Figure 5f: KEB006 (bottom side)

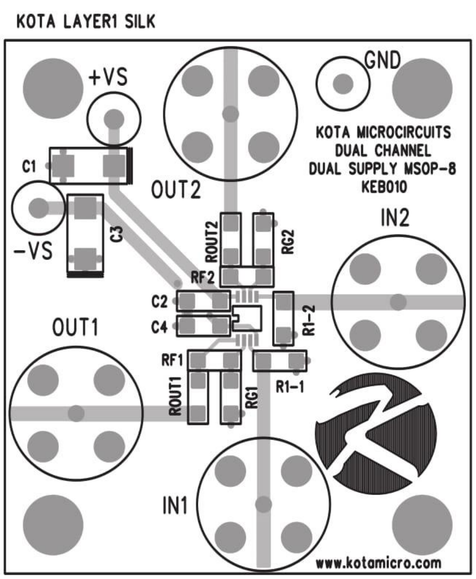


Figure 5g: KEB010 (top side)

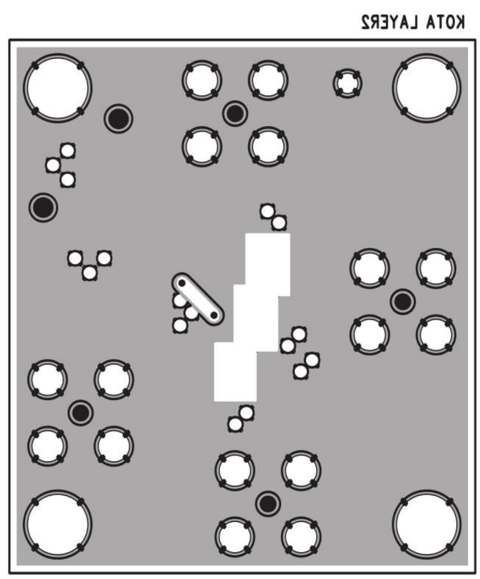


Figure 5h: KEB010 (bottom side)

LMV324 Evaluation Board Layout

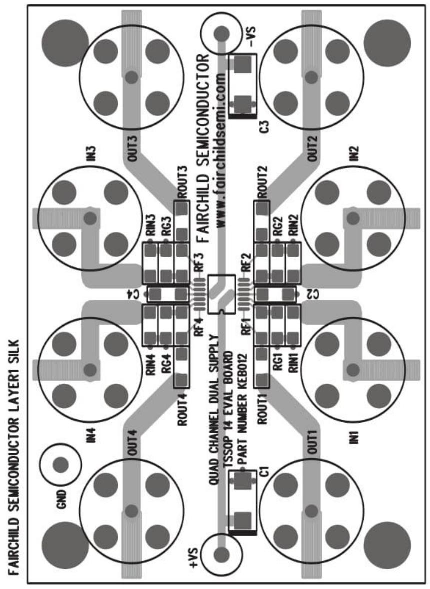


Figure 5i: KEB012 (top side)

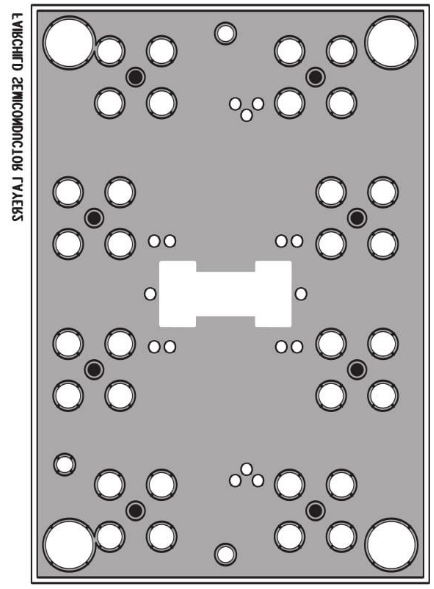


Figure 5j: KEB012 (bottom side)

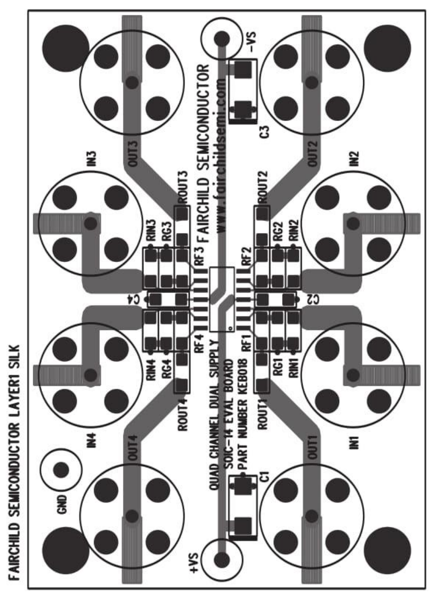


Figure 5k: KEB018 (top side)

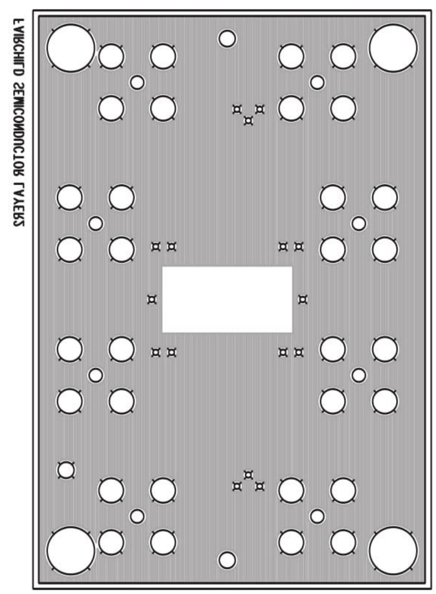
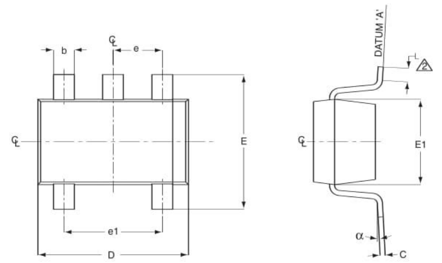


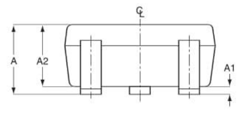
Figure 5l: KEB018 (bottom side)

LMV321 Package Dimensions

SOT23-5

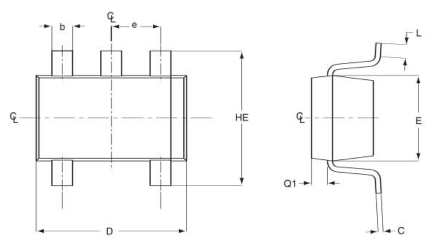


SYMBOL	MIN	MAX
A	0.90	1.45
A1	0.00	0.15
A2	0.90	1.30
b	0.25	0.50
C	0.09	0.20
D	2.80	3.10
E	2.60	3.00
E1	1.50	1.75
L	0.35	0.55
e	0.95 ref	
e1	1.90 ref	
α	0°	10°

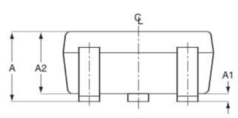


NOTE:
1. All dimensions are in millimeters.
2. Foot length measured reference to flat foot surface parallel to DATUM 'A' and lead surface.
3. Package outline exclusive of mold flash & metal burr.
4. Package outline inclusive of solder plating.
5. Comply to EIAJ SC74A.
6. Package ST 0003 REV A supercedes SOT-D-2005 REV C.

SC70



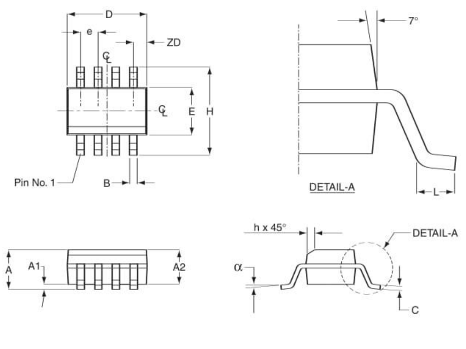
SYMBOL	MIN	MAX
e	0.65 BSC	
D	1.80	2.20
b	0.15	0.30
E	1.15	1.35
HE	1.80	2.40
Q1	0.10	0.40
A2	0.80	1.00
A1	0.00	0.10
A	0.80	1.10
c	0.10	0.18
L	1.10	0.30



NOTE:
1. All dimensions are in millimeters.
2. Dimensions are inclusive of plating.
3. Dimensions are exclusive of mold flashing and metal burr.
4. All speccifications comply to EIAJ SC70.

LMV358 Package Dimensions

SOIC

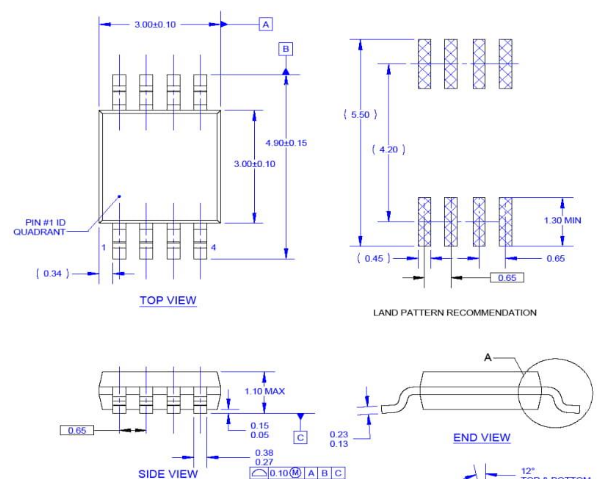


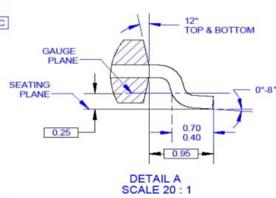
SOIC-8		
SYMBOL	MIN	MAX
A1	0.10	0.25
B	0.36	0.46
C	0.19	0.25
D	4.80	4.98
E	3.81	3.99
e	1.27 BSC	
H	5.80	6.20
h	0.25	0.50
L	0.41	1.27
A	1.52	1.72
	0°	8°
ZD	0.53 ref	
A2	1.37	1.57

NOTE:

1. All dimensions are in millimeters.
2. Lead coplanarity should be 0 to 0.10mm (.004") max.
3. Package surface finishing:
   (2.1) Top: matte (charmilles #18~30).
   (2.2) All sides: matte (charmilles #18~30).
   (2.3) Bottom: smooth or matte (charmilles #18~30).
4. All dimensions excluding mold flashes and end flash from the package body shall not exceed o.152mm (.006) per side(d).

MSOP



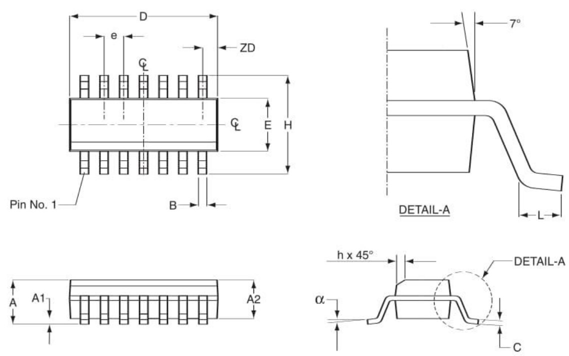


NOTES: UNLESS OTHERWISE SPECIFIED

A. THIS PACKAGE CONFORMS TO JEDEC MO-187.
B. ALL DIMENSIONS ARE IN MILLIMETERS.
C. DIMENSIONS ARE EXCLUSIVE OF BURRS, MOLD FLASH AND TIE BAR EXTRUSIONS.
D. DIMENSIONS AND TOLERANCES AS PER ASME Y14.5-1994.
E. LAND PATTERN AS PER IPC7351#TSOP65P490X110-8BL
F. FILE NAME: MKT-MUA08AREV4

LMV324 Package Dimensions

SOIC



SOIC-14		
SYMBOL	**MIN**	**MAX**
A1	.0040	.0098
B	.014	.018
C	.0075	.0098
D	.337	.344
E	.150	.157
e	.050 BSC	
H	.2284	.2440
h	.0099	.0196
L	.016	.050
A	.060	.068
	0°	8°
ZD	0.020 ref	
A2	.054	.062

NOTE:

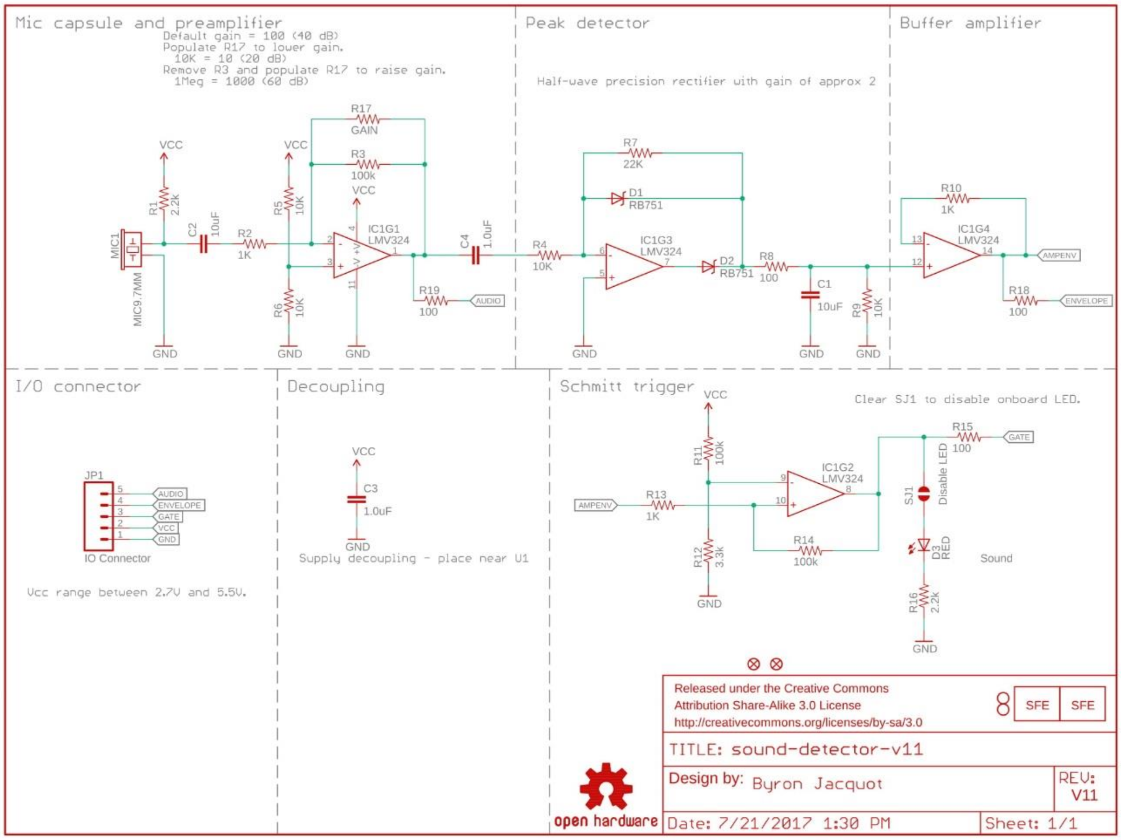
1. All dimensions are in inches.
2. Lead coplanarity should be 0 to 0.10mm (.004") max.
3. Package surface finishing:
   (2.1) Top: matte (charmilles #18~30).
   (2.2) All sides: matte (charmilles #18~30).
   (2.3) Bottom: smooth or matte (charmilles #18~30).
4. All dimensions excluding mold flashes and end flash from the package body shall not exceed o.152mm (.006) per side (d).

Ordering Information

Model	Part Number	Package	Container	Pack Qty
LMV321	LMV321AP5X	SC70-5	Reel	3000
LMV321	LMV321AS5X	SOT23-5	Reel	3000
LMV358	LMV358AM8X	SOIC-8 (Narrow)	Reel	2500
LMV358	LMV358AMU8X	MSOP-8	Reel	3000
LMV324	LMV324AM14X	SOIC-14	Reel	2500

Temperature range for all parts: -40°C to +125°C.

Microphone Circuit (Prototype)



Microphone (Final/ PCB Design)

knowles

SPW0442HR5H-1 Rev E
Datasheet

SPW0442HR5H-1

Precision Top Port SiSonic™ Microphone

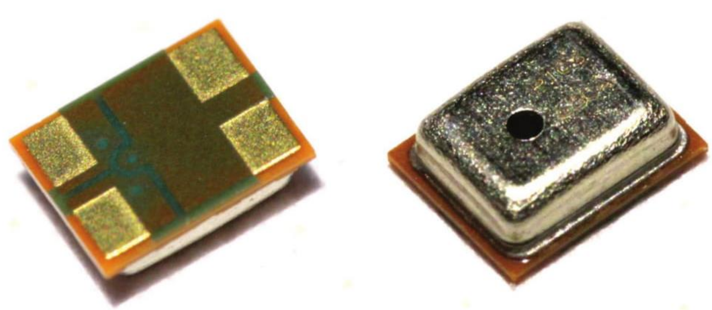
The SPW0442HR5H-1 is a miniature, high-performance, low power, top port silicon microphone. Using Knowles' proven high-performance SiSonic™ MEMS technology, the SPW0442HR5H-1 consists of an acoustic sensor, a low noise input buffer, and an output amplifier. These devices are suitable for applications such as cellphones, smart phones, laptop computers, sensors, digital still cameras, portable music recorders, and other portable electronic devices where excellent wideband audio performance and RF immunity are required.

Product Features

- Matched Sensitivity
- Small Package
- Low Current
- MaxRF Protection
- Top Ported Design
- Ultra-Stable Performance
- Standard SMD Reflow
- Omnidirectional

Typical Applications

- Portable electronics
- Cellphones
- Laptop Computers
- Tablets
- Digital Still Cameras
- Portable Music Recorders



knowles.com Datasheet SPW0442HR5H-1 Rev E 1

Absolute Maximum Ratings

Table 1: Absolute Maximum Ratings

Parameter	Absolute Maximum Rating	Units
Vdd to Ground	-0.5, +5.0	V
OUTPUT to Ground	-0.3, Vdd+0.3	V
Input Current to any pin	±5	mA
Temperature	-40 to +100	ºC

Stresses exceeding these “Absolute Maximum Ratings” may cause permanent damage to the device. These are stress ratings only. Functional operation at these or any other conditions beyond those indicated under “Acoustic & Electrical Specifications” is not implied. Exposure beyond those indicated under “Acoustic & Electrical Specifications” for extended periods may affect device reliability.

Acoustic & Electrical Specifications

Table 2: Normal Mode Microphone Specifications
Test Conditions: 23 ±2°C, 55±20% R.H., Vdd(min) < Vdd < Vdd(max), no load, unless otherwise indicated

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Supply Voltage	Vdd		1.5	-	3.6	V
Supply Current	Idd	Vdd = 1.8V	-	130	165	μA
Supply Current[1]	Idd	Vdd = 3.6V	-	150	185	μA
Sensitivity[1]	S	94 dB SPL @ 1 kHz	-43	-42	-41	dBV/Pa
Signal to Noise Ratio	SNR	94 dB SPL @ 1 kHz, A-weighted	-	59	-	dB(A)
Total Harmonic Distortion	THD	94 dB SPL @ 1 kHz, S = Typ, Rload > 3kΩ	-	0.15	0.25	%
Acoustic Overload Point	AOP	10% THD @ 1 kHz, S = Typ, Vdd = 3.6V, Rload > 3kΩ	128	130	-	dB SPL
Power Supply Rejection Ratio	PSRR	200 mVpp sine wave 50-20kHz @1kHz, Vdd = 1.8V	-	66	-	dB
Power Supply Rejection	PSR	100 mVpp square wave	-	-100	-	dBV(A)
DC Output		Vdd = 1.5V	-	1.3	-	V
Output Impedance	Zout	@ 1 kHz	-	-	500	Ω
Directivity			Omnidirectional			
Polarity		Increasing sound pressure	Decreasing output voltage			

[1] 100% tested.

Application Notes

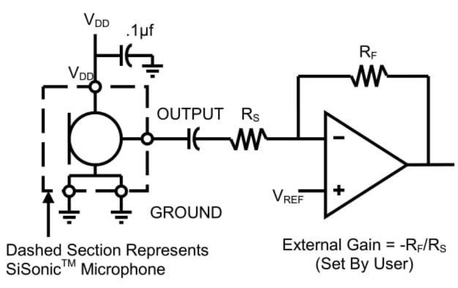


Figure 1: Typical Application Circuit

Notes: All Ground pins must be connected to ground.

Capacitors near the microphone should not contain Class 2 dielectrics due to their piezoelectric effects.

Detailed information on acoustic, mechanical, and system integration can be found in the latest *SiSonic™ Design Guide* application note.

Performance Curves

Test Conditions: Vdd=1.8V, no load, unless otherwise indicated

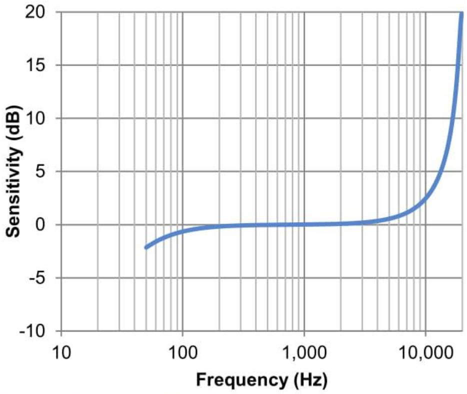


Figure 2: Typical Free Field Response Normalized to 1 kHz

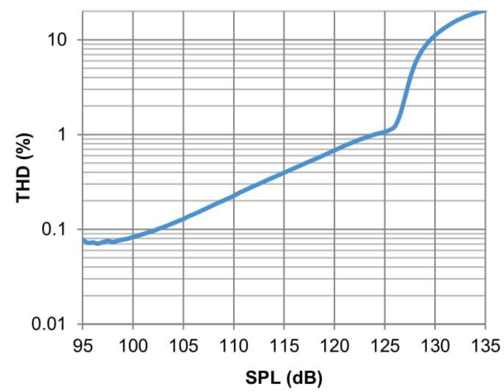


Figure 4: Typical THD vs SPL

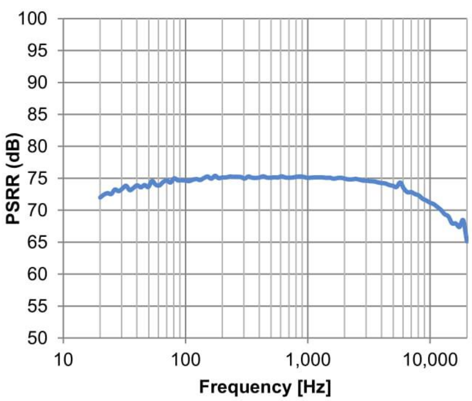


Figure 3: Typical PSRR

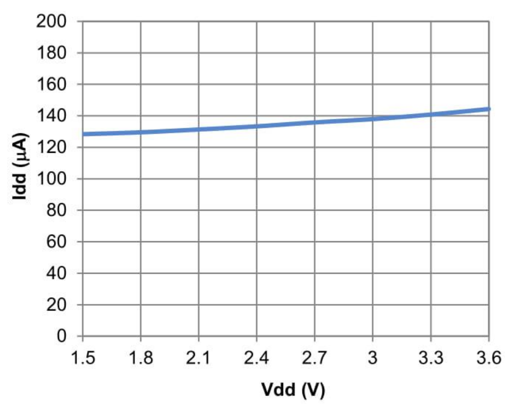
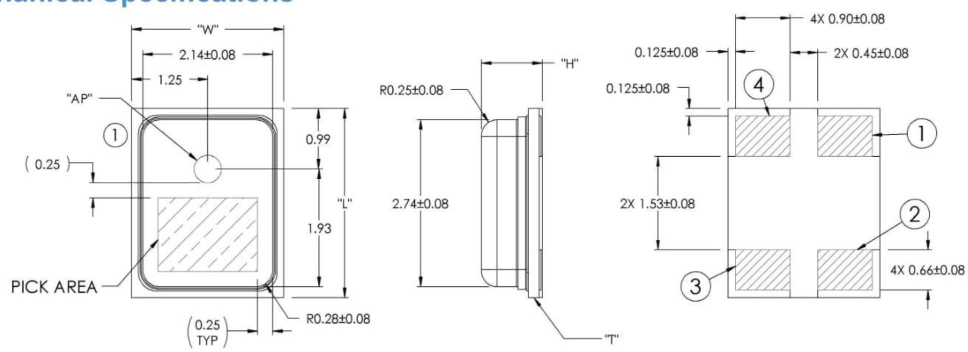


Figure 5: Typical Idd vs Vdd

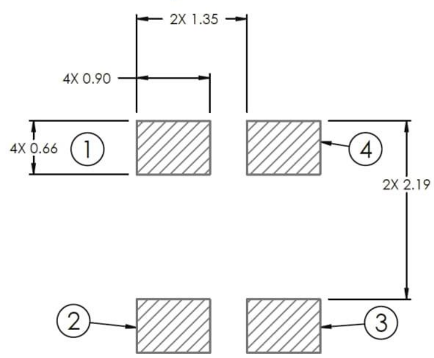
Mechanical Specifications



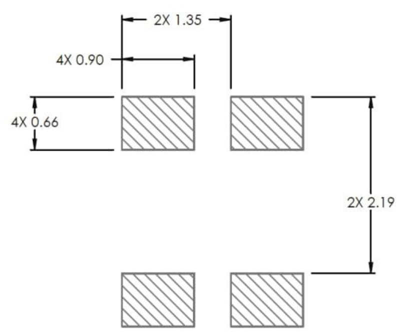
Item	Dimension	Tolerance
Length (L)	3.10	±0.10
Width (W)	2.50	±0.10
Height (H)	1.00	±0.10
Acoustic Port (AP)	Ø0.45	±0.05
PCB Thickness (T)	0.28	+0.05 -0.03

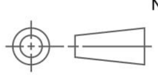
Pin #	Pin Name	Type	Description
1	OUTPUT	Signal	Output Signal
2	GROUND	Power	Ground
3	GROUND	Power	Ground
4	Vdd	Power	Power Supply

Example Land Pattern



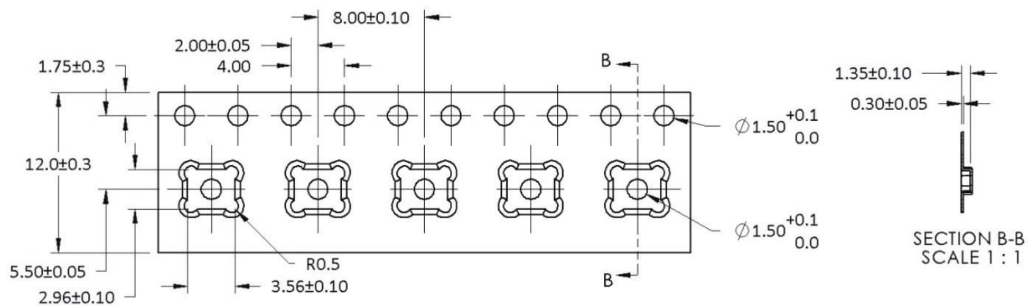
Example Solder Stencil Pattern





Notes: Pick Area only extends to 0.25 mm of any edge or hole unless otherwise specified.
Dimensions are in millimeters unless otherwise specified.
Tolerance is ±0.15mm unless otherwise specified
Detailed information on AP size considerations can be found in the latest *SiSonic™ Design Guide* application note.
Further optimizations based on application should be performed.

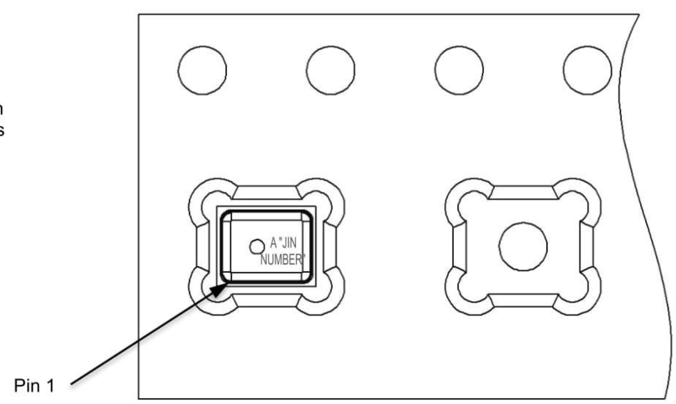
Packaging & Marking Detail



Model Number	Suffix	Reel Diameter	Quantity Per Reel
SPW0442HR5H-1	-7	13”	5,700

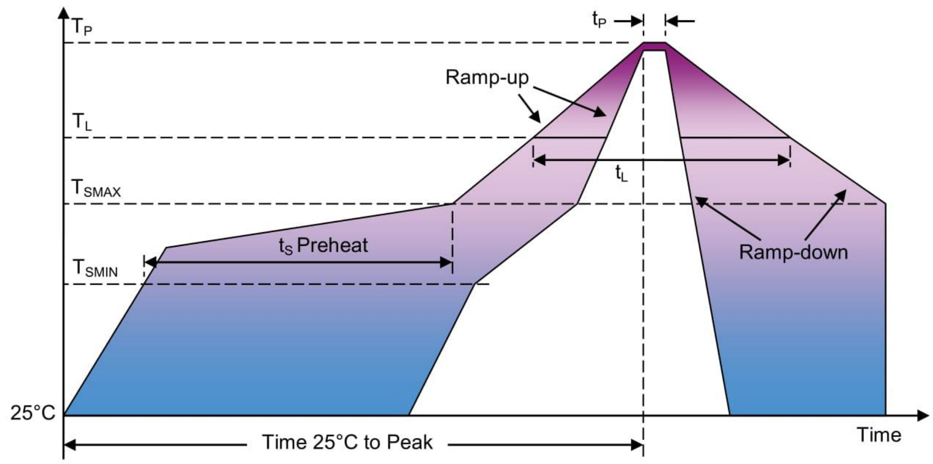
Alpha Character A:
- “S”: Knowles SiSonic™ Production
- “E”: Knowles Engineering Samples
- “P”: Knowles Prototype Samples

“JIN Number”:
- Unique Job Identification Number
- For product traceability



Notes: Dimensions are in millimeters unless otherwise specified.
Vacuum pickup only in the pick area indicated in Mechanical Specifications.
Tape & reel per EIA-481 Rev C.
Labels applied directly to reel and external package.
Shelf life: Twelve (12) months when devices are to be stored in factory supplied, unopened ESD moisture sensitive bag under maximum environmental conditions of 30°C, 70% R.H.

Recommended Reflow Profile



Profile Feature	Pb-Free
Average Ramp-up rate (T_{SMAX} to T_P)	3°C/second max.
Preheat • Temperature Min (T_{SMIN}) • Temperature Max (T_{SMAX}) • Time (T_{SMIN} to T_{SMAX}) (t_S)	 150°C 200°C 60-180 seconds
Time maintained above: • Temperature (T_L) • Time (t_L)	 217°C 60-150 seconds
Peak Temperature (T_P)	260°C
Time within 5°C of actual Peak Temperature (t_P)	20-40 seconds
Ramp-down rate (T_P to T_{SMAX})	6°C/second max
Time 25°C to Peak Temperature	8 minutes max

Notes: Based on IPC/JDEC J-STD-020 Revision C.
All temperatures refer to topside of the package, measured on the package body surface

Additional Notes

(A) MSL (moisture sensitivity level) Class 1.
(B) Maximum of 3 reflow cycles is recommended.
(C) In order to minimize device damage:

- Do not board wash or clean after the reflow process.
- Do not brush board with or without solvents after the reflow process.
- Do not directly expose to ultrasonic processing, welding, or cleaning.
- Do not insert any object in port hole of device at any time.
- Do not apply over 30 psi of air pressure into the port hole.
- Do not pull a vacuum over port hole of the microphone.
- Do not apply a vacuum when repacking into sealed bags at a rate faster than 0.5 atm/sec.

Materials Statement

Meets the requirements of the European RoHS directive 2011/65/EC as amended.

Meets the requirements of the industry standard IEC 61249-2-21:2003 for halogenated substances and Knowles Green Materials Standards Policy section on Halogen-Free.

Product is Beryllium Free according to limits specified on the Knowles Hazardous Material List (HSL for Products).

Ozone depleting substances are not used in the product or the processes used to make the product, including compounds listed in Annex A, B, and C of the “Montreal Protocol on Substances That Deplete the Ozone Layer.”

Reliability Specifications

Test	Description
Thermal Shock	100 cycles of air-air thermal shock from -40°C to +125°C with 15 minute soaks (IEC 68-2-4)
High Temperature Storage	+105°C environment for 1,000 hours (IEC 68-2-2 Test Ba)
Low Temperature Storage	-40°C environment for 1,000 hours (IEC 68-2-1 Test Aa)
High Temperature Bias	+105°C environment while under bias for 1,000 hours (IEC 68-2-2 Test Ba)
Low Temperature Bias	-40°C environment while under bias for 1,000 hours (IEC 68-2-1 Test Aa)
Temperature/Humidity Bias	+85°C/85% R.H. environment while under bias for 1,000 hours (JESD22-A101A-B)
Vibration	12 minutes in each X, Y, Z axis from 20 to 2,000 Hz with peak acceleration of 20 G (MIL 883E, Method 2007.2,A)
ESD-HBM	3 discharges of ±2kV direct contact to I/O pins (MIL 883E, Method 3015.7)
ESD-HBM (LID/GND)	3 discharges of ±8kV direct contact to lid while unit is grounded (MIL 883E, Method 3015.7)
ESD-MM	3 discharges of ±200V direct contact to IO pins (ESD STM5.2)
Reflow	5 reflow cycles with peak temperature of +260°C
Mechanical Shock	3 pulses of 10,000 G in each of the ±X, ±Y, and ±Z directions (IEC 68-2-27 Test Ea)

Notes: After 3 reflow cycles, the sensitivity of the microphones shall not deviate more than 1 dB from its initial value.

Specification Revisions

Revision	Specification Changes	Date
A	Initial Release (ECR 15-421)	10/8/2015
B	Updated Tolerances, landing pattern, and stencil (ECR 15-489)	11/17/2015
C	Added max Idd@1.8V; corrected PCB thickness and tolerance. (ECR 16-570)	1/6/2016
D	Updated AOP, added packaging resistivity, clarify T&R compliance, update Materials Statement (ECR 16-593)	1/26/2016
E	Updated carrier tape (ECR 17-1385)	1/12/2017

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