# Smart Digital Stethoscope

Design Document

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# Executive Summary

## Development Standards & Practices Used

- We will follow an Agile methodology of development.
  - Two week sprints
  - Weekly standups
  - Backlog of tasks
- We will use Branch-Review-Merge workflow.
- We will implement Test Driven Development.
- We will keep robust documentation.
- We will manage our tasks via the GitLab issue board.
- Agile methodology of development.
- Test Driven Development.
- We will keep robust documentation.
- Manage our tasks via the GitLab issue board.
- Bluetooth
- Organized and thorough design schematics
- Utilize cheap, yet effective components that fulfill requirements

## Summary of Requirements

- Digitize an analog signal
- Send data via bluetooth
- < 3 second delay from finishing the recording to having the file prepared
- Convert the data to a .wav file
- Desktop application can retrieve and store data
- Utilizes machine learning to identify certain anomalies
- The user interface must be intuitive to ensure ease of use by all users
- Cost of software licenses < $50
- Monthly expenses on data storage <$1/active user
- Collect pressure waves from the heart and lungs
- Convert pressure waves to usable electrical signal
- Filter out noise & amplify the result
- Run on battery power
- Minimum size
- Cost of hardware < $200

## Applicable Courses from Iowa State University Curriculum

- Electrical Engineering 201
- Electrical Engineering 230
- Electrical Engineering 324
- Electrical Engineering 224
- Computer Engineering 288
- Software Engineering 319
- Computer Science 309
- Computer Science 474

## New Skills/Knowledge acquired that was not taught in courses

- User interface design
- Ability to utilize online libraries in web application development
- Find solutions using online resources like Stack Overflow
- Angular development
- Hosting applications
- Choosing ADC and Bluetooth modules suitable for the project
- Mitigation techniques for interference between electrical components
- General microphone usage and implementation
- Expanding filters beyond 2nd order filters

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## List of figures/tables/symbols/definitions (This should be the similar to the project plan)

# 1 Introduction

## 1.1 Acknowledgement

Firstly, thank you to Dr. Ashfaq Khokhar and Dr. Nathan Neihart for providing technical assistance and support throughout the design process. Additionally, this project is, in part, made possible by Iowa State ECpE department funding.

## 1.2 Problem and Project Statement

Access to a doctor is often limited for billions of people around the world and this is only worsened during a global pandemic. These people would find it difficult to have a doctor personally diagnose their issue which may be easily treated if caught early on. Also, many times those who can see doctors have to talk to them virtually. However, these people may not have the means to easily send the high quality audio of their chest sounds that the doctor might need to diagnose the issue. This has created a need to introduce as much technology into the healthcare industry as possible.

The goal of this project is to design and manufacture a smart stethoscope that converts heart and lung sounds into a digital format while removing any perceived noises and amplifying signals of a certain range. Once in this digital format it will use machine learning to identify known irregularities in the sounds. The user will interface with the stethoscope via a web application on a device that is connected to the stethoscope by bluetooth. In this user interface users will also be able to easily listen to and send their audio recordings to doctors for further analysis.

## 1.3 Operational Environment

When designing a product, it is important to consider what environment a product will be used in throughout its lifetime. Most stethoscopes are typically used within the confines of a doctor's office. While this is accurate for this project, it could potentially be used in user's households as well. The goal is to make a stethoscope that does not need to be accompanied by a doctor. The smart stethoscope will be used indoors, in generally clean environments, similar to a typical stethoscope. However, the smart stethoscope will need to travel outside the doctor's office and into the homes of users, so handling magnitude will be increased, as well as the number of users. This must be considered when designing the stethoscope; it must be a durable product that can withstand heavy usage.

## 1.4 Requirements

For this project there are two categories of requirements, software and hardware.

For software requirements:

- Stethoscope can digitize an analog signal.
- It will be able to send data via bluetooth to a device of the user's choosing.
- There will be less than a 3 second delay from finishing the recording to having the file prepared.
- It must convert the data to a .wav file to store for later use.
- The desktop application can retrieve and store data using the .wav file.
- Project utilizes machine learning to identify certain anomalies within recorded sound.
- The user interface must be intuitive to ensure ease of use by all users.
- The users must be able to stream the audio from the device to another user remotely.
- Cost of software licenses must be under $50 and monthly expenses on data storage should be no more than $1 per active user on average.

For hardware requirements:

- The stethoscope must be able to collect pressure waves from the heart and lungs
- Convert pressure waves to a usable electrical signal.
- It must filter out noise within the signal and then amplify the result.
- Stethoscope will run on battery power for up to 12 hours, replacing the battery when needed.
- Minimum possible size is needed.
- Cost of hardware not to exceed $200.

## 1.5 Intended Users and Uses

For this project, there will be two users, the patient and the doctor. The patient will use this device to allow a doctor to listen to their heartbeat without needing to physically be in the office. Since the patient will be the one who has to do most of the setup, both the hardware and software need to be as simple as possible to be useful to the largest number of people. On the other hand, the doctor will primarily be using the web interface to interact with the patient and give them feedback on what they're hearing. However, the doctor will have multiple patients so they will need to be able to manage all their patients independently. Therefore, the interface for the doctor will be more intricate due to this increased volume of data to manage.

## 1.6 Assumptions and Limitations

Assumptions

- The user will have a device that can connect to bluetooth.
- The end product will be user friendly and easy to navigate.
- The product will resemble an average stethoscope.
- The product will be available for the common household.
- Batteries will be easy to interchange/ charge.

Limitations

- The end product will need to be roughly the size of a regular stethoscope.
- The end product will need to cost under ~$250.
- The user will need a computer or mobile device to utilize the full functionality of the product.
- The product will need to be battery powered.

## 1.7 Expected End Product and Deliverables

Once our project is completed there will be a set of deliverables from the software and hardware side we intend to show to our client. For the software side one goal is the stethoscope is able to digitize an analog signal and then send that signal via bluetooth to a web application. In addition, the conversion will be a .wav file that can be used by the user on the device. Also, machine learning will be used to alert the user if the recording sounds problematic within a three second delay from the recording ending. Finally, the interface we create will be intuitive for the user and the software costs will remain under $50. The web app framework for our product will be completed by October 2020, the bluetooth transmitter will be finished by March 2021 and our machine learning algorithm will be refined by April 2021.

To continue, for the hardware side of the project our end project should collect pressure waves from the heart and lungs. These waves will then be converted into an electrical signal and a filter will eliminate unwanted frequencies. Furthermore, an amplifier will be used to strengthen the signal and our product will run on battery power. The battery consumption will be minimized and the overall size of the product will be small for ease of use. The standard length of a stethoscope is 27 inches so we will remain consistent with this size. Finally, we will also work to keep the cost of hardware aspects to no more than a couple hundred dollars. We will work to have the pickup sensor completed by March 2021, the amplifier with the filter by December 2020, the buffer with the amplifier by March 2021 and overall user audio streaming by April 2021.

# 2 Project Plan

## 2.1 Task Decomposition

The various tasks that need to be completed can be seen in Figure 1 below. The pickup sensor will pick up the pulse signals of the user. Those sounds will then be sent through a preamplifier that serves to make the signal large enough for proper operation. The microphone will most likely output voltages in the millivolt range, so a preamplifier is needed for proper filtering. To ensure a clear signal, a filter will be added to remove any background noise. A buffer will ensure that the filter output does not affect our final amplifier. A final amplifier will increase the signal amplitude to match what the ADC requires. This signal may also be listened to with earbuds using another amplifier to control the output volume. The analog to digital converter (ADC) will take the analog signal and convert it into a digital signal that can be taken by the bluetooth transmitter and send it to the user device.

Once linked to the user's device the stethoscope can be interfaced with the web application. The web app will allow the user to record the audio from the stethoscope and play it back. This recording will be facilitated by RecordRTC [1] Then the user will be able to use a machine learning algorithm to determine if the recording indicates a cardiovascular or respiratory illness. To train this algorithm we need to have a large dataset, so we will be using an online database of heart and lung sounds from kaggle, a data science website [2]. Also the user will be able to stream their audio to another user on the web application through a shared session connection. Finally if the user is logged into the website they will be able to save their recordings and listen back to previously saved recordings.

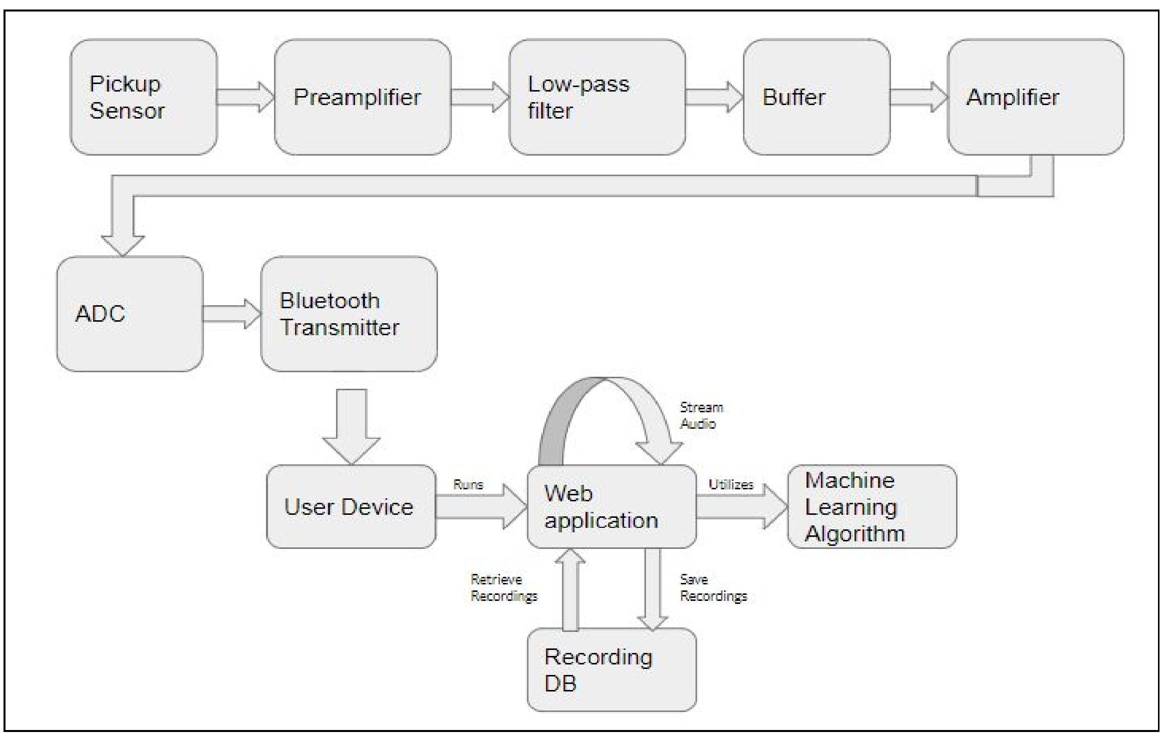


Figure 1: System Block Diagram

## 2.2 Risks And Risk Management/Mitigation

Our first task is creating a pickup sensor and the main risk is that the sensor is unable to detect the patient's chest sounds. The probability of this occurring is 0.8. This is a high risk because what the microphone we buy may not be sensitive enough to pick up the low amplitude, low frequency sounds. Extensive research into types of microphones and how to properly implement them is required to avoid this risk. Next, we will work on our preamplifier and the risk with this component is that it will amplify noise or the DC offset brought in from the microphone. This risk is only rated at 0.2 because the fix is quite difficult to get incorrect. To reduce the noise picked up by the microphone, a rubber insulating material can be placed to encapsulate the microphone when against the skin. This can block outside noises from reaching the sensor. For the DC offset, a series capacitor with the sensor output will block the DC offset. Then, we will incorporate our filter that has a risk of 0.6 because we could calculate values for our filter that block heartbeat frequencies. Our risk mitigation plan involves having a large passband range for initial testing. This way, it should include all heartbeat sounds and we can adjust the range if needed. A buffer can be integrated into the filter to ensure its output current does not affect our amplifier circuit. Voltage fluctuation can cause components to misbehave and this has a low risk of 0.2. This can be solved by providing decoupling capacitors [3] for supply voltages and before our digitizing circuitry. Lastly, the ADC may not have a sampling rate high enough to capture the signal properly. This has a risk of 0.4. To avoid this, buying an ADC with a sampling rate well above twice our frequencies being sampled should provide an accurate signal.

The next task is the bluetooth transmitter to send the digitized signals to the user device. The risk associated with this is that the transmitter won't be able to connect to the user device. This risk is relatively low at 0.05 since both the transmitter and user device will be products that we purchase off the shelf. After that is the web application. The risk here is that it won't run on a wide range of devices, this risk is rated at 0.6. With the wide range of devices and platforms that users can use it is very likely that for some it won't work. To mitigate this risk we are trying to narrow our focus to desktops running the web application. Also we are creating the app in Angular, this framework is very easy to style for mobile devices which should allow us to make it mobile friendly as a potential feature. Lastly is the machine learning algorithm, the risk is that the data set we are using to train the algorithm won't result in a trained model that can work off our own stethoscope. This is very possible at 0.5 so to mitigate it we have a few options. Firstly, we can try to find another data set that matches our own stethoscope data better. We could also adjust the stethoscope itself to match the data set. Lastly, we could do preprocessing on the data after it is transmitted to the program in order to make it match.

## 2.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

The smart stethoscope can be split into two major projects, the hardware of building the stethoscope, and the software of analyzing and presenting the signal from the stethoscope. These two projects each have their own milestones and metrics. The progress of significant tasks and milestones is recorded through interpersonal communication and within the team Gitlab task board.

Implementing the hardware of the stethoscope requires meeting specific criteria for each component of its circuit. Once a pulse signal is received from a patient, the hardware of the stethoscope will meet the following vital milestones and criteria:

- The wireless stethoscope should be able to operate on battery power for 12 hours.
- A preamplifier will increase the raw pulse signal with a gain of 100.
- A bandpass filter will filter out any frequencies not associated with human pulse signals; it will filter out any frequencies above 200Hz and below 20Hz.
- A final amplifier will extend the filtered signal amplitude to match the input requirement of the ADC.
- The final amplified signal should be digitized and transmitted via bluetooth for signal analysis.

With a filtered and amplified signal being transmitted to a web application of choice, the following software milestones and criteria will be met:

- The signal will be recorded, converted into a .wav file, and analyzed by the machine learning algorithm within 3 seconds of the recording finishing.
- The web application will save recordings to a user's account to allow playback.
- A machine learning algorithm will detect anomalies in the pulse signal and express the anomalies with 70% accuracy.
- The web application will allow for sharing of live audio with another user with less than a 2 second delay.

## 2.4 Project Timeline/Schedule

The Gnatt chart can be seen in figures 2 and 3 below. We have split the development between two teams, software and hardware. This division will allow for concurrent development between the two deliverables which are the physical hardware to capture the heartbeat and the software interface to allow transmission/sharing.

Development for the hardware will follow a linear direction since the various components will build off of each other. For example, the preamplifier will need the signal generated from the pickup sensor in order to function. Therefore, the timelines on the Gantt chart for the hardware components will generally not overlap.

Development for software can be somewhat more flexible. For example, the transmission of information via Bluetooth will not rely on the machine learning or web application being done. While they all still interact, we can work on these things separately and likely will need to. As a result, we can see on the chart that there is some overlapping.

| Task | Start Date | End Date | Expected hours to complete | Project Timeline | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 9/7 | 9/14 | 9/21 | 9/28 | 10/5 | 10/12 | 10/19 | 10/26 | 11/2 | 11/9 | 11/16 | 11/23 | 11/30 |
| Build Initial Web App Framework | 9/7 | 9/13 | 10 hrs | | | | | | | | | | | | | |
| Design Document v1 | 9/7 | 10/5 | 15 hrs | | | | | | | | | | | | | |
| Build Initial Machine Learning Algorithm | 9/7 | 10/19 | 10 hrs | | | | | | | | | | | | | |
| Refine Web App Framework | 9/14 | 2/15 | 30 hrs | | | | | | | | | | | | | |
| Refine Machine Learning Algorithm | 10/19 | 3/8 | 30 hrs | | | | | | | | | | | | | |
| Pickup Sensor | 9/21 | 3/1 | 15 hrs | | | | | | | | | | | | | |
| ADC | 10/5 | 3/1 | 30 hrs | | | | | | | | | | | | | |
| Bluetooth transmitter | 10/5 | 3/1 | 30 hrs | | | | | | | | | | | | | |
| Design Document v2 | 9/28 | 10/19 | 20 hrs | | | | | | | | | | | | | |
| Preamplifier | 9/28 | 1/25 | 20 hrs | | | | | | | | | | | | | |
| Low-pass Filter | 10/26 | 2/15 | 20 hrs | | | | | | | | | | | | | |
| Saving and Retrieval functionality and Recording DB | 10/19 | 11/11 | 35 hrs | | | | | | | | | | | | | |
| Design Document v3 | 10/26 | 12/7 | 25 hrs | | | | | | | | | | | | | |
| Buffer | 11/9 | 2/8 | 20 hrs | | | | | | | | | | | | | |
| Amplifier | 11/30 | 3/1 | 20 hrs | | | | | | | | | | | | | |
| Condense circuitry into user friendly package | 3/8 | 3/15 | 25 hrs | | | | | | | | | | | | | |
| Streaming user audio | 2/15 | 3/21 | 30 hrs | | | | | | | | | | | | | |
| Intergrate Hardware and Software | 2/15 | 3/15 | 30 hrs | | | | | | | | | | | | | |

Figure 2: Semester 1 Gantt Chart

| Task | Start Date | End Date | Expected hours to complete | Project Timeline | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1/25 | 2/1 | 2/8 | 2/15 | 2/22 | 3/1 | 3/8 | 3/15 |
| Build Initial Web App Framework | 9/7 | 9/13 | 10 hrs | | | | | | | | |
| Design Document v1 | 9/7 | 10/5 | 15 hrs | | | | | | | | |
| Build Initial Machine Learning Algorithm | 9/7 | 10/19 | 10 hrs | | | | | | | | |
| Refine Web App Framework | 9/14 | 2/15 | 30 hrs | | | | | | | | |
| Refine Machine Learning Algorithm | 10/19 | 3/8 | 30 hrs | | | | | | | | |
| Pickup Sensor | 9/21 | 3/1 | 15 hrs | | | | | | | | |
| ADC | 10/5 | 3/1 | 30 hrs | | | | | | | | |
| Bluetooth transmitter | 10/5 | 3/1 | 30 hrs | | | | | | | | |
| Design Document v2 | 9/28 | 10/19 | 20 hrs | | | | | | | | |
| Preamplifier | 9/28 | 1/25 | 20 hrs | | | | | | | | |
| Low-pass Filter | 10/26 | 2/15 | 20 hrs | | | | | | | | |
| Saving and Retrieval functionality and Recording DB | 10/19 | 11/11 | 35 hrs | | | | | | | | |
| Design Document v3 | 10/26 | 12/7 | 25 hrs | | | | | | | | |
| Buffer | 11/9 | 2/8 | 20 hrs | | | | | | | | |
| Amplifier | 11/30 | 3/1 | 20 hrs | | | | | | | | |
| Condense circuitry into user friendly package | 3/8 | 3/15 | 25 hrs | | | | | | | | |
| Streaming user audio | 2/15 | 3/21 | 30 hrs | | | | | | | | |
| Intergrate Hardware and Software | 2/15 | 3/15 | 30 hrs | | | | | | | | |

Figure 3: Semester 2 Gantt Chart

## 2.5 Project Tracking Procedures

Our group has chosen to use GitLab to keep track of upcoming tasks, current tasks, and completed tasks. GitLab provides us a platform where we can assign different group members to specific tasks and is a great way to keep our team organized. Git will be used as a source control for the software development. All software developers will be able to branch off the master repository to implement their respective features without interfering with one another. In addition, we use Slack for fast communication between members because we can create different chat groups within our team that can still be visible to everyone. Finally, our team has taken advantage of Zoom and Webex to conduct weekly team meetings and weekly client meetings.

## 2.6 Personnel Effort Requirements

| Task | Person-Hours Required |
|---|---|
| Pressure sensor detects pulse signals of the user. | 15 Hours |
| Create a preamplifier and filter to remove noise from the signal. | 20 Hours + 20 Hours |
| Create a buffer and amplifier to ensure signal integrity and increase signal amplitudes. | 20 Hours + 20 Hours |
| Convert the analog electric signal to a digital signal. | 30 Hours |
| Integrate bluetooth capabilities between the stethoscope and user device. | 30 Hours |
| Create a database to store and retrieve signals within the application. | 10 Hours |
| Define a machine learning algorithm to identify cardiovascular and respiratory illnesses. | 10 Hours + 30 Hours |
| Securely share confidential data to health professionals through a network connection. | 30 Hours |
| User’s can replay previously recorded signals and save other recordings. | 35 Hours |

Figure 4: Table of Expected Person Hours

## 2.7 Other Resource Requirements

Additional resources we require include:

- Circuit components
- Circuit board
- A small microphone
- Batteries
- Casing for the batteries
- Amplifier
- Google Firebase for hosting and storage [4]

## 2.8 Financial Requirements

The individual components are listed below and expected to cost a total of $135:

- Software licenses will be under $50 and the cost of hosting will be less than $1 per active user on average.
- Analog to Digital Converter will cost around $40.
- A bluetooth transmitter will be around $30.
- Circuit components vary between $0.2 and $5
- Microphone $10
- Battery Casing $3

There will also be a cost associated with development. For this we are expecting no more than an additional $100. This will cover purchasing test components, software licenses, and hosting fees that are not relevant to the final product. We will seek funds for this project from Iowa State but can purchase what we need to if we can't get the funding.

# 3 Design

## 3.1 Previous Work And Literature

Currently on the market there are numerous smart digital stethoscopes that act similarly to how ours will. One example of this is the Eko DUO ECG + Digital Stethoscope [5] which can be seen below.

Figure 5

Our design will try to implement most of the features that are offered in this device and expand in some areas. One example of this is that we plan to implement audio streaming to other users. This means that someone could stream their stethoscope audio to someone else via the web application. Also we will use machine learning to indicate to the user if their audio sampling suggests a health concern. Finally, we will develop the stethoscope for a cheaper overall price than the other comparable products on the market.

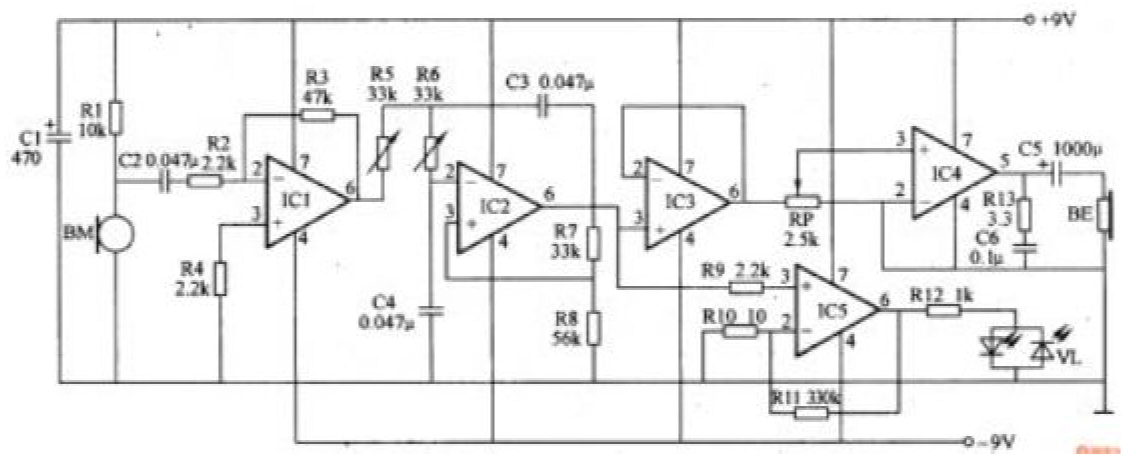


Figure 6 [6]

Beyond digital analysis and audio streaming, it will function like any stethoscope would. Not only will the stethoscope send audio to a user interface for one or multiple people to visually see, but it will also be compatible with standard earbuds for a more traditional experience. A sample digital stethoscope circuit can be seen above in figure 6. This sample contains many of the same units that our stethoscope will, including a microphone, pre amplifier, filter, and power amplifier.

## 3.2 Design Thinking

Some of the most important aspects of the design process is to keep the application simple and keep the current draw of the stethoscope to a minimum. Since this product needs to be usable to a wide variety of people and situations, a longer battery life and simplifying the user interface will allow the greatest amount of accessibility.

Ideas that were originally considered for application simplicity involved creating a mobile application or designing a computer program. However, we decided that a web application would be the most accessible to most people since all they would need is a web browser which widens the scope of devices that could be used with the application.

The entire stethoscope design is centered around keeping current draw to a minimum, but still being sufficient in collecting and converting  pressure waves, followed by filtering and amplifying them. Any wireless application always requires a long battery life for user convenience. This design deliverable influenced the way the pressure waves are filtered and amplified; we are using components with minimal current draw and a minimal amount of amplification.

### 3.3 Proposed Design

The main goal of our digital stethoscope is to collect pressure waves from a human heart and lungs and display them visually and audibly for further examination. This process begins with a transducer to collect the sound waves coming from a human heart or lungs. The transducer, in our case, a microphone, converts the sounds waves into an electrical signal. This electrical signal is going to be weak and may be full of noise. To fix this, it must be filtered and amplified.

The signal will be filtered using one of a couple designs. We are looking into a second order low pass filter or a fourth order low pass in tandem with a fourth order high pass. They will both allow sounds below 200Hz and the high pass filter would allow sounds above 20Hz. However, because the signal is very weak, before it can be filtered, the signal must be amplified slightly to allow for optimal operation. Now that it has been filtered, the signal can be amplified significantly so it's easier to hear and analyze. The output for this amplifier will go to a standard 3.5mm jack for headphone users and to a web application, via bluetooth, for analysis and visualization. The entire hardware circuitry will be battery powered and draw minimal amounts of current.

To be able to visualize the signal, the analog signal provided from the amplifier must be digitized using an Analog-to-Digital Converter (ADC). This digitized signal will then be sent via bluetooth to the user's device, which must have bluetooth capabilities. These steps will ensure the requirements that the stethoscope can digitize the analog signal and send data via bluetooth to a device of the user's choosing.

The user device will then be able to run a web application that will convert the audio into a .WAV file so it can be reviewed, downloaded, or saved. Once saved the user will be able to retrieve previous recordings from a database. In our case we are using Google Firebase to access/store recordings while also hosting the web application and storing user credentials. The web app will also have streaming functionality to ensure that the patients can directly communicate with their health professional in real time, while also using machine learning algorithms to give the health professional some potential issues indicated in the .WAV file recording. These will ensure that the stethoscope satisfies the requirements of storing/retrieving the .WAV file using the web application, streaming to another user remotely, and utilizing machine learning to identify certain anomalies within the recorded sounds.

Throughout the entire process designers will focus on keeping the product intuitive for all potential users and minimizing software licenses required. This will ensure that all function and nonfunctional requirements for the software side are completed.

## 3.4 Technology Considerations

**Application:**

During the process of selecting how the user can interact with the stethoscope we looked into creating a mobile app. This would be beneficial because many users prefer to do work primarily on their phones. Also it would be relatively easy to develop and provide a clean user interface. However, it would be harder to maintain and would restrict usage to just phones.

We also considered using a desktop application. This again would be nice because it would be easier to develop and would provide us with a lot of freedom in functionality. However, that would make it harder for users to get started and limit the scalability of the application.

Finally, we decided on using a web application. The benefits of this include being able to quickly deploy and not requiring any downloads to function. Also it is available on both desktop and mobile devices. However, one tradeoff is that the UI won't be as tailored to either desktop or mobile, since it must work on both, and we have limited control of the application since it must run in a browser. Another disadvantage is that it would not function without internet connection. This was decided to not be a significant disadvantage because there are not very many use cases where the internet would not be available.

**Connection to device:**

In order to connect the stethoscope to the device that runs the web application we could use Bluetooth, USB, or an rf dongle. We decided to use bluetooth because most modern devices have it available and we wanted the connection to be wireless . Also bluetooth is commonly used to stream audio so we were confident that it would be applicable to our problem. Finally, we thought that this would have more potential documentation for us to utilize while developing it.

We also looked into using a direct USB connection between the device and the stethoscope. However, this creates hardware limitations as now phones are made much more difficult to use. Also this is wired and thus less convenient. However, it would be possible to use the USB as a power source and obfuscate the need for batteries on the stethoscope itself.

Lastly, we considered using an rf dongle. The strengths of this would be that it allows us complete control of the connection as we could develop the transmission ourselves. Also it would work on devices that don't have other connection types, like bluetooth. However, like USB this would limit mobile use and it would be a significant amount of work to develop. Ultimately making this design not feasible.

**Physical Stethoscope:**

The main goal of the stethoscope is to provide an easy to hear and digitize signal coming from a patient's heart. Along with this, the current draw must be to a minimum. There are many problems that can occur when designing a stethoscope circuit. There can be voltage fluctuations, noise within the circuit, or interference between components. All of these issues are solved in very static practices. However, there are some considerations that need to be made.

A big consideration to make is what microphone we want to use. There are many different types of microphones available, including dynamic, MEMS, and electret condenser microphones. After some research into these microphones, MEMS were determined to be the best [7] because they have high sensitivity and low output impedance. Next, the type of filtering must be considered. There are passive and active filters, as well as many orders of filters that can be used. Passive filters are cheaper, but less effective. Active filters can be manipulated to effectiveness that is required by a design. For our case, a stethoscope needs a very specific range of frequencies, so a highly effective filter is needed. This is why we are trying a fourth order filter. The higher the order, the more components, and thus, the more current draw and cost.

## 3.5 Design Analysis

Thus far, the majority of the project has not been implemented. However, where the project is currently at, most design choices that have been implemented were generally successful. A caveat to this is the transducer; the microphone is going to struggle to pick up human pulse signals. As we progress, there are some design choices that may need modification. First, the microphone will need to have a casing designed to stop most outside noise, making quiet human pulses easier to pick up. Secondly, audio samples that are stored within the web application are currently taking up more storage than we anticipated. This will require us to iterate over that portion of the design until we come to a more optimal solution.

## 3.6 Development Process

As a team, we are utilizing a form of the Agile development process. There are weekly standups for the team where progress is reviewed, problems are addressed and sprints for the next meeting are outlined. Every two weeks, there are design reviews with the client. These design reviews are where the client is brought up to speed on the progress the team has made and the goals for the next iteration are set.

By using this process, the team aims to maintain consistent progress throughout the development phase. Additionally, by having regular meetings and keeping constant communication between members, the hope is that issues are being addressed in a timely manner. The design reviews with the client allow them to be included in the design process and offer feedback throughout the development of the product to ensure that the final result will address their needs.

### 3.7 Design Plan

In order for the user to be able to take a reading using the stethoscope, the hardware will need to be completed. This means that we will need to have power, amplification, filtering, signal digitizing and bluetooth transmission completed.

The stethoscope will be battery operated, and the batteries will power the microphone offset, active amplification, filtering, signal digitizing, and bluetooth transmission. It will need to filter out noise above 200Hz and amplify the signal for clarity during data processing.

In order for the user to be able to transmit data from the device to the computer, we will need the ADC and bluetooth module to be working and able to connect to the computer.

In order for the user to be able to upload, analyze and send the reading, the web application will need to be completed. This means it will need to be able to receive a signal from the hardware via bluetooth, have storage capabilities to store the signal, have a machine learning algorithm to analyze the reading and have a communication protocol in place that can transmit the reading to another host via the web.

# 4 Testing

### 4.1 Unit Testing

Modules that need to be individually tested:

**Software:**

- Digitize an analog signal using an ADC.
- Transmit signal to the user device via bluetooth.
- Convert digital signals to .WAV files.
- Website User Authentication (done with AngularFire [8]).
- Website Page Navigation.
- Store and retrieve data from Google Firebase.
- Machine learning algorithms ability to detect anomalies.
- Data streaming to remote devices.

**Hardware:**

- Pickup sensor/ microphone
- Pre amplifier
- Filter circuit
- Final Amplifier

## 4.2 Interface Testing

Modules that need to be tested in combination:

**Software:**

- Send digitized analog signal to bluetooth transmitter. We will do this by feeding the ADC arbitrary values and observing the transmitter to verify that it is sending what we would expect.
- Receive and parse the bluetooth data on the device. We will accomplish this by giving the bluetooth transmitter a known set of data and sending it to the computer. We will then compare the sent data to the known set and see if they are the same.

**Hardware**:

- The microphone and the filter need to be tested together to make sure that the filter is correctly removing frequencies.
- The microphone and the pre amplifier will be tested together.The microphone that we selected does not have a strong signal, so it is important that we use the pre amplifier to read the signal.
- The filter and final amplifier will be tested together to ensure that the filtered signal is readable and is not too noisy.

## 4.3 Acceptance Testing

Firstly we will demonstrate that our functional requirements are met by using unit tests on each individual component. Then we will implement end to end tests on the system to ensure that it all is working together as expected.

We will verify our non-functional requirements are achieved by first enumerating them with our mentor so that the final product satisfies his expectations. Then we will use end to end testing to ensure it is all met or exceeded. If any requirement is unable to be met we will discuss it with our mentor and try to find another solution or reframe our reevaluate our requirements.

Finally we will involve our client in the acceptance testing process by regularly discussing and showcasing the progress made so far. This will give him the opportunity to give us constructive feedback before too much time is spent on any given feature. Once the project is near completion we will have a longer hands-on demo for our client so he can give us any last minute feedback that we can use to improve our final product.

### 4.4 Results

At this point in the project, testing is basic. We're still in the process of beginning implementation for most of these design components. However, there is some basic acceptance testing that has been done.

- Web App
    - Web application is live and reachable
    - Currently capable of storing audio files
        - Size of audio files is larger than expected currently so it requires revision
    - Users are able to create accounts
- Machine learning
    - Preliminary model has been created
        - Initial runs were not producing desired output
        - New model being developed
- Microphone
    - First microphone tested contained lots of noise in its output
        - Rubber casing to prevent outside noise needs development
        - Further testing required
    - More and different microphones will be ordered and tested
- Filters
    - Successfully designed in PSPICE
        - Parts being ordered
        - Physical model being developed

# 5 Implementation

In the next semester, the entire hardware circuit for the stethoscope will be assembled and tested. Breadboards will be used for testing so it is easy to make changes if needed. The designs for the filter and microphone will need to be tested with a microcontroller that we pick out. Amplification of the signal will depend on the intended input for the microcontroller; the amplification will most likely result in a signal between 2 and 5 volts. If time permits, we would like to implement our final circuit design on a printed circuit board. This circuit board could also be designed around the constraints of a housing for the product. It is unlikely that we will get to this point, but it would make our stethoscope much more professional and closer to a real product.

We plan on implementing the ability to stream audio between users on the website. This will be the first feature we work on next semester so it will be completed within one month of the semester start. We also need to integrate the machine learning algorithm into the website to use it on the recordings. This will be implemented after the algorithm is completed. Both of these features will continue to be developed by Andrew because he is familiar with web development.

We  have already developed numerous machine learning algorithms with encouraging results. Once next semester begins we will continue to refine what we have and continue researching new potential methods. We plan on finalizing the algorithm half way through next semester to give us time to implement it into the website and test it with real world data. Also, Joe and Maggie will join Andrew in the development process to improve the quality of the final algorithm.

Finally, we have done extensive research into the ADC and bluetooth transmitter we will use. We are also in active communication with Dr. Neihart to find the best solution. At the moment we plan on ordering a microcontroller by the end of this semester. Then we will integrate the ADC and bluetooth on it by the two months into next semester. Once that is done we can connect it to the hardware stethoscope and start testing to refine our design. Joe and Maggie will continue working on this as at this point they are extremely familiar with the subject matter.

# 6 Closing Material

## 6.1 Conclusion

Our digital stethoscope product is designed to provide simple, yet large functional improvements to others on the market. In addition to providing the audible heart feedback most stethoscopes produce, our digital stethoscope utilizes the convenience of technology to make visualization and analysis easy. After linking to the user's device, our stethoscope will be able to save the recordings so they can be viewed later. We will also develop a machine learning algorithm that can alert the users of recordings that indicate a potential illness.

So far we have completed the website that the users can login to in order to save and listen to their audio recordings. This includes the hosting and the database which is setup through Google Firebase. We have also devoted resources to improving the user experience by implementing wave forms of the audio being played or recorded. Additionally, we have a high end design for the hardware circuitry, including multiple potential filter designs.

The machine learning aspect has been a learning experience for all of us. It has given us the opportunity to dive into the subject matter and try out many different strategies. We have created around five different algorithms that take in an audio .wav file and can predict if it is healthy or not. They've had various levels of success but they generally can predict it correctly roughly 70-80% of the time.

The original plan for the analog-to-digital converter and bluetooth transmitter was to take two independent components and use them together, however the issue was the scale of these components. They were about 5 millimeter by  millimeter making them extremely difficult to work with. We then began exploring the use of microcontrollers, however they do not correspond to the original guidelines provided to us. We are now in the process of connecting with a faculty member who specializes in signals and who will aid in our search for an analog-to-digital converter and bluetooth module.

The best plan for our goals will depend on the specific problem we need to solve. We will continue to develop quickly as the nature of software development enables us to quickly test changes to find the optimal solution. This strategy so far has given us a lot of progress in the web application and machine learning algorithms. Additionally, we will continue to methodically do our research to come to the best possible solution the first time. This is because hardware doesn't have nearly as quick of a turn around time as software. So far this plan has given us a lot of knowledge and designs that we can take into next semester to use in our final implementation.

### 6.2 References


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[4] *Firebase*. (2020). Google. Accessed: September 4, 2020. [Online]. Available: https://firebase.google.com/

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[8] *AngularFire*. Open source. Accessed: September 27, 2020. [Online]. Available: https://github.com/angular/angularfire

## 6.3 Appendices

Any additional information that would be helpful to the evaluation of your design document.

If you have any large graphs, tables, or similar data that does not directly pertain to the problem but helps support it, include it here. This would also be a good area to include hardware/software manuals used. May include CAD files, circuit schematics, layout etc,. PCB testing issues etc., Software bugs etc.

Microcontroller Datasheet
[PDF Download]

Bluetooth Module Datasheet

[PDF Download]

Software UI Screenshots

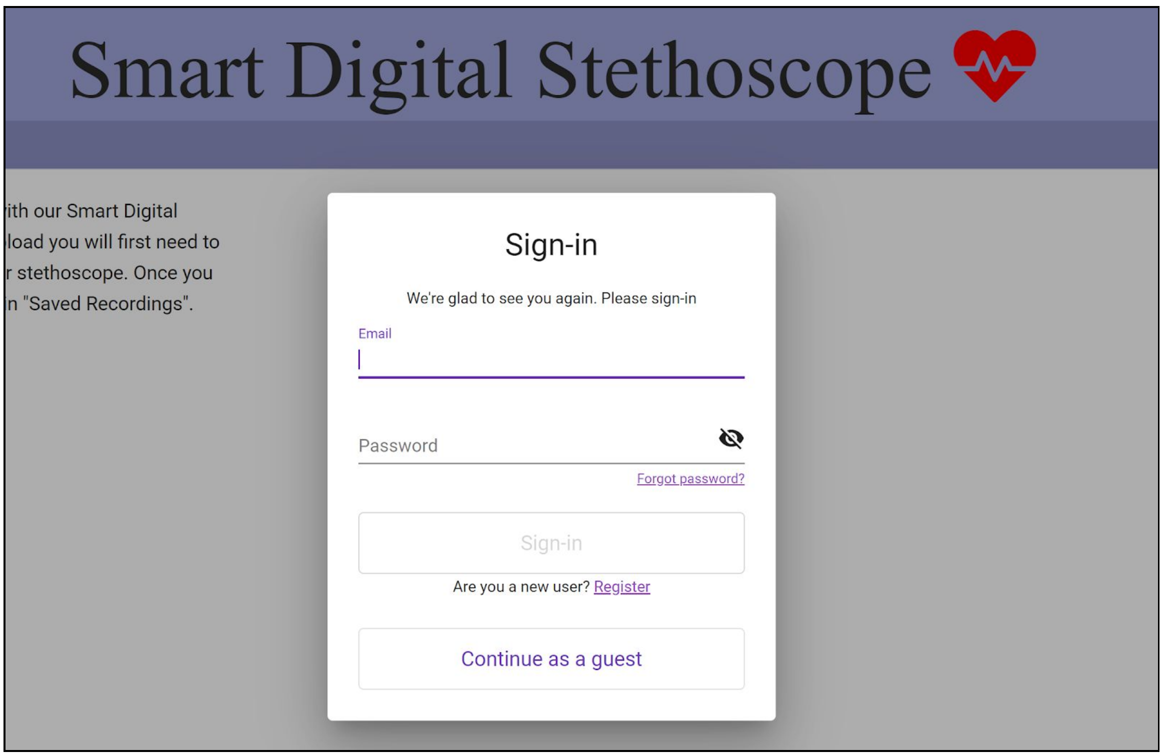


Figure 7: Website Login Screen

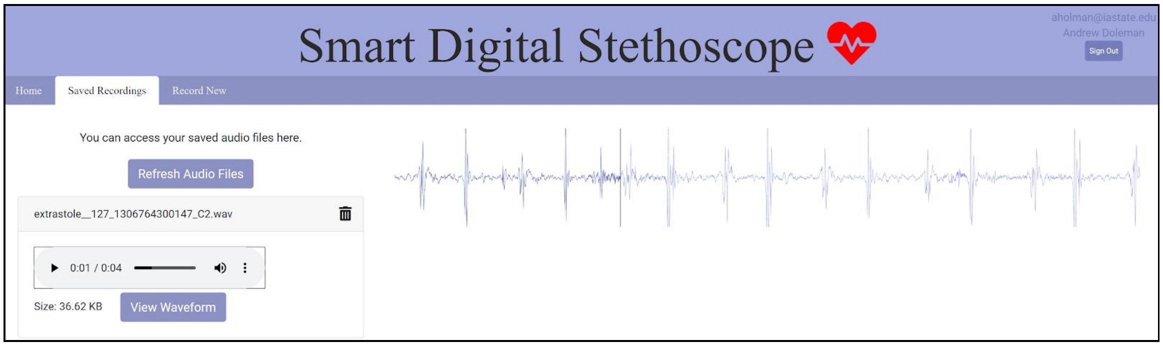


Figure 8: Saved Recordings Screenshot

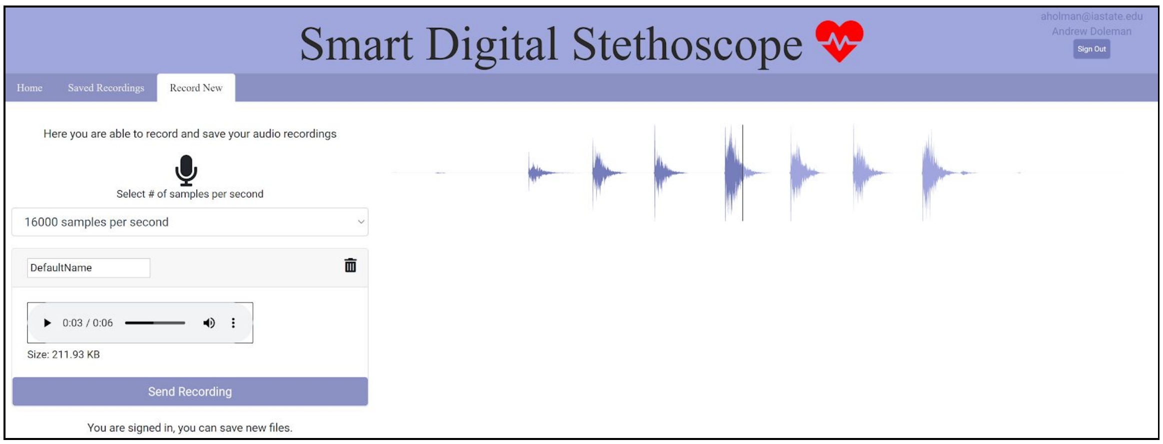


Figure 9: Recording Screenshot

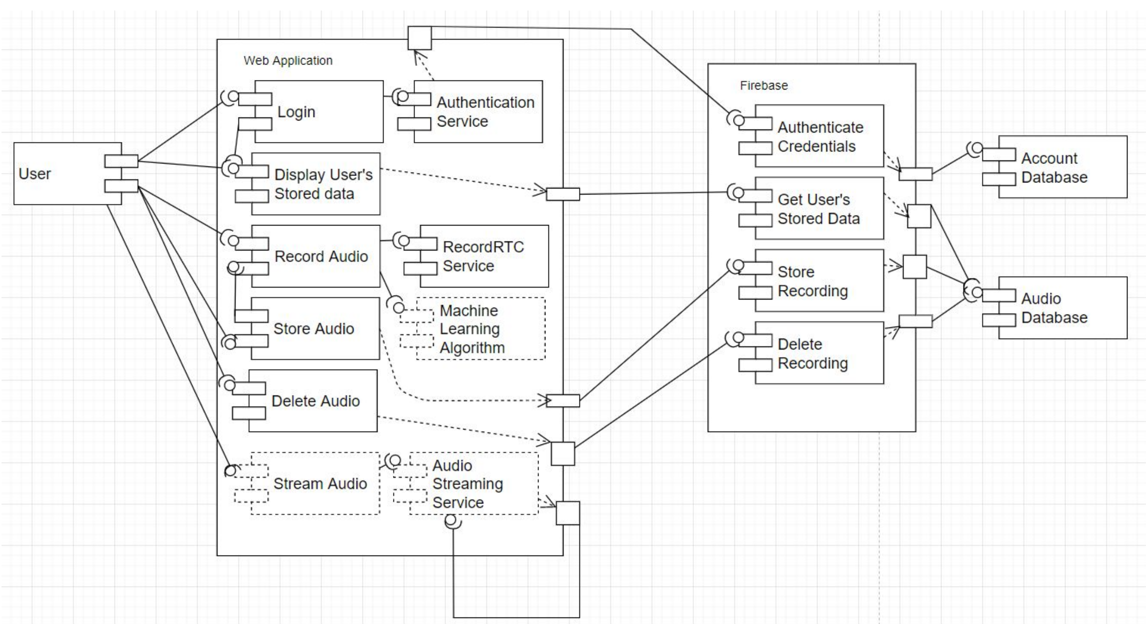


Figure 10: Software Component Diagram

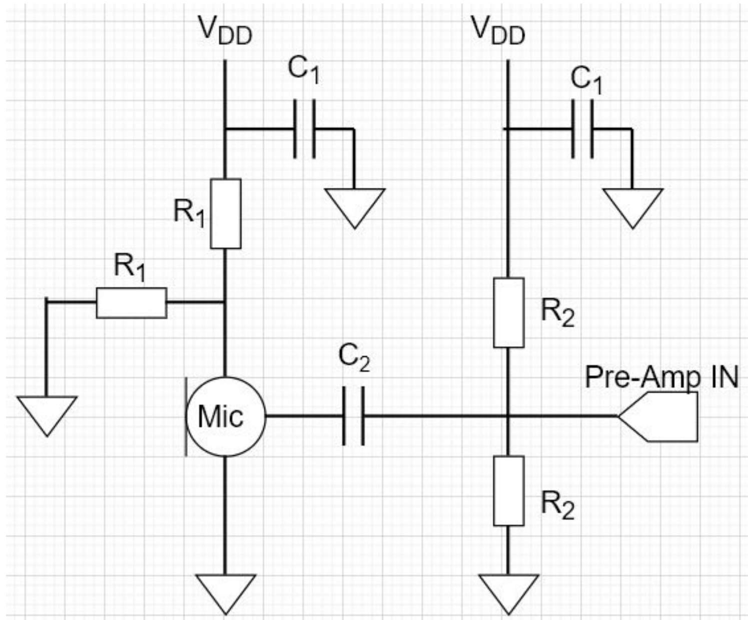

Figure 11: Transducer Circuit

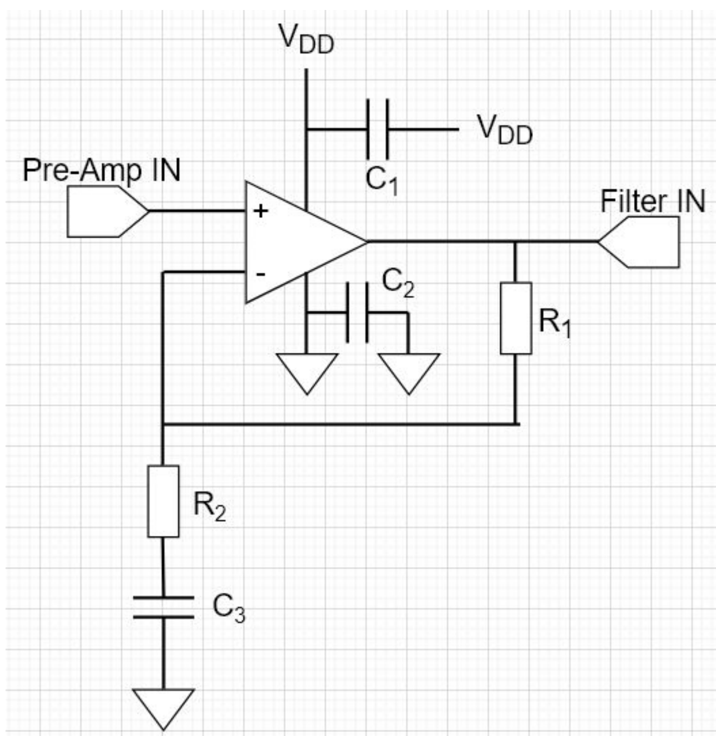

Figure12: Preamp Circuit

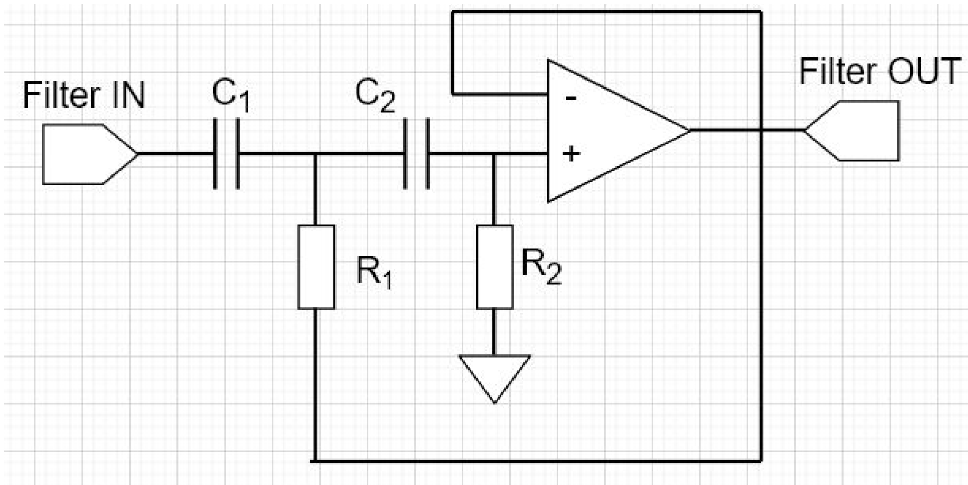


Figure 13: Highpass Filter Circuit*

*This is one second order filter. There would be two of these cascaded for a fourth order filter.