Multi-Channel High-Gain Low Noise Amplifier for High-Frequency Ultrasound Signal Acquisition

DESIGN DOCUMENT

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Executive Summary

Our project aims to develop a way to amplify the signal generated from a photoacoustic imaging system, used for research here at Iowa State. This system is designed to shoot a laser at a cell and measure the response of the cell. Something that they have done research on so far are tumors in mice, and other cell cultures. This amplifier circuit will need to amplify a radio frequency or RF signal to generate higher quality images, from which better conclusions can be drawn. Our design requirement goals include low noise, high gain (of about 40 to 60 dB), 8 or 16 channels, 100k to 100M bandwidth, and a lower cost than the original system, while using the same family of amplifier components that have worked well for the lab in the past.

Initially, we started by looking at an existing prototype for the amplifier designed by the client and tried to simulate the circuit. This, unfortunately, did not prove to be very fruitful, as we did not have and could not obtain a Spice model for the amplifier used in the design. We still used the simulation for the first few weeks to learn more about the circuit and what changing each component did to the functionality of the circuit. At this point we decided to stick with testing out the changes we wanted to make and stopped using the simulations.

While testing, we used our project advisor's program on LabView to run frequency response and provide a graph of it for interpretation. This showed us the first problem that we worked through: Our signal was being clipped at the second stage of amplification when using a higher input voltage due to a limitation of our output voltage swing. We fixed that problem by introducing another amplifier from the same family that has a higher operating voltage for the second stage, allowing for a wider output voltage swing. In order to accommodate the higher operating voltage for the new amplifier we reconfigured the circuit to run off 10 volts. We then ran into a new problem with the new amplifier introducing a sharp peak at the beginning of the frequency response. We believe that increasing the value of our AC blocking inductor on the biasing circuit can equalize the gain across the full bandwidth.

As of now, our client says the performance of the amplifier is already better than it was and would be acceptable for usage. We know this by looking at the frequency response and the health of the output waveform seen on the oscilloscope. This improvement aside, we plan to improve the gain more next semester and start some EMI testing before going to the production steps. For the production steps, we have designed a power supply that will work to supply the voltage rails for our circuit. We have also gotten started with the design of the enclosure that will be needed for the boards. Going forward, we will first work to remove the peak in the gain, and then evaluate whether an additional amplification stage is necessary. Finishing the enclosure design will be completed concurrently with this process. After that we will make the boards, solder all components and build the enclosure.

Learning Summary

Development Standards & Practices Used

We used standard circuit and hardware practices on this project to prioritize the safety of the group members or longevity of the materials and equipment being used. This includes:

- Turning off power before handling electrical components
- Verifying equipment voltage/current ratings and not exceeding them
- Verifying component power ratings and not exceeding them
- Circuit documentation to avoid mixing up parts
- Connecting circuit to an earth ground to avoid build up on board
- Evaluating solder joints and wires
- Wearing safety glasses when soldering
- Maintaining a safe distance from person soldering
- Letting components cool before handling after soldering
- Blowing emitted particles from solder flux towards vacuum
- Not setting sensitive components on the outside of ESD casings
- Using proper ESD precautions
- Knowing where the eye-washing station and the fire extinguishers are

For software practices, we didn't have that many that we needed but here's the few that we did need: Sharing simulation and testing files securely, updating ourselves with current technology and techniques, and saving frequently and with multiple versions in case of system failure.

The engineering standards considered that are applicable to this project are:

- IEEE Std 287-2007: Standard for Precision Coaxial Connectors
- IEEE Std 370-2020: Electrical Characterization of Printed Circuit Board and Related Interconnects
- IEEE Std C63.4-2014: Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment
- ISO/IEC/IEEE 60601-1: Medical Electrical Equipment – General Requirements for Basic Safety and Essential Performance
- IEEE Std 1857.7-2019: Standard for Advanced Audio and Video Coding Techniques for Ultrasonic Imaging Applications
- IEEE Std 1516-2010: Standard for Modeling and Simulation High-Level Architecture
- IEEE Std 469-2018: Calibration and Test of RF Power Amplifiers for Measurement Systems

Summary of Requirements

Functional Requirements:

- Low noise: Less than 2 dB
- Low input impedance: About 50 Ohms
- Bandpass filtering: 10kHz-10MHz (Constraint)

- High Gain (~100 to ~10000 V/V) (Constraint)
- Output voltage must be less than 10 V
- Handling input voltages from 100 μV to 10 mV

Physical Requirements:

- Protection from ESD and EM interference
- Small size (< 5x5 cm each) (Constraint)
- Modularity - Usable with 8 or 16 amplifiers (Constraint)
- Thermal Dissipation
- Ability to mount on PAT machine

User Experience Requirements:

- Low maintenance
- Easy to set up
- Modularity ensures the ability to change components easily

Applicable Courses from Iowa State University Curriculum

The courses that we have taken here at Iowa State University that have helped us develop the knowledge needed for this project include:

- EE 201: Electric Circuits
- EE 230: Electronic Circuits and Systems
- EE 330: Integrated Electronics
- EE 311: Electromagnet Fields and Waves
- EE 333: Electronic Systems Design
- EE 414: Microwave Engineering
- ENGL 314: Technical Communications

New Skills/Knowledge acquired that was not taught in courses

New skills and knowledge that we have learned from this project that we have not learned in class are:

- PCB design and testing
- Surface Mount Device (SMD) Soldering
- Through Hole Technology (THT) Soldering
- Advanced amplifier theory
- RF-Choke theory
- Enclosure material and design
- Power supply design
- EMI with RF signals
- Photoacoustic imaging technology and applications

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1. Introduction

1.1. Problem Statement

Photoacoustic Tomography (PAT) is a technology currently in development that can be used to obtain high resolution images of biological tissues. This has many potential applications both in medical practice and research. Professors and post-graduate students at Iowa State University are currently using photoacoustic imaging for research in Iowa State's Microelectronics Research Center, but their system could be better. One issue encountered in developing these systems is that the sensors used to capture these images produce very weak signals with a relatively high amount of noise. Currently researchers are dealing with very low amplitude signals and are having difficulty in getting a high enough resolution. Our project aims to solve these issues using a Low Noise Amplifier (LNA), which can boost the signal without introducing noise in order to produce a clear, high resolution image. Our task is to improve upon the design of the current amplifier to make the signal easier to tell from the noise and boost its strength. Additionally, the current amplifier enclosure takes up a lot of space and is hard to use, so our project aims to create a new modular enclosure which can be directly mounted on the PAT machine. This is an important issue in the new applications of this acoustic imaging system. It is a newer field, and improved image quality can help get better quality images for determining cell structure and small parts of tissues that were blurry before.

1.2. Intended Users

The Amplifier that we are designing will be used primarily by Iowa State postdoc researchers in the EE/BME fields. It will help them to be able to see smaller variations in output from their photoacoustic imaging setup. Alongside the postdoc researchers, postgraduate researchers and professors will also be using the amplifier. Finally, once research is complete, medical professionals will also use the amplifier.

Postdoc and postgraduate researchers will have almost the same characteristics and needs, although the postdoc researchers will likely have slightly more interaction with the amplifier. These researchers will be Iowa State University students who are doing research using the MRC's photoacoustic imaging setup. The nature of this research will vary, however the amplifier will be used in the same way; with up to 16 input channels plugged into the photoacoustic outputs and the outputs of the same number of channels plugged into the input of the oscilloscope used to measure. These researchers will want a simple device that requires little to no technical knowledge and can simply be plugged into the system and forgotten about. They also want the amplifier to have enough gain to clearly see all possible information. Their needs are for a modular device that can amplify up to 16 very low voltage inputs to a level of up to 3.5 volts each while not introducing noise. Additionally they would like to have a device that is very simple to use and preferably can be set up and then completely forgotten about. In accordance with wanting limited interaction with the amplifier, the researchers will likely also want an amplifier that is small in size, so that it does not take up additional space on the lab bench. These researchers will derive a lot of value from a high quality amplifier, as it will aid them in their research, and perhaps even be able to measure values that they could not before.

The professors' interactions with the amplifier will be even more hands-off and limited. The professors will not want to have to interact with the amplifier in any way and will want to simply have a device that works. Their needs are simply for an amplification device that will allow their research to be completed. While they will want to make the student researchers' lives easier, the smaller minutiae of the design falls under the umbrella of the student researchers' needs more than the needs of the research professors. Like the student researchers, the research professors will benefit from this amplifier by having the ability to continue to do the research that they were already engaged in, albeit in a more simple and precise manner.

Medical professionals will be the users who will interact with the amplifier the least. The best-case scenario would be for them to not even know it is separate from the rest of the system. Their needs include functionality and integration with the rest of the system. These medical professionals will not be expected to perform maintenance on the amplifier, so a simplified design is less important than robustness and functionality to them.

1.3. Personas

Postdoctoral Researcher.

Name: Dr X.

Motivation: Publish high quality research on medical device imaging.

Needs: Not an electrical engineer hence needs a robust system that is easy to use and will not need a lot of time to use it.

Behavior: Balances a lot of projects relies on lab assistants to fix and set up projects.

Feel: Accomplished after using the amplifier to get high quality images due to the amplified signals.

Medical Professional:

Name: Dr Z.

Motivation: Use the PAT device to catch and diagnose diseases and use the high contrast imaging the device will produce.

Needs: Limited understanding of the technology hence needs a cheap user-friendly system that will produce high quality and accurate images.

Behavior: Focuses more on the images produced by the device and will try to interact with the device the least.

Feel: Relieved due to catching or diagnosing a disease early with the help of the PAT device.

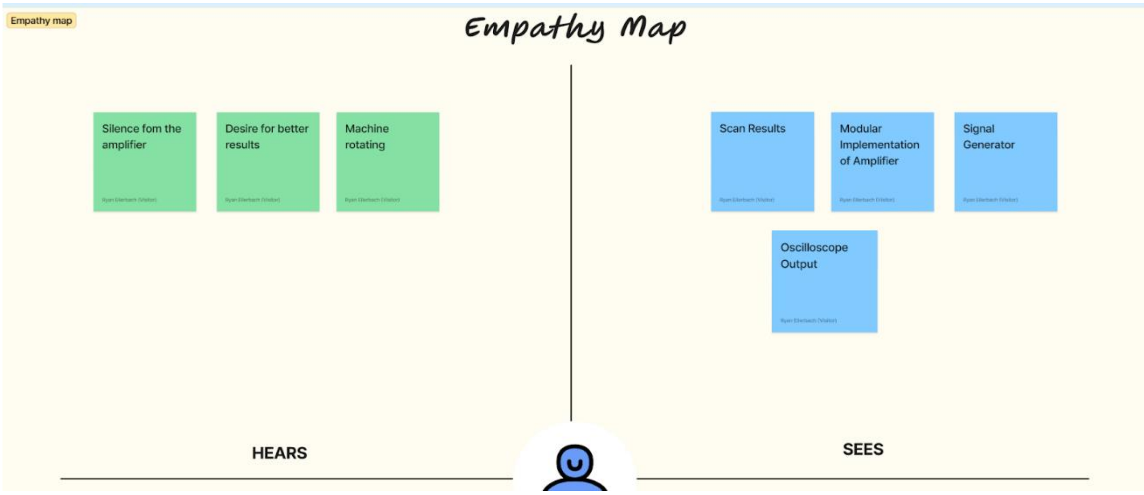

Figure 1

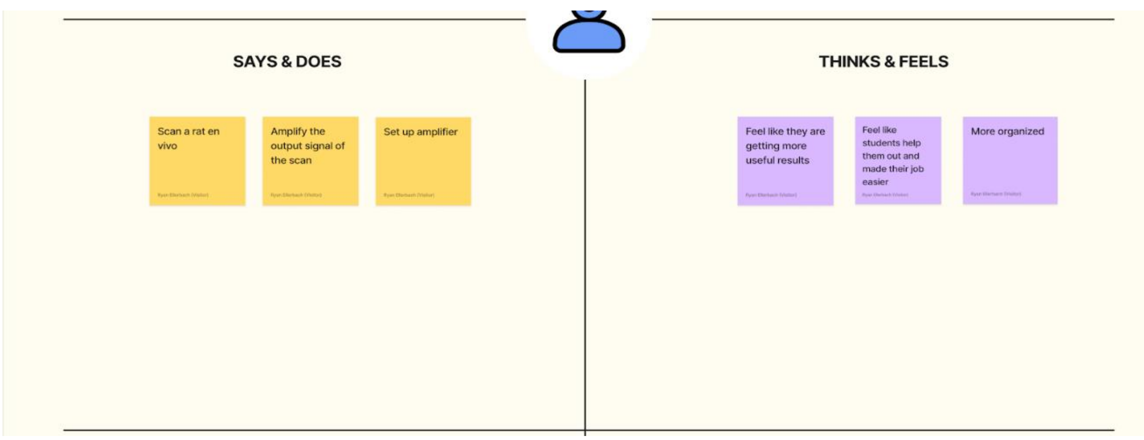

Figure 2

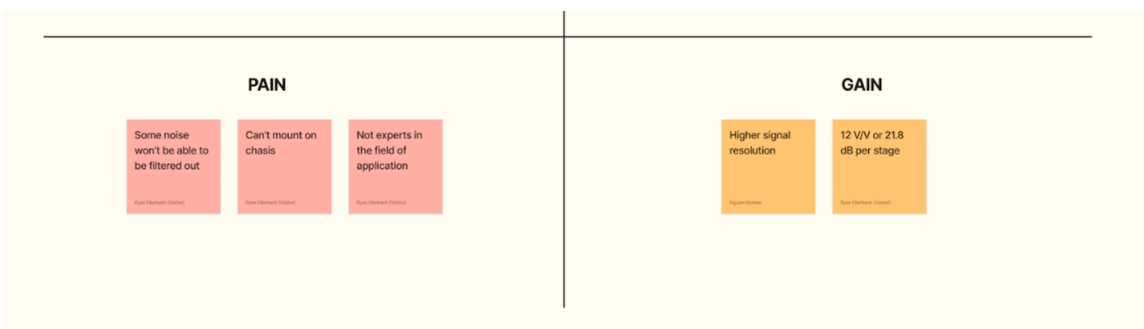

Figure 3

2. Requirements, Constraints, And Standards

2.1. Requirements & Constraints

Functional Requirements:

- Low noise: Less than 2 dB
- Low input impedance: About 50 Ohms
- Bandpass filtering: 10kHz-10MHz (Constraint)
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Physical Requirements:

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User Experience Requirements:

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- Modularity ensures the ability to change components easily

This project is primarily intended to be “behind the scenes” and will focus on functionality. The main non-functional and non-physical requirements are that it can remain both out of sight and out of the mind. It does this by being simple to install and by not needing to be worked on or fixed often or ever. The non-physical requirements therefore lead to some of the physical requirements. To facilitate a device with easy maintenance, the device will be modular so that if something goes wrong, that channel of the amplifier can be removed and replaced quickly. The other listed physical requirements of Electrostatic Discharge (ESD) protection and a small size also gives the device a better user experience, as ESD protection will mean less necessary maintenance and a small size will make the device take up less space on the workbench. As far as functionality goes, the device has to amplify the input signal without adding in a large amount of noise that will lower the quality of the measurements. This means low noise levels, filtered outputs, and a high gain. The low noise levels are achieved through the design of the amplifier itself and through filtering the outputs, as most of the noise that we expect to see falls outside of the bandpass filter. The high gain is the final requirement and constraint, and the most important one. The project aims to filter the output of an acoustic imaging system to a level that can more accurately be recreated by an oscilloscope and imaging software. Because of this, if the gain is not high enough, the rest of the project is far less important.

2.2. Engineering Standards

Engineering standards are essential because they provide consistency and reliability. Without standards, devices from different manufacturers would be unable to work together, and they may even cause other devices to malfunction or become damaged. Engineering standards allow engineers to know what to expect from existing devices.

Review of Relevant Engineering Standards

IEEE 1597.1-2022 – IEEE Standard for Validation of Computational Electromagnetics Computer

This standard provides methods of validating simulations of electromagnetic systems. This is relevant to our project because we need to design an enclosure to provide electromagnetic compatibility (EMC) for our amplifiers. We may need to use computational electromagnetics software to simulate our enclosure and ensure it provides protection, so this standard will be important to make sure our simulation is correct.

IEEE C63.2-2023 - American National Standard for Specifications of Electromagnetic Interference and Field Strength Measuring Instrumentation in the Frequency Range 9 kHz to 40 GHz

This standard is important to our project. The standard is needed for all projects with a detection frequency of 9 KHZ to 40 GHZ. The project we are working on has a frequency of 100Mhz which falls in this frequency. As listed above one of the requirements is ESD shielding that will also fall under the standard of IEEE c63.2-2023.

IEEE 790-1989 - IEEE Guide for Medical Ultrasound Field Parameter Measurements

While this standard might not directly apply to our project, it still holds relevance. This is because the amplifier we are designing is primarily going to be used in a medical imaging tool. In conclusion even though the amplifier itself does not need to follow the standard the overall imaging device does.

IEEE/AIEE 33-1927 AIEE Standards - Electrical Measuring Instruments

This standard does not have much relevance to the project. This is because while the imaging device that we are building the amplifier for has an oscilloscope, the amplifier does not fall under this category.

While these were not all the standards discussed, they were the standards that were deemed most relevant to our project. However, some alternate standards could be helpful. IEEE 1573-2021 is a standard relating to electronic power subsystems. This amplifier assembly will require a power supply, and this standard could help with designing a power supply.

These standards have not suggested any modifications necessary to the amplifier at this design stage, but they will be useful once we begin to design the enclosure and shielding. IEEE C63.2-2023, in particular, will be very useful to us when designing the enclosure, as it will provide us with ways to ensure we are not receiving or providing interference to any device operating within the same frequency range. Additionally, IEEE 1597.1-2022 will allow us to validate our simulations and ensure EMC compatibility before the device is even manufactured.

3. Project Plan

3.1. Project Management/Tracking Procedures

We are adopting a strategy that is a mix of waterfall and agile. The waterfall style makes sense because we have tasks and components of our project that depend on others to be completed before we can move on to the next. Agile makes sense in order to be flexible to be able to do the tasks simultaneously. Who does each task will depend on who is best suited for which parts are being worked on at the time. We will be tracking our progress on a Trello board, which is accessible to everyone in the project. We will also have weekly meetings with our advisor and biweekly meetings with our client.

3.2. Task Decomposition

The first thing we did was to simulate our amplifier in a realistic setting to get a sense of how it works. After doing this, we got some ideas on how to start changing the initial design to make it work for our application. One of our first main tasks is to determine which capacitor values for our filtering capacitors to give us a desirable gain. After that we will test the amplifier circuit in an abstracted system and then start adding stages. We anticipate needing to make adjustments and do simulations and more testing to make this work. We will then design and fabricate new boards. Once we get to building and testing, those will be the main parts that are able to be done simultaneously and individually. After we get one board working like we want, we will move to start building the enclosure and the other boards for the other channels. Once it all comes together, more testing in a closed system before we move to test it in the application setting.

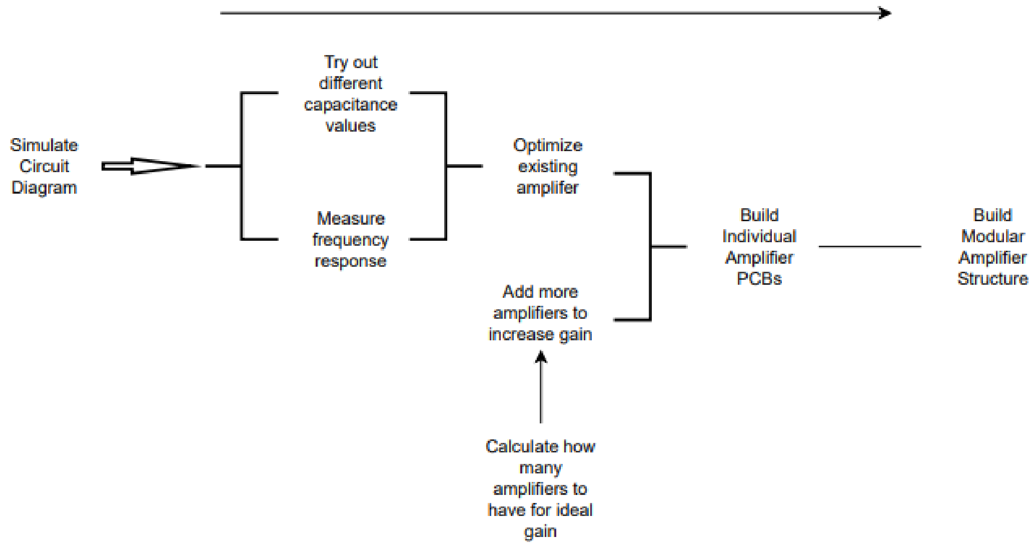

Figure 4

3.3. Project Proposed Milestones, Metrics, and Evaluation Criteria

Milestone 1: Creating a simulation of the amplifier. The circuit simulation will behave the same as the real prototype, with a gain and bandwidth within 10% of what is measured. Creating the simulation will allow us to more easily test different values and layouts.

Milestone 2: Improve the prototype based on information gathered from the simulation. Decrease the noise of a single stage and simplify the design.

Milestone 3: Add stages. We will increase the gain of the amplifier by increasing the number of stages so that it meets the 1000 to 10000 V/V design requirement. The original prototype had two stages and a gain of 100 V/V so we will add 1 or 2 stages to increase the gain to within our range. We will determine how many stages to add based off of the stability of the amplifier.

Milestone 4: Design a new board. Use PCB editing software to create a new board that will implement all of our changes.

Milestone 5: Fabricate new PCBs based off of improved design and perform lab testing on boards.

3.4. Project Timeline/Schedule

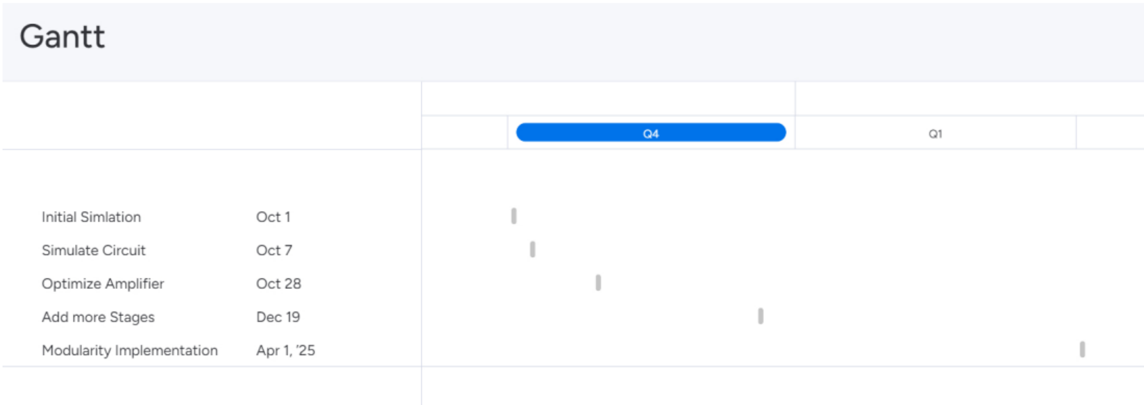

Figure 5

3.5. Risks and Risk Management/Mitigation

Risks for Milestone 1: May not be possible to get this level of accuracy from our simulations. The probability of this happening is likely around 0.7. The reason for this probability is that we do not have the spice files for the MAR6SM+ amplifier, so we must build the amplifier ourselves to simulate the circuit in software's like NI-Multisim. If this happens, we will have to rely more on prototype testing than we would like. To mitigate this risk, we will do a lot of work on the hardware version to have as much data as possible to feed the simulation.

Risks for Milestone 2: Minimal, only large risk is the one mentioned above for milestone 1.

Risks for Milestone 3: Possible that the desired gain is not attainable with the components we have selected. Probability of about 0.4. Also, it is possible that the noise ends up being larger than expected, a probability of about 0.45. For mitigating these risks, we could use different components if we find out that we need to.

Risks for Milestone 4: Minimal risks, possible delays from inexperience. We will work to refamiliarize ourselves before beginning work in order to decrease these risks.

Risks for Milestone 5: Delays in component arrival times, as well as the possibility of incorrectly putting the boards together. To mitigate this, we will factor in extra time to deal with late times, as well as order more than just 1 set of components and boards in order to make sure that we can build a new one if the first prototype board is built incorrectly.

3.6. Personnel Effort Requirements

Task:	Simulation	Improve prototype	Increase gain	Fabrication/Testing
Hours:	70	60	40	50

Table 1

3.7. Other Resource Requirements

We will require no other resources apart from any free websites/articles/software we use for research. We are using NI MultiSim and ADS to simulate our design. Both NI MultiSim and ADS are already available to us through ETG or by using a university computer.

4. Design

4.1. Design Context

4.1.1 Broader Context

The amplifier we are designing is being used in a large context as a part of a PAT device. The amplifier that was developed before this was very expensive to use hence the team is trying to build a cheaper one. The communities we are trying to design for is the Medical Device industry. The societal need our design is fulfilling is the need for better medical imaging devices. The communities that the device affects are medical society and even to an extent the material science industry.

Area	**Description**	**Examples**
Medical Industry	The amplifier is being used as a part of the PAT device. This PAT device will help introduce a new medical imaging technology.	The product will help the medical imaging device industry make high contrast pictures quicker
Global, cultural, and social	This project helps in the advancing field of Photoacoustic Tomography. It will be used to achieve better results for a team of researchers already working to research its implementation in healthcare	PAT could be used in the future for imaging of human organs such as the brain. It could be used to find problems such as cancer earlier.

Environmental	The environmental impacts of the project are minimal. Due to a small number of components and low production quantities the project will not be very impactful on the environment.	Resource production for raw and processed materials such as silicon or ICs will not be impacted by the small number of components that would be used, even if there were a large number of units produced.
Economic	This project will save the client's university, Iowa State, a small amount of money, as the current set up is expected to cost a lot more than the new product.	Cost savings will be low, however, as a large number of units is not necessary.

Table 2

4.1.2 Prior Work/Solutions

One device that is similar to our project is the ZFL-500LN+ from mini-circuits. However, we believe that we will be able to create a device that will be cheaper and more focused on our needs. While we are building from previous work, it is not documented work, which makes it more difficult to build from.

4.1.3 Technical Complexity

Our project includes many factors that contribute to the complexity of its design. First, we need to consider many different parameters which will characterize the performance of our amplifier: gain, bandwidth, power supply, noise levels, distortion, and other factors. The project also includes in-depth knowledge about PCB design. Knowledge of SMD components such as the difference between linear and switching regulators is paramount to the power supply system and therefore the functioning of the device. Knowledge of crosstalk and how to avoid it in PCB design is also necessary in order to reduce noise levels as low as possible. While other amplifiers that can achieve similar results do exist, our project aims to make a product that will both function better for our client's application and also cost less.

4.2. Design Exploration

4.2.1 Design Decisions

One design decision we had to make was determining our supply voltage and bias network. The limit we have for the amplifiers' output voltage is 10V, but our design was supposed to have a 5V supply based on the original specifications. The problem with this is that the amplifier we use is biased, so if we want a high enough gain without clipping, the output voltage must go up to 7V. Therefore, we had to make a design decision on whether to increase our supply voltage or accept a reduction in gain due to clipping. We decided to switch to a 10V power supply, as our client desired a high gain, and the 5V supply was not as high of a priority for them.

Another design decision we had was to make our layout on the PCB physically linear. For example, the first amplification stage is on the left, and then they cascade to the right. The primary purpose is ease of understanding, which will look cleaner on the PCB. It will make it much easier for users to be able to see what the circuit is meant to do and be able to change out components quickly and easily without mix-ups. Additionally, it will minimize the lengths of our traces to prevent interference and parasitic impedances.

One decision we will make is how to shield each signal from the noise and crosstalk coming from the other amplifier boards when we create the 8 or 16 channels in the same enclosure. We must determine which material, what thickness, and how to format placing the boards together. We will need to keep it quickly operational and interchangeable for the user. This will be important to limit the noise for our primary goal of increasing the signal contrast while keeping multiple channels for increased throughput and e efficiency of research.

4.2.2 Ideation

One thing that we had to choose carefully while planning the initial design was determining which amplifier we would use for the design. We examined and researched many different amplifiers and some that came with the application board design.

One option we considered was a nonspecific multipurpose op-amp. We could design the resistor network to reach the correct gain, but it would not be low noise.

Another option we looked at was using multiple amplification stages for a higher gain. We have decided to use this to reduce the specs needed for our amplifier. The third thing that we looked at was using a low-noise amplifier. Because these are commonly used for audio applications, they often can't operate at a high enough frequency.

For the fourth option, we thought about the input bias currents. Minimizing the input bias current and offset voltages will decrease the noise and interference in our circuit. Because of this, we chose to use a maximum of 16 mA, which is the lowest that works for our amplifier.

The last thing we will mention here is to filter both the input and the output of the circuit. This can make sure that we are filtering out noise and anything outside the typical region that our instrument will be operating in. One drawback of this method is that it can cause capacitive alteration if not used with a resistor.

4.2.3 Decision-Making and Trade-Off

We considered the many options available when selecting our amplifier and the number of stages. This mostly started with comparing the data sheets of the different possible options. Using data sheets, we could easily compare operating frequencies and gain. We also compared the footprints of each of our possibilities. We decided the most accessible and straightforward option would be to use the multi-stage amplifier.

4.3. Proposed Design

4.3.1 Overview

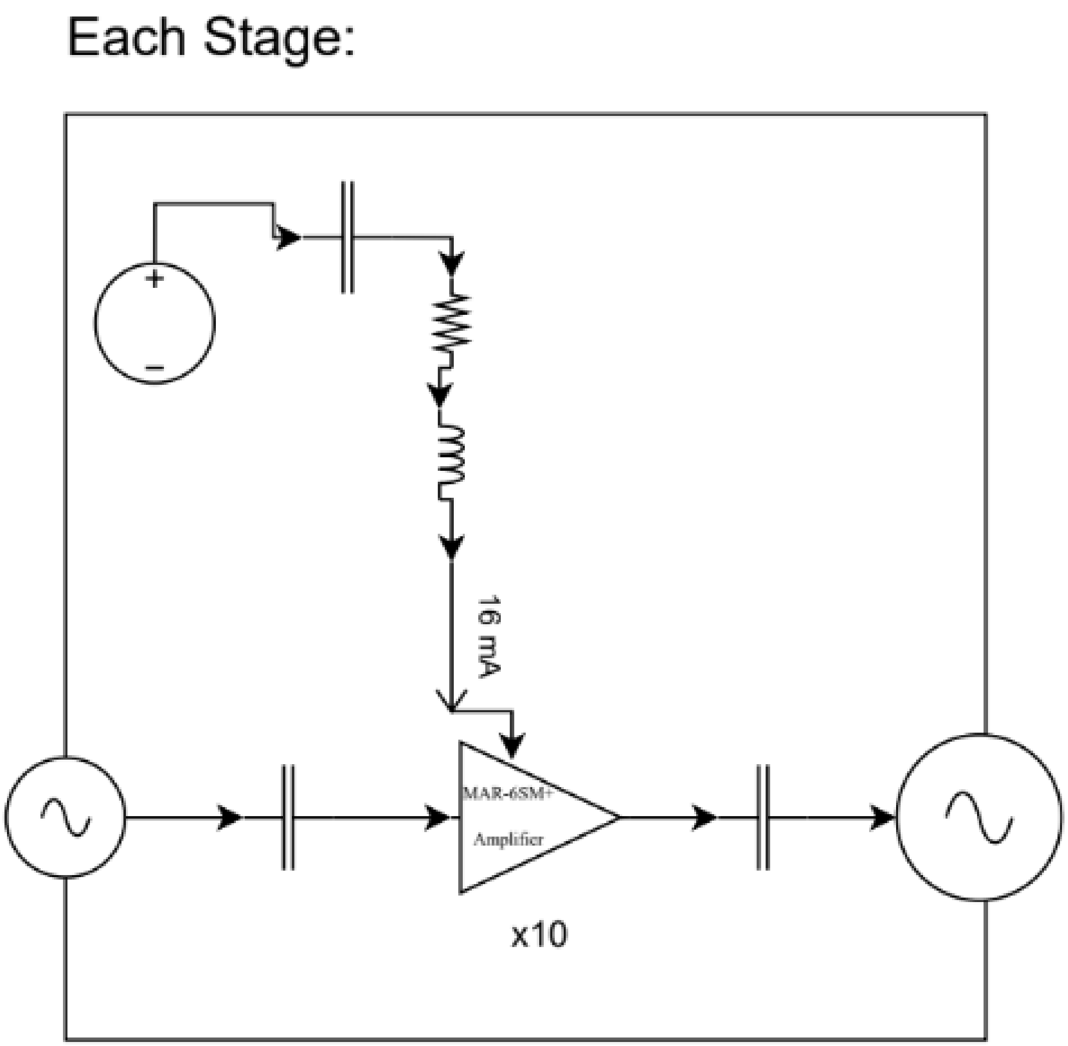

Figure 6

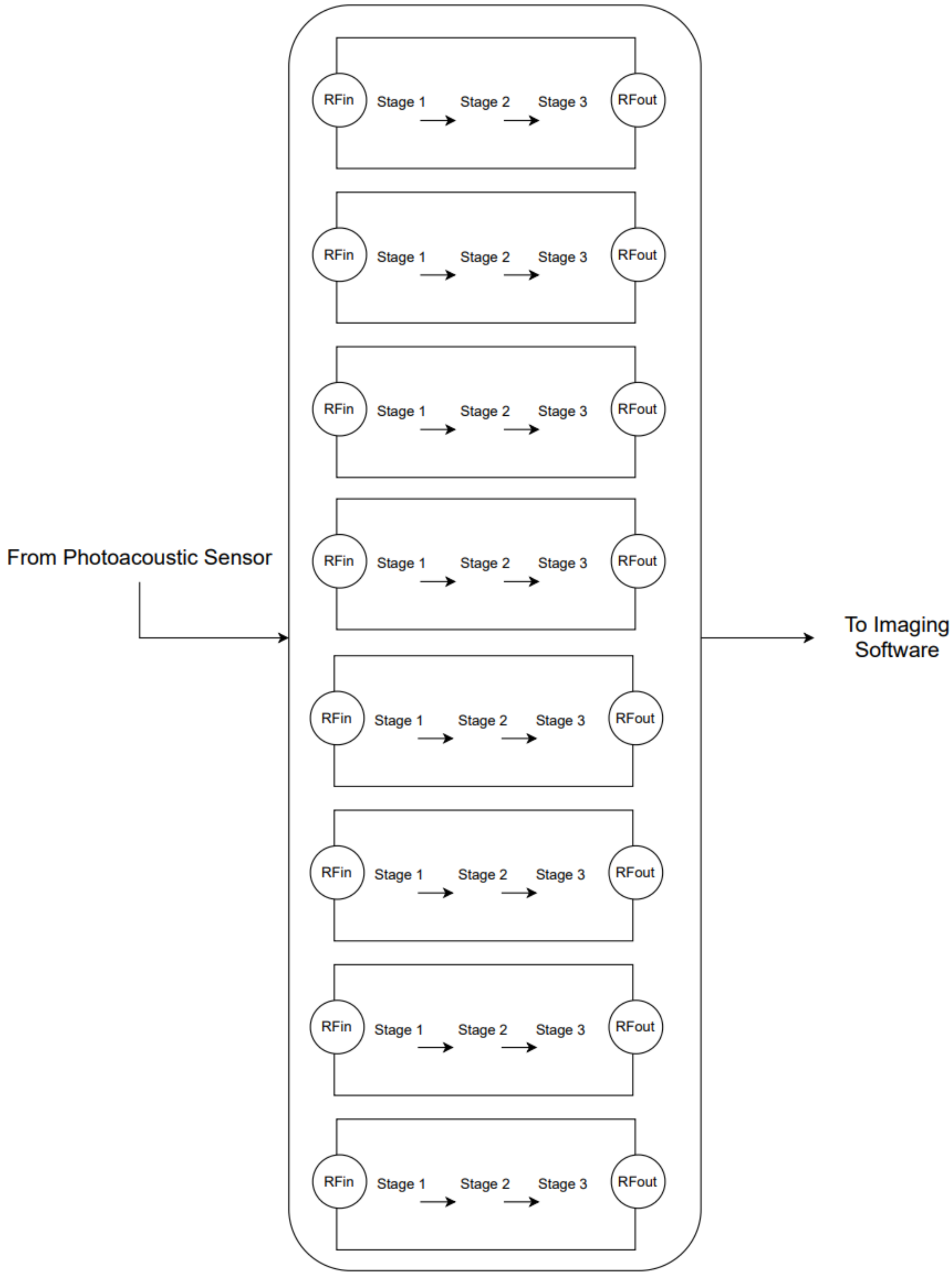

Figure 7

The problem is that the quality of the imaging software for receiving ultrasound signals is currently lower than our client would like. Our solution will include an 8/16-channel amplifier (8 shown here) to boost signal strength. The number of stages in the amplifier will be two to four, depending on how much gain can be derived from each stage. Additionally, each stage will be implemented slightly differently, with the last stage using the MAR-3 amplifier and the first stage using the MAR-6 amplifier. If more than two stages are necessary, an earlier stage using another MAR-6 amplifier can be used. The different stages using different components comes from the tradeoff between gain and maximum output. The MAR-3 amplifier doesn't have as high of a gain as the MAR-6, but the MAR-6 is unable to reach the voltage levels necessary at the output.

4.3.2 Detailed Design and Visual(s)

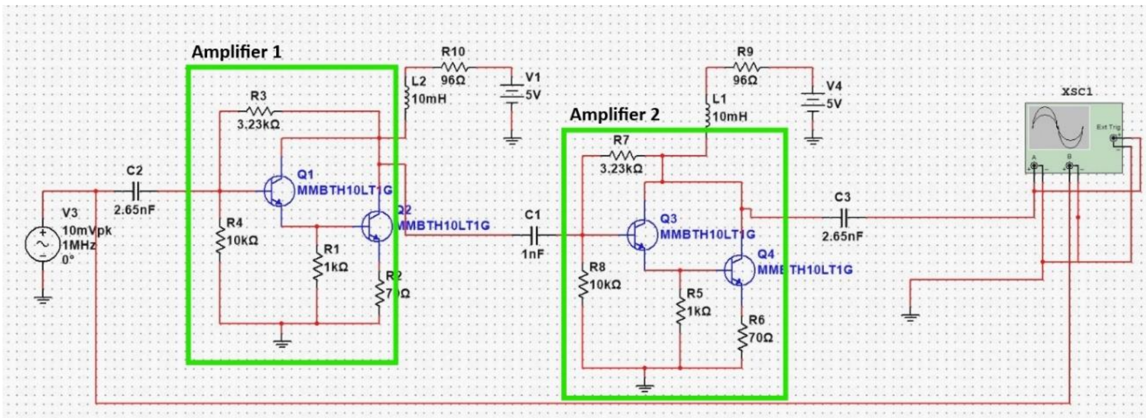

Figure 8

We have our initial simulation above, which includes two amplifier stages. We have modeled our input signal as a 10 mVpp sine wave at a frequency in the pass band determined by our filtering capacitor. We have two separate voltage sources to provide our biasing current for each amplifier. Our signal goes through filtering and amplification from amplifier 1, which we have abstracted as a simple Darlington amplifier using two transistors. The signal then hits a DC-blocking capacitor to limit offset from the first stage.

After the first stage, the signal goes through the second amplifier and the last filtering capacitor, which has the same biasing current as the first amplifier. The biasing circuit for the second amplifier is adjusted for the 10V source because we are trying a higher voltage source to fix an issue with saturation that we will talk about later in area 4.3.4. To help with the noise, we have included a bandpass filter at each stage to filter out low-frequency mechanical and high-frequency electrical noise. The inductor in the biasing circuit prevents AC components from impacting the signal transmission.

4.3.3 Functionality

The design is a modular, 8/16-channel amplifier on a PCB board with an RF input and output. This means that the user can plug the amplifier into the two signal RF cords between the PC and the laser device of the photoacoustic biosensor. Then, they can continue with the device's standard procedure to scan their target object. With the design of our enclosure, it should be straightforward to take out and change components off each PCB individually.

4.3.4 Areas of Concern and Development

Right now, the design meets all the requirements regarding design suggestions, but we are still working on achieving the goals we set out to meet. These goals include a high gain, low noise, a particular frequency band, modularity, and a 5V source. The current design is experiencing clipping at specific input voltages, limiting the gain we want to achieve. It also seems like the pass band for our filter is slightly off, but that shouldn't be too hard to adjust once everything else is working. Our immediate plan is to test smaller portions of our circuit to see which parts are working and which are causing our problems. At the same time, we will also be trying out different component values to fix our gain issues.

4.4. Technology Considerations

We used NI Multisim and ADS for the simulations. An advantage ADS had over Multisim was that we could use the S parameters of the amplifier to model it better there than we could on Multisim. It would be most helpful to have the component Spice file available for the simulation for the best results. An advantage of NI Multisim is that we could use an oscilloscope to hook up to our circuit to provide a more accurate portrayal of our testing environment. For testing, we have been using some firmware that our project contact made for us on LabVIEW that automates frequency analysis and dramatically speeds up the testing process.

4.5. Design Analysis

We have simulated and tested both our initial and modified designs. This included many iterations of simulations, research, and physical testing. Our initial design did not work as expected, so we first brainstormed what could be causing that and are now trying out some different things we think could fix the problem. We question whether or not the problem is caused by having 5V as a source, so we are trying the current design with a 10V biasing source to see if that fixes the problem and what else changes in the results. To do this, we must order new parts, wait for them to come, and then change out the old components for the new ones.

5. Testing

5.1 Unit Testing

The single module amplifier itself was the main device under test. The most important test for this was the frequency response, where gain was measured across a large bandwidth of frequencies. This was done using 3 main tools, a signal generator, an oscilloscope, and a computer running LabVIEW. LabVIEW utilized code that would sweep through a range of frequencies and send them, along with an input voltage, to the function generator and to channel one of the oscilloscopes. This generator was then connected via SMA to the board, which was then connected to the second channel of the oscilloscope using another SMA connector. LabVIEW would then take the information from the oscilloscope and plot gain in volts per volt against frequency.

5.2 Interface Testing

The interfaces of our design are the two amplifier stages, the power supply circuit, and the input and output SMA connectors. The amplifier stages are tested jointly as described earlier, under section 5.1, however a single stage was also tested independently using the same methodology by assembling a second board with the second stage shorted, as seen below. The amplifier stages were also isolated in some tests from the input and output SMA connectors by using scope probes instead of the SMA connectors to connect to the oscilloscope. The power supply has yet to be fully realized but we have been testing how it will interface with each module of the amplifier. Both the voltage and current of the power supply are being measured by using both the desktop power supply currently in use, as well as a handheld multimeter.

5.3 Integration Testing

Nearly the entire system is part of the critical path. While each module is not critical for the functionality of the other modules, the intended implementation of the device will use all modules in parallel. A single channel of the device could fail without affecting the other modules, however this will cause the overall system to not work as intended, as the users would like to be able to use all 8 channels of the device. This is why the channels are implemented as individual modules, a nonfunctioning module will be able to be removed and replaced with a new, functioning board. Along with the amplifier channels, the power supply circuit is critical, as if it doesn't function properly, none of the channels will be able to function properly. The non-electrical components of the design, such as the enclosure, are not critical, as they will only serve to hold the modules in place.

5.4 System Testing

The future strategy for testing the system is like the strategy for testing a single module. Testing will vary because this strategy will not work to test all stages at once. The single module strategy will, however, work for testing up to three modules at once, as the oscilloscope in use has four channels and one must be used to measure the input. Testing three modules at once should be enough to verify functionality of the complete system by rotating through which channels are under test. The power supply circuit will be tested using a multimeter to measure the voltage and current outputs. The functionality of other parts of the system can be verified in the same way that they would in the single module scenario.

5.5 Regression Testing

New additions to this project only exist in increasing the number of modules being used. Because of the modularity of the design, the only ways in which more modules could affect the existing design are in electrical interference, heating, or power draw. The enclosure is not complete but should be designed in a way that heating and EMI interference are not a major issue. The power supply circuit has been chosen in a way that will ensure that it can accommodate all current draw requirements for an 8-channel system. If the design is increased to 16 channels, either a redesign of the power supply is necessary, or the 8 additional channels will need an additional power supply.

5.6 Acceptance Testing

The design requirements can be proven to have been met by comparing the testing data to the requirements. For less specific requirements we have worked with the client to verify that they are being met.

5.7 Security Testing

Security is not a concern for this project. The amplifier is intended to be used in a secure area and does not have any software that could be compromised.

5.8 Results

Testing thus far has been useful in eliminating some issues the original prototype had. For example, we were able to verify that the clipping issues at the high end of the input range have been removed. This also makes it possible to increase the number of stages in a single amplifier if that is something that will be necessary in the future. This improvement can be seen by the elimination of the dip in the second test compared to the first test, where both tests are run at the same input amplitude with the same range of frequencies. The first test in the below graphs is using the original unmodified prototype and the second test uses the same design but with a higher voltage power supply and a slightly different amplifier arrangement.

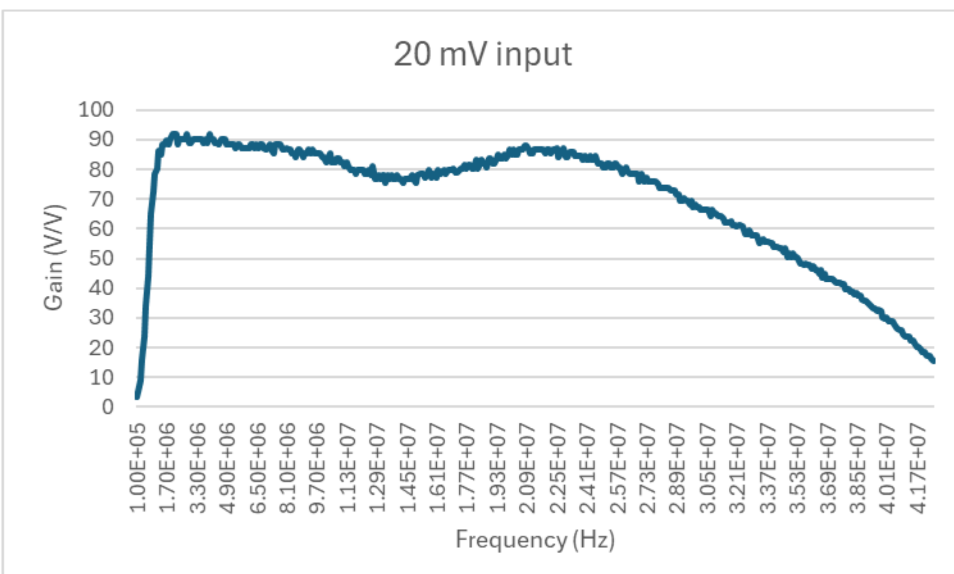

Figure 9

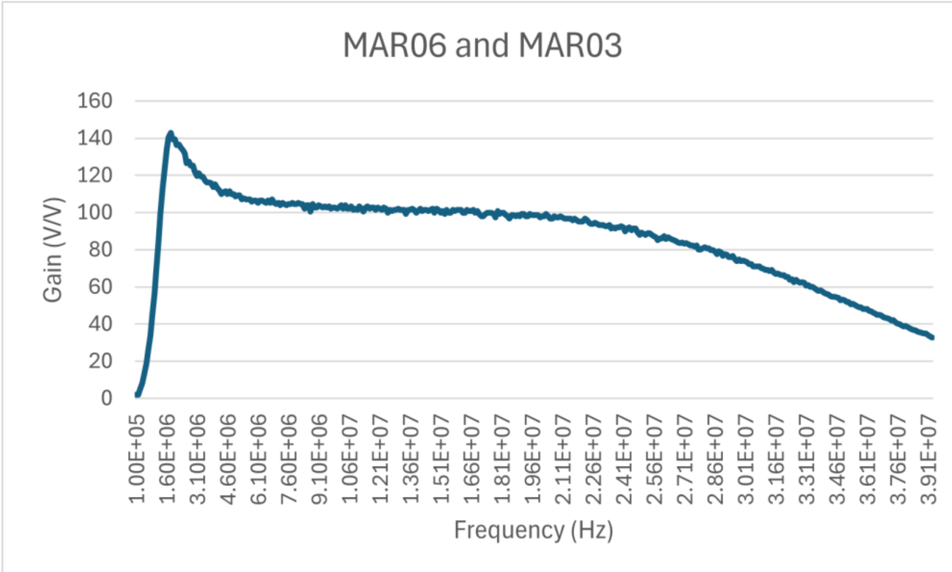

Figure 10

Future tests will be done on further iterations of the design, one goal we have is to eliminate the spike seen at low frequencies on the above graph. Testing for this will continue in the same way that all previous testing has.

We are using the data that we measure to ensure that we meet our user needs by verifying that our measured values will fall within the range of acceptable values that the client has given us.

6. Implementation

For the team to implement the amplifier we are building, the team will have to make an enclosure. This enclosure must be modular, have some EM shielding and Heat sinks, and connect to the larger PAT device the amplifier is being developed for. The amplifier will also have a battery-operated power source to run. This semester the team has worked primarily on designing the amplifier. The team has developed the preliminary implementation for the enclosure and power source.

The enclosure we are designing is currently planned to be 10 x 20.27 x 0.5 cm dimensions. It needs to have some method of heat dissipation to avoid overheating and some EM shielding. Our preliminary design concept needs heat sinks or connection holes to connect the amplifier to the PAT device. The team is still determining how many stages the amplifier design will be, but the enclosure will be large enough to fit eight. The team is looking into materials like copper, aluminum, or steel for the EM shielding to encase the inputs and outputs to prevent Electromagnetic Interference. The amplifier boards will also be spaced out at 2cm between each other, and a GND plane will be added to the outside of the boards. In case of on-board heat sinking, the amplifier boards will be designed in the PCB design software using wide power traces, and for additional heat protection, the boards will have thermal relief added to the power and GND vias.

While designing the power supply, the team had to consider how much power the amplifier would draw in. A single amplifier stage draws in around 51mA of power from a 10v supply so we needed at least 4.08W of power. The amplifier being designed is also a Low-Noise amplifier; hence, we could not use a switching regulator. This is because the inherent switching will generate high-frequency noise, thus degrading the signal quality. The power supply we are designing will use three 11.1V lithium-ion batteries, specifically the L111A26-3-2-2WX. These batteries will feed into the HiLetGo Li-Ion charging circuit, and we will use a linear regulator which has low noise and outputs a stable 10V.

7. Ethics and Professional Responsibility

Our ethical and professional responsibilities in this project are grounded in our commitment to ensuring quality and integrity in everything we do. We prioritize human well-being and safety, sustainability, honesty, competence, and social responsibility in our simulations, design, development, testing, and fabrication of our product.

7.1 Areas of Professional Responsibility/Codes of Ethics

Area of Responsibility	Definition	ACM Principle	Our Team's Interaction
Work Competence	Completing work with high efficiency and quality, progressing towards the goal.	2.1 Strive to achieve high quality in both the processes and products of professional work. 2.6 Perform work only in areas of competence.	Splitting up work to each member that knows the most about that subject. If nobody knows enough, we research to not be going blind.
Financial Responsibility	Being transparent about financial budgets, risks, gains, loses, and economic impact.	1.3 Be honest and trustworthy	We all discuss the financial impact of decisions as a part of determining the best outcome. For example, during component selection and circuit design.
Communication Honesty	Being truthful and transparent about intentions, statistics, and all things the public or company needs to know.	1.3 Be honest and trustworthy.	We tell every concern or question we have to our client who we work with every week or our project advisor with whom we meet biweekly.

Health, Safety, Well-Being	Practice all of the applicable safety procedures. Have the public's well-being at the forefront of every decision.	1.2 Avoid Harm.	Adhere to the electrical safety standards talked about at the beginning of this document.
Property Ownership	Only use technology you are permitted to use. Only give information out to people who are authorized to have it if permission is given by the owner of the information.	1.7 Honor Confidentiality. 2.8 Access computing and communication resources only when authorized or when compelled by the public good.	Our testing results, designs, plans, are never discussed with anybody outside of the group. All the software we need is provided to us by ETG.
Sustainability	Think about how this decision will last in the long term, how long this technology will be relevant, and what long term impacts will be seen from the result of this decision.	1.1 Contribute to society and to human-well-being, acknowledging that all people are stakeholders in computing.	Making sure that our design will be energy efficient and long lasting. Ensuring that the design is good to use for a while before new technology replaces it.
Social Responsibility	Think and act without discrimination, think about the target audience, users of the product and how it impacts them or what messages your project could send others.	1.4 Be fair and take action not to discriminate.	We aim to make our product more affordable even though the target audience would be people who have access to very expensive photoacoustic imaging systems.

Table 3

One area our team is doing well is communication honesty. We all feel comfortable working together and working with our project contacts. When we have any concerns or anything that needs to be addressed, we do not hesitate to bring it to your attention to be worked on. Another way we demonstrate this is by asking questions. We feel that we do an excellent job asking questions about technical information and also what we can be doing better in the project. These signify a strong performance in the communication honesty area because we are truthful and transparent with each other.

An area that our team could improve in would be work competence. This applies mostly to the start of the project when we were doing research. We feel that we all could have done more research because none of us had extensive experience with photoacoustic imaging systems or RF amplification. In the future, we should make sure we are keeping up with the knowledge needed to perform well intuitively within the scope of this project.

7.1. Four Principles

	Beneficence	Nonmalificence	Respect for Autonomy	Justice
Medical Industry	Increasing accuracy of instruments can help detect diseases/conditions for patients.	Increased accuracy reduces the chances for false positives or negatives that can cause harm to the patient's recovery.	Improved image quality increases the amount that can be learned from the system.	Reducing the cost of the amplifier reduces the cost of the system, waterfalling to a reduced bill that can be more affordable for all patients.
Global, Cultural, and Social	Increased accuracy can help with rapid detection of disease where it's not readily available	Ensuring the amplifier doesn't harm individuals by emitting EMI that could disrupt other medical devices.	Intuitive silkscreen labeling and component placement to allow for users to see how it works.	Affordability and accessibility for all markets and communities
Environmental	Long-lasting design can reduce transport and material usage impacts of replacements.	Try to minimize energy loss by designing a power supply specific to this circuit's needs.	Modular design allows for boards to be deactivated if all channels don't need to be used. This gives users control over the total power consumption.	Doesn't have a significant impact on a specific region or area.
Economic	Making a cheaper alternative than is on the market right now.	Making sure the amplifier is long-lasting and doesn't have any parts that waste money.	Ensuring the users know how it works, why it works, and what repair or replacement might cost.	Try to make it affordable for everybody to be able to use that needs it.

Table 4

One broader-context principal pair that is important to our project is the beneficence in the medical industry. Generating a product that can improve the accuracy of the existing technology can help increase the speed of detection for diseases and conditions. Increased accuracy can also reduce the number of false positives and negatives which will greatly improve the usefulness of the technology and patient satisfaction.

One broader context principal pair that is lacking in our project would probably be respect for autonomy is the economic space. This is mostly because we think it is hard to communicate with users of technology about this small piece inside of a bigger system. Non-experts in the field, which might be the company's CFO or someone who approves of buying this system will have no idea our design is even inside the technology. To help with this we could send information to potential customers/users and inform them.

7.2. VIRTUES

Three virtues that are important to our team are honesty, commitment to quality, and commitment to the public good.

Honesty in terms of our project means each member being truthful and transparent about their thoughts on ideas and decisions. It also means being honest with ourselves and what we are each capable of. We have been doing a good job communicating with each other and sharing opinions, concerns, and future plans.

Commitment to quality means that we will not settle for anything less than the best that we can do in the time frame allotted to us in this class. We all try to accomplish each group-assigned task as well as we can for the benefit of the group and for the users that need the project to be successful.

Commitment to the public good entails making decisions while thinking of other's needs before ours. An example of this in our project is when we thought about designing a breaker circuit at the end of our amplifier to ensure that there's not too much power going back into the computer, which could potentially harm the user's equipment.

Ryan: One virtue that I have demonstrated throughout our work so far is courage and work ethic in testing and simulation. I am always enthusiastic about trying out new ideas that we have, to try to improve the circuit. This is important to me because effort and willingness are important to get work done and are particularly essential in group projects. One thing that I haven't demonstrated as much individually is patience. It can be very stressful with all the other schoolwork we all have and when I feel like we are behind where we want to be it is not easy to think calmly and clearly. One way I can demonstrate this is by letting my teammates know that it's okay if they must take a step back from project work for a little bit if they have put forth good effort and have other priorities.

Ethan: One virtue that I have demonstrated through our works so far is honesty. This virtue is important to me because it can prevent miscommunication and prevent potential problems with the project from being hidden or minimized. I have demonstrated this virtue by representing our progress as accurately as possible, without trying to cover up for failures or trying to make our team look better. One virtue that I believe I have not demonstrated adequately is leadership. Leadership is important to me because it can help a team work together more effectively and reach their fullest potential. One thing I can do to demonstrate that virtue is to take responsibility for the work of the entire group as if it were my own, instead of focusing on my assigned portion of the project.

Yash: One virtue I have demonstrated throughout the project is perseverance. This virtue is important to me because it means that we must keep working towards meeting the client's demands and present the best amplifier we can. I have demonstrated this virtue by trying different capacitor and inductor values to determine which gets the best frequency response. One virtue I haven't shown and still need to explain is creativity. Creativity is essential because it helps me come up with ideas when the team is at a dead-end and can breathe new life into a project that seems impossible. One thing I can do to demonstrate this virtue is to study different aspects of other biasing circuits or amplifiers and apply them to this project.

Jon: One virtue that I have demonstrated in this project is open-mindedness. I have demonstrated this by being receptive to other group members' opinions and ideas. Different ideas helped us to find more and better ways to solve the design problems we faced. We were also able to find ways to explore the implementation of multiple ideas. This open-mindedness also fostered teamwork and improved the team dynamic. A virtue that I could have done better with is being organized. While this wasn't something I lacked completely, there were times when I could have been more organized, either with notes, my time, or equipment. While this didn't cause many issues, keeping more organized notes and a more organized workspace could help the team to complete our tests even faster.

8. Closing Material

8.1. Conclusion

Our project goal is to develop a way to amplify the signal generated from a photoacoustic imaging system, used for research here at Iowa State. This amplifier circuit will need to amplify a radio frequency or RF signal to generate higher-quality images, from which better conclusions can be drawn. Our design requirement goals include low noise, a gain of about 40 to 60 dB, 8 or 16 channels, 100k to 100M bandwidth, and a lower cost than the original system, while using the same family of amplifier components that have worked well for the lab in the past. So far we have taken the initial design and fixed a few issues with it. These issues are clipping occurring with higher input voltages and an issue with the frequency response of our amplifier. We are still running into an issue with a peak at low frequencies, which we want to eliminate. We have designed a low-cost power supply to be used with the amplifier and have started the design of the enclosure that will later hold multiple boards, fulfilling the multi-channel design requirement. Some things that could be done differently in the future are documenting our exact thoughts and actions better and thinking more about the big picture from the very beginning if we must go back to the drawing board.

8.2. REFERENCES

[1] Mini-Circuits, "Surface Mount Monolithic Amplifier," MAR-6SM+ datasheet.

[2] Mini-Circuits, "Surface Mount Monolithic Amplifier," MAR-3SM+ datasheet.

[3] IEEE Standards Association, "Standards," *IEEE Standards Association*, Available: https://standards.ieee.org/standard/ [accessed Dec. 7, 2024].

[4] Association for Computing Machinery, "ACM Code of Ethics and Professional Conduct," *Association for Computing Machinery*, Available: https://www.acm.org/code-of-ethics [accessed Dec. 7, 2024].

8.3. APPENDICES

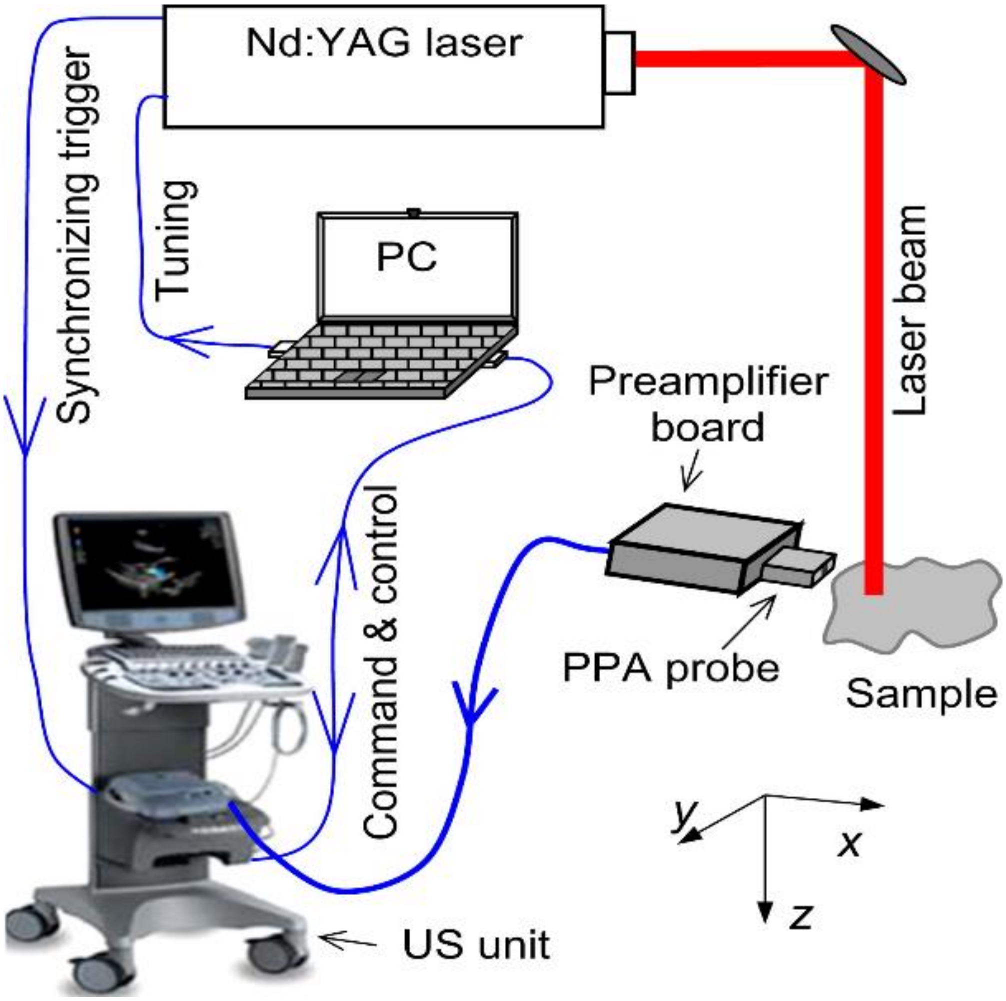

Figure 11

9. Team

9.1. Team Members

Ethan Hulinsky

Jon Wetenkamp

Ryan Ellerbach

Yash Gaonkar

9.2. Required Skill Sets for Your Project

For this project, the team demonstrated several technical and soft skills. This included technical skills like Circuit Design and Analysis, Signal processing, and PCB design, as well as soft skills like critical thinking and team collaboration.

Circuit Design Analysis: The team had to design amplifier circuits and see how changing the capacitor and inductor values would affect the circuit's frequency response.

Simulation Tool Proficiency: The team had to use simulation tools like LabVIEW to see the frequency response of the circuit as well as the software NI-Multisim to simulate the different testing parameters.

Lab Equipment Proficiency: The team had to use Oscilloscopes, multimeters, signal generators, and other lab equipment to run different tests on the prototype.

Power Electronics: The team had to know the basics of power electronics to design the battery-operated power supply of the circuit.

PCB design: we had to know about PCB design to understand how the amplifier boards worked and how to solder different components on the boards.

Critical Thinking: The team had to use critical thinking on several occasions to analyze different design Trade-Offs.

Problem Solving: The team used problem-solving to determine why the output was clipping at higher voltages.

Adaptability: The team had to adapt to the different requirements or feedback from the client and the advisor; for example, the client wanted us to use the MAR6SM+ Amplifier only, even though we didn't have the spice file.

Documentation: The team had to document all the weekly progress reports as well as the design docs and notes from the advisor meetings

9.3. Skill Sets covered by the Team

Yash: Circuit Analysis, Lab Equipment, Power Electronics, Documentation, Problem Solving, Adaptability, Critical Thinking

Ryan: Circuit Analysis, Lab Equipment, Power Electronics, Documentation, Problem Solving, Adaptability, Critical Thinking, PCB design, Simulation Tool Proficiency

Ethan: Circuit Analysis, Lab Equipment, Power Electronics, Documentation, Problem Solving, Adaptability, Critical Thinking, PCB design, Simulation Tool Proficiency

Jon: Circuit Analysis, Lab Equipment, Power Electronics, Documentation, Problem Solving, Adaptability, Critical Thinking, PCB design, Simulation Tool Proficiency

9.4. Project Management Style Adopted by the team

We had a waterfall and agile project management mix for the Project Management style. Typically, the waterfall is a style of project management where the team sets certain deadlines, which normally don't change. Agile has deadlines and milestones that are prone to change. Our team worked closely with our project contact, so the deadlines and stuff we worked on changed based on what was done the previous week. The client, though, had some hard deadlines that we had to meet. For example, he wanted at least a board prototype done before the semester's end. This is why some of the project management style that was adopted was a mix of the two.

9.5. Initial Project Management Roles

Yash: Team Organization

Ryan: Client Interaction

Ethan: Part Orders

Jon: Testing

9.6. Team Contract

Team Members:

1) Jon Wetenkamp

2) Yash Gaonkar

3) Ethan Hulinksy

4) Ryan Ellerbach

Team Procedures

1. Day, time, and location (face-to-face or virtual) for regular team meetings:

12:00 on Mondays, in person in the TLA in Coover.

2. Preferred method of communication updates, reminders, issues, and scheduling (e.g., e-mail, phone, app, face-to-face):

Text messages in the group chat, as well as face to face updates.

3. Decision-making policy (e.g., consensus, majority vote):

The majority voted to decide when the group doesn't completely agree.

4. Procedures for record keeping (i.e., who will keep meeting minutes, how will minutes be shared/archived):

Yash will keep records and will share a google doc.

Participation Expectations

1. Expected individual attendance, punctuality, and participation at all team meetings:

All team members are expected to attend all meetings and arrive within 5 minutes of the agreed upon start time. If a team member can't make a meeting notice of absence is expected an hour ahead of time. If a team member will be later than 5 minutes late, it is expected that they notify the group as soon as possible.

2. Expected level of responsibility for fulfilling team assignments, timelines, and deadlines:

All team members are expected to complete individual assignments and participate in completing group assignments in pace with the agreed upon timeline.

3. Expected level of communication with other team members:

Team members are expected to communicate any issues they have so that the group does not fall behind as well as reply in a timely manner.

4. Expected level of commitment to team decisions and tasks:

Each team member is expected to be present and prepared to help with all team decisions and tasks.

Leadership

1. Leadership roles for each team member (e.g., team organization, client interaction, individual component design, testing, etc.):

Yash: Team Organization

Ryan: Client Interaction

Ethan: Individual Component Design

Jon: Testing

2. Strategies for supporting and guiding the work of all team members:

Team members are expected to create an open and engaging environment where the group will help any team member who needs it. To facilitate this, team members are encouraged to reach out for help if they know they will need it.

3. Strategies for recognizing the contributions of all team members:

Team members will be congratulated for all work that is done.

Collaboration and Inclusion

1. Describe the skills, expertise, and unique perspectives each team member brings to the team.

Yash has expertise and interest in VLSI, which can help with the modularity constraint on the project. Ryan, Jon, and Ethan all have experience in PCB design which is a lot of what this project will entail. We all have taken different classes and many have different sequences which will give us a variety of perspectives and expertise.

2. Strategies for encouraging and supporting contributions and ideas from all team members:

All team members are expected to contribute as much as possible as well as encourage others to contribute whenever they can.

3. Procedures for identifying and resolving collaboration or inclusion issues (e.g., how will a team member inform the team that the team environment is obstructing their opportunity or ability to contribute?)

Team members should bring up any issues they have as soon as possible and the group will discuss solutions. Teammates are also encouraged to identify any other issues with another member they see so that the group is aware. The group is then expected to meet and discuss what they believe the best solution will be.

Goal-Setting, Planning, and Execution

1. Team goals for this semester:

Learn useful skills from the project and complete as much of the project as possible. Another goal is to take pride in our work and at the end of the year have a project that the team is proud of.

2. Strategies for planning and assigning individual and team work:

Break down our next task into individual steps and then categorize based off of time/difficulty and then distribute to those best suited for each task.

3. Strategies for keeping on task:

Keeping weekly meetings brief and to the point to give time for us to finish our other work outside of the time spent for this project.

Consequences for Not Adhering to Team Contract

1. How will you handle infractions of any of the obligations of this team contract? What will your team do if the infractions continue?

First major infraction: Brought up and discussed at team meeting

Repeated minor infractions: Discussed at weekly team meeting

Repeated major infractions: Discussed with team member first, then brought to the advisor and professors teaching the class

****

a) *I participated in formulating the standards, roles, and procedures as stated in this contract.*

b) *I understand that I am obligated to abide by these terms and conditions.*

c) *I understand that if I do not abide by these terms and conditions, I will suffer the consequences as stated in this contract.*

1) ________Ryan Ellerbach______________________________ DATE ______9/17/24__

2) ________Jon Wetenkamp______________________________ DATE ______9/17/24_____

3) _______Yash Gaonkar__________________________________ DATE ______9/17/24______

4) _______Ethan Hulinksy ____________________________ DATE ______9/17/24______

5) ____ DATE __________________

6) ____ DATE __________________

7) ____ DATE __________________

8) ____ DATE __________________