Purdue ECE Senior Design Semester Report
(Team Section)

Course Number and Title	ECE 47700 *Digital Systems Senior Design Project*
Semester / Year	Spring 2024
Advisors	Phil Walter, Joseph Bougher, and Rohan Sakar
Team Number	Team 12
Project Title	Microphone Interface

Senior Design Students – Team Composition			
Name	**Major**	**Area(s) of Expertise Utilized in Project**	**Expected Graduation Date**
Liam Roach	CompE	Embedded Software, Soldering, Design	May 2024
Jakub Kowalski	CompE	DSP, Embedded Software, OOP	May 2024
Joshua Hom	CompE	PCB Layout, Hardware, Embedded Software	August 2024
Shubo Xie	EE	Prototype, Power electronics, Schematic	May 2024

Project Description: Provide a brief (2-3 page) technical description of the design project, as outlined below:

(a) Provide a general description of the product to be delivered by this design project.

The Microphone Interface is a device that can apply several real time audio effects to a microphone's audio.This interface would receive the input from the microphone, or other audio device, and perform various kinds of DSP (EQ, distortion, and delay) to the signal using a microcontroller, with additional physical inputs in the form of knobs in order to adjust any of their parameters. This would allow the user to fine tune various effects which they would like to apply in order to adapt to their relevant environment, microphone, as well as intended sound they would like to achieve. The interface also contains UI on an LCD screen in order to help the user navigate the different effects and visualize the changes being applied to the signal, allowing the process to be more intuitive for users. The interface can be connected through an audio connector to a computer, or other audio device, as its output.

(b) What is the purpose of this product? For whom is it intended?

As a device geared towards audio the Microphone Interface has a large range of applications. The ability to quickly equalize audio on the fly makes it useful for people like live streamers, amateur podcastors, or even public speakers. The other audio effects and the convenient interface gives it utility for amateur and live musicians.

(c) Describe how the engineering design process used to create your product was utilized in this project. Include how you were able to develop and conduct appropriate experiments, analyze and interpret data, and use engineering judgment to draw conclusions related to the development of your product.

The first step of our design process was determining the specific hardware needed to execute the function of our product with certain criteria. Then the product was split into modules that could be prototyped and analyzed independently. These modules condensed down to the controls, touch screen, and audio (hardware & software). During this process we discovered that our initial plan of using USB to digitally transmit and receive audio was going to take

significantly more effort than we originally expected. This was because the libraries for USB audio for the microcontroller we were using were significantly under developed, and if we wanted to continue with that, we would have to likely write our own driver entirely. Therefore, we decided to make a design change, and switch to using analog audio using a codec connected to our microcontroller via I2S. The determined necessary parts were taken from each module to be integrated sequentially into a final product. Since the output of the product is heavily dictated by user input, most of the end testing consisted of evaluating the range of possible parameters. After the software was optimized, the device was assembled with the packaging and tested a final time.

(d) Describe the design constraints, and resulting specifications, incorporated into your product (list a minimum of 3).

- The biggest constraint of our device was to be able to receive and send audio through a standard audio jack. Initially, we envision the device receiving audio data from a USB microphone, and then transmitting that audio to a computer, also via USB. However, while conducting research and going through the prototyping process, we determined that the design effort for such functionality was much higher than initially expected, so we pivoted to using analog audio via a codec and two 3.5mm TRS audio jacks.

- A crucial aspect of our device was to perform DSP algorithms on the incoming signal. Oftentimes DSP algorithms are intensive and slow. In order to accommodate the other aspects of our design, we chose an STM32F7 MCU which offers more memory and higher clock speeds compared to MCUs from the other series.

- We also required that there be a user interface with controls and an LCD displaying a GUI. However, despite choosing a higher end MCU, we had some issues along the way with having both the user interface as well as multiple DSP audio effects running simultaneously while also being able to output audio continuously. In order to get around this, we had to maximize our clock speeds and use compiler optimizations in order to reduce the amount of time spent on processing, and used DMA to continuously receive and transmit audio data without relying on the CPU.

(e) Describe how each of the following factors influenced your design specifications and constraints.

Public Health, Safety, and Welfare: For safety concerns, we use 2.0 standard downstream ports which are able to deliver up to 500 mA to avoid overloading and fire. We also set up ESD protection on the LCD and control part to limit the reception of electromagnetic energy that may cause physical damage, like static electricity. For the packaging, we design an adequately rounded shape instead of rectangle shape to avoid the risk to people.

Global Factors: To be able to use our product everywhere in the world, we design the USB port as a power supply so that everyone with a USB port can use our product. The input and output jack are also very standard ports which can be commonly found in the world.

Cultural Factors: To avoid the cultural difference of understanding our device, we use a very simple UI without any complicated symbols, and we only use English as the language to be displayed on the LCD. Different cultures may have varying preference for audio effects so we create some presets to cover most of the common music effects.

Social Factors: One of the social factors we take into consideration is the market demand for different age groups. We make our user manual and instruction more understandable so even children can make some simple audio effects on our device.

Environmental Factors: We are able to design the PCB to be as small as possible to reduce

the environmental impact of our device. In this way, the amount of material can be reduced, thereby reducing the weight of toxins produced per item. To minimize the impact, we will use the smallest possible LCD and try to place it as far away from where the user “hits” it as possible to avoid any accidental damage that may be needed. ABS 3D printer filament as an advanced packaging material has great potential to reduce environmental impacts compared to traditional packaging materials. It has no negative impact on the environment during the usage phase. After using it, we recommend to reuse or recycle it instead of landfills or burning to reduce the environmental impacts.

Economic Factors: The product is designed to be affordable due to our limited controls, quality, and effects. The total cost for producing the device is a little bit under $100. This price is cheaper compared to other products on the market which can range from usually a little over $100 up to even $1000. Some of these devices usually offer more capabilities and probably at better quality; however, more capabilities and better performance can be added to our device’s software with no cost.

(f) Describe the appropriate engineering standards incorporated into the creation of your product.

Due to the nature of our project, there weren’t many standards considered in the design. However, we did decide to have the device be powered via USB port, so it was necessary that it comply with that standard and be able to operate at the voltage and current that is typically supplied via USB. Additionally, since user input was involved, we made an attempt to integrate electrostatic discharge protection into our design. Our device complies with FCC standards as a Class B digital device as it most likely does not emit 150 microvolts per meter at 3 meters. This device is also ROHS compliant, not containing an exceeding amount of materials like mercury, lead, or cadmium.

(g) Describe the final status of your product.

From top down perspective, the bottom of the interface consists of three rotary encoders used to adjust effects’ parameters, and two buttons to switch between them and navigate through the different pages on the UI. In the center there is an LCD screen which indicates the current effect and the status of its parameters to help the user visualize the changes they are applying. The LCD also is capable of detecting touch input which allows the user to navigate the UI and set which parameters they wish to edit. The top of the product consists of three female audio jacks, two of them being inputs, one stereo and one mono, the third being a stereo output. Currently, the default supported input is stereo. Next to the jacks you will also find a micro USB port used to supply power to the device and turn it on. The product supports up to three audio effects: 5 band parametric equalizer, simple delay supporting up to 1 second of delay time, and distortion. All three effects are running simultaneously and are applied in the following order: distortion, EQ, and delay.

(h) Describe the makeup of your project team and how you were organized to establish goals, plan tasks, and meet the objectives of this project.

Our team consists of three computer engineers that worked on software, hardware, mechanical, and systems design, and one electrical engineer that worked on power and hardware design. We used a Discord server with several channels for various aspects of the project in order to communicate and organize outside of the lab. We used google drive to collaborate on written work, and additionally used GitHub to host our project files. For most core tasks on the project, we worked in pairs to increase efficiency and provide redundancy.

(i) Did your project require the production of any written documentation other than this document (i.e., manuals, educational materials, etc.)? If so, describe the types, composition, and nature of the audiences for whom these materials were intended.

It was required of us that we all document our work in detail in an online project journal. The purpose being to illustrate the status of our project to the course staff, fellow group members, and potentially even other students. Additionally, since this project is considered an open source project, any individuals who wish to recreate our work in the future can use our journals to aid in that effort. We were also required to write several formal reports covering the different aspects of the design of our project, as well as a legal and regulatory analysis, a reliability and safety analysis, an ethical and environmental analysis, and a user manual.

(j) Describe the types, composition, and nature of the audiences in attendance for the final oral design review. Discuss how you prepared for this audience.

The audience of our final design review will have the professors for ECE477. This audience includes professionals with expertise in audio engineering, signal processing, hardware design and software development. They may be interested in the technical specifications, performance metrics, and implementation details of our microphone interface. We need to prepare for this audience by ensuring that our presentation includes in-depth technical information, such as schematic diagrams, component specifications, and software architecture.

Purdue ECE Senior Design Semester Report
(Individual Reflections Section)

Course Number and Title	ECE 47700 *Digital Systems Senior Design Project*
Semester / Year	Spring 2024
Advisors	Phil Walter, Joseph Bougher, and Rohan Sakar
Team Number	12
Project Title	Microphone Interface

Senior Design Student Completing This Section			
Name	**Major**	**Area(s) of Expertise Utilized in Project**	**Expected Graduation Date**
Liam Roach	CompE	Software, Soldering, Design	May 2024

Individual Reflection: Provide a brief (1-2 page) individual reflection of the design project, as outlined below:

(a) Describe your personal contributions to the project.

As the team leader, I spearheaded the initial design and architecture of the project. Alongside coming up with tasks for myself to work on, I also assigned many tasks to my fellow group members throughout the course of the project. Most of my early work on the project revolved around research and microcontroller selection. Somewhat early in the project, as a group we decided that we might have to abandon using USB as a way to send and receive audio, and I worked on getting a codec to work with the microcontroller we had picked as a backup. I ended up developing a custom setup driver for the codec tailored for our use case and spent a considerable amount of effort on debugging a difficult timer issue. Another aspect of the project that I worked on was the packaging design. I had some prior experience with 3D modeling software, and had previously made a mockup model for the project for our initial project proposal. Additionally, I did all of the soldering on our PCB.

(b) Describe how your contributions to this project built on the knowledge and skills you acquired in earlier course work.

I was able to use my knowledge of C and embedded programming that I had attained from previous classes such as CS 159, ECE 264, ECE 362, and ECE 368, to great effect in this project. This can best be seen in the I2C setup driver that I wrote. I implemented the driver on top of an already existing driver, but I had to take care in making sure that the right sequences of bits were sent to the codec in order to comply with the I2C standard, as well as properly configure the codec for our needs. I used the experience I gained from taking a class in software engineering, ECE 461, to help with not just the architecture of the software, but the project's design as a whole. Additionally, I used the problem solving skills I have built up over my time studying engineering to overcome several major problems we were having.

(c) Describe how you acquired and applied new knowledge as needed to contribute to this project. What learning strategies did you employ to do so?

I spent a lot of time in this project reading datasheets and researching embedded communication protocols. I had some basic knowledge of things like SPI and I2C from previous classes, but this project required me to gain a much more in depth understanding of I2C. I additionally had to gain a detailed understanding of I2S for the purposes of this project, and I was able to do this mostly by reading datasheets, but also by visualizing the

signals via an oscilloscope and experimenting with changing values and parameters until I got things to work. I was also able to gain some very valuable knowledge on micro soldering techniques from this class's lectures, as well as practice that I did in the lab.

(d) Discuss your ethical and professional responsibilities as they relate to this engineering design experience.

My ethical responsibility to this project was writing my own original code, and citing sources when needed. Besides the libraries provided by the manufacturer for our microcontroller, I did examine some example code of how to interface with the codec we were using, but I was sure to cite this in my engineering journal. Additionally, since the code was written for a different microcontroller, and for a different use case, I ended up having to write my own original code anyway. In terms of professional responsibilities, I kept an engineering journal detailing every bit of work that I did on the project. I also wrote up several professional reports, such as a software formalization report and a user manual.

(e) Consider what the impact of the product of this engineering design experience could have in economic, environmental, societal, and global contexts. Discuss how you would make (or did make) an informed judgement as to your product's impact in each of these four contexts?

From an economic perspective, at approximately $80-$90 per-unit, our prototype that we designed is fairly cheap. This is due to the fact that the core functionality of our project, which would have required complex and expensive hardware, was instead implemented in software. Further design iterations could bring this price tag even lower as we picked a fairly expensive codec and microcontroller that were probably overkill for what we needed, but was necessary in the prototyping phase because we were unsure if less powerful components would be capable enough. One unfortunate aspect of the project from a societal and global context is that we used both tantalum capacitors, which use a metal that is scarce and is considered a "conflict mineral", as well as electrolytic capacitors, which are known to have a high rate of failure. In future design iterations I would probably experiment with using other more sustainable types of capacitors, such as ceramic. From an environmental perspective, our device is fairly low power, being capable of being powered just by USB, which means that it is fairly eco friendly. We could take steps to reduce the power consumption even further, such as using a non-backlit display, but it likely wouldn't be a very large reduction in power consumption.

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Senior Design Student Completing This Section			
Name	**Major**	**Area(s) of Expertise Utilized in Project**	**Expected Graduation Date**
Jakub Kowalski	CompE	DSP, Embedded Software, OOP	May 2024

Individual Reflection: Provide a brief (1-2 page) individual reflection of the design project, as outlined below:

(a) Describe your personal contributions to the project.

During the initial stages of coming up with the project, I came up with the idea of creating a USB microphone interface which became our initial goal for the semester. During the first few weeks, I spent my time researching and prototyping the USB protocol. Eventually we decided to abandon USB and instead opt for analog input and output. At this point I began working a little bit on digital filter design and created a testing environment inside of a Jupyter notebook where I imported algorithms written in C and analyzed their outputs. I also worked alongside Shubo to prototype interfacing with the LCD display controller, and I additionally prototyped interfacing with the LCD's touch controller to be able to reach our stretch goal for touch input. At the same time I learned the architecture behind the TouchGFX library in order to design the UI and understand how it interacted with the hardware. Once we individually prototyped all of our components, I began the integration process to support them simultaneously, namely the codec and the LCD. Towards the end of the semester I took charge of designing the UI and programming the logic to handle the user interacting with the touch screen to navigate through the different effects and selecting which parameters to edit, as well as reflecting the changes in user input from hardware buttons and rotary encoders. I additionally worked on most of the implementation and testing of DSP algorithms, mainly the parametric EQ and delay effects.

(b) Describe how your contributions to this project built on the knowledge and skills you acquired in earlier course work.

I was able to use my experience from previous hardware courses like ECE 20007 on operating lab equipment such as the oscilloscope when it was necessary to verify and test things like communication lines. My previous embedded courses such as ECE 362 and ECE 40862 helped me understand what considerations to take when designing embedded systems, as well as being familiar with communication protocols such as SPI and I2C. On top of this I had some fundamental knowledge of signal processing from previous signals or DSP courses such as ECE 301 and ECE 438 which made me familiar with some of the concepts discussed when researching the implementation of the algorithms needed for our effects. Finally, my coursework in C++ in ECE 39595 allowed me to easily understand how to work with the TouchGFX library which helped me quickly design and implement our user interface.

(c) Describe how you acquired and applied new knowledge as needed to contribute to this project. What learning strategies did you employ to do so?

My previous experience in DSP was in python on signals with finite length. This project required me to learn about strategies used to implement these algorithms in real time systems that have limited memory and processing power compared to something like a laptop or PC. I acquired this knowledge through online resources such as videos, articles, and forums on DSP topics. I also had to implement live parameter updates which was new to me and I had to design the logic behind them and test their performance manually.

(d) Discuss your ethical and professional responsibilities as they relate to this engineering design experience.

My ethical responsibilities for this project is citing any sources from which I derived my code from when implementing algorithms for DSP, as well as crediting authors of libraries we used for interfacing the touchscreen LCD. My professional responsibilities were to document the design process from my perspective, fill out necessary documentation for the software overview and safety reliability, as well as assisting my team and clearly communicating with them in the face of any concerns or setbacks during the design process.

(e) Consider what the impact of the product of this engineering design experience could have in economic, environmental, societal, and global contexts. Discuss how you would make (or did make) an informed judgement as to your product's impact in each of these four contexts?

In the economic context, we have created a product which is a cheaper alternative to similar products on the market, making it more affordable for consumers on a budget. Additionally this product is powered via USB cable, eliminating the need for the use of batteries which can be harmful for the environment when discarded incorrectly. On the other hand, this product could potentially create more waste in the case of a short life span across multiple units; however, we can only be one hundred percent sure of this with data collected over a longer period of time. In terms of societal impact, we have created a product with both practical and leisure applications which is easy to use for the general public. One consideration is the lack of support for people with disabilities who may not have fine motor skills required for adjusting parameters with the use of the knobs. This could be solved by including more specialized touch elements on the screen to help increment the parameters directly by touch. In the global context, our product could be marketable in most parts of the world, but this can only be determined if we submit our product to be certified for following regulations in other countries.

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Team Number	Team 12
Project Title	Microphone Interface

Senior Design Student Completing This Section			
Name	**Major**	**Area(s) of Expertise Utilized in Project**	**Expected Graduation Date**
Joshua Hom	CompE	PCB Layout, Hardware, Embedded Software	August 2024

Individual Reflection: Provide a brief (1-2 page) individual reflection of the design project, as outlined below:

(a) Describe your personal contributions to the project.

Prototyping the controls (in both hardware and software) was one of my contributions on the project. I was able to configure buttons and incremental rotary encoders so that we could change parameters in software. I also 3D printed caps for these controls. I also designed most of the schematics and PCB layout related to the peripherals to the MCU of course with the help of the person in charge for prototyping each of them. After making sure integration would succeed, I assisted the other leads. Specifically, helping with PCB assembly and reviewing the DSP software.

(b) Describe how your contributions to this project built on the knowledge and skills you acquired in earlier course work.

When developing controls I utilized my knowledge of earlier courses. For instance, when understanding the rotary encoders, I measured their waves on an oscilloscope and connected them to a microcontroller through its timers. This was prevalent knowledge from ECE 20007. Basic knowledge of C accelerated this process. Similar coding was taught in ECE 36200 and ECE26400. I also had the chance to review my foundation of electrical components and circuits from 20001 through designing and helping with assembling the PCB.

(c) Describe how you acquired and applied new knowledge as needed to contribute to this project. What learning strategies did you employ to do so?

I acquired many skills during the development of this project. I was able to learn the process of working with microcontrollers with STMCubeIDE, the design process of creating schematics and a PCB layout in KiCad, and the basics of 3D modeling and printing through AutoDesk and Ultimaker Cura. To learn all of these, I read official documentation and forums, and utilized the core concepts taught in lecture.

(d) Discuss your ethical and professional responsibilities as they relate to this engineering design experience.

Since I was focused on being systems leads, I tried to uphold my responsibility of working in a team and supporting them in a professional setting as much as possible. This entails

discussing with other team members on what they are working on, how it would fit into the project as a whole, and helping them when problems arise within reach. I also produced project journals and reports which aided this process. In an ethical sense, I never plagiarized another's work and always wrote down the source of which I researched methods on.

(e) Consider what the impact of the product of this engineering design experience could have in economic, environmental, societal, and global contexts. Discuss how you would make (or did make) an informed judgment as to your product's impact in each of these four contexts?

Our product is relatively cheap, making it economically more viable to more people who are looking for it to use in their work and or personal projects. This product also has minimal hardware and is powered by a USB cable, making its environmental impact on E-waste nominal as well. In a societal context, we have given the ability for people to modify their audio which can be used professionally or casually. In a global context, this product would be available and usable in most places.

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Senior Design Student Completing This Section			
Name	**Major**	**Area(s) of Expertise Utilized in Project**	**Expected Graduation Date**
Shubo Xie	EE	Prototype, Power electronics, Schematic	May 2024

Individual Reflection: Provide a brief (1-2 page) individual reflection of the design project, as outlined below:

(a) Describe your personal contributions to the project.

I contributed three parts of our project including power electronics, prototyping of control systems and schematic diagrams. For power electronics, I implemented a power regulator and noise filter to output necessary power for all components of our project. I also take charge of the power electronics part of the PCB layout and schematic diagram. Besides that, I designed the ESD protection for the LCD interface and control interface. For PCB layout and schematic diagram, I mostly assist another teammate to check and fix the possible errors appearing in the electrical rules checker. I am also responsible for exporting and checking the gerber file of PCB layout. For prototyping, I integrated the control system with other components and set up testing LEDs for each part of the control system through a software implementation.

(b) Describe how your contributions to this project built on the knowledge and skills you acquired in earlier course work.

The knowledge acquired from the Electrical Engineering Fundamentals course (ECE2k1 and ECE2k2) helped me with the power electronics part. Also, the skill of building filters in the Electrical Engineering Fundamentals lab (ECE2k7 and ECE2k8) contributed to the designing of the noise circuit of our project. The use of an oscilloscope in Electrical Engineering Fundamentals courses (ECE2k7 and ECE2k8) gave me a hand on debugging the integration of the project. The Microprocessor Systems and Interfacing course (ECE362) helped me on programming the STM32 microcontroller.

(c) Describe how you acquired and applied new knowledge as needed to contribute to this project. What learning strategies did you employ to do so?

The first new knowledge I acquired is the PCB layout design on Kicad. I learned the procedure of designing a PCB by starting from verifying the footprint, placing the components, routing the components and drilling vias. There are a lot of rules in PCB design which makes PCB layout better. The second new knowledge I learned is the use of STM32CubeIDE. In the previous course, I only learned about using the workbench. Using STM32CubeIDE is more convenient and understandable for beginners. Finally, I learned about using different libraries for LCD and the touch module, like ILI9341 and TouchFX.

(d) Discuss your ethical and professional responsibilities as they relate to this engineering design experience.

My ethical responsibilities include keeping the safety of our product and protecting the design privacy of our design. Since I was taking care of the power supply part of our design, I needed to prevent the power circuit from overheating and other physical damage to the human body. I should avoid giving our design ideas to other people. While it is not a fully mature product, the design architecture and method are still important.

(e) Consider what the impact of the product of this engineering design experience could have in economic, environmental, societal, and global contexts. Discuss how you would make (or did make) an informed judgment as to your product's impact in each of these four contexts?

Our senior design project has six major components including a microcontroller, a LCD display screen and the LCD screen which will be held on top of the PCB. We will use ABS(acrylonitrile butadiene styrene) 3D printer filament as our packaging material, and the standoffs and screws will be stainless steel. For economic impact, our product is too expensive compared to other similar products. One way to reduce the price is to have a cheaper MCU. Instead of using F7, we can use F4. One way to reduce the environmental impact of a product is to design the PCB to be as small as possible. In this way, the amount of material can be reduced, thereby reducing the weight of toxins produced per item. For societal impact, our design may not be used by children, but we will design more understandable instruction for children to use in the future.For global impact, we still not have any other language user manual but we use English which is widely used language around the world as our menu language.