Ultrasonic Transponder

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Abstract:

The Ultrasonic Transponder senior design project is a multi-semester effort focused on developing a reliable short-range ultrasonic communication system using a master–slave architecture. The system consists of an interrogator that transmits commands and multiple transponders that receive, decode, and respond using ultrasonic signals. Applications of this technology include localization, object tracking, and identification systems where electromagnetic interference is undesirable.

This work builds upon the foundation established in previous semesters and focuses on stabilizing, integrating, and validating the system at both the hardware and firmware levels. Major improvements were made to the ultrasonic receiver, including the completion and validation of a six-stage analog signal processing chain composed of pre-amplification, automatic gain control, filtering, and a redesigned envelope detector capable of producing reliable digital outputs. Extensive breadboard testing and measurement were used to resolve distortion, timing, and signal integrity issues that prevented earlier designs from operating consistently.

In parallel, significant progress was made in embedded firmware development using the ATmega2560 microcontroller. An inherited, nonfunctional codebase was debugged and restructured to restore stable one-way ultrasonic communication. Transmission and reception logic were integrated with the receiver hardware and verified using real-time visual indicators and oscilloscope measurements. Additionally, a dedicated ultrasonic receiver PCB was assembled and continuity-verified, addressing legacy design and component-value constraints and transitioning the system toward a more repeatable and manufacturable platform.

Overall, this work transformed a partially functional prototype into a stable, testable ultrasonic communication system. The project now provides a solid foundation for future development toward full two-way communication, multi-node operation, and spatial localization.

Keywords:

Ultrasonic communication, Transponder, PCB design, Envelope detection, Transducer, UART communication, Signal processing Arduino, ATmega2560, Two-way communication

I. Introduction:

Ultrasonic waves are acoustic signals with frequencies above 20 kHz, exceeding the upper limit of human hearing. Their ability to propagate through air with relatively low signal loss, combined with immunity to electromagnetic interference, makes ultrasonic carriers suitable for applications such as distance measurement, indoor localization, short-range wireless communication, and object identification. The general sound spectrum and ultrasonic operating range are illustrated in Fig. 1, highlighting the frequency region utilized by the ultrasonic transponder system.

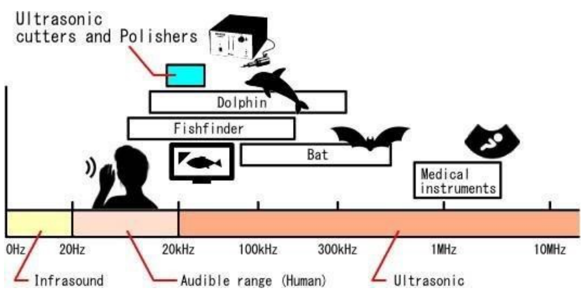


Figure 1: Sound Frequency Spectrum and Common Ultrasonic Applications

The goal of this senior design project for the Fall 2025 semester is to demonstrate reliable one-way and, if possible, two-way ultrasonic communication using a single transmitter module, a single receiver module, and an Arduino microcontroller for system control and validation. A conceptual overview of this simplified transmitter–receiver architecture is shown in Fig. 2. In this configuration, the Arduino enables the ultrasonic transmitter, processes the system's digital inputs/outputs, and uses LED indicators to confirm the system's operational status. Specifically, an LED confirms when the transmitter is active, and for the two-way mode, a separate LED confirms when the receiver has successfully decoded a signal.

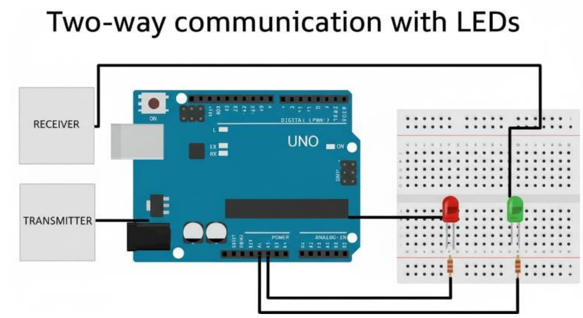


Figure 2: Master–slave ultrasonic transponder architecture

Previous iterations of the project focused primarily on circuit-level development, including the design of a transmitter PCB (Fig. 3) and the construction of the breadboard receiver.

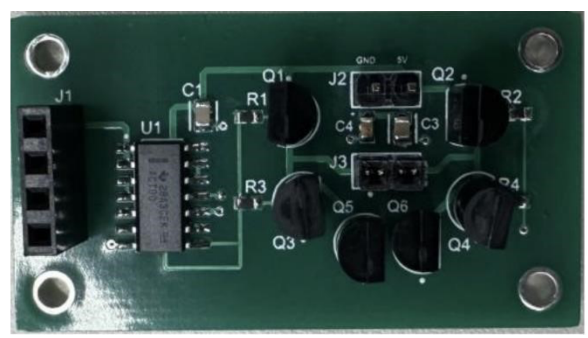


Figure 3: PCB Transmitter

The receiver incorporates a six-stage analog processing chain consisting of a JFET preamplifier, automatic gain control (AGC), a two-stage amplification block, a fourthorder Butterworth band-pass filter, and an envelope detector. A simplified block diagram of the receiver signal chain is shown in Figs. 4a and 4b. These hardware efforts produced a fully functional breadboard receiver that reliably converted amplitude-modulated (AM) ultrasonic signals into a digital envelope suitable for microcontroller processing.

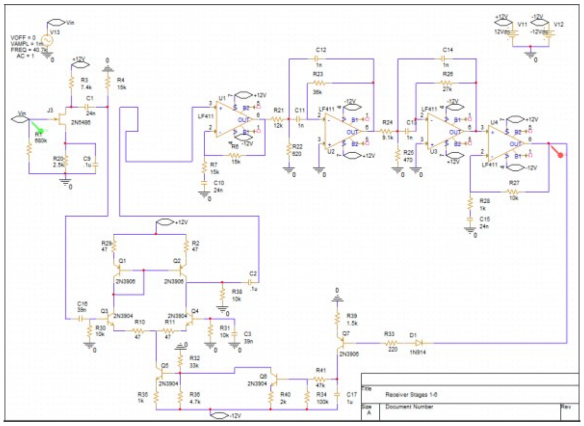


Figure 4a: Schematic of the Amplifier and Filter stages of the Receiver (Stages 1-5)

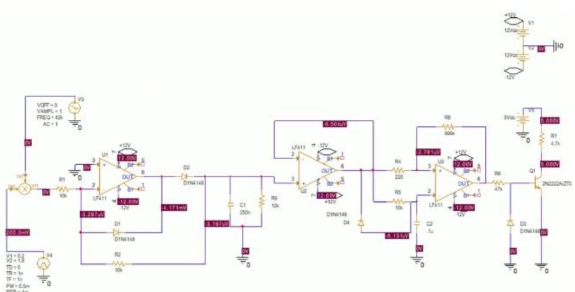


Figure 4b: Schematic of the current Envelope Detector of the Receiver (Stage 6)

In contrast, the Fall 2025 semester centered on two major goals: restoring functional microcontroller communication and assembling a working PCB version of the ultrasonic receiver. At the start of the semester, the Arduino firmware inherited from the prior team was nonfunctional. The code exhibited inconsistent pin mappings, incorrect UART configuration parameters, and logic errors that prevented basic one-way communication from operating correctly. After detailed debugging and restructuring of the TX and RX routines, the team restored one-way ultrasonic communication using the breadboard receiver. A test configuration of the Arduino-to-transmitter and receiver-to Arduino wiring setup is illustrated in Fig. 5, which also shows LED indicators used to verify carrier generation and valid envelope detection. Two-way communication is currently nearing completion.

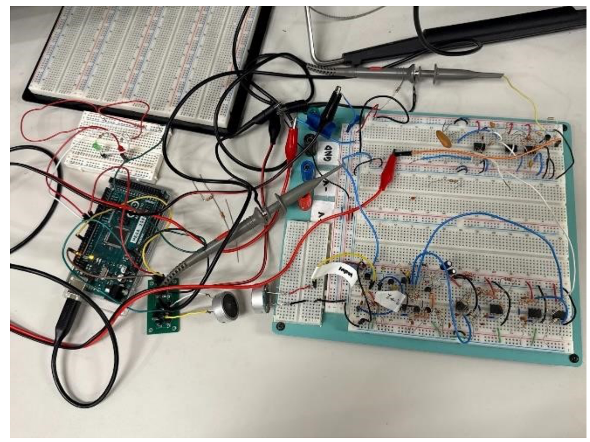


Figure 5: Arduino communication and LED indicator wiring setup

In parallel, the PCB team fabricated a new receiver PCB board based on the validated breadboard design. However, the schematic inherited from prior semesters contained several non-standard component values— such as 2.5 kΩ resistors and 24 nF capacitors— because the breadboard implementation achieved these values through combinations of series and parallel components. The PCB captured these values as single components, making them difficult or impossible to source. To address this, the team used precision measurement equipment to hand-select the closest-value components and populated the complete receiver PCB as shown in Fig. 6. Although full electrical testing was not completed due to time limitations, the board has been fully assembled and verified component by component for correct placement.

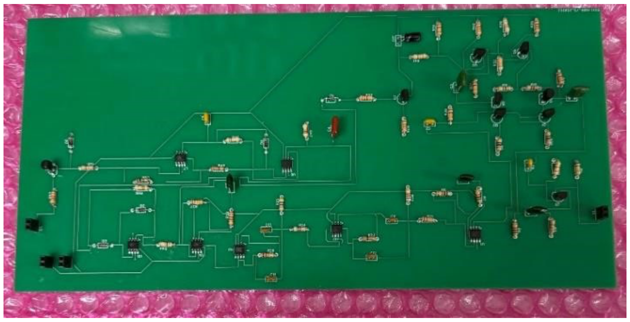


Figure 6: Fully populated receiver PCB

This report presents a complete overview of the system architecture, previous hardware achievements, this semester's progress in Arduino communication debugging, PCB population, testing methodology, and ongoing efforts toward establishing full two-way ultrasonic transponder communication. The work completed this semester establishes the foundation necessary for future development of a multi-node ultrasonic network capable of distance measurement and spatial localization.

II. Electronics: Transmitter and Receiver

System Overview and Subsystems The ultrasonic communication system developed in this project consists of a single ultrasonic transmitter module, a single receiver module, and an Arduino microcontroller responsible for controlling and validating communication. Rather than a multi-node network, this semester's work focuses on demonstrating reliable one-way and two-way ultrasonic signaling using a simplified transmitter–receiver configuration. In this setup, the Arduino enables the ultrasonic transmitter, monitors digital outputs from both the transmitter and receiver, and activates LED indicators to confirm successful signal transmission and detection. The system is realized through the efforts of three major subsystems:

- Electronics Subsystem: Implements the core six-stage analog signal processing chain for the receiver, including amplification, automatic gain control (AGC), filtering, and envelope detection. The transmitter PCB was designed and manufactured in a previous semester.

- PCB Subsystem: Responsible for translating the functional breadboard receiver design into a manufacturable Printed Circuit Board (PCB), encompassing schematic capture, layout, component selection, and final assembly.

- Arduino Subsystem: Provides digital control and communication functionality. The microcontroller platform (ATmega2560) is used to implement UART-based protocols, manage signal processing, and demonstrate stable one-way and two-way ultrasonic communication. In prior semesters, the focus was on developing and refining the Electronics subsystem, culminating in a functional breadboard receiver and transmitter PCB. This semester's work shifted toward integration, with the Electronics subsystem remaining the stable, unchanged foundation for the Arduino firmware and the receiver PCB assembly.

Six-Stage Analog Signal The receiver's primary role is to detect and process weak ultrasonic transmissions from the transmitter so that the microcontroller can interpret them. This is accomplished via a six-stage analog signal process that recovers the amplitude-modulated (AM) carrier (40.3 kHz) and produces a digital pulse for the Arduino. The stages consist of JFET-based preamplification, Automatic Gain Control (AGC), a non-inverting amplifier stage, a fourth-order Butterworth bandpass filter, a final amplification stage, and an envelope detector for analog-to-digital conversion, as illustrated in Fig. 7.

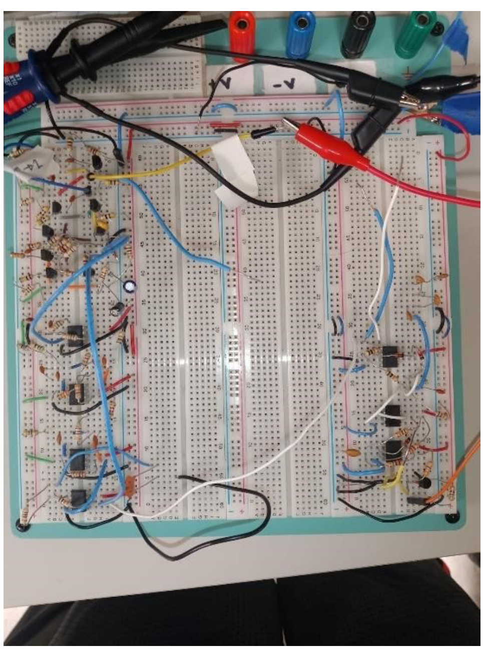


Figure 7: The finalized full receiver on a breadboard

The analog processing is divided into the following functional stages:

A. Stage 1: Preamplification (JFET): The initial stage boosts the extremely weak signal captured by the piezoelectric microphone. A Junction Field-Effect Transistor (JFET) preamplifier is used for its high input impedance, minimizing the loading effect on the microphone and maximizing initial signal voltage gain while maintaining a high signal-to noise ratio **(SNR)**.

B. Stage 2 & 3: Main Amplification: The signal is then passed through two stages of voltage amplification utilizing LF411 operational amplifiers. These stages provide the bulk of the necessary gain to raise the signal amplitude to a level suitable for subsequent filtering and detection.

C. Stage 4: Fourth-Order Butterworth Band-Pass Filter: To isolate the desired 40.3kHz carrier signal and reject background noise, a fourth order Butterworth band-pass filter is employed. The Butterworth topology provides a maximally flat passband response, which is crucial for minimizing distortion to the received signal before demodulation.

D. Stage 5: Automatic Gain Control (AGC): To manage the significant amplitude variation caused by changes in distance between the nodes, an Automatic Gain Control (AGC) circuit dynamically adjusts the system's gain.

This prevents saturation of strong signals while ensuring sufficient amplification for weaker signals, yielding a consistent output level. Stages 1-5 are illustrated in Fig. 8.

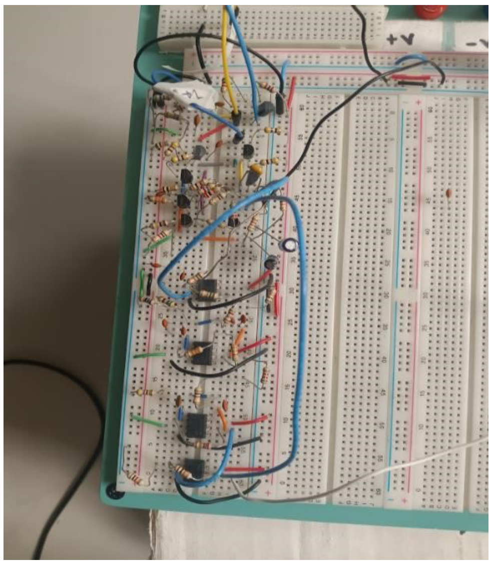


Figure 8: Stages 1-5 Receiver Circuit

E. Stage 6: Envelope Detector and Digital Conversion: The final and most critical stage is the envelope detector. This circuit recovers the low-frequency data (the "envelope") from the high-frequency AM carrier wave. The recovered data is output as a clean digital square wave (logic HIGH or LOW), which is then fed directly to the Arduino's digital input pin for protocol processing as demonstrated in Fig. 9a, 9b, 9c.

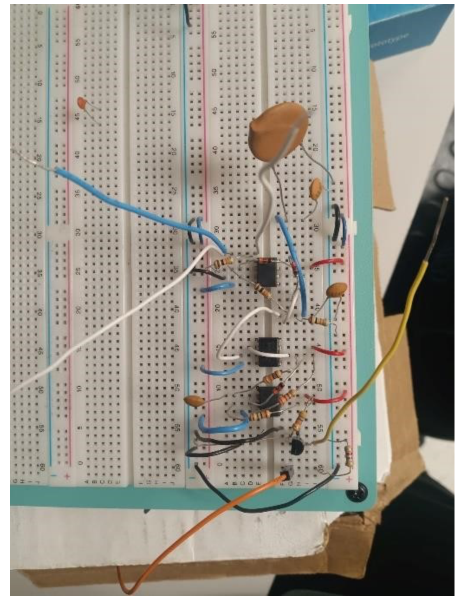


Figure 9a: The finalized envelope detector after the changes made this semester

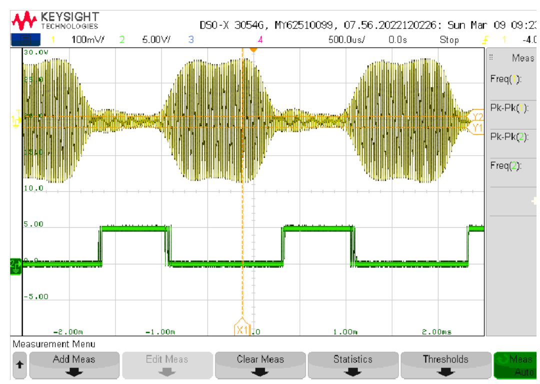


Figure 9b: The full receiver functioning properly with transmitter providing the input, even with distance

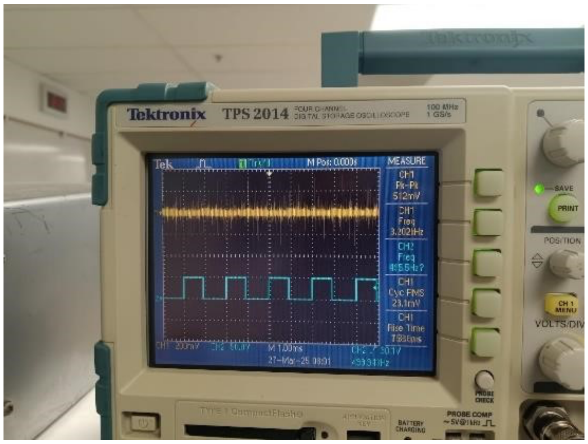


Figure 9c: The full receiver functioning properly with transmitter providing the input

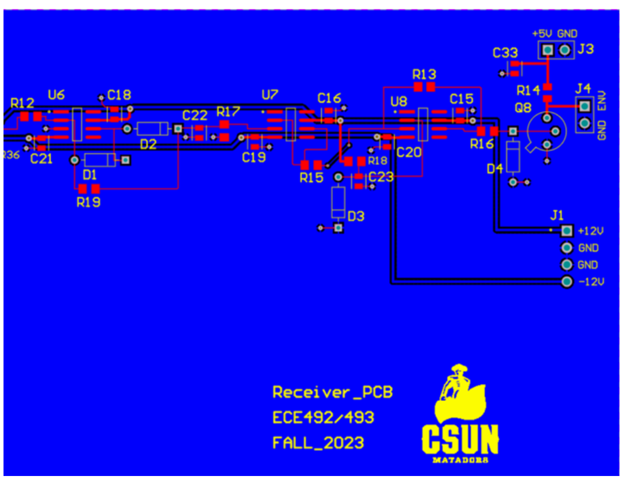
III. *Printed Circuit Board Design*

In fall of 2024 the PCB team was asked to initially conduct research and training on using Altium Designer as no one on the current 492/493 team had any experience with the actual design aspects. Videos and training were assigned as parts of assignments to build skills to later change and implement a PCB design using Altium. This semester, the PCB group was tasked to do a variety of jobs in order to make major advances in the project. Where it was left off from last year, we had one working PCB receiver circuit on the breadboard that at times decided to fail and two completely working transmitter PCB Circuits. Due to this it became fairly crucial to begin and finish the PCB circuits in order to have successful two way communication in a 360 field. From last year there were no major changes made to the schematic of the circuit yet.

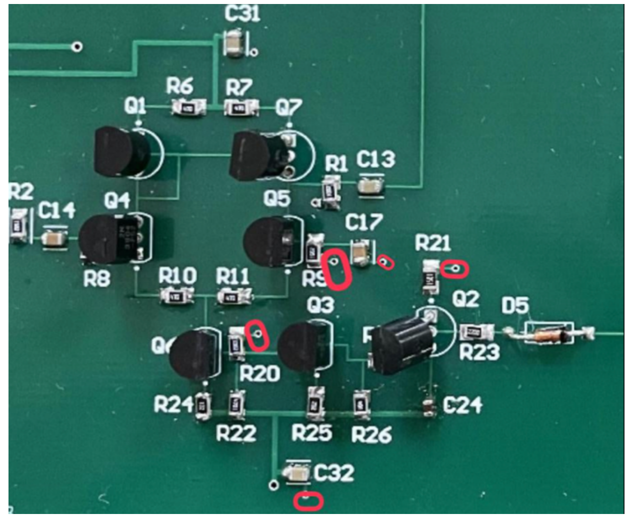
Having said this, we had empty printed circuit boards created using Altium that were scaled and designed to 0805 size components from the previous year. When they were printed we were essentially tasked with soldering and pasting all of the small components onto the printed circuit board. We learned and started soldering these components for a couple of weeks when we realized how much time consumption was being required with the lack of obvious advancements. We decided to take the last circuit board and take it to a soldering company to mass produce the circuit boards to some degree to have a faster process in order to make further advancements into the testing phase, as the Arduino team was in need of having a live circuit in order to test their code throughout the process.

Throughout this process we realized that because we were in the experimental stage, we still had many improvements to build upon. In the meantime we worked on integrating the analog signal processing chain, the envelope detector and the AGC all into one receiver PCB, since in the beginning we had multiple PCB circuits that were in different pieces that did not work together. To do this we created new schematics, new PCB layers in order to incorporate such ideas into one single design. The perfecting and the correct collectiveness of a single board builds an essential stepping foundation of the project as in the future the project is essentially composed of multiple of this board.

In the process of using the previous design of the receiver and incorporating the analog signal processing chain, the envelope detector and the main receiver were all integrated into one circuit PCB. We realized that the previous PCB boards were printed out with parts of the component places that were not connected to ground and voltage. Within that time period we also analyzed the PCB board and we realized that the PCB boards were also composed of components that were soldered on with some dry solder paste which was affecting the function of the circuit. Having encountered all of these problems, we took a step back and consulted with professionals in the PCB field and with our advisor. We came to the conclusion that we would need to redesign the circuit board. This was concluded due to the fact that there were new changes that were implemented in the breadboard version of the receiver, along with the other problems that were stated. In consulting with professionals in the PCB field, we were also suggested to change the layout and size of the components to get the smallest size of error. It was suggested that we use 1206 components, in order to have a larger space to solder and to have a smaller chance of damaging components as we tested with larger frequencies, since smaller components are prone to more errors. Although components of such a small size are said to be designed for certain high frequencies, it is not recommended to use the maximum frequency as a frequent source; only a percentage should be used.



This schematic shows a more clear understanding of the layering process that the previous teams did where they did not incorporate ground connections to some components and had missed a couple connections to voltage in the places that required it.



The instances that were seen to have mistakes in having no connections to ground or voltage.

The primary objective of the PCB Subsystem this semester was to transition the validated, six-stage analog receiver design from the breadboard prototype to a manufacturable Printed Circuit Board (PCB). This process aimed to improve noise immunity, reduce physical footprint, and create a robust, final stage hardware platform. The receiver PCB was designed to accommodate all necessary components, including the LF411 operational amplifiers (used in the amplification and filtering stages), resistors, capacitors, and input/output connectors.

A. Fabrication and Initial Setbacks

The initial phase of the PCB process involved coordinating fabrication with an external vendor. This process faced immediate delays due to issues with the inherited schematic file submitted for fabrication. The vendor required a re-submission of the schematic, which necessitated a re-order of the board. Although the vendor provided a refund for the initial order, this setback caused a significant delay in the project timeline.

Once the new, blank PCB boards were received (see Fig. 10a, 10b, 10c for the layout schematic), the team performed a component audit and discovered several crucial parts were missing from the inventory, including the LF411 chips, various capacitors and resistors, and the necessary input/output headers for connections for the voltage sources and ultrasonic transducer.

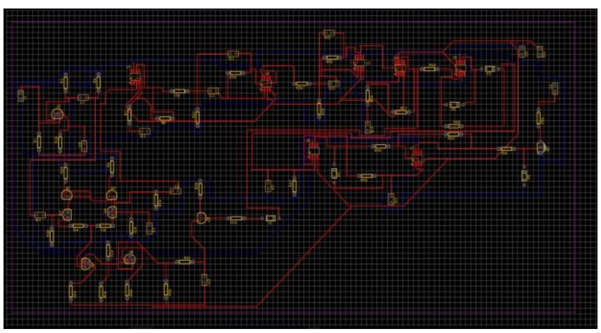


Figure 10a: Receiver Layout Schematic (Top Layer Of The PCB Layout)

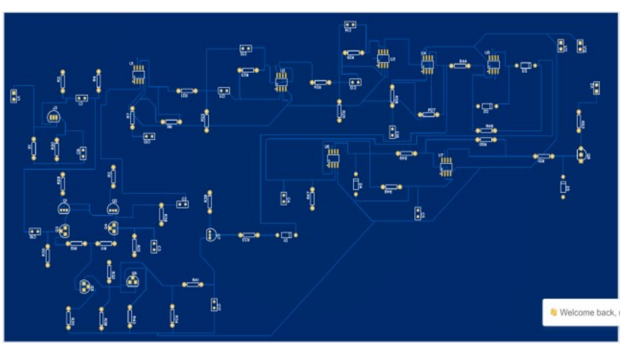


Figure 10b: Receiver Layout Schematic (Front)

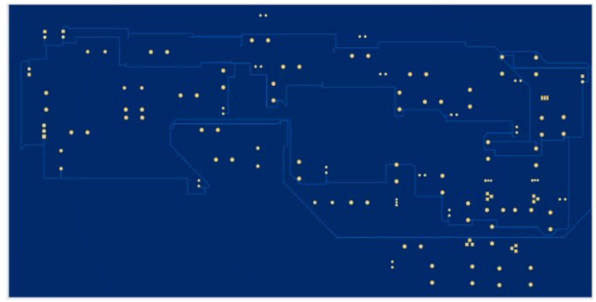


Figure 10c: Receiver Layout Schematic (Back)

B. Challenge of Non-Standard Component Values

The most significant technical challenge encountered during the assembly phase involved component sourcing. The inherited PCB schematic was found to contain several non-standardized resistor and capacitor values that are not commercially available in standard electronic catalogs.

The primary technical challenge during assembly arose from the non-standard resistor and capacitor values specified in the inherited PCB schematic. On the breadboard, these values were achieved by combining standard components in series or parallel
(e.g., two resistors to obtain 2.5 kΩ), but the PCB schematic listed the components as single components, calculated non-standard values, rendering them unavailable through most commercial suppliers. Critical components included 2.5 kΩ resistors and
24 nF, 39 nF, and 250 nF capacitors (Fig. 11). Using the closest standard E12 or E24 values (e.g., 2.4 kΩ or 22 nF) would have introduced unacceptable

deviations in the Butterworth filter's center frequency and bandwidth, potentially shifting the passband away from the 40.3 kHz carrier and compromising overall filter performance.

Component	Required Value	Closest Standard Values
Resistor	2.5 kΩ	2.4 kΩ or 2.7 kΩ
Capacitor 1	24 nF (3 required)	22 nF
Capacitor 2	39 nF (2 required)	33 nF or 47 nF
Capacitor 3	250 nF (1 required)	220 nF or 330 nF

Figure 11: Important non-standard values required for the filtering and amplification stages of the receiver

C. Verification and Outstanding Work

Although the PCB was fully assembled and visually verified, the team was unable to complete full functional testing before the end of the semester due to delays caused by the initial ordering error and the extensive effort required to source non-standard component values. As shown in Fig. 12, the empty PCB layout illustrates the planned component placement and routing, while Fig. 13 demonstrates the fully populated board with all components soldered and verified for continuity.

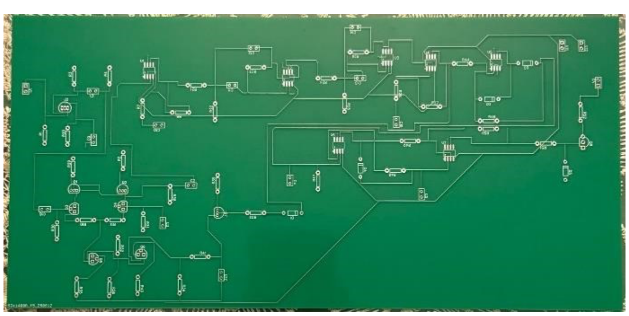


Figure 12: Receiver PCB Board (Blank)

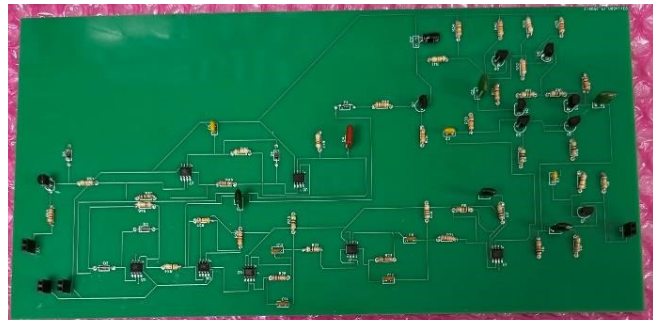


Figure 13: Receiver PCB Board (Fully Populated)

As a result, the receiver PCB has not yet been evaluated under real ultrasonic signals. Nevertheless, this semester successfully produced a fully populated and continuity verified PCB that is ready for the next stage of evaluation. This accomplishment represents a significant milestone for the transponder project, as it enables a transition away from the bulky breadboard prototype toward a more robust, manufacturable hardware platform.

With the PCB subsystem assembled but awaiting full functional validation, the team shifted its focus to the Arduino subsystem, which centered on ultrasonic transmission control, communication protocol development, and two-way signal detection using LED indicators. The next section provides a detailed overview of this microcontroller-driven communication work.

IV. Arduino Subsystem Design and Communication Development

The Arduino Subsystem served as the digital control layer for the ultrasonic transponder system, managing signal transmission, reception, timing, and LED-based status indication. Unlike previous semesters, which focused primarily on the analog receiver and transmitter hardware, this semester concentrated heavily on debugging and restoring the Arduino communication framework, integrating the breadboard receiver, and developing a functional demonstration of one-way and, if possible, two-way ultrasonic communication. The goal was to ensure that the microcontroller could reliably detect incoming ultrasonic signals, trigger indicator LEDs, and control outgoing transmissions in a stable and repeatable manner.

A. Inherited Codebase and Initial Issues

At the start of the semester, the Arduino team received an existing codebase developed by the previous senior design group. Although the earlier team had claimed partial success with one-way communication, the firmware was highly unstable and non-functional upon initial evaluation. Several critical issues were identified:

1. Inconsistent Pin Assignments: Multiple functions referenced mismatched digital and analog pins, resulting in signals being read from or written to the wrong locations. Some pin definitions were duplicated, overridden, or unused.

2. Incorrect Timing Parameters: Ultrasonic communication requires precise timing for transmission and detection. The inherited code contained incorrect delays, inconsistent baud-rate assumptions, and hardcoded timing values unrelated to the actual modulation scheme.

3. Overly Complex and Unstructured Additions:

The previous team had added additional layers of code—likely in an attempt to implement two-way communication—that introduced logic conflicts, unreachable states, and redundant functions. These additions contributed significantly to the code instability.

4. Nonfunctional One-Way Communication:

Although earlier reports claimed one-way communication was functional, this semester's testing revealed that the Arduino was not successfully detecting the transmitter, nor receiver, output signal nor triggering the corresponding LED.

Before progressing toward two-way communication, the team made the strategic decision to strip the firmware down to its essential components, rebuild the logic from the ground up, and reestablish reliable one-way communication.

B. Restoring One-Way Communication

The primary objective of the one-way communication demonstration was to validate that the Arduino could reliably control the transmitter subsystem and correctly register a transmission event.

During this phase of testing, the Arduino was not connected to the analog receiver circuit, and therefore detection of ultrasonic waves was not performed through the envelope detector. Instead, the one-way demonstration focused solely on confirming that the microcontroller could initiate and acknowledge a transmission from the transmitter through internal logic and indicate this action using an LED.

The intended one-way sequence was as follows:

1. Arduino enables the transmitter.
2. The transmitter PCB emits a high frequency ultrasonic signal, around 40kHz.
3. The Arduino registers the transmission internally based on its output control logic.
4. The Arduino turns on the “Transmitter LED” to visually confirm that a transmission has occurred.

To accomplish this, the team first evaluated the inherited Arduino firmware and identified several issues that prevented proper transmitter control, including inconsistent pin assignments, redundant logic, and timing conflicts. Because the one-way demonstration relied solely on the Arduino’s ability to activate and internally acknowledge the transmitter output, the firmware required extensive revision. The team rewrote key portions of the code to create a clean and reliable control pathway for the transmitter. This included implementing the following improvements:

- Correct and consistent pin definitions
- A simplified state machine for transmitter activation
- Removal of conflicting or redundant code
- Implementation of a stable LED control routine tied directly to the transmitter enable signal

After extensive rewriting and correction of the inherited code’s pin assignments and communication parameters, the team successfully demonstrated stable one-way ultrasonic communication. The process was confirmed visually: when the Arduino issued the command to activate the transmitter, the corresponding TX LED illuminated, confirming proper software control and stable activation of the signal generation. This end functionality was validated across several distances and angles, confirming the stability of both the firmware-controlled signaling and the analog circuit’s detection capabilities.

A conceptual diagram of this one-way LED signaling flow is shown in Fig. 14a, 14b and 14c.

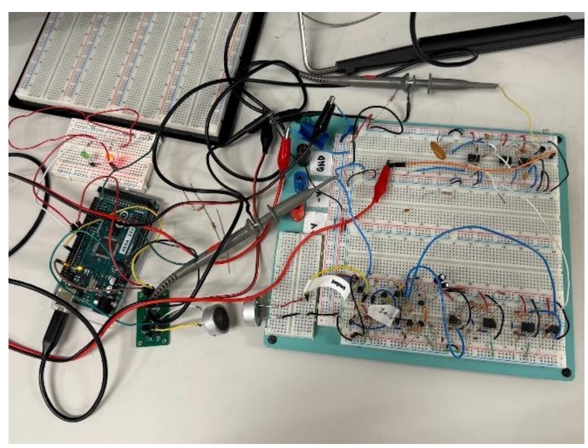


Figure 14a: Arduino Demonstration with the Transmitter PCB and Receiver Breadboard Circuit

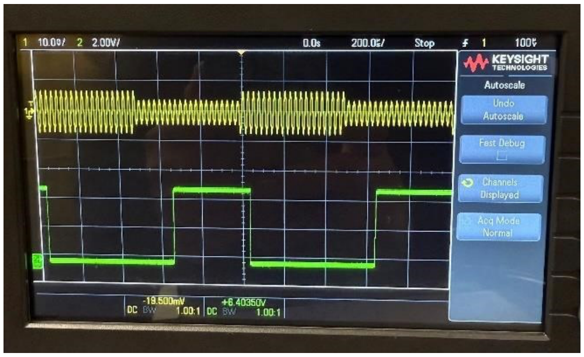


Figure 14b: Output of Arduino Demonstration With Transducers Close To Each Other

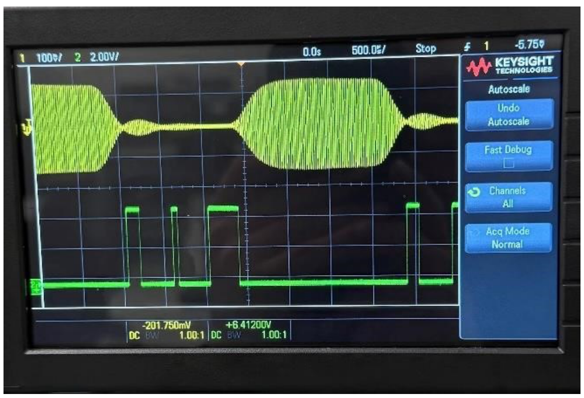


Figure 14c: Output of Arduino Demonstration With Transducers Further Apart From Each Other

C. Progress Toward Two-Way Communication

Following the successful restoration of one way communication, the team began implementing two-way communication functionality. The objective of this demonstration is to ensure that the Arduino can not only activate the transmitter but also detect both the transmitter's output and the receiver's envelope detector output in real time. To provide clear visual feedback, two LEDs were incorporated into the design:

- Red LED: Indicates transmitter activation and ultrasonic signal emission. As shown in Fig. 15a.
- Green LED: Indicates successful detection of the received signal after processing through the analog receiver chain. As shown in Fig 15b.

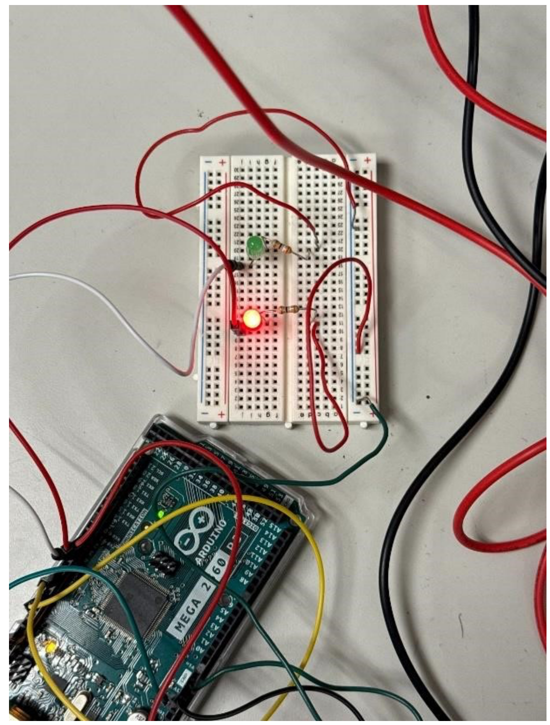


Figure 15a: Arduino Detecting Transmitter Output

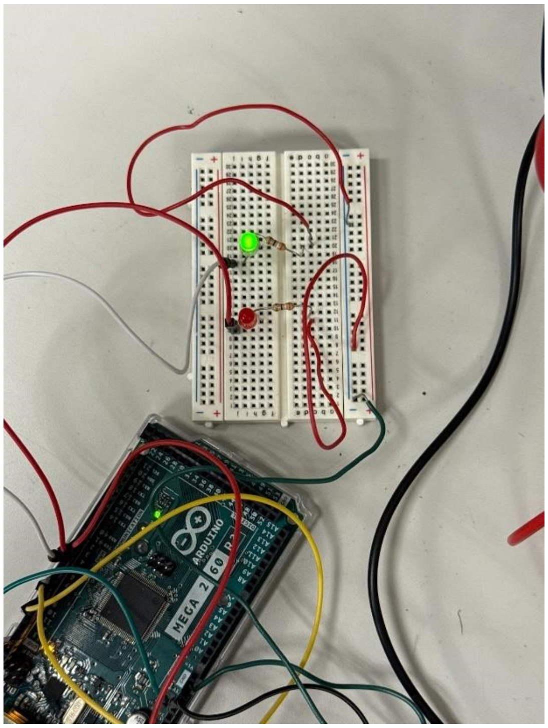


Figure 15b: Arduino Detecting Receiver Output

This configuration allows the Arduino to serve as a monitoring and control unit, verifying both ends of the communication link. The two-way sequence is designed as follows:

1. The Arduino enables the transmitter.
2. The transmitter PCB emits an ultrasonic signal (approximately 40 kHz).
3. The Arduino turns on the “Transmitter LED” to visually confirm that a transmission has occurred.
4. The breadboard receiver circuit processes the incoming signal through its six-stage analog chain and outputs the ultrasonic signal (Fig. 16).
5. The Arduino detects the digital output of the envelope detector and illuminates the green LED to confirm successful reception.

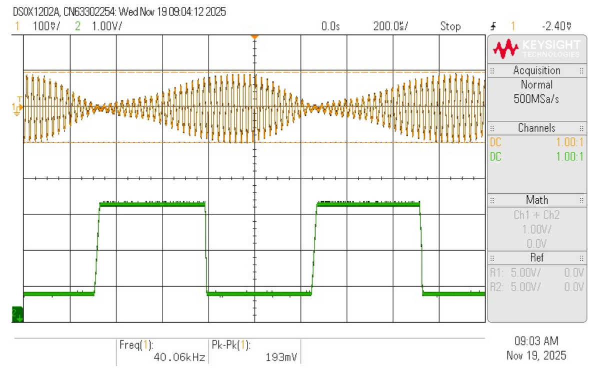


Figure 16: Receiver Output While Connected to the Arduino

At the time of writing, the two-way communication framework is nearing completion. Preliminary tests with the breadboard receiver have demonstrated partial success, with both LEDs responding to transmission and reception events. However, due to time constraints, the team anticipates limited opportunity to fully validate and refine the implementation before the end of the semester. As a result, future work will focus on extensive testing, debugging, and optimization of the two-way communication code to ensure stable operation across varying distances and environmental conditions.

V. Future Goals

A. Electronics

Future work on the electronics subsystem should target performance improvements and system efficiency:

Delay Investigation: Analyze the source of the ~100 µs delay in the receiver output and implement design modifications to minimize latency, critical for accurate Time-of-Flight distance measurements.

Power System Simplification: Explore opportunities to reduce the number of power supplies (currently +12 V, –12 V, and +5 V are being used) to create a more energyefficient and portable system.

Analog Signal Optimization: Consider incremental improvements to the analog chain to enhance robustness and minimize distortion under varying environmental conditions.

B. Printed Circuit Board Design The immediate priority is fully functional testing of the assembled receiver PCB. Due to the use of non-standard components, the electrical characteristics of the board must be rigorously evaluated to ensure reliable output:

- Output Comparison: Conduct end-to end testing of the PCB receiver and compare the envelope detector's digital pulse against the breadboard prototype to identify performance differences caused by component deviations.

- PSpice Verification: Model the receiver circuit in PSpice using the actual measured component values. Compare simulation results against both the original design and the physical PCB output to validate signal precision and circuit behavior.

- Future PCB Production: Replicating multiple receiver PCB boards. To support ongoing testing and future experiments, additional receiver PCBs will need to be fabricated as backups. Having multiple boards will allow the team to conduct parallel tests, replace boards that may be damaged during handling, and explore circuit modifications without risking the fully assembled prototype. These extra boards will also serve as a foundation for iterative improvements and scalability in future ultrasonic transponder designs.

C. Arduino

The Arduino subsystem requires further development to achieve reliable two-way communication:

• Two-Way Communication Completion: Refine and stabilize the firmware to enable full bidirectional data exchange between the Arduino, transmitter, and receiver, building on the two-way communication code already implemented. This will also include testing with the fully populated receiver PCB to verify reliable operation.
• Code Optimization: Refine and optimize the Arduino code, ensuring all parameters are properly configured for the receiver PCB. Implement improvements to enhance the demonstration of ultrasonic signal communication and ensure reliable system performance.

VI. Conclusion

The work completed across these semesters represents a significant step forward in the development of the Ultrasonic Transponder system. What began as a partially functional prototype with unresolved hardware and firmware issues was refined into a stable and testable communication platform. Through systematic debugging, redesign, and validation, the project transitioned from fragile breadboard experiments toward a more reliable and repeatable system.

On the hardware side, a six-stage ultrasonic receiver was fully integrated and validated, including a redesigned envelope detector capable of producing consistent digital outputs from modulated ultrasonic signals. Extensive testing and parameter tuning were performed to resolve distortion, timing delays, and noise-related issues, allowing the receiver to operate reliably under varying distances and obstruction conditions. These efforts established a robust analog front-end suitable for continued development and integration.

In parallel, the embedded firmware was reorganized and stabilized by addressing inherited design flaws related to pin configuration, timing, and communication handling. This work restored reliable one-way ultrasonic communication using the ATmega2560 microcontroller and created a clear structure for expanding toward two-way and multi-node communication. The assembly and continuity verification of a dedicated receiver PCB further strengthened the system by resolving legacy design constraints and enabling a more manufacturable hardware platform.

While full two-way communication and spatial localization remain goals for future development, the milestones achieved in this work provide a strong technical foundation to support those efforts. With validated hardware, stable firmware, and improved documentation, the Ultrasonic Transponder project is now positioned for scalable expansion and continued system-level refinement.

VII. References

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