Microphone Phase Detector and Indicator

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Summary

This project aims to design and construct a phase detector and indicator unit that will ultimately serve as a tool for audio engineers at amateur and professional levels. While recording audio, sound engineers strive to obtain the best possible sound quality. Due to phase cancellation, however, this quality can be limited when recording a source using multiple microphones. This device will detect the relative phase of multiple microphone signals used in a recording setting in order to indicate any out of phase signals to the user. In turn, the user will be provided with useful information regarding the quality of the current microphone setup, and will be able adjust microphones according to the indication results. The complete system will consist of four distinct modules: signal preamplification, input selection, phase detection, and indication. These four subsystems will all be linked through an Arduino microcontroller to properly direct signal flow and allow for multiple user options to help streamline the phase detection process. The phase detector must ultimately detect the relative phase of at least 4 microphone inputs with less than 3% error to allow for accurate, quantized indication. The device must also detect and indicate the magnitude of phase difference for all of the inputs with a turnaround time of less than 20 seconds to provide quick information to the user. The fully constructed unit should cost less than $300 to allow for amateur use and should be small enough to easily fit in a typical backpack for transport.

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1. Introduction

Audio engineers that work in recording studios or live music settings continually strive to achieve top-notch sound quality in any project that they partake in. While working on audio projects that involve mic'ing an instrument using multiple microphones, it is important to obtain good sounding recordings *before* moving on to the mixing stages of audio engineering. Multiple factors play a role in obtaining a solid raw recording including things like microphone quality and the acoustic response of the room. Among these factors also exists microphone phase. The phase of a microphone signal is the signal's time delay relative to a similar, reference signal [1]. An example of different microphone setups and their corresponding phase differences can be seen in Figure 1:

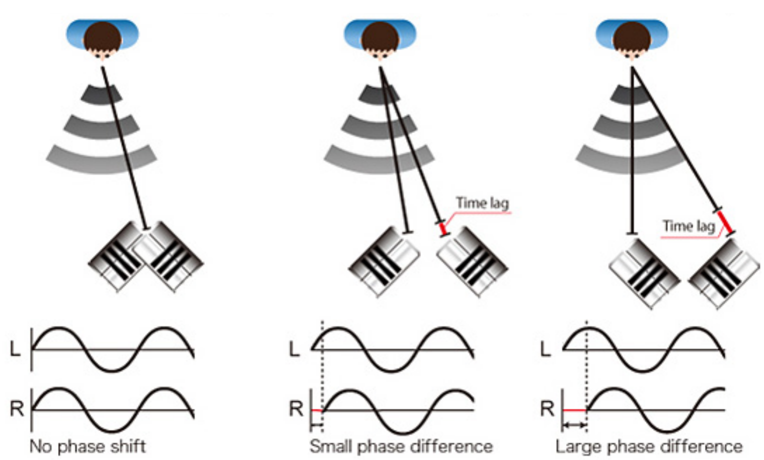


Figure 1: Phase Shifts due to Differences in Distance Between Microphones [2]

While using multiple microphones to record an instrument may be ideal to capture the full range of sound produced, this technique can also cause phase problems between the signals captured by different microphones. Due to variations in distance from the audio source to different microphones, each microphone will pick up the same audio signal with a slight time delay relative to the other microphones. When all of the microphone signals are added together, these time delays can cause cancelations of signal voltages at certain frequencies [3]. This phenomenon, called phase cancelation, can result in a dull sounding recording, which is far from ideal for an audio engineer. An simplified example of phase cancelation between two sine waves that are 180 degrees out of phase can be seen in Figure 2. Since the signal voltages in this example are completely inverted, the combined waveforms result in a complete phase cancelation. Most recording cases are not this simple, however, as real life audio signals are complicated, containing many frequency components. The combination of these intricate signals may result in phase cancelations of only certain frequencies, making cancelations hard to detect with the common human ear. Regardless, these cancellations can result in less than desired sound quality, so it is important for audio engineers to be able to detect and fix any phase problems between microphones before the audio is recorded.

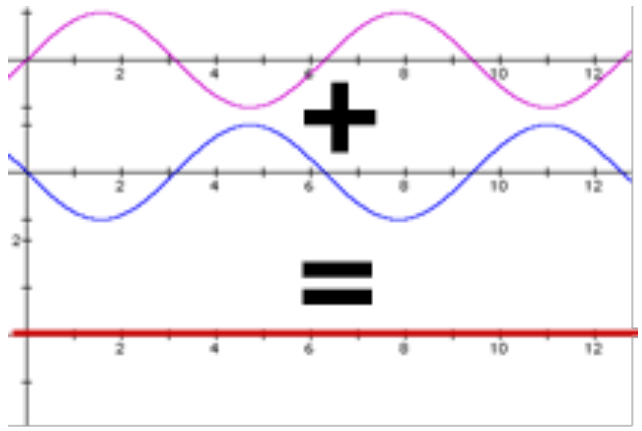


Figure 2: Complete Phase Cancellation Between Two Sine Waves [1]

This project aims to give the audio engineer or amateur recorder an indication of any phase cancelation problems between microphones *before* recording. An interface that visually shows the user which microphones are producing phase problems as well as the extent of these cancellations would greatly assist the user in finding the ideal microphone placement. If the audio engineer could see an indication of poor microphone placement prior to recording, the amount of time spent adjusting microphone placement and figuring out which microphones are causing problems would be greatly reduced and the final recording quality would contain minimum phase cancelation, resulting in top-notch sound quality.

The remainder of this report is organized as follows. Section two will cover some typical methods that audio engineers currently use to minimize phase cancellation in recordings as well as previous work similar to this project. It will also cover some potential impacts that this project may have on social, manufacturability, sustainability, and ethical factors. Section three will cover the design requirements of the project. These requirements outline how the device as a whole as well as each subsystem must perform. Factors such as cost, size, and look are also included. Section four will cover design alternatives and the reasons for choosing to implement certain technology into the final design. Section five will describe the preliminary design chosen in detail. Section six will detail the final design and implementation. Section seven will cover the testing and results for the final design. Sections eight and nine will show the production schedule and cost analysis, respectively. Section ten will contain a detailed user's manual. Section eleven will contain some conclusions and section twelve will contain a list of references.

2. Background

2.1 Previous Methods for Minimizing Phase Problems

There are multiple methods that audio engineers currently use to minimize phase cancelations between microphones. The first, and most straightforward method is good microphone placement. There are many known techniques for recording instruments with multiple microphones while minimizing phase problems. One such method is the 3 to 1 rule, which states that when recording with multiple microphones, "the distance between microphones should be at least three times the distance from each microphone to its intended sound source" [4]. A visual representation of the 3 to 1 rule can be seen in Figure 3. Multiple stereo mic'ing techniques, seen in Table 1, also exist to provide quality recordings with reduced phase problems. Although these techniques can help reduce phase problems, they don't guarantee perfect results.

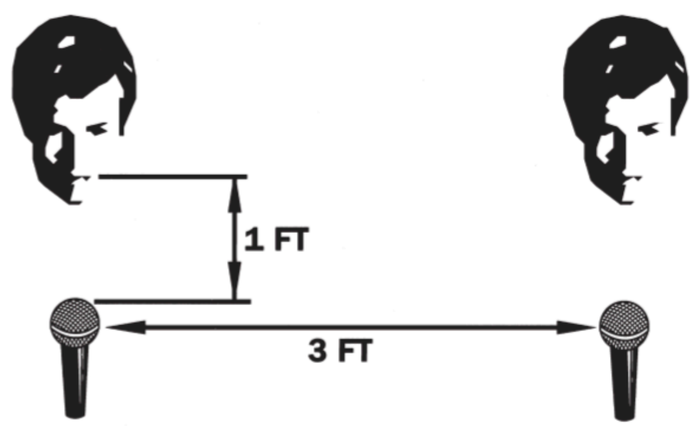
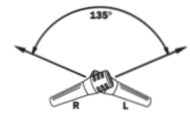
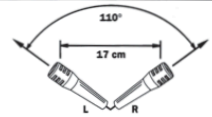
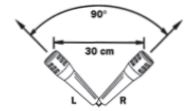
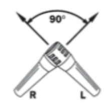
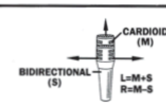
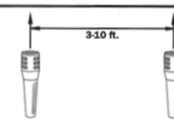


Figure 3: The 3 to 1 Rule [4]

Table 1: Stereo Mic'ing Techniques [4]

STEREO PICKUP SYSTEMS	MICROPHONE TYPES	MICROPHONE POSITIONS	
X-Y	2 - CARDIOID	AXES OF MAXIMUM RESPONSE AT 135° SPACING: COINCIDENT	
ORTF (FRENCH BROADCASTING ORGANIZATION)	2 - CARDIOID	AXES OF MAXIMUM RESPONSE AT 110° SPACING: NEAR-COINCIDENT (7 IN.)	
NOS (DUTCH BROADCASTING FOUNDATION)	2 - CARDIOID	AXES OF MAXIMUM RESPONSE AT 90° SPACING: NEAR-COINCIDENT (12 IN.)	
STEREOSONIC	2 - BIDIRECTIONAL	AXES OF MAXIMUM RESPONSE AT 90° SPACING: COINCIDENT	
MS (MID-SIDE)	1 - CARDIOID 1 - BIDIRECTIONAL	CARDIOID FORWARD-POINTED; BIDIRECTIONAL SIDE-POINTED; SPACING: COINCIDENT	
SPACED	2 - CARDIOID OR 2 - OMNIDIRECTIONAL	ANGLE AS DESIRED SPACING: 3-10 FT.	

It is possible for to somewhat fix phase problems after a source has been recorded as well. Modern audio engineers often use Digital Audio Workstation (DAW) software to edit, mix, and master audio recordings. This software allows the user to zoom into a recorded sample far enough to be able to see the relative phase of the signal. A screenshot of a snare drum soundwave recorded into Logic Pro X can be seen in Figure 4. Once zoomed in far enough to see a signals relative phase, an audio engineer can decide to invert the polarity of a sample to potentially reduce phase cancellation. The audio engineer also has the option to slightly shift the whole recording so that it is in phase. This method, however, can be risky and often results in an unnatural sound, making this technique unreliable. While it is possible to reduce phase problems using proper microphone placement and post-recording editing, a lot of the technicalities surrounding these methods are learned over time through individual trial and error.

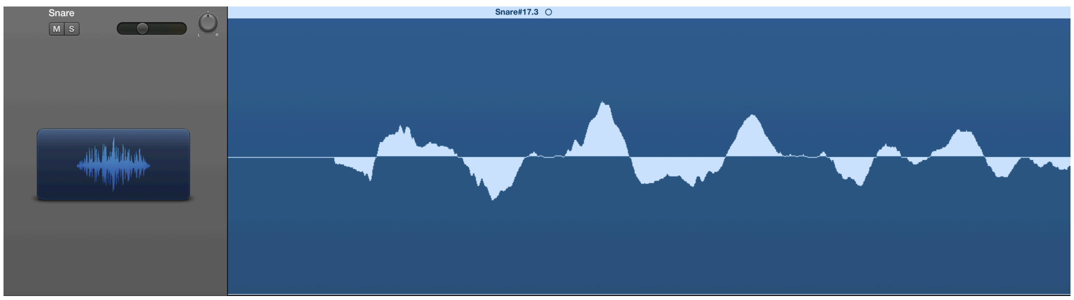


Figure 4: Snare Drum Sound Wave Recorded in Logic Pro X

2.2 Previous Work

After searching the United States Patent and Trademark Office database, no patented designs were found that met the design requirements for this project. A few, somewhat similar systems were found that involved phase detection in different forms. One patent found, entitled *"Audio Signal Phase Detection System and Method"* [5], detects the phase of two stereo speaker signals and indicates if their polarities are inverted. This has more to do with the actual wiring of the audio signal flow and the speakers themselves. Multiple other papers have to do with phase correlation meters, which are readily available in hardware and software.

Logic Pro X's default correlation meter can be seen in Figure 5. Correlation meters indicate the phase difference between the two channels of a stereo signal. The meter will indicate in the blue zone (Figure 5), if the left and right channels are generally in phase with each other and will indicate in the red zone if the two channels are certainly out of phase. These meters are generally used to view the stereo spread of an audio signal with a reading of closer to zero without entering the red zone representing a wider stereo image. No correlation meter designs that were to be used on microphone signals were found, but similar technology with some slight adjustments can be used to achieve the design requirements for this project.

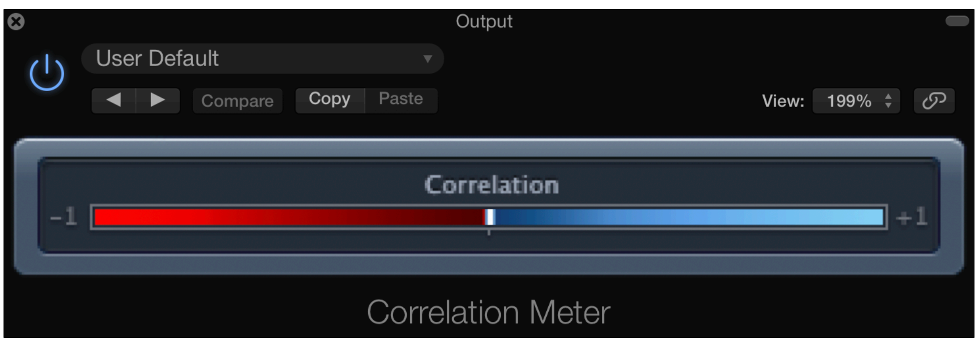


Figure 5: Phase Correlation Meter from Logic Pro X

2.3 Potential Project Impacts

This project's impacts will lie mostly within the audio engineering and recording community. It will most likely have the biggest impact with amateur recorders. This device will allow those who haven't developed strong recording techniques to identify what they're doing wrong and adjust it, providing them with a sense of proper microphone placement for the future. This device will be a leaning tool as well as a tool used to achieve ideal recordings for many. It will also impact more established sound engineers as well, however, as it will provide a quick and easy system to check microphone phases in multi-microphone recording scenarios. A portable, easy to use phase detection and indication device will drastically reduce the microphone set up for both on-the-go, live sound engineers and engineers generally settled in a studio. This device may also be an experimental learning tool for professionals and amateurs alike as it will allow the user to experiment with unconventional mic'ing techniques and easily check for any major phase cancellation. These unconventional mic'ing methods may result in unique sounding recordings, allowing for an expansion of the artistic side of capturing sound.

This device is designed to be easily manufactured, using generic microphone preamplifiers along with a fairly inexpensive and widely available microcontroller as the bulk of the cost. The phase detection system will also be composed of inexpensive and available components and the unit will be contained in a brushed aluminum casing. As the main customers for this product are arguably young audio engineers, it is important that the manufactured device remains relatively inexpensive. At the same time, a level of quality needs to be ensured for proper phase detection and indication, so component quality still takes priority.

Ethically, this device should have a positive impact on all users. Some established audio engineers may believe that it is not a necessary device or that proper microphone placement needs to be learned through trial and error, but this device will potentially be able to speed the learning process up for amateurs, which is never a bad thing. If anything, this device will allow for more young engineers to flourish, increasing interest in the audio engineering field. It may also help professionals try new things and reach their full artistic potential, resulting in a step forward in the sound engineering field.

3. Design Requirements

There are a number of design requirements that the microphone phase detector must meet in order to function properly while remaining available and useful to the customers. These requirements were chosen to satisfy all of the major goals of the project. The design requirements for the device are divided into the requirements of the four separate subsystems and the requirements of the fully operational system. The four subsystems include the signal receiver and preamplifier, the input selection module, the phase detection system, and the indication module. Each of these modules are distinct from one another and are all necessary to meet the overall requirements of the device.

3.1 Signal Receiver and Preamplifier Design Requirements

The signal receiver and preamplifier is the connection between the microphone signal and the device. This module has multiple design specifications to make sure that the device rest of the device receives the proper input waveform. First off, this module should contain at least four XLR inputs to allow this device to be for an array of multi-microphone project. It is important that these inputs are all XLR inputs, as the vast majority of microphones on the market use XLR connections [4]. One of these inputs must be defined as the reference input, which is the input signal that all other input phases are in reference to. This is important as the user must choose a microphone that has priority over the others to represent the reference [3]. This module must also contain a microphone preamplifier for each input. This is because typical microphone voltage levels are extremely low (below 1/100 of a volt) [7]. This low voltage means that the transients in the signal may be difficult to pinpoint. By using microphone preamplifiers, the input signals will be increased to line level (~1V), therefor ensuring that the entire signal will be easily read by the phase detector. Finally, all of the XLR inputs must be the same model and all of the preamplifiers must be the same model to ensure that each input signal has the same signal path and, if altered, altered in the same way as all of the inputs.

3.2 Input Selection Design Requirements

The input selection module gives the user flexibility while using the device. The user should be able to select which inputs (other than the reference input) they would like to test the phase of. They should also be able to simply choose to test all active inputs for an initial diagnostic. This system allows for a faster overall phase detection process as the user won't have to retest every microphone's relative phase when it has already been determined that only one or two microphones are out of phase. This module must also contain a cancel button that automatically stops the current device processing. All of these options also need to be implemented in an ergonomic and appealing manner.

3.3 Phase Detection Design Requirements

The phase detection module is the most important module, as it contains the circuitry that determines the phase differences between each input signal relative to the reference signal. This subsystem must detect phase differences with less than a 3% error to ensure proper indication later on. This module must also detect the phase difference of all of the input signals relative to the reference input signal within 15 seconds to provide a fast turnaround time for the whole system. This will allow for audio engineers to quickly check for phase problems.

3.4 Indication Design Requirements

The indication module indicates any out of phase microphones to the user. This subsystem must have one indicator for each input besides the reference input to provide phase information for each microphone relative to the reference. Each indicator must also provide the user with the magnitude of the phase difference relative to the reference signal, not just an indication of in-phase or out-of-phase. Once each indicator specifies the magnitude of phase difference, it should remain at that value until the user presses the cancel button on the input selection module. This allows for the user to properly read all of the indicated data and make adjustments if needed.

3.5 Design Requirements for Complete System

The overall system will need to be able to detect and indicate phase with less than 3% error with a turnaround time of less than 20 seconds. The completed unit should be able to operate in an indoor environment as well as an outdoor (but covered) environment. The device does not need to be waterproof, but should be able to operate in higher than normal humidity as well as temperatures ranging from 20°F to 110°F to allow for outdoor live music scenarios. The unit should also be secure enough to withstand strong vibrations caused by sound for an elongated period of time. The completed product should cost less than $300 and be around 9”W x 6”D x 2”H. These dimensions are based on the dimensions of the Steinberg UR44 audio interface [8] and allow for easy portability. Finally, the device should be powered by line voltage with a transformer to ultimately supply the unit with 12V DC. The power supple should be sufficient to power the entire device.

4. Design Alternatives

Multiple design alternatives were thought up for each module based on the design specifications given. The following sections include the alternatives for the overall approach of each subsystem as well as the major components used in each subsystem. The justifications for each chosen method or component are also included.

4.1 Signal Receiver and Preamplifier Alternatives

The signal receiver and preamplifier module was fairly straightforward given the design specifications. It was known that the module had to contain an XLR input and a microphone preamplifier for each input, so components were chosen based on quality and price. The microphone preamp was the major decision in this module as there were multiple options to implement preamplifiers. After extensive research, no options to buy a simple circuit board containing a quality microphone preamplifier were found. The remaining, satisfactory options were to build four separate microphone preamplifiers based on the Texas Instruments PGA-2500 preamplifier IC chip [9], or build four separate Velleman K1803 microphone preamplifier kits [10]. Both options would suffice, with the PGA-2500 based preamp resulting in better quality but far more expensive and complicated. Due to these factors, the Velleman K1803 kit was chosen for the microphone preamplifiers. This kit will be fairly quick to build and provide an amplification of 40dB with a frequency range of 20Hz to 20kHz, which is the desired frequency range for audio recording. This kit is also inexpensive, which will help reduce the total cost of the final device.

4.2 Input Selection Alternatives

To connect the input selections to the inputs and the rest of the circuit, it was decided that a microcontroller would be used. This would allow for far more organized circuitry as well as simplicity of circuitry and signal flow. The microcontroller would be linked to each module and provide a smooth phase detection and indication system. Due to prior experience, it was decided that an Arduino board was to be used. Since the main function of the implemented Arduino was to regulate signal flow, only a simple Arduino was required. Two Arduinos easily satisfied this condition, the Arduino Uno Rev3 [11] and the Arduino Mega [12]. While both would work, the Mega provided more inputs and outputs (which may or may not be utilized) without a huge boost in price. Therefor, the Arduino Mega was chosen to be implemented into the final design.

For input selection itself, multiple selection buttons were chosen to be implemented based on the design specifications. First, an "auto-cycle" button was chosen to be implemented. When pressed, this button would prompt the Arduino to cycle the signal inputs through the phase detection circuitry to determine the phase correlation of each input, one after another, in relation to the reference signal. This way, only two signals are being tested at a time, resulting in ease of construction and a lower cost. Based on the input selection design specification, it was decided that one button for each microphone input besides the reference input would also be implemented. When one of these buttons are pressed, the Arduino cycles only the selected input into the phase correlation circuitry to test the relative phase of only that input.

4.3 Phase Detection Alternatives

Multiple methods for phase detection were considered. The phase difference calculations could have been done within the Arduino board using cross correlation or FFT [13]. Another option considered for phase detection was the construction of an analog phase correlation circuit. After extensive research on cross correlation and FFT calculations, it was found that these methods would not be able to reliably detect the phase difference between two signals. These methods would also require an extensive amount of coding which is not ideal. Although slightly more expensive, an analog phase correlation meter design was found that detects the phase difference between two signals with less than 1% error [14]. Because of its reliability, this option was chosen to be implemented into the final design. Since this circuit measures the phase difference between only two signals, one circuit input will be connected to the reference input while the other circuit input will be connected to the Arduino. The Arduino will then cycle through each microphone input to eventually determine the phase difference between each input and the reference input. The output of the phase detection circuit will also be connected to the Arduino, which will transfer the received phase information to the proper indicator output.

4.4 Indication Alternatives

For the indication module, it was known that there had to be an indicator for each microphone input besides the reference input. Based on the fact that each indicator had to show the magnitude of phase difference relative to the reference, multiple alternatives were considered. The two main alternatives considered were a digital numeric display and an LED bar display [15]. Since numbers weren't required to indicate the phase difference, it made more sense to go with a 10-step tri-colored LED bar display. This indicator contains green, yellow, and red zones, allowing for easy an easy reading. An indication in the green zone would represent a generally in-phase signal while an indication in the red zone would represent a definite out of phase signal. A 10-step display was chosen as 10 levels are adequate for an accurate reading while keeping the indicator small enough to fit three indicators comfortably within the dimensions given in the design specifications. A picture of the 10-step tri color display can be seen in Figure 6.

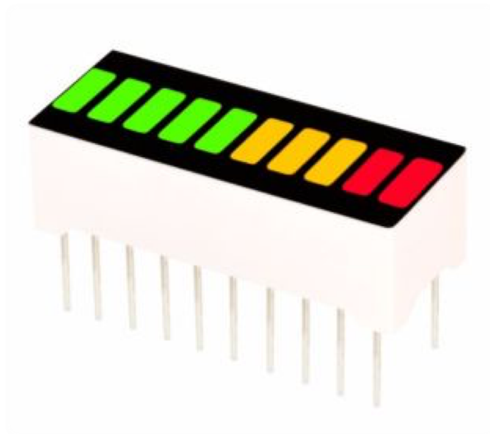


Figure 6: 10-Step Tri-Color LED Bar Display

5. Preliminary Proposed Design

The detailed design of each of the four separate modules is discussed below. A top-level schematic of all of the subsystems combined can be seen in Figure 7. This schematic shows how the subsystems are connected as well as the general signal flow of the entire system.

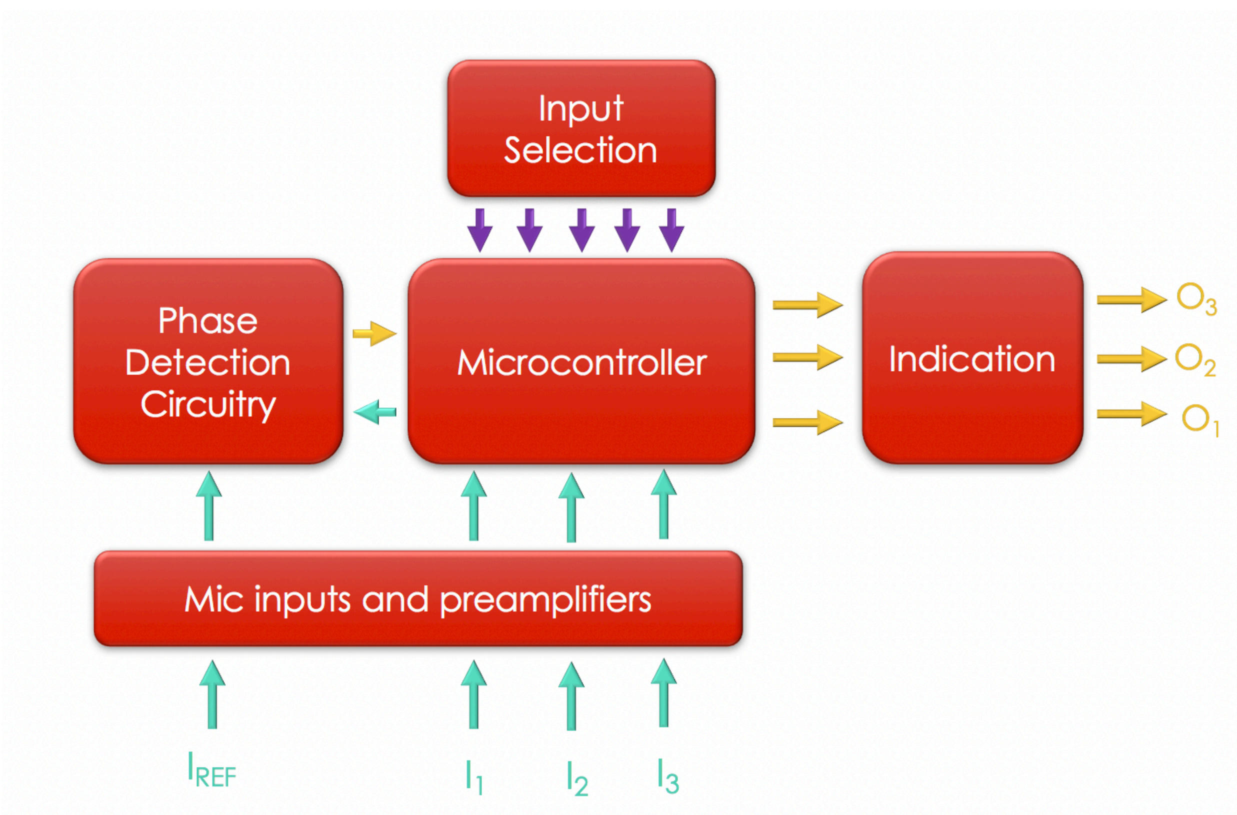


Figure 7: Top-Level Schematic of Complete System

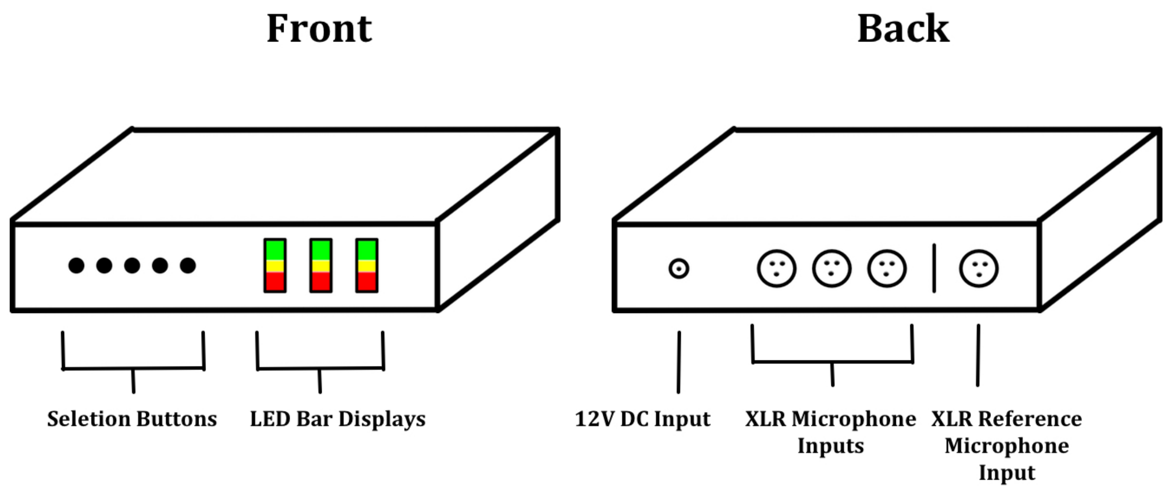


Figure 8: System Casing Design Concept

5.1 Signal Receiver and Preamplifier Design

The signal receiver and preamplifier module will contain four XLR inputs as well as a Velleman K1803 preamplifier for each input. This module is designed to accept and amplify each microphone separately. The Velleman preamplifier kit schematic can be seen in Figure 9. These preamplifiers will be run on the 12V DC power supply from a power bus for the entire system. Once the microphone signals are amplified, they will be outputted to the Arduino, which will eventually run them through the phase correlation circuit. The reference input preamplifier will output directly to the phase correlation circuit.

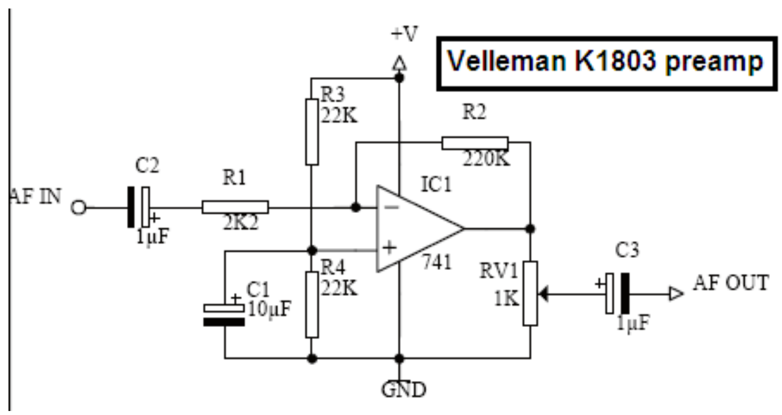


Figure 9: Velleman K1803 Preamplifier Schematic [10]

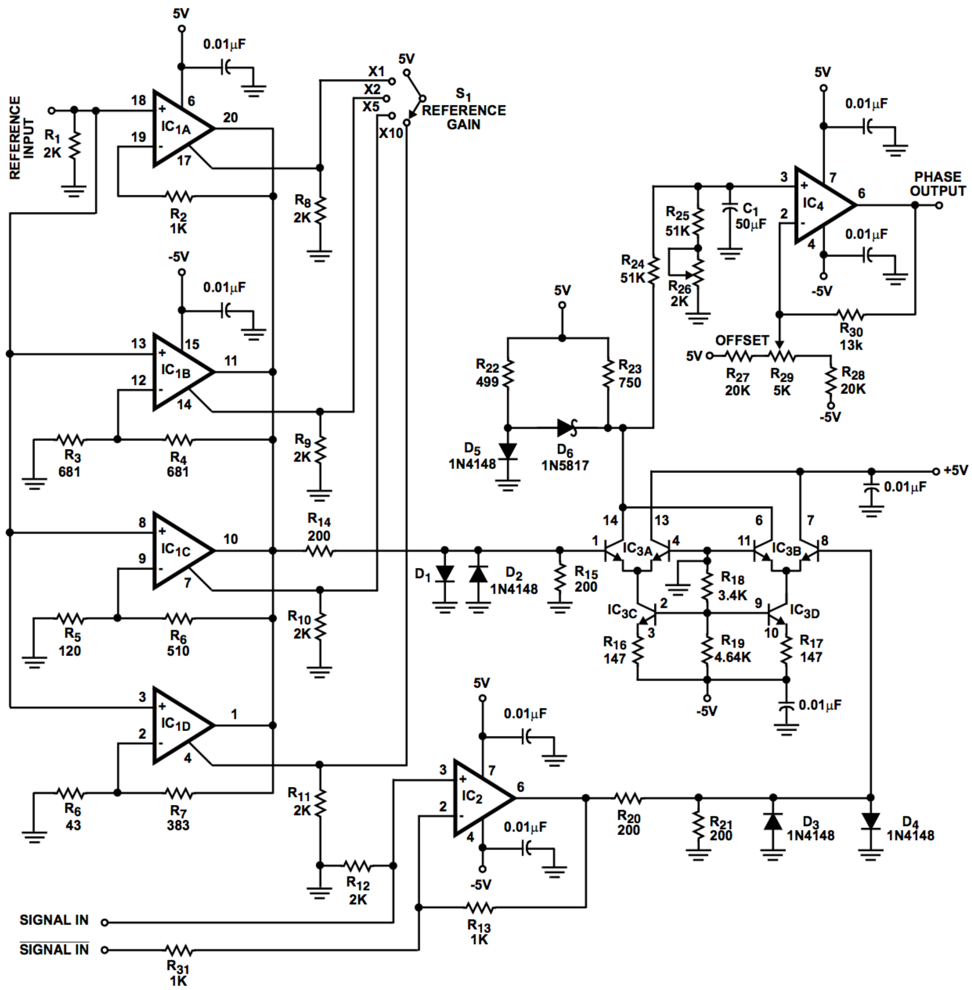
The XLR inputs and 12V DC input will be mounted in the back of the of the aluminum body for the system (Figure 8), with a preamplifier mounted behind each input (inside the casing). The reference input will be clearly separated from the other three inputs, and all of the inputs will be clearly labeled on the exterior of the casing.

5.2 Input Selection Design

The input selection module will contain a total of five buttons, which will all connect directly to the Arduino board. One button will prompt the Arduino to cycle all three of the microphone signals inputs through the phase correlation one at a time. The next three buttons (one for each microphone input besides the reference input) will prompt the Arduino to shift the microphone input specified with each button into the input of the phase correlation circuit, where only the selected inputs phase will be tested. The final button will be a cancel button, which, when pressed, will automatically reset the Arduino and therefor stop all current processing. These five buttons will be mounted in the left side of the front of the aluminum body and will be clearly labeled (Figure 8).

5.3 Phase Detection Design

The phase detection subsystem is the most important module of this project as it measures the actual phase differences between the microphone inputs and the reference input. As stated in the design specifications of the phase detector module, the phase correlation measurements will be implemented with an analog circuit [14]. A schematic of this phase correlation circuit can be seen in Figure 10. This circuit contains four integrated circuits, which are all specified in the notes of the schematic. The other circuit components are also specified in the schematic. This circuit ultimately converts two input signals into square waves of identical amplitude in order to measure the phase difference between the two signals. Once the square waves have an equal and constant amplitude, the phase difference can be determined from the average of the time difference between the square waves. When the two inputs have no phase difference (0° phase shift) the circuit outputs 0V. When the inputs are 90° out of phase, the circuit outputs $V_{OS}/4$, where V_{OS}=output voltage swing, which is a constant value. When the inputs are 180° out of phase, the circuit outputs $V_{OS}/2$. This output voltage has a linear relationship.



NOTES:

1. IC_1 = HA5024
2. IC_2 = HA5020
3. IC_3 = HFA3102
4. IC_4 = HA5170

Figure 10: Phase Correlation Detector Schematic [14]

This phase detector circuit will be mounted on the inside of the aluminum casing alongside the Arduino board. One phase correlation circuit input will be the reference microphone input. The other phase correlation input will be connected to an Arduino output which is programmed to cycle between the three remaining microphone inputs. Each microphone signal phase will be measured relative to the reference input by the phase correlation circuit separately. The resulting correlation measurement will then be outputted back to the Arduino board, where the information will be transmitted to the indicators.

5.4 Indication Design

The indication module will contain three separate tri-colored LED bar displays, one for each microphone input besides the reference input. These LED indicators will each be connected to an output of the Arduino board. After the Arduino receives the relative phase information for each input from the phase correlation circuitry, it will output the magnitude of the phase difference for each input to their corresponding LED indicators. The magnitude of the phase difference relative to the reference signal for each input will then be indicators. These three LED bar displays will be mounted in the right side of the front of the aluminum body and will be clearly labeled (Figure 8).

6. Final Design and Implementation

Overall, the final phase detector and indicator varied fairly drastically from the proposed design. This was due to factors such as complexity and discontinued parts which will be discussed later in this section. The major difference from the preliminary design was the elimination of the Arduino board to control signal flow. Simplification of circuits was able to be made allowing for the use of four separate phase correlation circuits instead of one correlation circuit with cycling inputs. The final product exterior front can be seen in figure 11, which shows the selection buttons and the LED bar displays. The final product exterior back can be seen in figure 12, which shows the XLR inputs and power input. The final product interior chassis plate can be seen in figure 13, which shows the microphone preamplifiers, phase correlation circuits, and power and ground busses.

Figure 11: Completed Device Exterior Front. Shows, from left to right, power button, four selection buttons, and four bar LED indicators corresponding to selection buttons.

Figure 12: Completed Device Exterior Back. Shows, from left to right, power input, four XLR microphone inputs, one XLR microphone reference input.

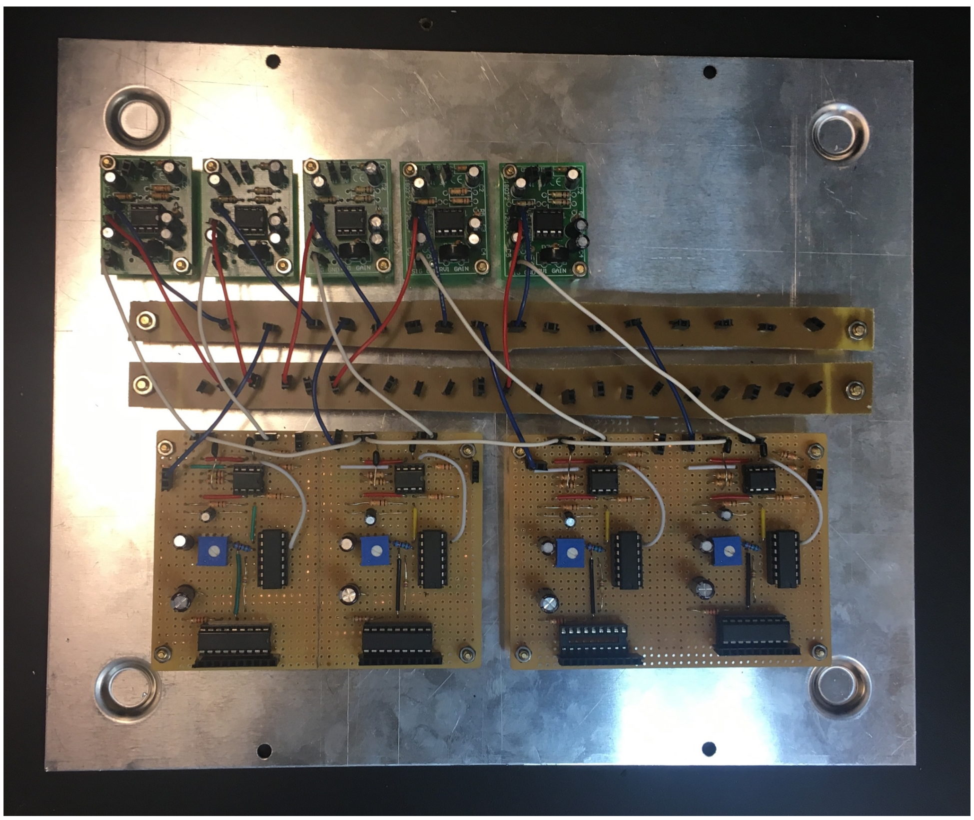


Figure 13: Completed Device Interior. Shows, from top to bottom, five Velleman microphone preamplifiers, ground bus, power bus, and four phase correlation circuits.

6.1 Signal Receiver and Preamplifier Implementation

The signal receiver and preamplifier module followed the preliminary design almost exactly. The only change from the proposed design was the addition of one more input to make a total of 4 microphone inputs plus one reference microphone input. This change was due to the availability of space within the aluminum chassis. There was space for another phase correlation circuit, so the addition of one more input wouldn't hurt, as some recording setups do use five or more microphones. Power consumption of all added components was considered and estimated to still be below 12W (12V/1A DC power).

Five different XLR microphone inputs were used and mounted into the back of the aluminum chassis (figure 12). These inputs were then each connected to a Velleman K1803 preamplifier, which were mounted on the bottom plate of the chassis (figure 13). A picture of a soldered Velleman preamplifier can be seen in figure 14. These preamplifiers ran on the 12V DC power supply, which was also mounted into the back of the chassis (figure 12).

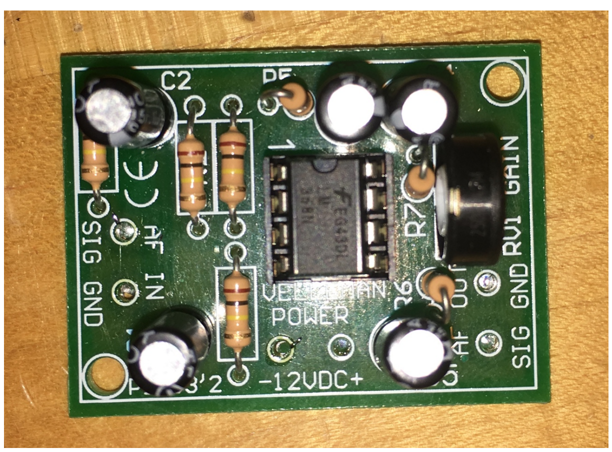


Figure 14: Soldered Velleman K1803 Microphone Preamplifier

6.2 Input Selection Implementation

The implemented input selection module can be seen in figure 11. For the final design, this module used E-Switch PVAL6 Anti-Vandal pushbutton switches. These switches were single pole single throw (SPST) latching switches with LED indicators for the ON position. A picture of one of these switches can be seen in figure 15. A green LED switch was used as the power switch while blue LED switches were used for the four correlation selection switches (figure 11). Each switch LED was powered by the 12V power supply with a 1Kohm resistor in series before the LEDs to allow for the proper forward voltage through the LEDs.

Figure 15: E-Switch PVAL6 Anti-Vandal Switch

The power switch had a wire from the power input soldered to one SPST lead and a wire going to the master +V bus soldered to the other lead to allow for proper power switching. The ground lead of the power input was wired to the master ground bus as well as directly to the aluminum chassis to create an earth ground. Each other switch had one lead of the SPST wired to the master +V bus while the other SPST lead was wired to each switch's respective phase correlation circuit. This allowed for the correlation circuits to be activated only when their respective switches were on. In figure 11, the leftmost blue switch corresponds to input 1 while the three switches to the right correspond to inputs 2, 3, and 4, from left to right.

6.3 Phase Detection Implementation

The phase correlation circuitry varied greatly from the preliminary design. As parts were being ordered for the original correlation circuit (figure 10), it was found that most integrated circuits (ICs) used in this design were discontinued. This was, at first, a major issue in the design process. However, upon a deep analysis of the purpose of each stage of this circuit, it was able to be completely redesigned and reduced drastically in size and complexity. This reduction in size and complexity allowed for the implementation of four separate correlation circuit (one for each microphone input besides the reference input) instead of one correlation with inputs cycled by the Arduino board. As the Arduino board was only controlling this signal flow, it was able to be eliminated completely, resulting in a much simpler and more reliable overall design. A schematic of the redesigned phase correlation circuit can be seen in figure 16.

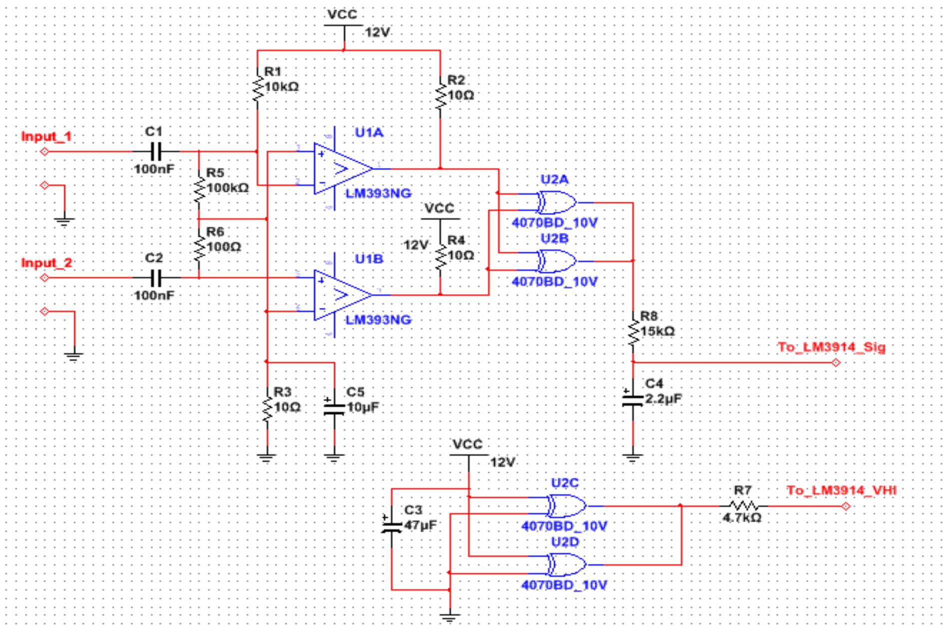


Figure 16: Final Phase Correlation Circuit Schematic

This redesigned phase correlation circuit contained three major stages of analog signal processing including high gain clipping amplification, XOR logic, and signal averaging. The first stage of signal processing contained high gain clipping amplifiers that essentially converted both input signals into square waves of equal amplitude (±12V). The ICs used for this were LM393 amplifiers. By converting these signals to square waves, the exact zero crossings of the waveforms relative to one another could be seen. It should be noted that one of the amplifiers inputs are inverted to allow for proper XOR execution down the line. The second stage contained a 4070B XOR IC that took the exclusive OR of the two new signals, outputting a single 0-12V square wave. The third stage was a low pass filter that acted as a moving averager, taking the output of the XOR stage and converting it into a constant voltage level based on the PWM of the square wave. This output DC voltage acted as the input to an LED controller and determined the height of an LED bar display. The soldered correlation circuitry can be seen in figure 17, which contains two identical correlation circuits on one perf board.

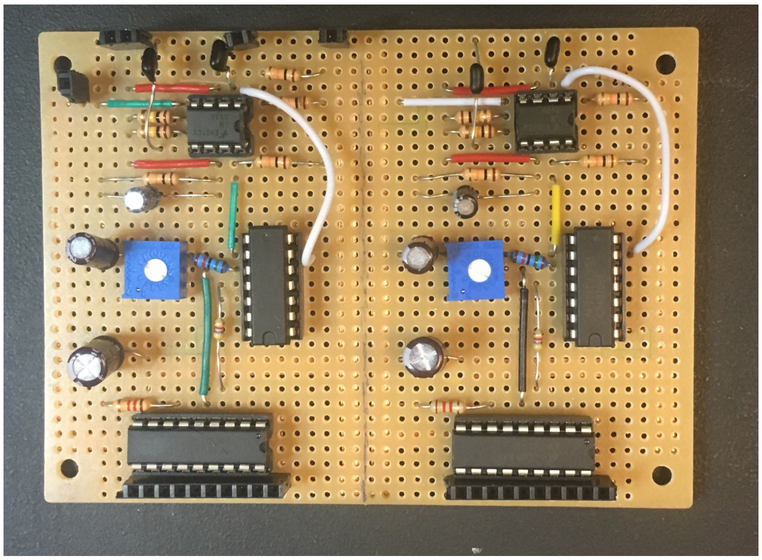


Figure 17: Soldered Phase Correlation Circuitry

Four total correlation circuits were implemented in the final design. Each circuit was powered by 12V DC. A common reference signal input was used for one input of each correlation circuit. This reference signal came from the reference microphone preamplifier. The other input for each correlation circuit came from their respective input preamplifiers. In figure 13, correlations circuits with respective inputs 1, 2, 3, and 4 can be seen from left to right.

6.4 Indication Implementation

The indication module contained four ten step, tri colored bar LEDs. These LEDs were controlled by their respective LM3914 LED controller chips. The circuit design for these chips can be seen in figure 18, which was taken from the Texas Instruments LM314 datasheet. The signal source, in this case, was the output of the phase correlation circuit which ranged from 0V to 12V DC. This voltage range proved work more accurately than the 0-5V signal source shown in the datasheet. A high voltage resulted in all of the LEDs being on while a low voltage resulted in all of the LEDs being off. These LED controllers were implemented on the same perf boards as the correlation circuits.

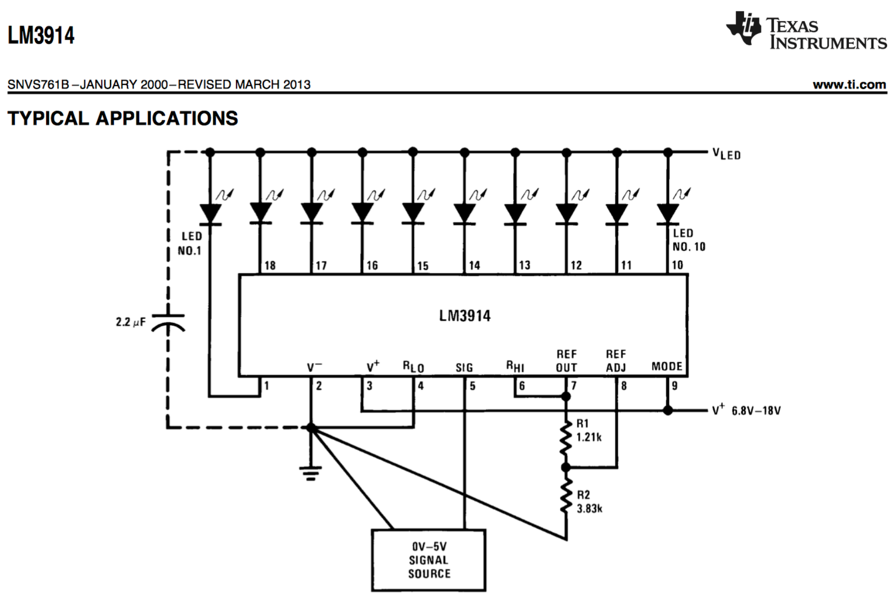


Figure 18: LM3914 LED Controller Schematic

The actual bar LEDs were all mounted on a perf board that can be seen in figure 19. The top of this figure shows the front of the perf board while the bottom of the figure shows the back. On the back of the perf board, connections for the LED controllers can be made. This perf board also contained +V and ground busses used for the mounted switches. These busses can be seen on the bottom right of the backside of the perf board. This LED perf board was then mounted on the inside of the front of the aluminum chassis (figure 11).

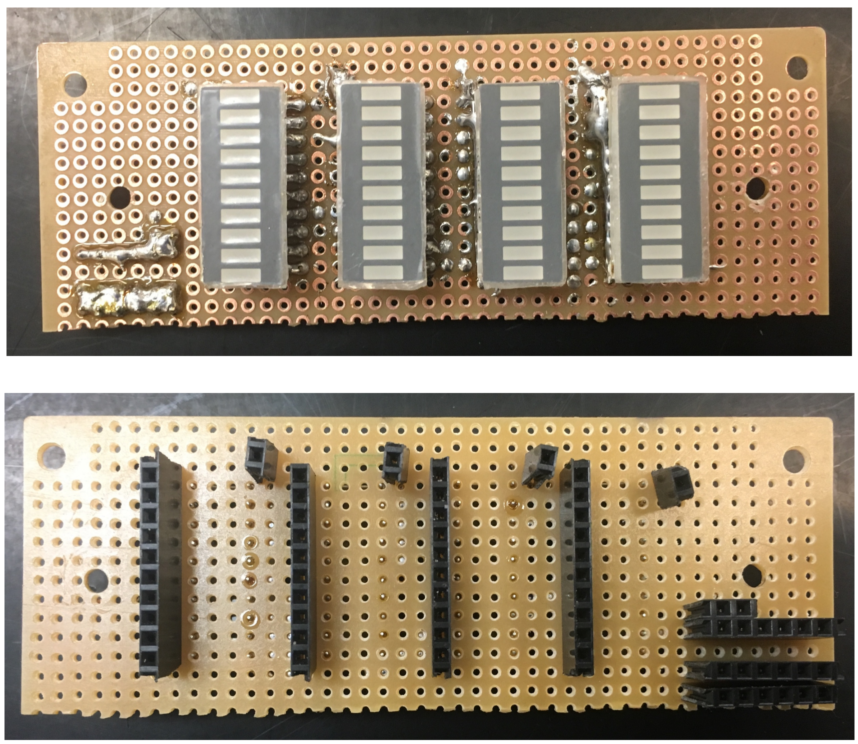


Figure 19: LED Perf Board Module. Shows front (top) and back (bottom)

7. Performance Estimates and Results

Overall, the completed microphone phase detector and indicator worked extremely well. The final design properly detected and indicated the phase difference between microphones. This design also met all of the original design specifications, being only slightly larger than originally intended. The device measures phase difference continuously and with an extremely short turnaround time (nearly instantly). It can measure the phase difference of up to four microphones relative to a reference microphone simultaneously. It is also small enough for easy transportation, relatively inexpensive, and extremely easy to use. Multiple tests were done on the device to ensure that all of this was true. The three major tests included preamplifier testing, phase correlation testing with sinusoids, and phase correlation testing with complicated signals. The results of these tests can be seen in detail below.

7.1 Preamplifier Testing

Preamplifier testing was done to ensure that the microphone preamplifiers worked as expected. It was imperative to make sure that the preamplifiers increased the amplitude of the input signals significantly without effecting the phase of the signals at all. To test the preamplifiers, they were hooked up to a 12V DC power supply with a small microphone level sinusoidal signal as the input. Both the frequency and amplitude of the signal were varied during testing to ensure that the preamplifier worked similarly for all cases. The frequency ranged from 50Hz to 20kHz to cover the audible hearing spectrum and the amplitude ranged from 10mVpp to 30mVpp to cover the range of microphone level signals. Oscilloscope probes were attached to the input and output of the preamplifier and results were recorded for each variation. An example of the amplification of a 1kHz sine wave input with an amplitude of 20mVpp can be seen in figure 20. In this figure, the blue line is the input waveform and the orange line is the amplified signal. It can be seen that the signal was amplified by quite a large factor, as the input line looks nearly flat. For all cases tested, the gain was found to be around 130, which raised the microphone level signals perfectly to around line level (~2Vpp). Along with this, no phase shifts occurred through the preamplifiers. All of this means that the preamplifiers worked as expected.

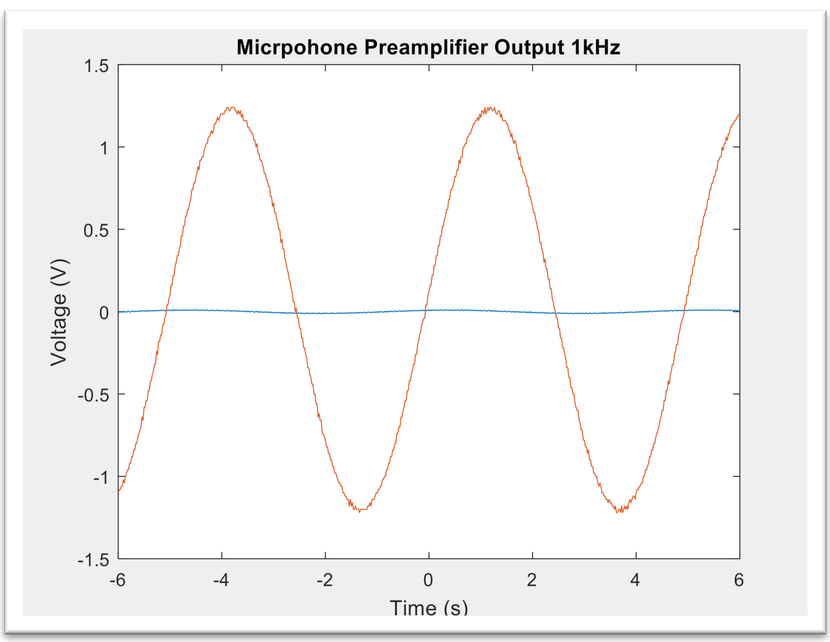


Figure 20: Microphone Preamplifier Results. Shows input (blue) and output (orange). Gain=130.

7.2 Phase Correlation Sinusoid Testing

The phase correlation circuits were first tested using simple sinusoids. This allowed for easier interpretation of results. In order to test the correlation circuitry, one of the circuits was connected to a 12V DC supply. The circuit inputs were identical sine waves with varying phase shifts relative to each other. The inputs were monitored by an oscilloscope to keep track of both of their phases. One input signal's phase was shifted relative to the other and results were recorded for phase shifts of 0°, 90°, and 180°. For each of these phase shifts, oscilloscope plots were recorded for the signal input, high gain clipping amplifier output, XOR gate output, and low pass filter output (final output). Results for 1kHz inputs with magnitudes of 2Vpp (average line level) can be seen in the figures below.

Figure 21 shows the signal processing progression for the 0° phase shift case, figure 22 shows the progression for the 90° case, and figure 23 shows the progression for the 180° case. For each figure, the top left plot shows the input signals, the top right plot shows the signals after the high gain clipping amplifiers, the bottom left plot shows the signal resulting after the XOR gate, and the bottom right plot shows the output signal. It can be seen that each signal processing stage of the correlation circuit works as expected. For the 0° phase shift case, the final output can be seen as a constant voltage of 12V. This resulting voltage lies at the top end (12V) of the potential outputs, indicating no phase shift. In this case, all of the LEDs are on. For the 90° phase shift case, the final output can be seen as a constant voltage of about 6V. This resulting voltage lies halfway between the top (12V) and bottom (0V) ends of the potential outputs, indicating a phase shift halfway, or 90°, out of phase. In this case, the bottom half of the LEDs are on (mostly red and yellow LEDs). For the 180° phase shift case, the final output can be seen as a constant voltage of around 0V. This resulting voltage lies at the bottom end (0V) of the potential outputs, indicating complete phase cancellation. In this case, all of the LEDs are off. All of this shows that the phase correlation circuits work properly and accurately.

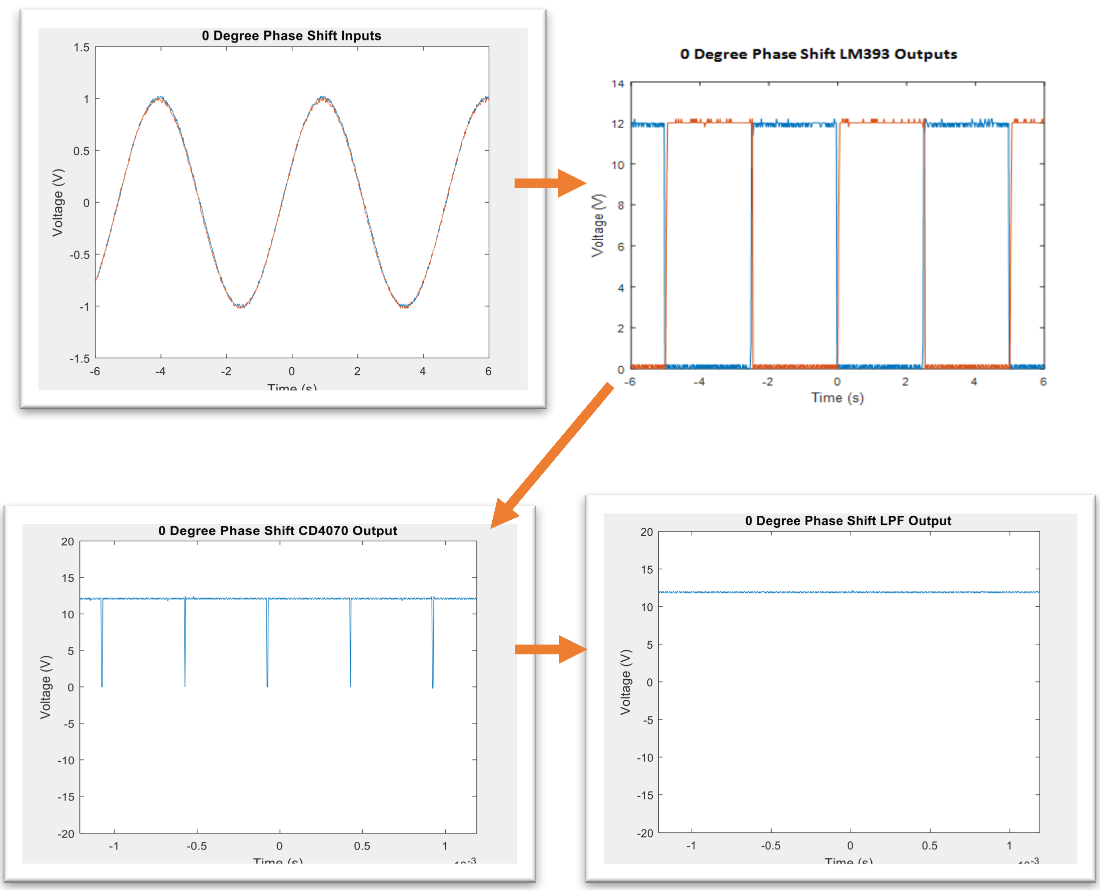


Figure 21: Phase Correlation Progression for 0° Phase Shift Case. The arrows denote the signal flow. Output can be seen as a constant 12V value.

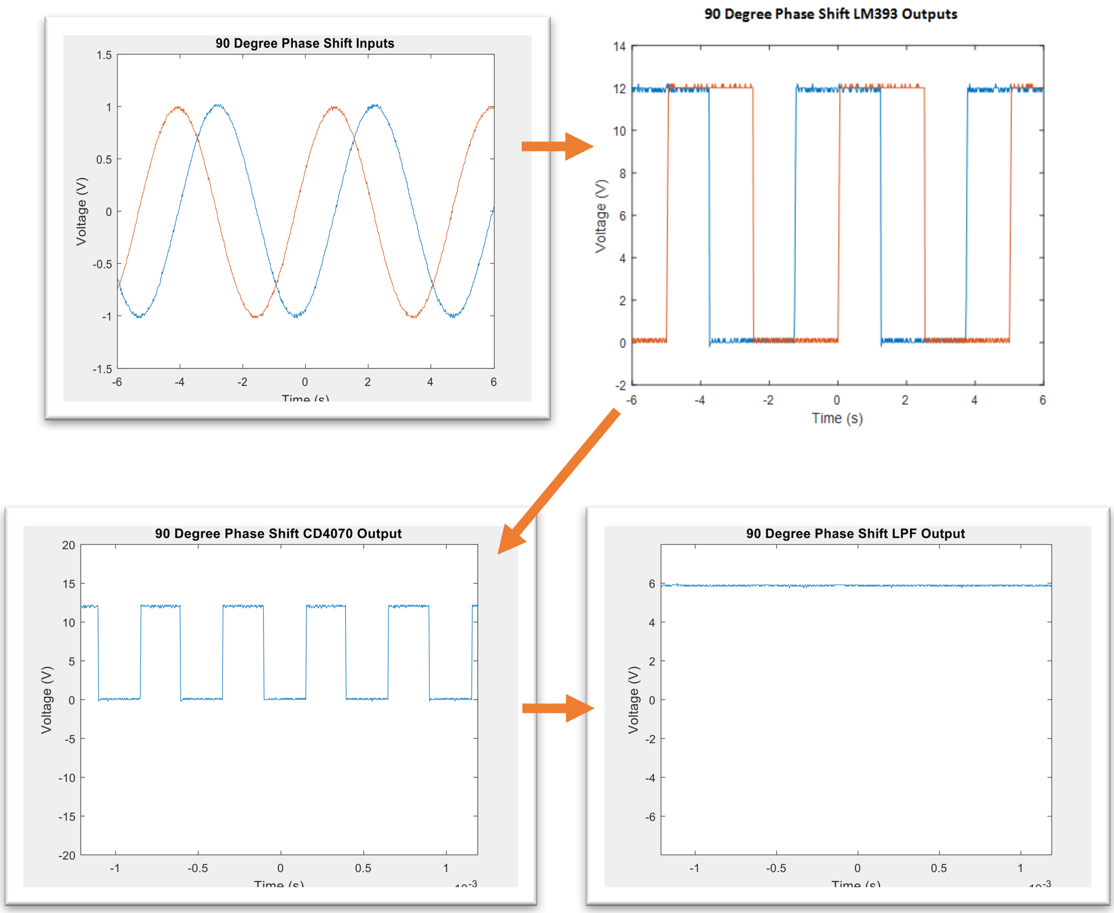


Figure 22: Phase Correlation Progression for 90° Phase Shift Case. The arrows denote the signal flow. Output can be seen as a constant 6V value.

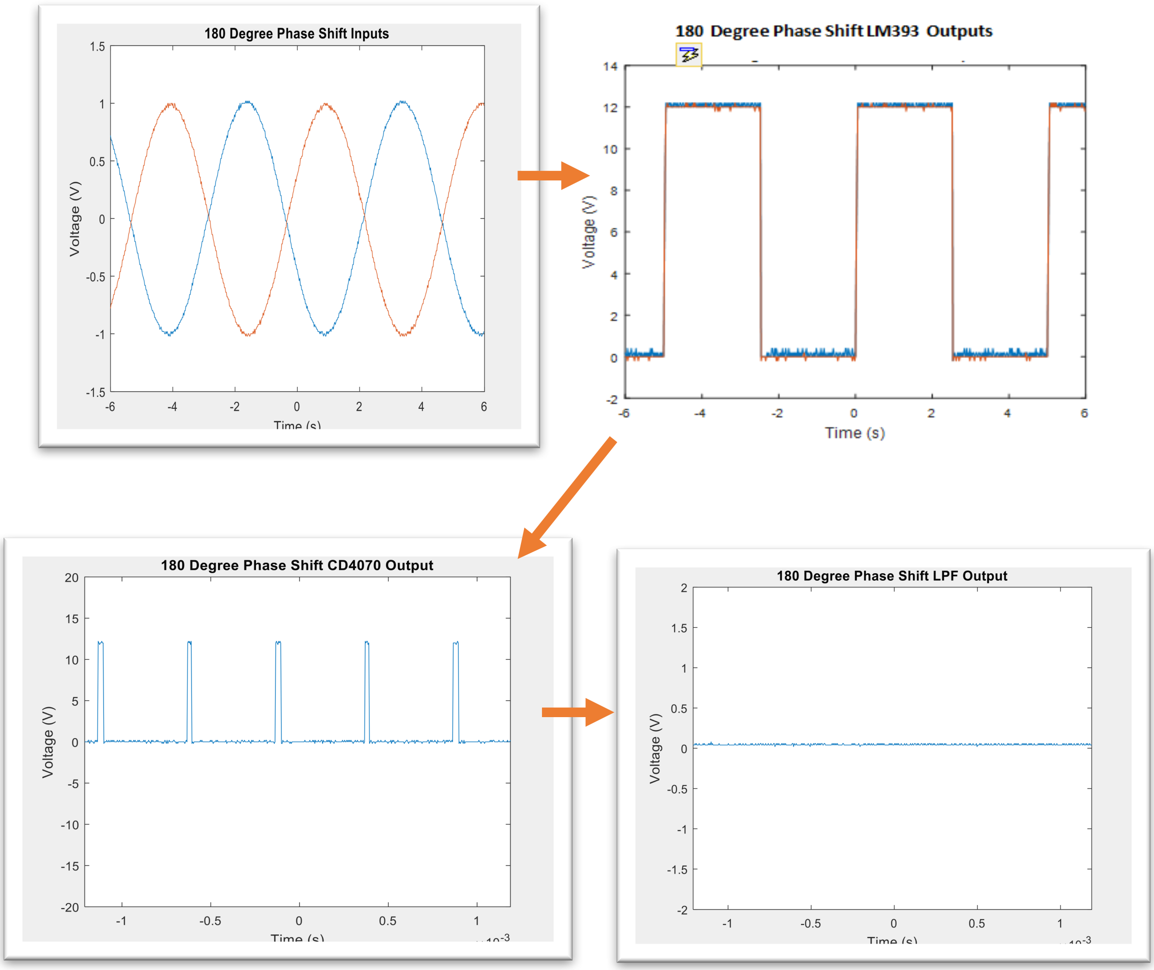


Figure 23: Phase Correlation Progression for 180° Phase Shift Case. The arrows denote the signal flow. Output can be seen as a constant 0V value.

7.3 Phase Correlation Complicated Signal Testing

After testing the phase correlation circuitry with simple sinusoids, it was imperative to test the circuitry with complicated signals, as any real life application for the device would require it to work with such signals. To test this, guitar waveforms were captured by microphones of varying distances from the sound source and from each other. Again, oscilloscope plots were recorded for each stage of the circuitry. Figure 24 shows the signal flow of a much more complicated waveform monitored with two microphones which varied by 6 inches away from a common sound source. Although this data is much harder to interpret, the device successfully outputted a single DC voltage that varied with differences in phase. In this case, the output voltage can be seen as 9.33V, indicating a generally in-phase signal. In other cases, the output voltage was as low as 3V, indicating that the input signals were generally out of phase. This shows that, although these signals are much more complicated, the circuitry still works properly and quickly, resulting in correct phase correlation measurement. Overall, the phase correlation circuitry worked properly. When the bar LEDs were connected to the phase correlation outputs, the device showed proper indication as well.

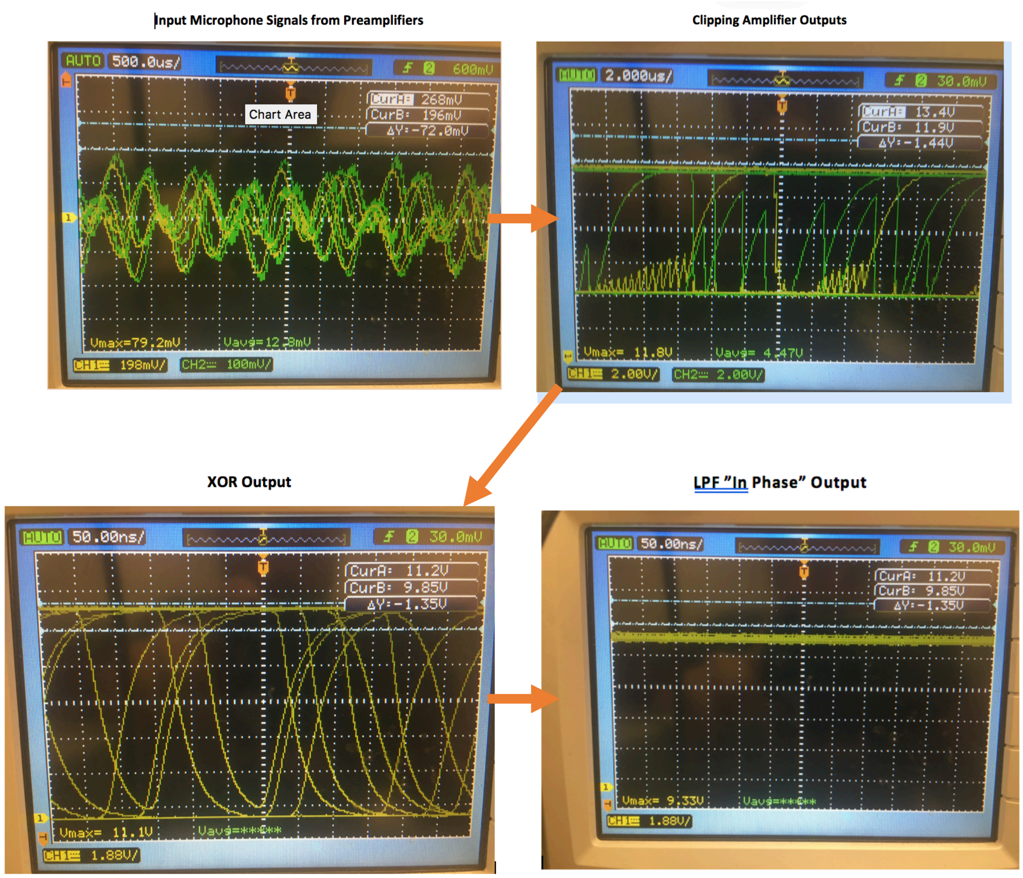


Figure 24: Phase Correlation Progression with Complicated Input Waveforms. The arrows denote the signal flow. Output can be seen as a constant 9.33V value.

8. Production Schedule

For this project, the preliminary design took place in the fall of 2017. During this period, a phase correlation design was found and the main modules of the device were thought through. Parts were ordered early in winter 2018. While ordering parts and starting the building process, however it was discovered that the phase proposed correlation circuitry could not be built due to discontinued parts and complexity. Because of this, the phase correlation circuit had to be redesigned. This took a decent amount of time and created a lot of added stress. By February 2018, the correlation circuit was redesigned and all parts were ordered.

Throughout February, the entire device was constructed. First, all of the circuits were soldered. The correlation circuits took some time to solder as the organization of the perf board was challenging. The organization of the bar LED perf board was also required some out of the box thinking to be able to properly mount the indication LEDs. All of the circuitry was soldered by mid-February. At this point, the mounting design of all of these circuits inside the aluminum chassis was considered. This was also challenging, as the mounting needed to be organized properly for minimum wire crossings and complexity. Once everything was mounted, the device was wired up and completed.

The device testing took place throughout the entire construction process. After a circuit was soldered, it was tested and results were recorded. Once the entire device was complete, final tests were conducted. This final testing took place in late February and early

March. All of this left a short amount of time in March to complete the final presentations and paper for the project.

The main improvements that could have been made to the scheduling of this project involved ordering parts and design. A more thorough design should have been in place by the end of fall term, with all parts ordered or at least researched. This would have allowed for much more time during the winter to build and test the device and would have alleviated a lot of stress. Overall, a more structured schedule would have resulted in a smoother design, construction, and testing process.

9. Cost Analysis

All of the costs involved in this device can be seen in table 2. It can be seen that the total estimated cost was $230 while the actual total cost was $236.41. This actual cost was quite close to the estimated cost. The E-Switches were the most unexpected price increase from the estimated cost. Realistically, these LED switches were not required, but used to add to the aesthetic of the overall design. The cost for the correlation circuit components turned out to be far less than expected, which is good as this is the most important part of the device. Parts such as the wires, connectors, screws, and mounting supplies were ordered in large quantities as these components were only sold in “bulk”, which resulted in a lot of left over material which could be used to construct more devices, resulting in lower cost. Overall, the total cost would be reduced if parts were ordered in bulk, as the individual costs of components were generally high. Regardless, the device was still built well within the initial budget of $300.

Table 2: Device Cost Analysis

Part	Estimated Cost	Actual Cost
Aluminum Chassis	$30	$37.11
LED E-Switches (5)	$20	$34.88
Power Mount and Wall Plug	$15	$16.97
Velleman Preamplifiers	$35	$34.97
Correlation Circuit Components (4 circuits)	$80	$58.38
Bar LEDs	$10	$10.70
Wire and Connectors	$20	$26.47
Screws and Mounting Supplys	$20.00	$16.93
Total	$230.00	$236.41

10. User's Manual

The microphone phase detector and indicator is a simple to use tool for checking the phase between microphones in a recording setting. By using this device, you will be able observe any phase cancellation between microphones, assisting you in obtaining the best possible recordings. To use, follow the instructions below, which correspond to figure 25.

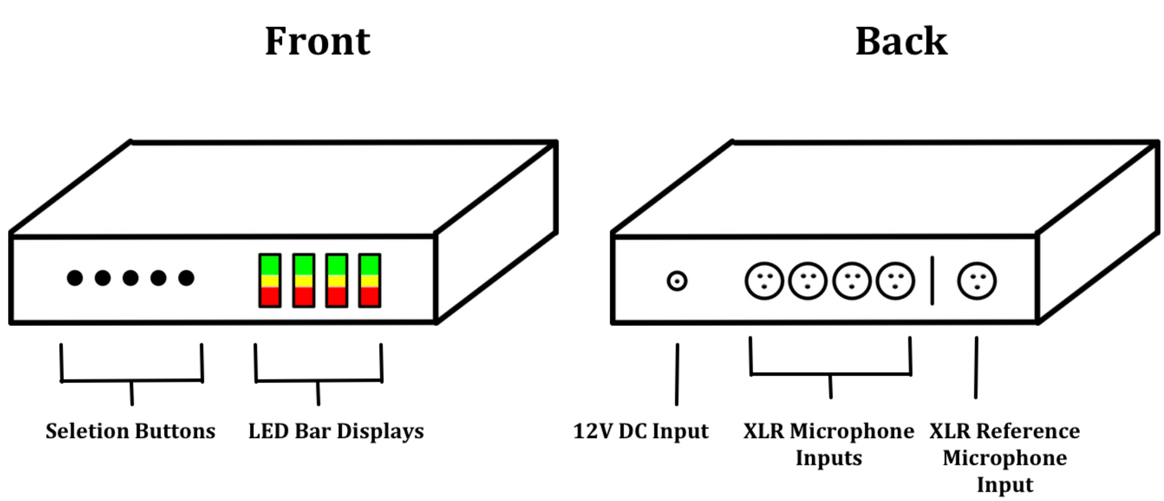


Figure 25: Microphone Phase Detector and Indicator User's Manual

Microphone Inputs

This device has a total of five XLR microphone inputs, with one input being a reference input. These inputs can be seen in figure 25. To use this device, at least two microphones must be plugged in. One of these microphones must be plugged into the reference microphone input. After this, more microphones can be plugged into the remaining inputs. The rightmost of the "XLR Microphone Inputs" seen in figure 25 is considered input

1, with inputs 2, 3, and 4 continuing in order to the left of input 25. The phases of all microphones plugged into these four inputs will be compared to the phase of the reference input, so it is important to consider which microphone to use as the reference. Generally, the “most important” microphone being used should be the reference input.

Power

To turn this device on, first plug the 12V DC wall adapter into the 12V DC input shown in figure 25. Once plugged in, press the leftmost “selection button”. The button should light up green, indicating that the device is on.

Input Selection

The input selection buttons are organized so that the second leftmost “selection button” in figure 25 corresponds to input 1, with buttons corresponding to inputs 2, 3, and 4 continuing in order to the right of input 1 button. While the device is on, pressing any of these buttons will cause the button to light up blue, indicating that the button’s corresponding input microphone phase is being compared to the phase of the reference input.

Indication Reading

Once a selection button is pressed, the bar LED corresponding to that input should also light. The leftmost "LED Bar Display" seen in figure 25 corresponds to input 1, with bar LEDs corresponding to inputs 2, 3, and 4 continuing in order to the right. When a bar LED is lit, it is indicating the phase correlation between the reference microphone and the microphone that the given bar LED corresponds to. If the bar LED is green, the two microphones are in phase, and everything is okay. If the bar LED drops down to the yellow at any point, there may be some phase cancellation happening between the microphones and microphone placement may be changed to eliminate this. If the bar LED ever drops down to the red, phase cancelation is certainly occurring and microphone placement should be changed. Generally, microphone placement should be tweaked until all bar LEDs show mostly green (maybe some yellow). This will result in ideal recordings.

11. Discussion, Conclusions, and Recommendations

After months of hard work, a device which can be used to greatly aid audio engineers in the recording process has been developed. This device, which meets or exceeds all of the design requirements, proves to be a simple and reliable tool to check for phase cancellations between microphones in a recording setting.

11.1 Discussion

Audio engineers, whether professional or amateur, constantly strive to capture quality sounding recordings. When recording music using multiple microphones, the sound quality may be limited due to phase cancellations between microphones. These cancellations occur due to differences in microphone distance from a common sound source. When the positive and negative portions of a sound signal are added together, cancellations at certain frequencies can occur, resulting in a dull sounding recording. This project aimed to give audio engineers an indication of any phase cancellation problems that may be present in a recording setting prior to recording an instrument.

To properly achieve this, a device was created using phase correlation hardware to measure the phase difference between microphones. The final device contained four main modules: microphone input and preamplification, input selection, phase correlation, and indication. Using these four modules, the resulting system detects and indicates the phase difference of up to four microphones relative to a reference microphone.

The completed device met or exceeded all of the original design requirements. The system is able to successfully determine and indicate to the user any phase cancellations between microphones, showing the magnitude of cancellation with great accuracy. The completed device can continuously monitor phase difference for up to five microphones with virtually no lag. The device is small for easy transportation and extremely easy to use. It also fit well within the initial budget. All of this allows for use by professionals and armatures alike.

11.2 Recommendations

Future work for this project will include more in depth testing with live instruments as well as testing with all five input microphones. Testing the full functionality of the device with different instruments in multiple different acoustic settings is imperative to fulfilling the initial goals of the project. Other future work may include implementing a phase shifting option which would allow the user to manually shift the phase of a microphone. This, however, would require audio outputs in the device and would likely be a whole other project. Another expansion on this fundamental concept could be to implement this technology into an audio interface to allow for phase indication directly before or even during recording. This technology would act as a simple tool within an interface to allow audio engineers to quickly check the phases of their microphones. This way, there would be no need to have a separate device to do this, which would allow for a simpler and more practical way to check for phase cancelations.

Throughout the process of designing, constructing, and testing this device, multiple lessons were learned. One major lesson involved keeping a strict schedule for completing the device. A lot of stress was added due to procrastination and the occurrence of unexpected problems. With a strict project schedule, it is possible to add in time to deal with inevitable problems that may come up, resulting in a much smoother design process. Relating to this, another lesson learned is to always expect problems. Throughout the design and construction of this device, problems were constantly occurring. Most of these problems were completely unexpected, but had to be resolved in a timely manner.

11.3 Conclusion

In conclusion, this project faced the problem of microphone phase cancellation in a recording setting, a problem that frustrates both amateur and professional audio engineers all the time. The completed device was a practical, simple, and useful device that gives accurate and valuable feedback to the user. While the final design did vary from the preliminary proposed design, the result was ultimately more reliable and straightforward, making it quick and easy to use. Throughout the design process, many setbacks occurred, but with perseverance, a quality product was successfully constructed. This device does have the potential for expansion, and future work will take place. Overall, this project was an amazing learning experience and the entire process turned out to be truly rewarding.

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