Consumer Emergency Vehicle Alert System

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Abstract

For this senior design project, the real-world feasibility of an emergency vehicle alert system is evaluated. A proof of concept model will use an ultrasonic frequency transmitted by emergency vehicles and received by consumer vehicles to trigger light and sound notifications to drivers. A prototype is being constructed using computer programs, such as MATLAB and LabView, data acquisition equipment (National Instruments 6211), speakers and microphones, and an Atlys Spartan-6 FPGA development board. The driver will be notified via an optical and audible warning system. This system will include LEDs and a small speaker in the proof of concept. Ideally in a final design the LED would be a light on the dash and a sound would be emitted upon lighting the LED – much like a seatbelt LED and sound in cars today. Obstacles, such as the Doppler Effect and sound dissipation, are examined to determine their impact on a full-scale system. More validation is required to prove that this alert system is a feasible option. Initial testing of the microphone shows promising results for the proof of concept. Overall, functional tests have been completed and integration of the components has begun.

Introduction

According to the National Highway Traffic Safety Association (NHTSA), 50 people in the United States were killed in 2011 due to traffic accidents involving an emergency vehicle. Annual reports from NHTSA show a continuing trend of such accidents as these[1]. This problem is compounded by the improved noise suppression[2] in modern passenger vehicles, as well as by the increasing number of electronic devices with the potential to distract or isolate the driver from their surroundings. According to Ohio State laws (along with other states as well), the emergency vehicle must be able to alert drivers from 500 ft away when responding to an emergency, using at least one light source and an audible signal[3]. For the entirety of this document, the use of the term "emergency vehicle" shall refer to an emergency vehicle responding to an emergency in accordance to Ohio State law as paraphrased above. The CEVA system will at least adhere to this distance constraint, but a greater distance is ideal. The purpose of this Senior Capstone project is to design a device or system that will alert motorists to the presence of an emergency vehicle.

As seen in Figure 1, the system consists of three subsystems: one for signal transmission, another for signal detection, and another for driver notification. The signal transmission subsystem begins with a high frequency audio signal emitted from the emergency vehicle. This can be accomplished through a slight modification to the existing siren system. Whenever the lights are turned on, a voltage oscillator will activate and emit an ultrasonic frequency as an audio signal. In the passenger vehicle, a microphone receives this signal, passes it through an analog-digital converter (ADC), and then sends it to a microprocessor. This is the signal detection subsystem. Once the signal has been detected and validated, a visual and audible warning will trigger to notify the driver.

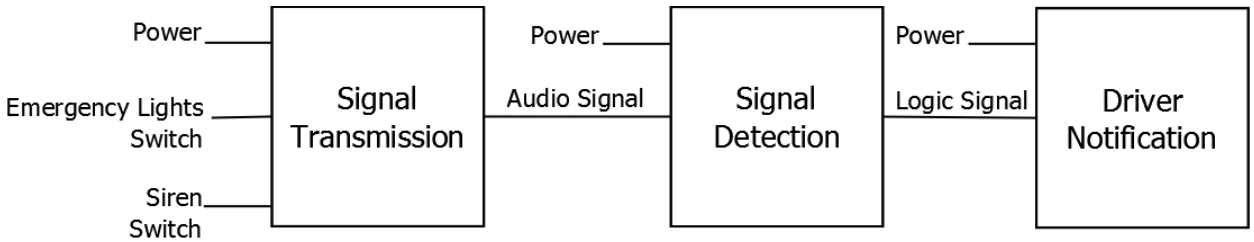

Figure 1: High-Level Block diagram

To prove the viability of this concept, a prototype is being built using a field-programmable gate array (FPGA) to implement a filter and the notification logic. One or more microphones will be used to detect the signal and the output of the filter will verify if the ultrasonic audio signal was detected. The audio signal will be generated via computer program, and the sound will be emitted through the speakers. This will validate that our concept is viable by proving that a high frequency audio signal can be transmitted through a medium and successfully detected using our device. This concept will be further verified through various testing scenarios in an attempt to simulate real-life operation. For the proof of concept, a 19.5 kHz signal will be used to test the receiver. The filter has a target pass-band of 16kHz to 25kHz. A full-scale product would use a higher frequency to fully exceed the 20 kHz upper bound of human hearing ability. This would result in a modified pass-band if it were to be implemented as a final design.

Constraints and Criteria

When marketing this product, certain criteria and constraints must be considered in order to satisfy the consumer and automotive industries. The manufacturing cost should be low considering that this system would be included in trim packages offered by the auto manufacturer. Minimizing the price, while still producing a quality product, is a high priority; this includes having aesthetically pleasing hardware where visible to the driver and durability in multiple conditions. It is important for the microphone to withstand reasonable driving conditions in order to reliably detect an audio signal produced by emergency vehicles. The microphone should not be bulky or obtrusive because it would negatively impact the car's performance and aesthetics. Inside the car, it is important to minimize wire visibility and length for a clean and attractive appearance. This can be accomplished by incorporating the product into the manufacturer's trim package. The most important factors in product marketability are processing time and detection range of the receiver. The optimized device will have a high detection range while minimizing signal processing time for appropriate actions to be taken.

There are five constraints that need to be met for this project to be successful. The system must detect signals within 500 feet due to various state laws[3]. This system must be usable by disabled drivers as well as not interfere with any existing safety features of the vehicle. The alert system must function in reasonable driving conditions. Furthermore, the system needs to be safe and not distracting to the driver.

Prototype Design

The overall design of the system includes three parts, an audio signal transmitter, an audio signal receiver, and a driver notification subsystem. Figure 2 demonstrates how the audio signal transmitter will exist in the emergency vehicle. Anything demarcated with an asterisk in the figure is already present in current emergency vehicle siren systems. Slight modifications must be made to the emergency vehicle in order to transmit an ultrasonic frequency through the existing loudspeakers. This modification is expected to be a voltage oscillator although the exact details of this are to be determined.

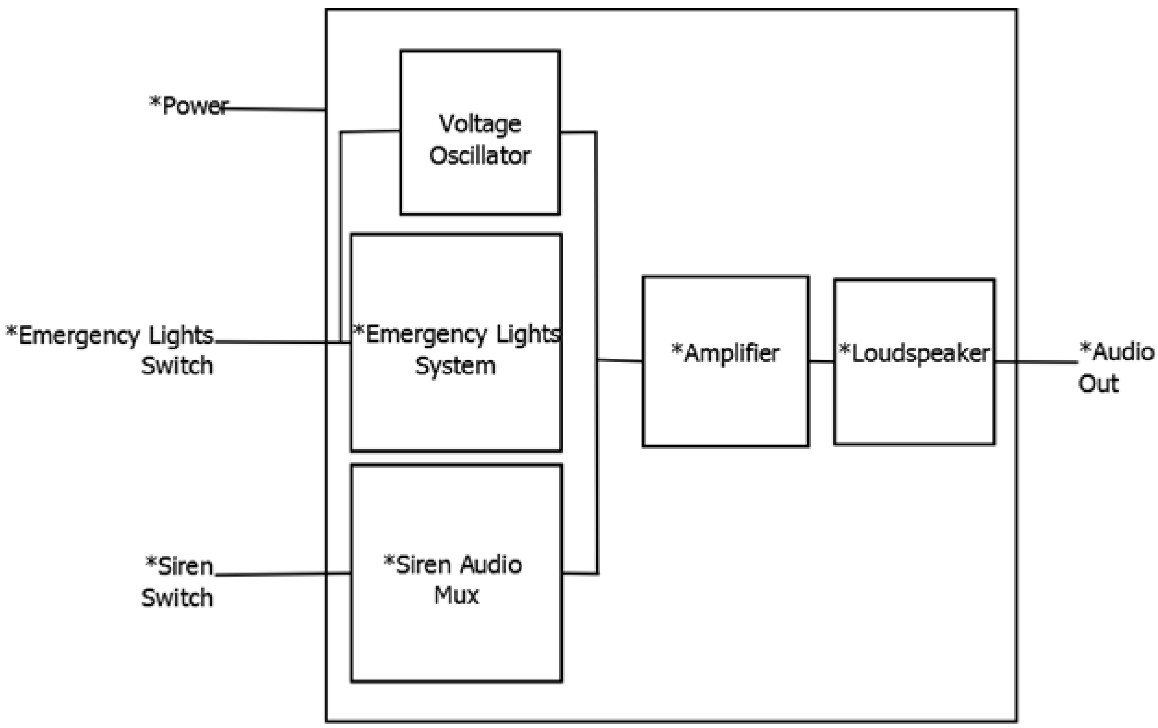

Figure 2: Block Diagram of Signal Transmission (* denotes existing vehicle components)

The audio signal receiver, as seen in Figure 3, will consist of a CMA-6542PF electret condenser microphone from CUI, Inc., an AD7731-BN ADC, and an Atlys Spartan-6 FPGA development board. The microphone will receive the ultrasonic frequency signal, then pass the analog data to the ADC. The filter implemented on the FPGA will then determine if the converted signal is within the target frequency band. If the signal is indeed within the specified range, the FPGA will produce a logic signal for the driver notification system.

The microphone being utilized for the prototype is a CMA-6542PF electret condenser microphone. According to its specifications, it should be able to receive a 20 kHz audio signal without difficulty[4]. Signal conditioning will be performed between the microphone circuitry and the ADC. The signal conditioning itself includes a voltage amplifier and a DC offset made from an op-amp and resistors. An AD7575JNZ-ND ADC is being utilized for the prototype. It is an 8-bit ADC with parallel output pins, thus interfacing seamlessly with the Atlys Spartan-6 via the VHDCI port[5]. An Atlys Spartan-6 FPGA development board will be utilized in the prototype due to its ability to simulate a pass band filter using VHDL (which stands for VHSIC [Very High Speed Integrated Circuit] Hardware Description Language), as well as interface with the variety of hardware used in this prototype[6].

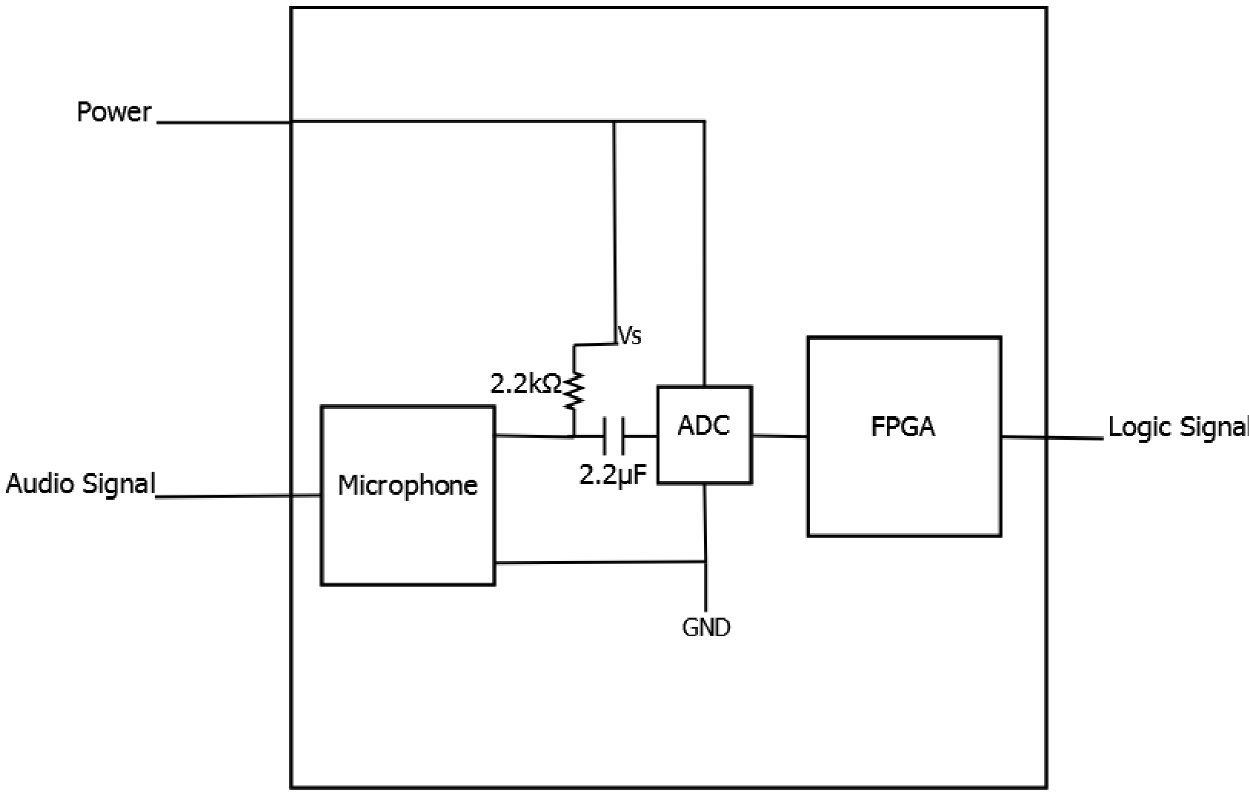

Figure 3: Block Diagram of Signal Receiver

Currently, a filter has been implemented in MATLAB for verification purposes; the code will be ported to VHDL and downloaded to the Atlys FPGA. The filter will be a band pass IIR (infinite impulse response) filter. The type of band pass filter (i.e. Butterworth, Chebyshev, etc.) will determined from noise data collected using the microphones in a moving vehicle. The target pass band frequency will be centered at 19.5 kHz and the window will be 9kHz wide. The width of the pass band has been determined from calculations using the Doppler Effect equations[8]. The calculations have been tabulated in the Results and Discussion section.

After considering various forms of notifications, the best choice was determined to be a combination of a speaker and an LED light. The criteria used to make this decision included cost, aesthetics, driver reaction time, energy usage, and reliability. This decision was made due to the low cost and the high reliability of the parts. The notification system is basic and the components can be seen in Figure 4.

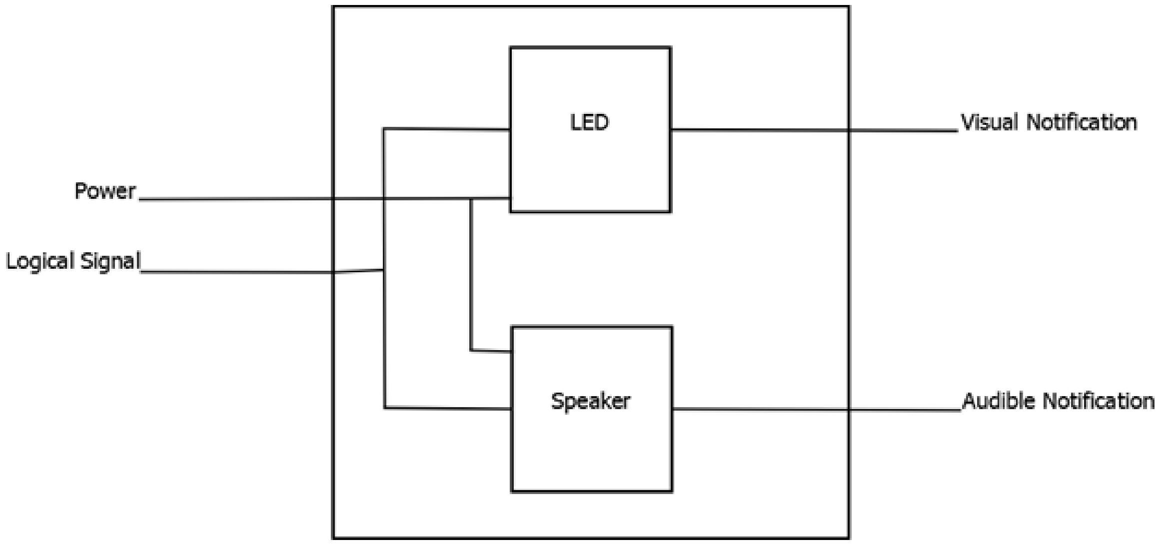

Figure 4: Notification System Block Diagram

Testing and Validation

The emergency vehicle detection system will be tested through a scaled model of the actual system as a proof of concept. Generating an audio signal within the typical specifications of a standard speaker allows for the use of a simplified receiver.

In order to prove that the audio system will operate properly, a frequency near the upper limit of standard speaker hardware will be transmitted at a specified decibel level. The Atlys FPGA also provides for an easy interface between the audio signal receiving hardware and the implemented filter. Since the chosen frequency is within the typical speaker transmission and microphone detection ranges, one of these FPGA boards will be able to detect the audio signal.

In order to confirm that the design criteria are met, the speaker will be placed at a specified distance from the simplified receiver described above. The speakers available will not be able to output the same decibel level of the loudspeaker sirens on the emergency vehicles[7]. Consequently, the specified test distance will need to be a scaled distance from the distance in our design criteria. This distance will be determined through sound dissipation equations and based on the speaker dB output capabilities. In order to verify audio signal detection, the FPGA will turn on an LED and emit an audible pitch from a speaker. This will be the equivalent of simulating the driver notification in a full-scale prototype since the receiver will be placed inside a car. Unit testing will be performed in order to verify that each component is working properly throughout the design process. This will include black box and white box tests of the receiver as necessary.

In order to unit test the microphone, it was necessary to verify the functionality of the microphone circuit. The circuit was built, and a speaker was utilized to transmit test frequencies of 2.5 kHz, 5 kHz, and 10 kHz. Using an oscilloscope, the microphone functionality was successfully verified.

In a full-scale prototype, frequency of the transmitted signal becomes more of a concern. Ideally, a frequency will be chosen above the audible human range while maintaining feasibility of transmission. Standard speakers are certified to output signals up to 20 kHz. However, 20 kHz is only a soft cap of the frequency. They are actually capable of transmitting frequencies much higher, but there is decibel fluctuation in that output. With proper control, it is feasible to output a higher frequency from standard speakers. The sound of an emergency vehicle siren is typically the output of a loudspeaker, which operates with the 20 kHz soft-cap described above.

The Doppler Effect will be taken into account through the pass band of the band-pass filter utilized. The upper and lower thresholds of the band are determined using worst-case scenarios of driving situations on the road. For instance, the Doppler Effect will have the strongest effect on the transmitted frequency when two vehicles are traveling in opposite directions at 75 mph.

The prototype of the emergency vehicle detection system would be tested in phases. Initially, efforts were focused on simulating as much functionality as possible prior to ordering parts and attempting to physically build the functioning prototype. Simulations for circuit elements were completed in PSPICE, while VHDL test bench implementations were simulated using ModelSim. Each physical subsystem of the prototype has undergone functional testing. The microphone output and the ADC outputs were verified using an oscilloscope. The Atlys FPGA had its VHDCI input and output ports verified using a custom VHDL implementation. Once all the individual components have been successfully verified, integration tests were run on the system as a whole. The overall functionality will be tested by passing a variety of audio signals through the microphone and observing the filter output. This ensures that the individual components still worked as intended when introduced to the entire system. A wide range of tests will be performed on the prototype once initial integration tests have been successfully completed. This includes passing the sound through various media, such as glass and sheet metal, and simulating the Doppler Effect by fluctuating the frequency of the sound wave. Tests also need to be completed to verify distance scaling.

Results and Discussion

The target pass band frequency for the filter will be determined via Doppler Effect equations[8] as well as noise data collected using microphones in moving vehicles. Table 1 shows a variety of scenarios that can impact the perceived frequency that would be sent through the filter. The values in the body of the table are the perceived frequencies, f', calculated using the following equation:

$$f' = f_0\left(\frac{v \pm v_0}{v \pm v_s}\right) \quad (1)$$

The frequency of the sound as it is perceived by the observer is defined as f' whereas the actual transmitted frequency is defined as f_0. Both of these values are measured in hertz. For this particular application of the Doppler Effect equations, v is the speed of sound and is measured in meters per second (the Doppler Effect is observed in all types of waves, not just sound). This value is estimated to be 340 m/s in Doppler Effect calculations. The velocity of the observer is represented by v_0 while the velocity of the source of the sound wave is represented by v_s. Both of these values are measured in meters per second.

	PV = Passenger Vehicle, East of EV	**Actual Transmitted Frequencies**			
	EV = Emergency Vehicle, West of PV	25000	20000	22000	23000
Description of event	PV moving 25mph E, EV moving 35mph E	25345	20276	22303	23317
	PV moving 25mph W, EV moving 35mph W	24686	19749	21723	22711
	PV moving 25mph W, EV moving 35mph E	27067	21654	23819	24902
	PV moving 25mph E, EV moving 35mph W	23115	18492	20341	21265
	PV idle, EV moving 70mph W	22893	18314	20146	21062
	PV moving 70mph E, EV moving 70mph W	20786	16629	18292	19123
	PV moving 70mph W, EV moving 70mph W	25000	20000	22000	23000
	PV moving 70mph W, EV moving 70mph E	30068	24055	26460	27663
	PV moving 70mph E, EV moving 70mph E	25000	20000	22000	23000
		Perceived Received Frequencies			

The proof of concept will also be validated using the sound dissipation equation[9]. These calculations have yet to be completed but the following equation will be utilized:

$$L_2 = L_1 - \left|20 \cdot log\left(\frac{r_2}{r_1}\right)\right| \qquad (2)$$

The ability to measure the sound decibel level at a distance requires two reference distances, r_1 and r_2, measured in feet. The sound level L_1 (decibels) is the measured at reference distance r_1. The calculation will yield the sound level L_2 (decibels) at reference distance r_2.

Using this equation, the scaled distance can be determined where our proof of concept will effectively prove that the final design would be capable of detecting the presence of an emergency vehicle from a minimum of 500 feet away. Correct utilization of the sound dissipation equations and multiple microphones can also allow for directional presence detection which would provide the ability to determine if an emergency vehicle were approaching or retreating from the driver's position.

Conclusions

There is still work to be done on this project despite the work already completed. A prototype is currently being constructed and some functional testing has been done. As mentioned, scaling plays a vital role in the proof of concept for this project. Once the expected sound dissipation has been effectively worked out, it should be straightforward to accurately scale the prototype signal decibel level and distance between transmitter and receiver. It is expected that testing this prototype will serve as a sufficient proof of concept for the system design. For successful completion of this project, construction and testing with thorough documentation of results will need to be completed. Testing for this project has a strong focus on generating an irrefutable argument that the scaled down prototype type proves that full scale product will work in the industry.

Acknowledgment

Progress on the development of this prototype and the details that were formed through the ideation process would not be possible without the expertise and support of the faculty and staff at Ohio Northern University. Namely, Dr. John Estell and Dr. David Sawyers, our capstone advisors; Dr. Firas Hassan for his expertise on signal processing; Brad Hummel, for hardware support and part acquisition; and the Archer Fund at Ohio Northern University for project funding.

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