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Digital Device Detector: Effective Detection and Recognition of Radio Signals Generated by Digital Devices

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Distracted driving involving the use of digital devices has become one of the greatest pandemics plaguing America's roadways. The purpose of this project was to investigate possible solutions to the engineering problem: Is it possible to construct a receiving device designed to detect, interpret, and respond appropriately to radio signal transmissions? The results from this investigation are significant because early, accurate detection and response to transmissions sent by automobile operators has the capacity not only to alert other automobile operators to the presence of an impaired driver, but also to potentially save lives. This investigation was subdivided into eight phases of an engineering design process, during which a receiver that could detect cellular phone transmissions was successfully designed, constructed, and tested with twenty different cellular phones. The effective range of the detector was 50cm and 70cm for low and high power cellular phones respectively. Thus, this project was both an educational foray into the engineering design process and an introduction to product development.

Introduction

Undoubtedly, fatalities and automobile accidents due to distracted driving involving the use of digital devices have become one of the greatest pandemics plaguing America's roadways. Common digital devices that could be responsible for distracting drivers include not only the familiar flip or slide cellular phone, but also modern smart phones such as the iPhone™, BlackBerry®, or Droid™. This term can also be used to describe handheld radios or other digital communication devices. As a motorist, driving defensively is a necessity. In order to help ensure the safety of motorists against the threat of distracted drivers due to digital devices, a device should be constructed that alerts fellow motorists who are nearby to the presence of a distracted driver.

This could potentially lower fatalities connected to this pandemic on roadways throughout America.

In order to properly address this problem, both an Engineering Design Process and a Standard Design Process will be implemented. Based on conversations with Rose-Hulman Institute of Technology professors, an Engineering Design Process involves a brainstorming step followed by an affinity diagram. Then, before the design process can begin, all alternative approaches must be evaluated and considered. Once the Engineering Design Process has been completed, the Standard Design Process can begin. This is where the true research and experimentation starts, and quantitative experimental data will be gathered. To start with, the engineering problem and all background research should be clearly stated. Next, specific ideas should be generated and then evaluated utilizing a decision matrix where the optimal choice is highlighted with the lowest score. This initiates the preliminary design and testing stage, which involves prototyping and more engineering, interval decision matrices, with variables dependent upon performance during experimental trials. After this stage has been completed, the final design is constructed and tested.

The vision and purpose of this project is to develop a solution to the open-ended engineering problem: Is it possible to construct a receiver to detect, interpret, and respond appropriately to the recognition of cell phone transmissions made by digital devices? The results from this research project are important because a device that detects the presence of digital device transmissions made by drivers could alert other drivers of this threat and potentially reduce the number of automobile crashes and subsequently save lives. At the conclusion of this research project, the analysis of the results will highlight if a receiver which can detect, interpret, and respond to the transmission of a radio signal from a digital device has been successfully designed and constructed.

Research Plan

A. Goals and Objectives

Success in this research project will be defined as following an engineering research process to design and construct a device that not only detects the presence of radio signal transmissions, but also meets the criteria of three goals: engineering, science, and computer science. In order for a goal to be completed, a series of objectives must be successfully met.

To begin with, successfully completing the engineering goals necessitates that six objectives must be attained. First, the receiver must only work when the automobile is running. Then, before an appropriate response can be initiated, the automobile's transmission must be out of park with the car in motion. In addition, cost must be minimized. Also, the reliability and effectiveness of the receiver should foil a driver's attempts to evade the detecting device. Furthermore, an appropriate response for successful detection must be determined. Finally, the successful installation of the receiver into both a simulated and a real automobile while retaining all of its reliable qualities will be a final determining factor in the overall success of the engineering goals.

Additionally, meeting the scientific goals is dependent upon the completion of four objectives. Modeling the circuits to function off of an automobile's power system is crucially important. Similarly, the receiver must be capable of reliably detecting all brands and models of cellular phones in order to be effective. Thus, the focus of the receiver's bandwidth range of detection must be focused primarily on 900 MHz, 1,800MHz, and 1,900 MHZ, which the Federal Communication Commission, FCC, has allocated specifically for cellular phone use. Also, the ability to discern the origin of radio signal transmissions is vital to the overall success of the project because the purpose of this receiver is only to detect for a driver using a digital device and not the rest of the passengers. Still, cost once again must be examined to minimize production costs.

Moreover, after completing four objectives, computer science goals will be measured for success. Most importantly, the analog or digital logic circuit must be able to interpret incoming information from the receivers and successfully initiate an appropriate response. An investigation into the potential of the Programmable Integrated Circuit (PIC) microcontroller to discern the origin of radio signal transmission must be initiated as objective two. Also, an automobile operator's ability to evade the receiver must again be examined except from a computer science perspective. In this way, the potential effectiveness of the PIC microcontroller should be investigated. In the end, the impact that programming and the benefits of the digital logic circuit instead of the analog circuit on production costs should be examined.

B. Description of Phases

Ideas proposed for potential investigation included creating a cradle to hold the phone before the car would start, looking at the heart rate of the driver to detect when the driver is distracted, building a circuit that detects radio signal transmissions, or establishing a portion of the glove box that the phone had to sit in so that alarms would not sound while the car was running. Based on the available research, it was determined that the concept of using a circuit to detect digital device transmission was unique and would be pursued during this investigation. As part of the engineering process, the project was divided into eight phases in order for all of the research objectives, and subsequently all three goals specified for a successful solution, to be addressed. Phase one focused on constructing the optimal detecting circuit. Then, phase two contained an investigation of the impact of distance on the ability of the receiver to detect a radio signal transmission. Next, phase three involved the construction of a logic circuit to interpret the information supplied by the receiver before an appropriate response could be initiated. During phase four, additional work was to be done with the logic circuit from phase three so that it would be able to discriminate between the driver's and the passengers' phones and in addition only work when the car was running and the transmission was out of park. In phase five, this receiver was integrated first into a simulation of an automobile's light and horn circuitry before eventually being integrated into several different makes and models of automobiles. Simultaneously along with phase five, the investigation of the impact that material coverings potentially have on the receiver's ability to detect transmissions effectively will be initiated during phase six. In addition, the testing of different antennas to discover the optimal antenna paired with the optimal circuit would be investigated in phase six. Finally, phase eight involves simplifying the components of the circuit so that the cost of production can be kept at a minimum.

Methodology

A. Phase One

1. Design

The plan for this phase is to discover the most reliable circuit for detecting radio signal transmissions. In order to do this, four different circuits must be constructed. Next, careful calculations must be employed to increase the sensitivity distance of each circuit, which was the fine tuning of the amplifier. After all circuits have been constructed, an examination to determine the cost, size, and simplicity of each circuit must commence in order for these aspects of the interval decision matrix for phase one to be addressed. Each circuit must undergo rigorous experimentation to determine the maximum range of sensitivity for each receiving circuit in three modes of radio signal transmission: calling, texting with four or fewer characters, and texting with five or more characters. Thus the performance and reliability of the device can be determined for the interval decision matrix for phase one.

Before experimentation can take place, a large piece of butcher paper with a line drawn at 1.2 meters and additional lines at 0.05 meter intervals should be created. Tests involving calling, texting with four or fewer characters, and texting with five or more characters will be implemented in order to reveal the maximum range of 100% detection of each of the circuits for a wide variety of cellular phone models.

2. Procedure

To begin, the four different circuits were constructed using common electrical components such as electrolytic and non-electrolytic capacitors, operational amplifiers, 555 timers, resistors, diodes, transistors, and buzzers. The first circuit is unique in the sense that its antenna is a capacitor. Next, the second circuit needs to have the specific length leads of capacitors near the antenna and also has a 555 timer component, which starts after the op amp registers the detection of a radio signal transmission. Moreover, the third circuit contains an antenna paired with a half-wave rectifying bridge, an amplifier, and an operational amplifier. Finally, the fourth circuit has a potentiometer to adjust the sensitivity range.

After constructing the circuits with their amplifiers, the detector circuits will be placed at 0.0 meter mark of the butcher paper meter stick. Next, the Data Studios® program and the Pasco® PasPort voltage and current sensor should be attached to the load portion the circuit being tested in parallel with the buzzer so that both subjective and objective forms of data collection will take place. Moreover, once data collection began, a cellular phone was moved out by 0.1 meter intervals from 0.0 meter mark until the receiving circuit being tested could no longer demonstrate 100% of the time through subjective and objective data collection that the receiver had successfully detected the radio signal transmission generated by the cellular phone at that distance. To ensure reliability, each mode of transmission generated by every cellular phone was tested at every interval five times. Once the receiving circuit could no longer detect a radio signal transmission, the cellular phone was moved backwards by 0.01 meter intervals until the receiving circuit once again demonstrated 100% that the receiver had successfully detected a radio signal transmission generated by the cellular phone. The maximum distance from the receiving circuit that experimental testing revealed that the receiver still worked 100% of the time was shown to be the receiver's maximum range of detection for that cellular phone. Furthermore, an additional experimental trial was conducted to examine if the receivers detected at any other full or fractional wave length distances pertinent to space within an automobile. To accomplish this, the cellular phone was tested five times at 0.1 meter intervals past the determined maximum distance of detectability for another 1.0 meter. Moreover, this procedure was conducted with three models of cellular phones with the Verizon™ carrier and three models of cellular phones with AT&T™ carrier. After completing these experimental trials on the first circuit, these same experimental trials were repeated for the remaining three circuits.

B. Phase Two Design and Procedure

During this phase, the optimal circuit from phase one underscored by the interval decision matrix from phase one will be tested with twenty different models and brands of cellular phones utilizing the procedure described in Phase Two Procedure.

C. Phase Three

1. *Design*

During this phase of the engineering process, the two different logic circuits, the Quad NAND gates paired with a Hex Schmitt Inverter and the PIC microcontroller chip circuit, must be built. Also, the logic circuit must be able to initiate an appropriate response. For an automobile, this appropriate response involves sounding the horn and flashing the lights for a set amount of time in order to warn and to alert other motorists of impaired driving activity.

2. Procedure

After constructing these two logic circuits and testing them to verify that both worked when the input voltage fluctuated, additional time was taken to evaluate which logic circuit would be the best for the overall device. The PIC microcontroller will have to be programmed using the C programming language, the MPLAB IDE version 8.60 program, and the Microchip PICkit2 connector cord.

D. Phase Four Design and Procedure

For discrimination capability, three concepts should be investigated. First, partial faraday cage shields could prevent non-driver cell phones from triggering the device. Next, directional antennas could be constructed to be focused directly on the driver's portion of the car. Finally, triangulation with three circuits could be investigated along with the comparator capacity of the PIC microcontroller chip to discriminate between the driver's phone and other phones in the car using inequality statements. An experiment should be implemented to investigate the most viable option, keeping reliability, cost, and size as the most important variables in this decision. So that the automobile's transmission is out of park, a wire will be connected from the speedometer to the PIC microcontroller chip through an additional power transistor or a combination of resistors. This incoming voltage should fluctuate when the automobile's transmission is out of park and running. An experiment should be implemented to investigate this hypothesis. Any C programming commands created to either discriminate between circuits or register when the automobile's transmission is out of park and running can be transferred to the PIC microcontroller chip through the MPLAB IDE version 8.6 program and the Microchip PICkit2 connector cord.

E. Phase Five Design and Procedure

During this phase, simulated automobile 12 volt headlights, rear lights, and horn circuitry will be constructed, and the receiver will then be integrated into this simulated automobile to investigate its effectiveness at initiating an appropriate response upon the detection of a radio signal transmission from a cellular phone. Next, the receiver was installed in a real automobile, specifically a 1999 Dodge Caravan. Once a mechanic approves the attachment of the circuit to the car, then experiments to investigate the reliability of the device's features in the car should be implemented.

F. Phase Six Design and Procedure

Next, phase six will involve an investigation of the impact of material coverings, such as steel and plastic of both 0.003 meters and 0.006 meters, on the device's ability to scrutinize the transmissions effectively. The experiment will involve repeated experimental trials following the procedure from phase one except with the addition of material coverings over the receivers. In the end, all three materials will be investigated.

G. Phase Seven Design and Procedure

This phase involves the testing of different antennas to discover the optimal antenna for this device. Items included in the experiment were tuned long wire stainless steel, copper, iron, aluminum, and an iron bent wire that is raised a few centimeters off of the circuit board and composed of these previous materials. Testing all of the antennas with the same six previously tested cellular phone models under the same conditions as the preliminary circuit test implemented in phase one will ensure that the optimal antenna will be selected for the device based on its ability effectively to reproduce or to exceed the range of detectability of the receiver.

H. Phase Eight Design and Procedure

Finally, phase seven of the methodology involves simplifying the components of the circuit so that the cost of production can be reduced to fewer than ten United States dollars without taking into account that if manufactured on a large scale, the components would decrease in price and the circuits retain their beneficial qualities.

Results

A. Phase One

After completing the experimental runs with each circuit being tested at least 100 times by each of the six cellular phones, the first circuit had an average effective range of 0.1 meter for both calling and all forms of texting. The second circuit had an average effective range of 0.21 meters for text messages of four or fewer characters and an average effective range of 0.26 meters for calling and text messages of five or more characters. The third circuit has an effective range to 0.5 meters and 0.7 meters for low and high power cellular phones respectively for calling and all forms of texting. Finally, the fourth circuit was shown to be reliable to an average of 0.29 meters for calling and all forms of texting.

TABLE I
DECISION MATRIX FOR OPTIMAL RECEIVING DEVICE

Design	Receiver 1	Receiver 2	Receiver 3	Receiver 4
Reliability During Experimentation	4	2	1	3
Performance Radius of Sensitivity	4	3	1	2
Simplicity	2	3	1	4
Cost	3	2	1	4
Size	4	2	1	3
Total: Lowest Score is the Optimal Choice	17	12	5	16

B. Phase Two

After twenty cellular phones were tested, the effective ranges for the third circuit were supported.

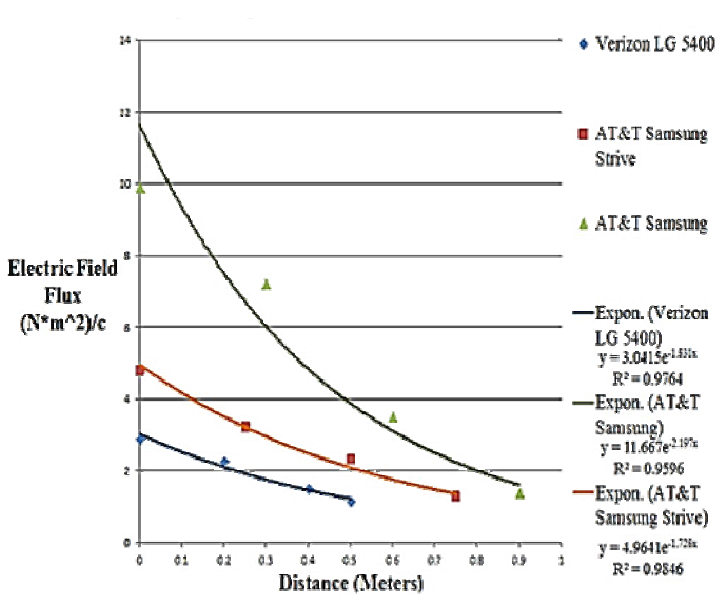
TABLE II
INVESTIGATION OF SENSITIVITY AND DISTANCE

Cellular Phone and Service Provider	High or Low Power Cellular Phone	Calling Radius (Meters)	Texting Radius for 2 Characters (Meters)	Texting Radius for 3 or More Characters (Meters)
UX 8350 LG Verizon	Low	0.49	0.2	0.48
UX 5400 LG Verizon	Low	0.58	0.43	0.54
Samsung AT&T (Conventional)	Low	0.52	N/A	N/A
NV3 LG Verizon	High	0.63	N/A	N/A
Reality Samsung Verizon	High	0.62	0.45	0.58
HTC Aria AT&T	High	0.56	0.45	0.59
Samsung AT&T (Slide)	High	0.7	0.65	0.92
Blackberry Verizon	High	0.65	0.45	0.72
Impression Samsung AT&T	Low	0.49	0.46	0.58
Strive Samsung AT&T	High	1	0.85	1.05
Prime LG AT&T	High	0.8	0.73	1
Droid Verizon	High	0.58	0.59	0.62
3G LG Verizon (Conventional)	High	0.68	0.6	0.75
Pan Tech AT&T	High	0.68	0.62	0.71
Old Verizon Flip Phone	Low	0.45	N/A	N/A
EV 1X LG Verizon	High	0.65	0.53	0.67
ENV2 LG Verizon	Low	0.55	0.48	0.55
3G LG Verizon (Slide)	High	0.69	0.57	0.65
Motorola AT&T	High	0.57	N/A	N/A
Motorola Verizon	Low	0.48	N/A	N/A

TABLE III
FLUX AND DISTANCE

Cellular Phone and Provider	Electric Field Flux (N*m^2)/C	Distance (m)
LG 5400 Verizon	2.9	0
	2.3	0.2
	1.6	0.4
	1.1	0.5
Samsung Strive AT&T	4.8	0
	3.2	0.25
	2.3	0.50
	1.3	0.75
Samsung AT&T (Slide)	9.9	0
	7.5	0.3
	3.3	0.6
	1.4	0.9

FIGURE I
FLUX VS. DISTANCE



Thus, the sensitivity of the device diminished at a ratio of $\frac{1}{r^2}$ where "r" represents the distance from the digital device to the detector, which is consistent with Gauss's Law for a spherical Gaussian surface,

$$\Phi_E = E * \Delta A * \cos(\theta) \quad \text{where} \quad E = \frac{k*q}{r^2}. \qquad (1)$$

C. Phase Three

Both the analog and the PIC microcontroller digital logic circuits worked flawlessly during tests. However, the potential to optimize the timer of the digital logic circuit and to increase the effectiveness of the device, since the microcontroller has the potential to compare receiver strengths, made the digital logic circuit the optimal engineering solution for this problem. This decision was supported by the result of the decision matrix for this phase in Table IV.

TABLE IV
OPTIMAL LOGIC CIRCUIT

Design Criteria	Logic Circuit 1	Logic Circuit 2
Reliability Interpreting and Initiating Response	2	1
Ease of Integration into Automobile	1	1
Simplicity	1	2
Cost	1	2
Ability to Optimize the Timer	2	1
Ability to Compare Receivers	2	1
Total: Lowest Score is the Optimal Choice	9	8

D. *Phase Four*

During this phase, the PIC microcontroller was successfully programmed with logic described in Figure III. Also, after implementing three experimental set-ups such as the set-up in Figure II, triangulation was determined to be the optimal method of discrimination between driver and passenger based mainly on the reliability of this method, which is highlighted in the decision matrix in Table V.

TABLE V
DISCRIMINATE BETWEEN OPERATOR & PASSENGER

Design Criteria	Triangulation	Directional Antenna	Partial Faraday Cage
Reliability During Experimentation	1	3	3
Cost	1	1	2
Size	2	2	3
Ease of Integration into Logic Circuit	1	2	2
Total: Lowest Score is the Optimal Choice	5	8	10

FIGURE II
TRIANGULATION EXPERIMENTAL SET-UP

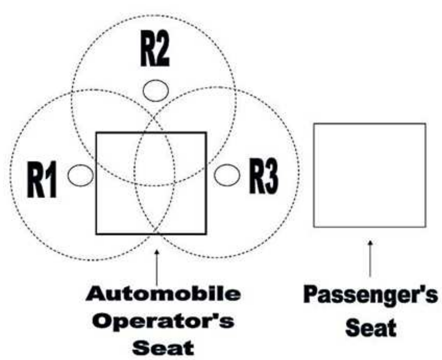
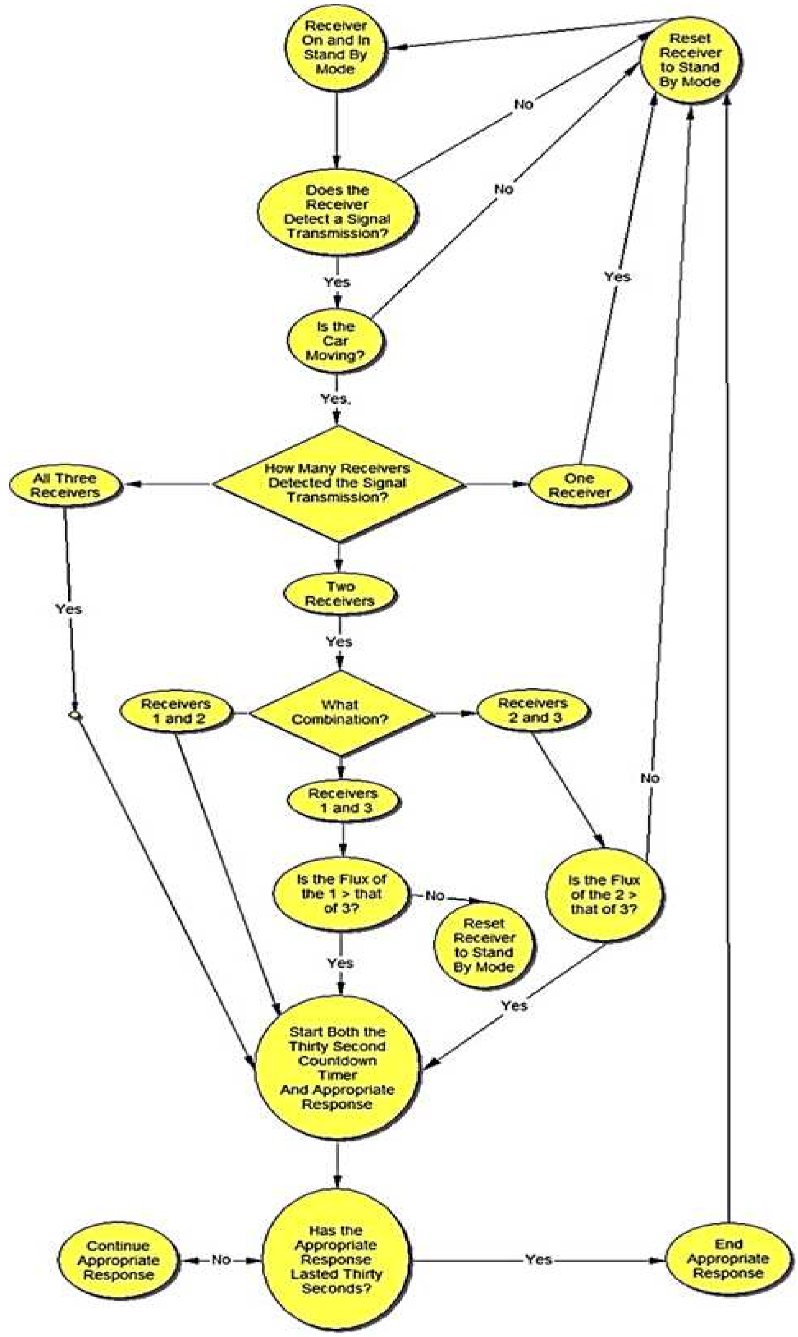


FIGURE III
LOGIC DESIGN



E. Phase Five

After creating a simulated automobile lights and horn circuit, testing revealed that the detecting device could be effectively integrated with this circuitry (Figure IV). Thus, the device was installed in a functioning Dodge Caravan (Figure V). Once the device had been installed, further testing revealed that the device worked flawlessly to detect digital device transmissions in the operator's portion of the automobile.

FIGURE IV
SIMULATED AUTOMOBILE CIRCUITRY

FIGURE V
INSTALLATION OF DEVICE IN DODGE CARAVAN

F. *Phase Six*

Testing the impact of encasing materials on the overall sensitivity of the device revealed that the device was not impacted by the presence of an encasing material, which is highlighted by the decision matrix in Table VI.

TABLE VI
IMPACT OF ENCASING MATERIALS

Design Criteria	Metal	Plastic	Plastic
Performance Radius of Sensitivity	1	1	1
Application To Automobile	1	2	1
Total: Lowest Score is the Optimal Choice	2	3	2

G. *Phase Seven*

After testing four different antenna materials and two different antenna orientations, the iron long wire antenna was determined to be the optimal antenna, which is supported by the decision matrix in Table VII.

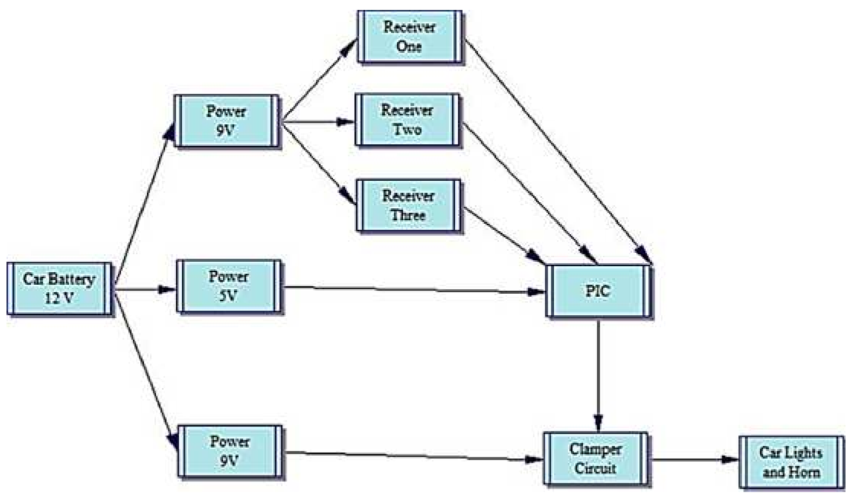
TABLE VII
OPTIMAL ANTENNA

Design Criteria	Iron Long Wire	Stainless Steel Long Wire	Copper Long Wire	Aluminum Long Wire	Iron Bent Wire
Reliability During Experimentation	1	1	1	2	3
Cost	1	3	4	2	1
Size	2	2	2	2	1
Theoretical Shortcomings	1	1	1	2	5
Total: Lowest Score is the Optimal Choice	5	7	8	8	10

H. *Phase Eight*

In the end, the circuit was simplified as much as possible, and the final production cost was minimized to be approximately ten United States dollars. Figure VI depicts the block diagram of the simplified device for effective integration into the automobile environment.

FIGURE VI
FUNCTIONAL BLOCK DIAGRAM



Discussion

A. *Phase One Reflection*

After completing the experiment in phase one of this research project, the experimental data which were collected highlighted that the third circuit was the optimal circuit for the detection of radio transmissions sent by digital devices. This phase was extremely effective at addressing the portion of the project goals to construct a device that reliably detected a radio signal transmission. Furthermore, the fact that this approach worked successfully underscored this device's uniqueness as compared to the solutions uncovered during the preliminary research. Also, the experimental data revealed that the third circuit was the most effective detector circuit constructed because it successfully detected every single cellular phone tested during the experimental procedure.

B. *Phase Two Reflection*

Completing this phase was an integral step towards the successful completion of this project because the logic circuit was necessary so that the spike in voltage from the detector circuit could be interpreted as a truly successful detection of radio signal transmissions. Although both logic circuits worked flawlessly as stated in the results section, the PIC microcontroller chip was selected as the logic circuit for the device because it offered more flexibility and opportunity for modification and improvement of this section of the device. Also, the fact that the logic circuit could initiate flashing lights and a pulsing horn (the optimal response chosen for its definite ability to alert all nearby motorists) demonstrated the successful completion of several engineering goals.

C. *Phase Three Reflection*

During phase three, the logic circuit from phase two was successfully programmed with the C programming language to discriminate between the driver's and the passengers' phones building off of established concepts of a comparator function, which compares input voltages. The inequality statements worked effectively to discriminate between radio signals transmitted by the passenger and the driver. Also, the directional antenna was successfully constructed and tested for effectiveness. The only shortcoming of this solution may be controlling the size of the three-dimensional region that the device will detect a radio signal transmission, which may include, due to the close quarters, the passenger's seat. In addition, the partial faraday cage shield that was built is still being tested to confirm its effectiveness. Yet before an optimal solution is determined, more experiments should be completed. Using voltage from the speedometer to alert the circuit that the car is on and out of park was a very creative solution, and when simulated with a power supply, worked successfully. Similarly to the first two phases, this phase demonstrates the successful completion of two more engineering goals.

Conclusion

Collectively, the research process has been effective at successfully achieving each of the three engineering goals. In the end, the effective range of the receiver was determined to be 50cm and 70cm on average for low and high power cellular phones respectively. Moreover, further investigation in other phases, such as designing and programming a digital logic circuit, testing the impact of circuitry encasing materials, and creating additional receiving circuits that triangulate the source location of the generated signal transmission, was completed, and confirmed the usefulness and potential benefits of this receiver for society. Investigation during phase two confirms the phenomenon of electric field flux decreasing at a rate of the inverse of the distance squared, which is described by Gauss's Law. Put simply, as a result of experimentation, the third receiver from phase one, the digital logic circuit from phase three, a triangulating method from phase four, either a metal or plastic covering from phase six, an iron long wire antenna from phase seven, and the simulated lights and horn circuitry found in an automobile from phase five were highlighted as together encompassing the optimal aspects of a receiving device to address effectively the three engineering goals and subsequently realize the engineering vision. Also, this device has been successfully installed and tested in a functioning automobile, thus substantiating the effectiveness of this device. In addition, the reasonable production cost of the receiving device at $10 makes this solution practical and affordable for every automobile and operator. Finally, the results revealed that a receiver, which fulfilled all requirements of the engineering objectives and goals, has been constructed. Also, all engineering projects must evaluate whether or not the solution proposed is ethical. Simply alerting other drivers to the presence of a distracted driver is ethical and does not infringe upon the rights of others due to the fact that if the driver is an impaired driver who could potentially crash into another motorist, then this distracted driver is infringing upon that other person's right to life, liberty, and the pursuit of happiness. Furthermore, by alerting other drivers to the presence of an impaired, distracted driver on the road, the potential to reduce the number of fatalities due to distracted drivers does exist.

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