Design Document

Tactile Feedback Glove to Detect Induced Electromagnetic Fields

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1. Introduction

1.1. Objective

The job titles “Electrical Worker” and “First Responder” consistently rank in the top ten most dangerous jobs in the United States. There are around two deaths by electrocution per day for electrical workers in the US, and even more in underdeveloped countries with less rigorous safety standards. These deaths frequently come as a result of accidentally touching a live wire the individual was not aware of, voltage leaks, arc flashes, etc. We need a measure to reduce the number of these preventable deaths [1].

The proposed device is an insulated glove that can detect the induced electromagnetic fields (EMF’s) generated by AC power lines and wires from a distance. The gloves would then vibrate with increased intensity as field strength increases. This tactile response would inform the electrician or first responder of a nearby live wire/electricity source that could harm them. The vibrations would allow one to increase their reaction time to avoid the hazard, similar to how one recoils when touching a hot stove.

We believe, if properly executed, these gloves would be of valuable commercial and safety use to electricians and power line operators who need to be diligent at all times, as well as first responders who need to be aware of live wires and other electrical hazards in the event of a building collapse, when visibility is low and they may be feeling around.

1.2. Background

There are two types of fields important to discuss that are relevant to this project: magnetic fields and electric fields. Magnetic fields are vector fields that describe areas where an object exhibits a magnetic influence. These fields affect neighboring objects along magnetic field lines. These fields can attract or push away other magnetic fields. Magnetic fields are commonly observed in everyday life in the form of permanent magnets, which are objects that retain magnetic properties in the absence of an inducing field. Magnetic fields are also able to be generated by a charge in motion, i.e, a current. This is particularly important to our project as current flows through live wires which is the exact thing we desire to detect [3].

The fact that current passing through a wire generates a magnetic field is a useful property we can potentially exploit for our design. If we can detect the magnetic field generated from the wire, we can safely avoid it. The issue lies in the fact that while power lines and transmission cables generate sizeable magnetic fields, AC wires in houses are generally current-balanced because wherever there is a current, ideally there should be an equal return current in the same cable and the magnetic fields cancel each other out [4]. This is almost never the case in practice however, and there will always be some small detectable magnetic field. The magnetic field will increase if there is an undesirable connection somewhere in the house between neutral and earth so the currents are no longer balanced, which is another thing this device could prove useful to detect.

This means that we need a device which can consistently detect magnetic fields in the nanotesla/microtesla range. A device that can perform this task is known as a magnetometer. The most advanced magnetometers can detect magnetic fields in the order of 10^{-18} Tesla [5]. This sensitivity is much more than we would need for our purposes and instead we will likely use Digital Magnetometer IC's. These digital magnetometers are cheap, sensitive and provide a high throughput of data. The latter proves extremely useful as we can differentiate between fields caused by 50/60 Hz AC power, and other extraneous sources by selecting for magnetic fields that oscillate at frequencies near 50/60 Hz. Magnetic field noise should also be limited in most environments so this is to our benefit.

The second field that is generated by wires, power lines and other electrical components is the electric field. Like the magnetic field, an electric field is also a vector field surrounding an electric charge that exerts force on other charges. Unlike the magnetic field however, the charge does not have to be in motion to generate an electric field. The electric field generated from a live wire is also much more powerful than a magnetic field, and thus is more easily detectable. Due to this same observation, there is much more electric field noise in our environment then there is magnetic field noise. As a result, electric field sensors are generally calibrated to the environment and then any large increase from the baseline level is generally due to some electrical source [6]. For example, near the bottom of a AC power line is in the magnitude of a few volts per meter, but within a foot of the wire it can increase to as much as 5 kV/m [2].

1.3. High-level Requirements

If this project is to succeed, there are three main objectives/requirement that must be met:

- ❖ The device must be able to detect live wires and other electrical hazards using a magnetometer and a electric field sensor.
- ❖ The device must be able to provide tactile feedback to the user in the form of vibration once a potential hazard is detected. The vibration will increase in intensity as magnetic/electric field strength increases.
- ❖ The glove must be well insulated enough to protect both the user and any internal electronics from current and voltages commonly found when working with commercial and residential AC power.

2. Design

2.1. Block Diagram

Successful operation of our system relies on three modules: a power module, a sensing module and a periphery module. The power module sends 5V regulated voltage to all components that need it. The sensing module is composed of a magnetometer to detect magnetic fields, as well as a non-contact electric field meter so that we may detect static voltage build up as well. The magnetic field sensor will send readings straight to the microcontroller, and the electric field data needs to be calculated by measuring voltage across the transistor and dividing by the gain of the circuit. These signals then feed into our microcontroller, which then displays these two readings on the LCD, as well sending voltage to the vibration disks in response to varying threshold values.

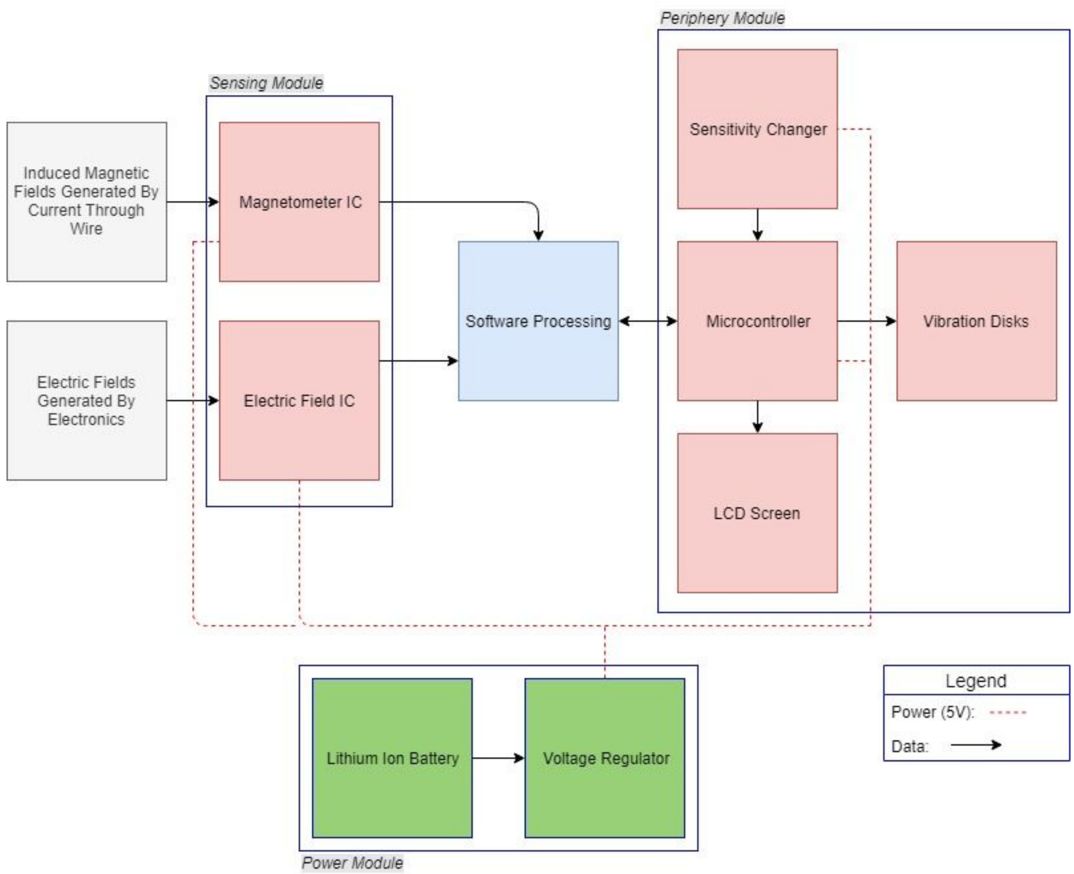

Figure 1: Block Diagram of Completed Design

2.2. Physical Design

Figure 2: Physical Layout of Glove

Our physical design is very important to the success of this project for many reasons. First, we need to utilize space as efficiently as possible. There are many different components to this design, and all of it will need to fit onto/in a glove. Secondly, there is the risk of other components interfering with each other, so we need to choose the location of the components carefully. For example, we have placed the power module and most of the electronics near the back of the glove, away from both the electric field meter and the magnetometer. We will magnetically shield these components so they do not interfere with our sensors.

2.3. Functional Overview, Requirements and Verification

2.3.1. Magnetometer

We will be using a DH Type Nanotesla Sensor from Aichi Micro Intelligent Corporation. This sensor is capable of detecting fields as small as 1 nanotesla. This is essential as we will be searching for fields that can be as small as 0.1 microtesla. By restricting the cut-off frequency to 0.1 Hz, this sensor is also able to ignore static magnetic fields such as geomagnetism and respond to only alternating magnetic fields with high sensitivity. This feature is ideal as we would like to negate as much magnetic noise as possible. We will need to experiment to find the exact threshold values to search for, but the fields will most likely be in the 0.1-5 microtesla range for wires, and 10-50 microtesla range for electronics carrying motors. We do not have a datasheet for this sensor so we will have to test it empirically.

Requirements	Verification
1. Filter out most static magnetic fields such as geomagnetism and permanent magnets, and detect alternating fields instead.	1. Hold a permanent magnet in place. Connect the MI-CB-1DH-S-A magnetometer's V+ pin to the bench's 5V power supply, the GND pin to the bench's ground, and the OUT pin to the bench oscilloscope. 2. Restrict the cut-off frequency to 0.1 Hz to ensure that most static fields are ignored. 3. Expose sensor to an oscillating magnetic field by shaking the magnet rapidly, and verify that the sensor magnitude output increases.

2. Detect fields of as low as 0.1 microtesla generated from AC wires from a minimum of 6 inches and a maximum of 48 inches.	1. Connect a 1 MΩ resistor to the bench digital multimeter, and generate a sinusoidal wave at 60 Hz with a magnitude of 76.2 mA. Make one of the wires longer, as it will be used for electric field measurement. 2. Connect the MI-CB-1DH-S-A magnetometer's V+ pin to the bench's 5V power supply, the GND pin to the bench's ground, and the OUT pin to the bench oscilloscope. 3. Place the magnetometer 6 inches from the longer wire, and record the sensor output magnitude. 4. Increase the magnetometer distance by one inch, and record the sensor output magnitude. Verify that the increase in magnetometer distance has resulted in a decrease of sensor output magnitude. 5. Increase the magnetometer distance to 48 inches, and increase the wave magnitude to 609.6 mA, and record the sensor output magnitude. 6. Decrease the magnetometer distance by one inch, and record the sensor output magnitude. Verify that the decrease in magnetometer distance has resulted in an increase of sensor output magnitude.

2.3.2. Electric Field Meter

There is the possibility of encountering a static build up of high voltage, which would not create a magnetic field that we could detect. For this purpose we are including a electric field meter in our design. The detector would be created with a LM386 Amplifier and a 10k Ohm Trimpot Resistor. The circuit's massive gain would allow us to detect the smallest movements of electricity, even those created at a distance by induction or static charge, by amplifying the signal to a detectable threshold. When the electric field detected crosses a certain threshold value it will send a signal to the microcontroller which will power the vibration discs.

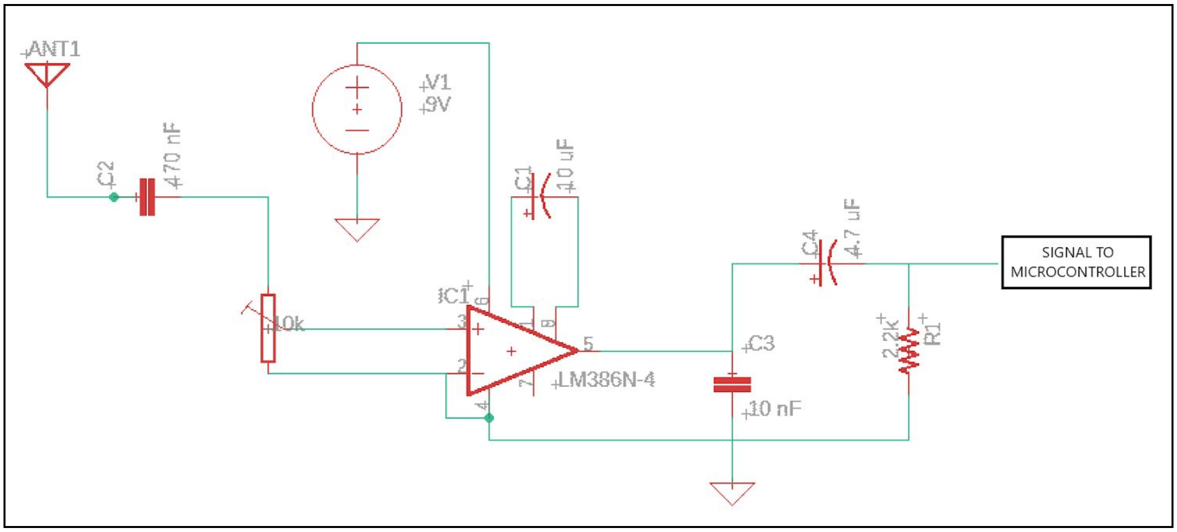

Figure 3: Electric Field Meter Circuit

Requirements	Verification
1. Must detect commonly encountered AC voltages (3-30 V/m) from a distance of 6 inches to 48 inches..	1. Connect the electric field meter circuit to power. 2. Connect a 1 MΩ resistor to the bench digital multimeter, and generate a sinusoidal wave at 60 Hz with a magnitude of 20 V. Make one of the wires longer, as it will be used for electric field measurement. 3. Place the sensor 6 inches away from the longer wire. If the electric field meter does not send a signal indicating an electric field, increase the electric field meter gain.

2. Must detect static electricity build up from a distance of 6-48 inches.	1. Connect the electric field meter circuit to power. 2. Generate a static electricity charge of 8 pC with a Van de Graaff generator. 3. Place the sensor 6 inches from the static electricity charge. If the electric field meter does not send a signal indicating an electric field, increase the electric field meter gain.

2.3.3. Voltage Regulator

Most components in our design require a steady input of ~(5.0V ± 0.1) for optimal operation. The only component that requires varying voltage are the vibration disks in order to increase or decrease the vibration, but this varying voltage can be provided by the microcontroller (0-5V). For this reason we have decided to use a 5V voltage regulator to provide constant voltage to our components. We will be using the Sparkfun L7805 voltage regulator, a three-terminal positive regulator with a 5V fixed output voltage. The regulator provides a local regulation, internal current limiting, thermal shutdown control and safe area protection for our project.

Requirements	● Verifications
1. Voltage throughout the circuit is regulated to (5.0V ± 0.1), regardless of the loads placed on it by the sensors and other components.	1. Assemble the entire circuit such that the magnetometer, electric field meter, LCD, vibration disks, and voltage regulator are all connected. 2. Test voltage when the maximum load (sensors, discs, LCD, etc.) is placed onto the regulator. 3. If voltage (5.0V ± 0.1) or current draw (varies by component) is lacking, add another voltage regulator to circuit.

2.3.4 Vibration Disks

In order to alert the user of an increase in electric or magnetic field magnitude we will be using five Adafruit Vibrating Mini Motor Discs. These discs will vibrate when the glove comes in contact with significant electric or magnetic fields. The vibration intensity of the discs will increase in intensity as the fields' magnitude increase, as determined by the microcontroller. The discs take an input of 2-5V and draw 40-100 mA of current. The circuit design will be simplistic with each vibration disk in series with a resistor leading to ground. We do not have a datasheet for these disks so we will have to test them empirically.

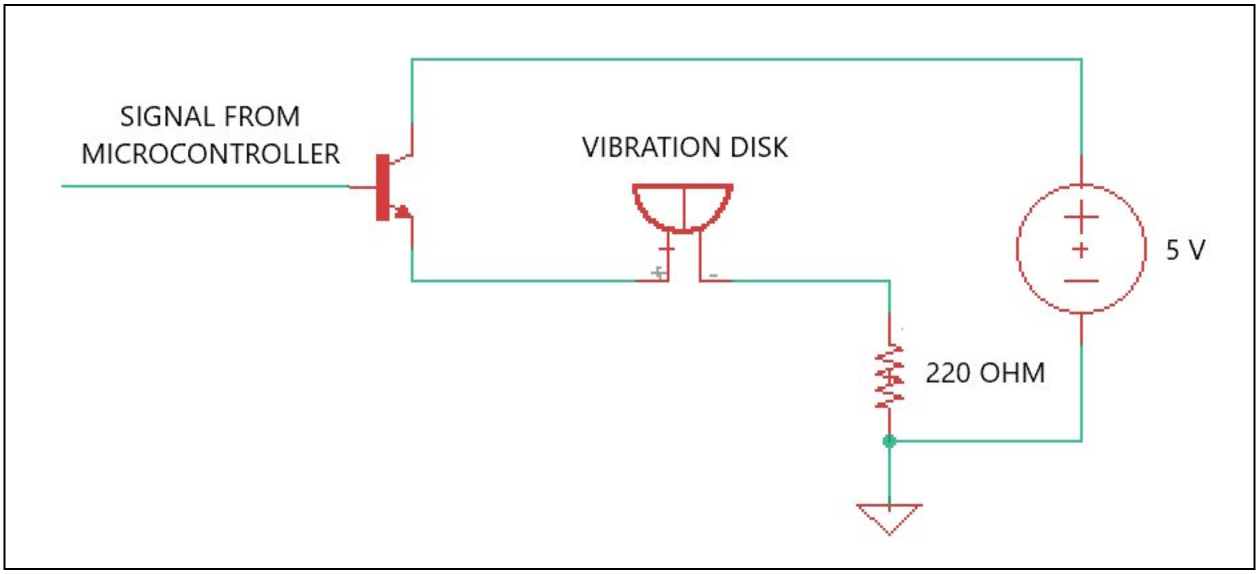

Figure 4: Vibration Disk Circuit

Requirements	Verifications
1. Vibration intensity must increase as supply voltage increases.	1. Connect the vibration disk to the bench DC power supply 2. Connect the piezoelectric sensor in parallel with a 1 MΩ resistor to the bench oscilloscope, with the other terminal connected to ground. 3. Tape one end of the piezoelectric sensor to the vibration disk, and the other to the bench (in order to neglect vibration of the bench). 4. Starting at 5V and ending, increase the DC power supply by 0.5 V. Record the peak voltage values from the

	piezoelectric sensor. 5. Plot the data and generate a line of best fit; this will determine the degree to which the vibration intensity increases with voltage.

2.3.5 LCD Display

The LCD display serves to provide a live reading for the values being reported by the magnetometer and the electric field sensor. This will allow the user to have an estimate of what kind of currents and voltages they are dealing with, and if data inconsistent with what is expected is seen, it will also aid in calibration of the device. It will display only two values: the magnetic field in microTesla, and the electric field in V/m.

Requirements	Verifications
1. Can reliably communicate with microcontroller to display magnetic field and electric field data.	1. Send test data from microcontroller to LCD display to verify proper communication.

2.3.6 Lithium-Ion Battery

The Lithium-ion battery needs to provide 9V to the electric field circuit and 5V to the voltage regulator. Operation length must be at least 2 hours.

Requirements	Verifications
1. Can reliably provide 9 V to circuits and voltage regulator for a minimum of 2 hours.	1. Assemble the entire circuit such that the magnetometer, electric field meter, LCD, vibration disks, and voltage regulator are all connected. 2. Test voltage when the maximum load (sensors, discs, LCD, etc.) is placed onto the regulator. 3. Run the battery for at least 2 hours and continue to verify at least 9 V are supplied.

2.4 Supporting Material

2.4.1 Software Flowchart

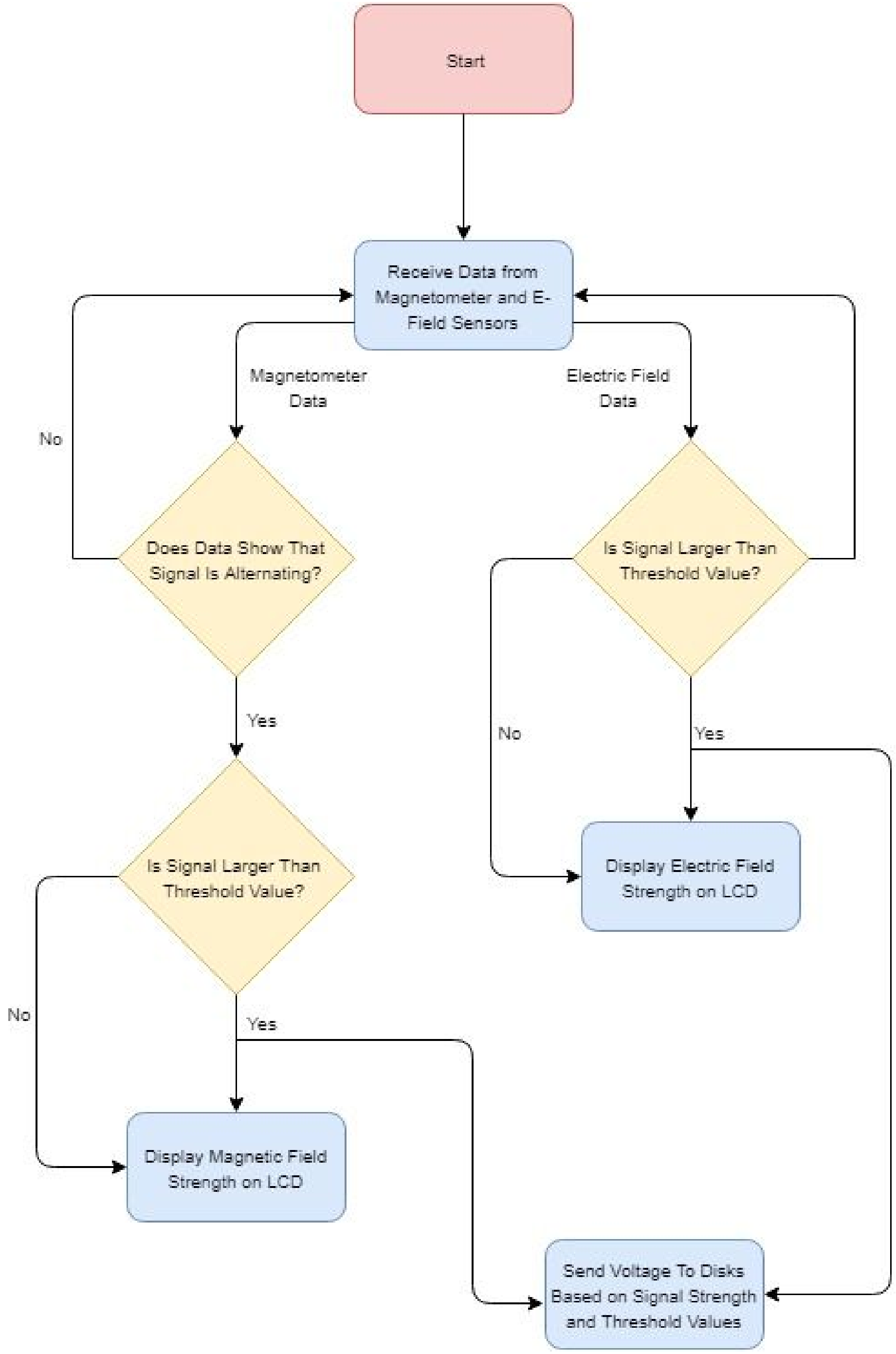

Figure 5: Software Flowchart Diagram

2.4.2 Nanotesla Sensor Device Characteristic

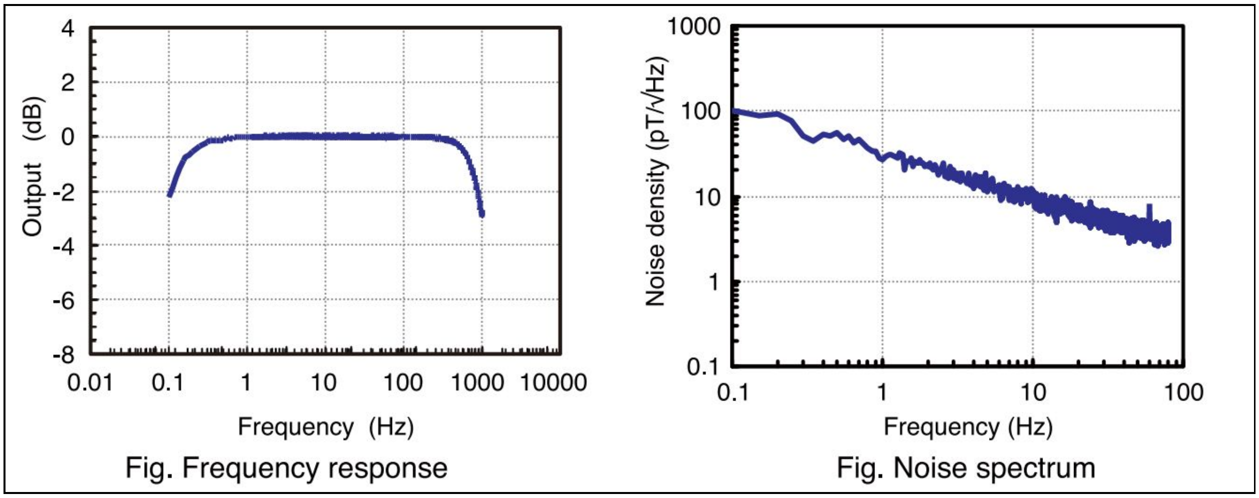

Figure 6: Frequency Response and Noise Spectrum of Nanotesla Sensor [10]

2.5 Tolerance Analysis

Among the most critical of our device's functionalities is its ability to detect the hazards presented by AC wires. As the voltage in a wire generates an electric field, we are taking advantage of simple physics by selecting electric field as the parameter to detect hazardous AC wires, to be accomplished by our electric field meter block.

As household electronics can generate electric fields as small as 3 V/m, we need to use an amplifier that will give us a gain of 200. We have therefore selected the LM386 low voltage amplifier from Texas Instruments, as its input voltage range allows for ±0.4V. This will give us a maximum output of 8V. However because our microcontroller has a maximum input voltage of 5V, we will scale down the output with the use of a 10 μC capacitor. The tolerances chosen for our resistors is ±5% and the tolerance chosen for our capacitors is ±10%. Our acceptable error for this circuit's output is ±5%.

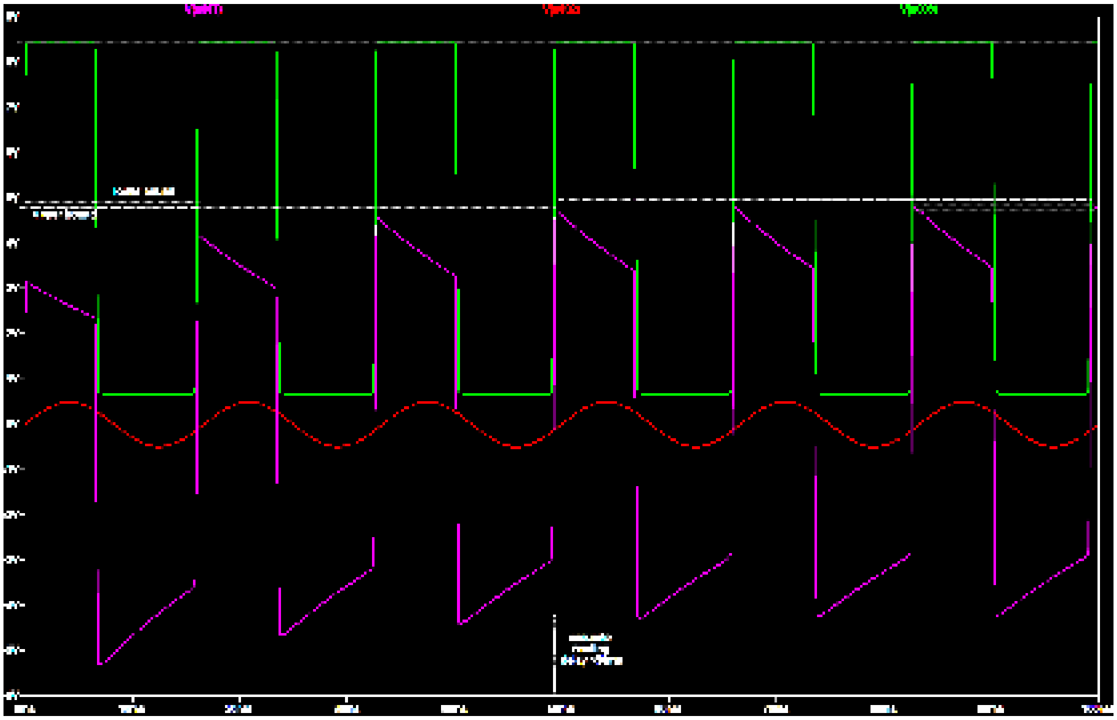

Figure 7: Electric Field Meter Tolerance

In Figure 7, the red trace represents the circuit input, the green trace represents the output from the amplifier, and the pink trace represents the circuit output. After running the simulations for the upper tolerance, lower tolerance, and ideal component values we added a dotted line at the maximum of each output signal. As we can see in Figure 7, the dotted line at the maximum of the amplifier output does not change as the tolerance values change, as all of the dotted lines overlap and appear to form one line. The circuit output, however, does change. When the components are at their upper tolerance values the output is 4.78V, at the ideal value its 4.87V, and at the lower tolerance value the output is 4.97V. We can also see that it takes about 50 ms for the signal to reach its maximum value, so we can expect a 50 ms delay.

The fluctuation in this capacitor's value is the most significant factor in our tolerance analysis. The output from the amplifier stays constant throughout the fluctuation at 8.46V. Increasing the capacitor before the circuit output decreases the circuit's output. The ±10% tolerance values for our capacitor only results in a ±2% fluctuation in the circuit's output. This fluctuation is well within our acceptable ±5% error.

3. Cost and Schedule

3.1. Cost Analysis

3 persons x 20 hrs/person/week x \$50 x 13 weeks = \$39,000

Parts and Labor	Cost
AT Mega Microcontroller	\$8.99
Nanotesla Sensor MI-CB-1DH-S-A	\$185.00
Adafruit Vibrating Motor Disc (5x)	\$9.75
5V Voltage Regulator	\$0.95
Lithium Ion Battery	\$54.95
OLED Display	\$10.99
Arc Flash Gloves	\$42.10
Magnetic Shielding Film	\$23.99
LM386 Low Voltage Amplifier	\$1.01
Piezoelectric Sensor	\$2.95
10 kΩ Trimpot Resistor	\$2.41
2.2 kΩ Resistor	\$0.10
220 Ω Resistors (x5)	\$0.50
4.7 µF Polar Capacitor	\$0.71
10 µF Polar Capacitor	\$0.22
10 nF Capacitor	\$0.10
470 nF Capacitor	\$0.10
1 MΩ resistor	\$0.10
2N2222 Transistors (x5)	\$12.90
Labor	\$39,000
Total	\$39,357.82

3.2. Schedule

Week	Baleigh	Bryn	Prabhakar
Feb 18-24	Design circuit for electric field meter	Design circuit for magnetometer	Finalize device list and order parts
Feb 25-Mar 3	Design circuit for voltage regulators	Design microcontroller	Overview of design
Mar 4-10	Characterize electric field meter	Characterize vibrating motor disk	Characterize nT sensor
Mar 11-17	Assemble and test electric field meter circuit	Assemble and test magnetometer circuit	Assemble power module and microcontroller
Mar 25-31	Integrate all modules	Integrate all modules	Test microcontroller
April 1-7	Test electric field response of glove	Test magnitude response of glove	Test magnetic field response of glove
April 8-14	Test electric field response of glove	Test magnetic field response of glove	Test magnitude response of glove
April 15-28	Rehearse presentation and draft waiver	Rehearse presentation and draft waiver	Rehearse presentation and draft waiver

4. Discussion of Ethics and Safety

As future electrical and computer engineers, we hold a responsibility to our society and to our profession to make a positive impact on the world. This can be best stated by the IEEE Code of Ethics- in particular, our promise to “hold paramount the safety, health, and welfare of the public,” as well as to “avoid injuring others [or] their property … by false or malicious action” [7]. Just like in all our future endeavors as engineers, we must take these considerations into account when designing and building our project. We’ll be approaching this by labeling the product with its safe range of use, so that the end user doesn’t use our glove outside of the tested parameters. By ensuring that the end user understands how to safely operate our device, we can avoid injuring our end users. We are considering including this information in a waiver that we require the end user to sign, in order to protect us from legal action.

A key risk associated with our project comes from our use of lithium ion batteries. If the lithium ion battery in our device is overcharged or introduced to extreme temperatures, there is the possibility of explosion [8]. Fortunately, Kevlar is a thermal insulator, which should prevent the device from seeing any spikes in temperature [9]. We will also carefully test all charging circuitry on our device to ensure that it remains within safe bounds for our selected battery.

Furthermore, we need to prepare for the possibility of the battery or other electronics in our project being introduced to water. While we can strongly discourage users from using our project in damp or moist environments, we still have the obligation to protect our users from the consequences of accidental exposure of components to water. We will address this by building our glove out of Kevlar, which is very water resistant. When exposed to water, the filament tenacity of Kevlar remains virtually unchanged even after 200 days, and hydrolysis only results in a 5% loss of strength after 20 hours [9]. We can thus rest assured that a Kevlar glove will keep our electronic components safe from brief exposure to water; however, to minimize the risk to the user, we will not recommend extended exposure.

In addition, considering the environment our project may be used in, there is also the concern of arcing from electrical equipment to our glove. Fortunately, Kevlar is also commonly used as protection from arc flashes and will thus offer protection from electrical hazards [9]. We'll also make sure to note how many cals the Kevlar gloves are rated for- although our gloves are not a replacement for personal protective equipment in the lab or production environment, we don't want to risk being liable to user injury by failing to specify the acceptable conditions for use of our project.

We must also acknowledge the hazards to our own safety while completing this project. In addition to the typical hazards associated with working in the senior design lab, we must keep in mind that our device is meant to detect hazardous sources, and therefore we need to exercise extreme caution while setting up and carrying out verification procedures. Our verification procedures, by necessity, include live wires with very high current magnitudes; as such, we will take notice of and avoid contact with any exposed wire, and keep our workstation free of moisture.

The largest risk to the successful completion of this project is being able to detect and establish threshold values for detection. It is our assumption that this will require a bit of experimentation, especially for the electric field aspect of our design. We need to establish threshold values for alternating magnetic fields, and electric fields which vary greatly from place to place. Once this is taken care of however, we are confident that the rest of the construction will go very smoothly.

5. Citations

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