60-HERTZ ELECTROMAGNETIC FIELD DETECTOR/INTERFACE SYSTEM

Design Review
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Introduction

Ambient electromagnetic radiation can be a problem in many applications where electronic instrumentation is involved; the motivation for this project stems from such a problem. Electro-encephalogram (EEG) readings in particular can be adversely affected by the presence of ambient 60-Hertz (60-Hz) radiation; this frequency is omnipresent in the United States due to the national standards for electrical power generation and transmission.

The first aim of this project is to create a portable 60-Hz electromagnetic radiation detection device that can be easily used to pinpoint areas of high radiation density. The second part of this project is aimed at developing a haptic feedback system that utilizes micro-transducers to deliver the field intensity information to the human body through its sense of touch. The applications of this project, however, extend far beyond locating hotspots for proper equipment placement; such a system would facilitate the three-dimensional mapping of static 60-Hz electromagnetic radiation fields in and around structures, which would make it possible to study the effects of such radiation on flora and fauna, for example. The haptic feedback system would also make it possible for human beings to experience a new "sense" through the existing sense of touch; the integration of these senses may open up new avenues of research in the field of neuroscience as well.

Goals

The main goals of this project are to create a 60-Hz radiation detection system using an inductive coil antenna as the sensing apparatus, and to create a haptic interface to deliver the field intensity information to a user. The signal generated by the inductive coil will be fed through an amplifier, and then filtered to obtain the relevant intensities. The intensity information will be fed to a microcontroller, which will control a micro-transducer on the subject's skin that will act as the interface.

Benefits

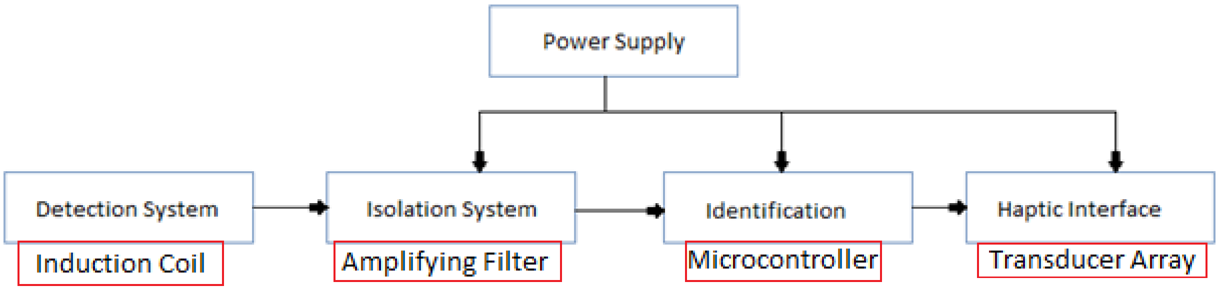
- Detection of 60-Hertz radiation using a compact device
- Intuitive user interface through haptic feedback array
- Provides a base for a wide variety of mapping applications
- Provides a platform for further research into augmented sensory systems

Features

- Static 3-axis coil configuration for detection of all polarizations
- Haptic feedback user interface
- Compact, portable design
- Detection of electromagnetic radiation between 55 and 65 Hertz

DESIGN

Block Diagram



Block Descriptions

Power Supply: The power requirements for the circuit will be provided by two 6V DC sources. The operational amplifiers will be powered using these sources, in order to ensure that the filter output cannot take on voltage values that may burn out pins on the microcontroller. The microcontroller will also be powered using one of the 6V sources, since it has a voltage regulator on board.

Detection System: This is the main component of our design. The detection system will comprise of an inductive ferrite-cored coil that will be able to transform ambient time-varying magnetic fields into currents proportional to the field through faraday induction. The output of this block will be the induced current, an AC signal consisting of various frequencies.

Isolation System: The isolation system will comprise of a band-pass filter with a gain around 500. The amplifier will boost the signal from the inductive coil by a factor of 500 and attenuate the signal outside of the frequency range of 55 to 65 Hertz. This block will take a multi-frequency input signal from the detection system, and output an amplified response at 60-Hz.

Identification: To identify the intensity of the radiation, the amplified 60-Hz signal will be fed into the analog inputs of an Arduino Microcontroller. Software will then be used to extract amplitude information from the waveform, and activate a certain number of digital outputs based on that information. This block will take as input a 60 Hz signal, and extract its amplitude.

Haptic Interface: The haptic interface will comprise of a micro-transducer array of size 4 by 2. Depending on the intensity of the ambient field, a proportional number of transducers will be activated; all of the transducers will be on when the operational amplifiers are nearly saturated. A BJT array will be used to switch the transistors based on the control outputs from the microcontroller, due to the high current requirements for each transducer. This block will take as input digital high/low control signals from the microcontroller, and output tactile vibrations through the transducer array.

SCHEMATICS

Sensory Apparatus Design:

The sensory apparatus will consist of three mutually orthogonally oriented detectors. The detectors are identical ferrite-cored, multi-layered solenoids that are able to convert ambient electromagnetic radiation into a potential, and thus a current, through induction. The specifications that follow were designed to deliver the optimum combination of sensitivity and portability.

Core Specifications: A ferrite rod with an initial permeability of 2000 was chosen due to its high permeability. The length of the core (l_c) is 63.5mm, and the diameter of the core (d_c) is 9.525mm. However, these dimensions reduce the effective permeability of the core, which depends on its geometry. The calculation of the effective permeability is as follows:

$$N = demagnatization\ factor = \frac{d_c}{l_c}\left(\ln\left(\frac{2l_c}{d_c}\right) - 1\right) = 0.0358 \qquad [3]$$

$$\mu_{app} = apparent\ permeability\ (at\ center) = \frac{\mu_r}{1+N\mu_r} = 27.562 \quad [3]$$

$$\mu(x) = \mu_{app}\left(1 + 0.106\left(\frac{2|x|}{l_c}\right) - 0.988\left(\frac{2|x|}{l_c}\right)^2\right) \qquad [2]$$

$$\mu_{eff} = \mu_{avg} = 19.946 \triangleq 20 \qquad [2]$$

Coil Dimensions: The coil comprises of 26 gauge magnet wire, which was chosen due to the optimization of the cutoff frequency (L/R), so that it ends up below 60 Hertz. The optimal diameter of the core was found to be about one-third of the diameter of the entire solenoid, so the design incorporates 15 layers of wire; the optimal length of the coil was found to be around 80 percent of the core length, or 50.8mm. With these parameters, the coil incorporates 1875 turns.

Resistance: The length of the wire needed for the construction of each coil is around 80 meters. When multiplied with the unit resistance of 26-gauge wire, this results in a total resistance of 21.588 ohms per detector.

Inductance: The inductance of a multi-layer, solid-core solenoid is obtained using the following formula, where r is the average coil radius, N is the number of turns,μ is the total permeability, and b is the coil build or thickness:

$$L = \frac{\mu \pi r^2 N^2}{l_c\left(1+0.9\frac{r}{l_c}+0.32\frac{b}{r}+0.84\frac{b}{l_c}\right)} \qquad [1]$$

$L = 0.488$ H

Operation: The cutoff frequency for normal operation of this solenoid is R/L, or around 44-Hz. This allows the detector to efficiently convert ambient 60-Hz radiation into an electric potential between the leads of the solenoid, as demonstrated by the series of equations below:

<u>Faraday's Law</u>

$\epsilon(t) = -N\frac{d}{dt}\left(\varphi(t)\right)$, where $\varphi(t) = BAcos(\theta)$

$$\epsilon(t) = -NAcos(\theta)\frac{dB(t)}{dt}$$

Due to the standards of power generation and transmission, 60-Hz noise will have the following form:

$B(t) = B_0\cos(\omega t)$, where $\omega = 120\pi$

Thus,

$$\epsilon(t) = NAB_0\omega cos(\theta)\sin(\omega t) = 2\pi f NA\mu_0\mu_{eff}H_0\cos(\theta)\sin(\omega t)$$

Due to the three-axis detector setup, the only fields of interest to any one detector are those having components parallel to its axis; additionally, only those components are of interest. Thus, $\cos(\theta) = 1$.

Finally:

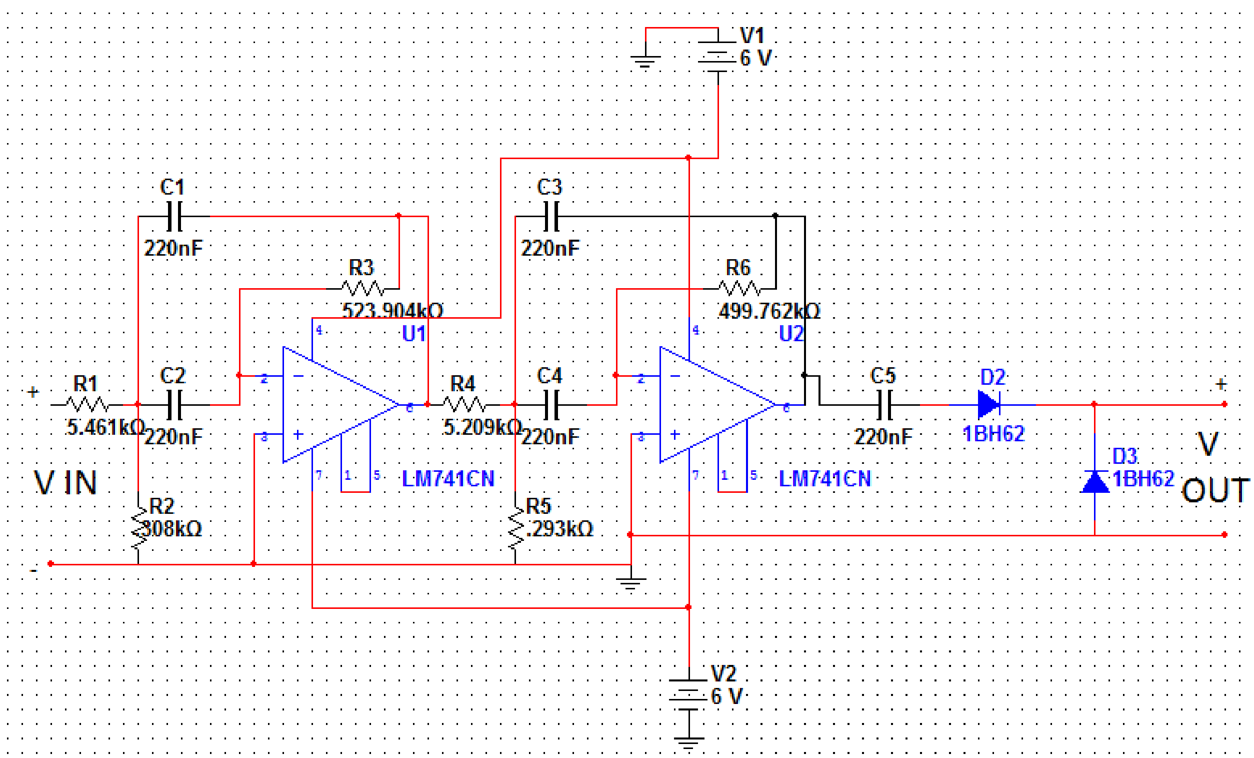
$$\epsilon(t) = 120\pi NA\mu_0\mu_{eff}H_0\sin(120\pi t) = 1.2658H_0\sin(120\pi t)\text{ mV}$$

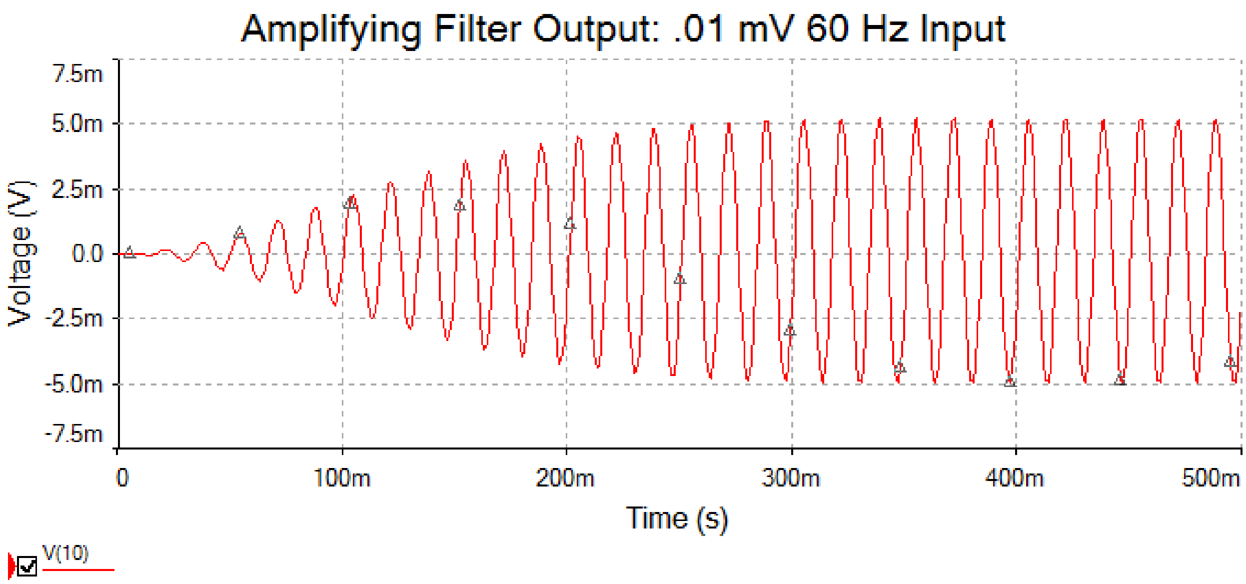
Common magnetic field intensities vary from 0.01 μT to 8000 μT, depending on the distance from the source and the strength of the source. Common household items emit less than 0.1 μT at distances of around a foot, so the range of detection for the system was designed to be from 0.01 μT to 10 μT. For higher ambient field strengths, the distances are too small for the device to be practically useful, so the system merely displays that it is in saturation. For ambient field strengths of .01 μT, we obtain an EMF of around .01 mV. For ambient field strengths of 10 μT, we obtain an EMF of around 10 mV.

Amplifier Design:

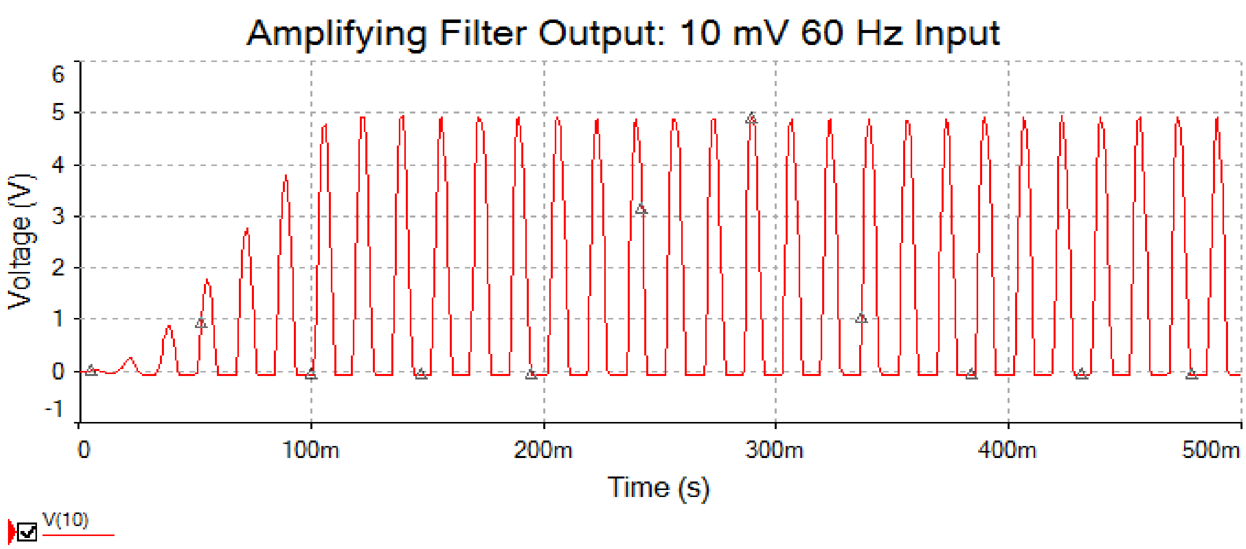
The Arduino used to do amplitude detection can only take analog voltage inputs from 0V to 5V, with a resolution of around 4 mV. Thus, the smallest value in the range of the system (0.01 μT → 0.01 mV), must be amplified to around 5 mV. This means that the largest value (10 μT → 10 mV) will be amplified to 5V. In order to ensure that the Arduino does not see values higher than 5V, the op-amps in the filter are powered using rail voltages of 6V. Likewise, to ensure that the Arduino does not see values significantly lower than 0V, a full-wave rectifier is added at the end of the filter.

Each signal will be fed through an active, narrow-band filter, built using LM741H operational amplifiers. The 4-pole filter will have a gain of around 500, in order to obtain the correct output waveform. The signal will be filtered around 60 Hz, a 3dB width of around 4-Hz. The filter schematic and simulation are shown below:

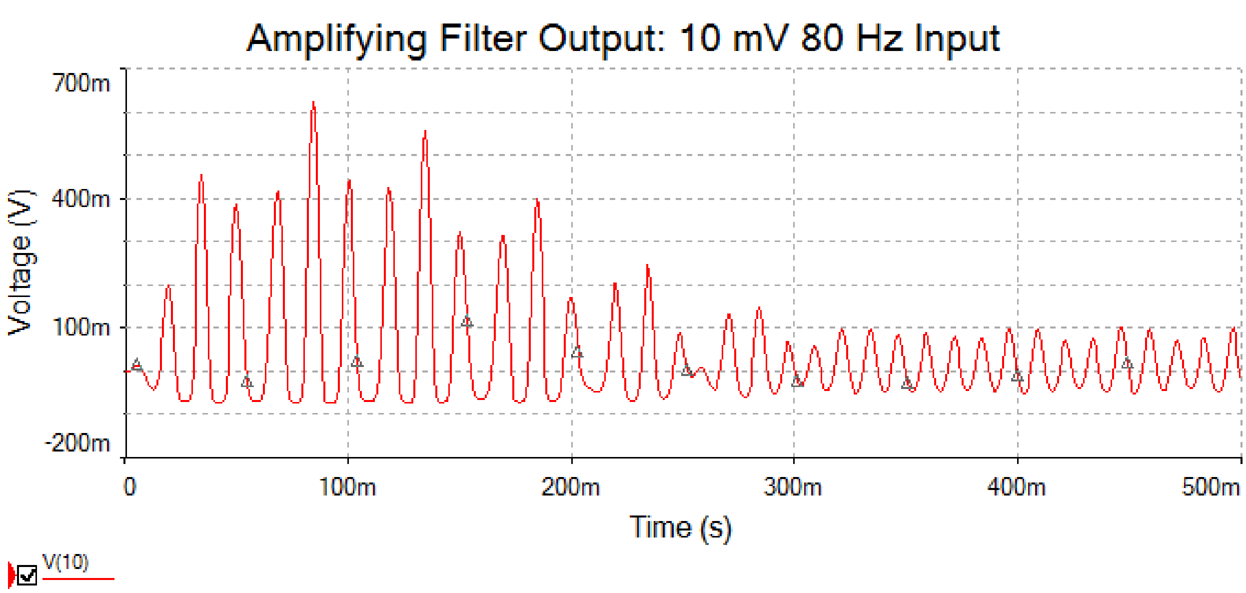




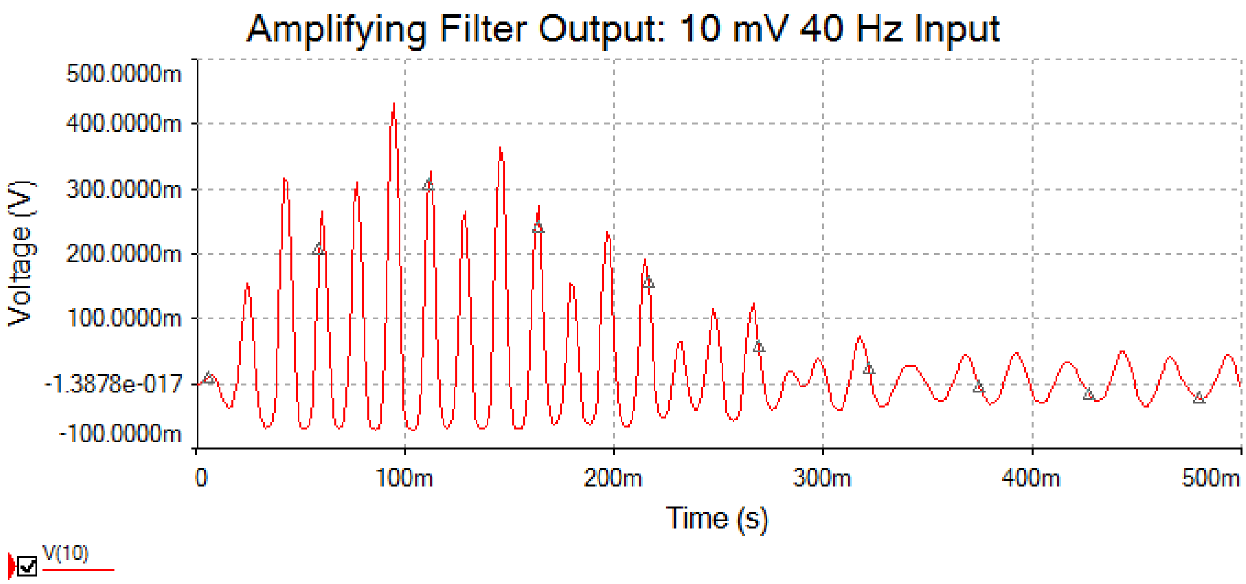
Amplifying Filter Output: .01 mV 60 Hz Input
7.5m
5.0m
2.5m
0.0
-2.5m
-5.0m
-7.5m
Voltage (V)
0
100m
200m
300m
400m
500m
Time (s)
V(10)



Amplifying Filter Output: 10 mV 60 Hz Input
6
5
4
3
2
1
0
-1
Voltage (V)
0
100m
200m
300m
400m
500m
Time (s)
V(10)



Amplifying Filter Output: 10 mV 80 Hz Input
700m
400m
100m
-200m
Voltage (V)
0
100m
200m
300m
400m
500m
Time (s)
V(10)



Amplitude Detector Design:

The intensity information will be drawn from the amplitude of the boosted, filtered signal through the use of an Arduino. The Arduino can sample its analog inputs at rates exceeding 100-kHz, which is enough for the given application. The amplitude detecting software will store a portion of the incoming waveform, and analyze it to detect peaks. It will take the amplitude of those peaks from each single-axis detector, sum them, and output a certain number of high digital control signals to the haptic feedback proportional to the weighted amplitude.

Haptic Feedback Design:

The control signals from the Arduino will be used to switch on and off a 4 by 2 array of micro-transducers hooked up to a wristband, using an array of BJT's. The BJT's are necessary because the current draw of the transducers is greater than an output pin on the Arduino can source.

Battery Supply Design:

Power will be supplied to the amplifying filter, BJT array, and microcontroller through a set of 6V battery supplies. The Arduino microcontroller has a built in voltage regulator that can handle 6 volts, while the operational amplifiers can work using two 6 volt supplies.

Requirements and Verification

The 60-Hz electromagnetic radiation detector will consist of 5 modules: a sensory apparatus, an amplifying filter, an Arduino-based amplitude detector, a haptic feedback system, and a power supply. Test equipment will include standard lab equipment, as well as a specially constructed Helmholtz Coil to generate uniform magnetic fields. The detection system will need to be able to detect ambient magnetic fields in the frequency range of 58 to 62 Hertz and intensity range of .01 uT to 10 uT.

At the top level, the system must be able to qualitatively determine the strength of the ambient 60-Hz radiation, and deliver that information to a user through the amplitude of a micro-transducer's oscillations. The system must be able to respond as quickly as the detector may be moved through the environment and output qualitative information to the user about its motion through an intensity gradient. The table below lists module and sub-module level requirements, along with verification processes for those requirements.

Module	Requirement	Verification
Sensory Apparatus <u>Common Field Strengths</u> - - - - -	1. Each detector must possess the ability to detect electromagnetic radiation within an intensity range of 0.01 uT to 10 uT and a frequency range of 58 to 62 Hertz.	1. The apparatus will be placed between the loops of a specially constructed Helmholtz coil, and the coil will be driven at the upper and lower limits of the specified intensity and frequency. The sensory apparatus will be rotated within the constant field to verify that the variation in changing orientation is no more that 10%. At the lower level of the intensity range, the average induced voltage should be 0.01 mV, and at the higher level of the intensity range, the average induced voltage should be 10 mV.
Amplifying Filter	1. Filter must possess gain of around 500, and 3 dB width of less than 10 Hz around 60 Hertz. a. Operational amplifier must behave correctly in amplifying configuration. b. Resistor values must match theoretical values (see diagram): i. R1: 5.461 kOhms ii. R2: 0.308 kOhms iii. R3:523.904 kOhms iv. R4: 5.209 kOhms v. R5: 0.293 kOhms vi. R6: 499.762 kOhms	1. Filter will be swept with various AC signals, from 1 Hz to 1 kHz, and the outputs will be displayed on the oscilloscope to confirm attenuation outside of band. a. Operational amplifier will be tested in inverting amplifier configuration with signals described above to assure proper operation. Input and output will be shown on oscilloscope. b. Resistors values will be checked using a DMM.
Arduino Amplitude Detector	1. Must be able to correctly identify amplitude of 60-Hz AC signal, and set a certain number of digital outputs high based on that amplitude.	1. Arduino analog inputs will be driven by 60-Hz signals of varying amplitudes, up to 1V peak-to-peak, and the outputs from the Arduino will be

		probed using a DMM.
Haptic Feedback	1. Output digital signals from microcontroller must be able to switch micro-transducers on and off using BJT array.	1. Each BJT will be tested individually to assure that a digital high base voltage turns on attached micro-transducer, and digital low base voltage turns off attached micro-transducer.
Power Supply	1. Constant voltage of +/- 6 Volts DC must be delivered to the operational amplifiers. +6V DC must be delivered to BJT array and Arduino.	1. The power supplies will be probed with a voltmeter. The current across a 1kOhm resistor will be measured in order to confirm the battery is capable of delivering the required current.

Contingency Plans:

Sensory Apparatus: We will switch to using a longer core for each detector, in order to raise the inductance and thus the response to lower power radiation.
Amplifying Filter: No contingency. This module must work.
Envelope Detector: No contingency. This module must work.
Haptic Feedback: If we are unable to properly implement the haptic feedback, we will create a visual or auditory feedback system that may be cheaper.
Power Source: No contingency. This module must work.

ETHICAL CONSIDERATIONS

We commit ourselves to abide by the ethical code laid down by the IEEE. A few considerations specific to our product are outlined below.

1. Safety may be of concern, if this product will be used in areas of high radiation density. To this effect, we will implement a safety mechanism to ensure that currents do not exceed normal levels.
2. Many Electromagnetic Field Detectors are marketed as Ghost Hunting Devices. As no evidence is currently available to us regarding the viability of this application, we clearly state that our product is not intended for detecting paranormal activity.
3. Developing this product for a doctoral student in the neuroscience program requires that the team not promise to deliver a product that may not meet specifications or may be excessively costly.

COST AND SCHEDULE

Cost Analysis

Labor Cost

Name	Hourly Rate	Hours	Total = Hourly Rate * Hours * 2.5
Bhaskar Vaidya	$35	130	$11,375.00
Gaurav Jaina	$35	130	$11,375.00
Kuei-Cheng Hsiang	$35	130	$11,375.00
		Total:	$34,125.00

Parts List

Part Name & Number	Vendor	Website	Quantity	Unit Cost	Total Cost + Shipping
C2 Tactor	Engineering Acoustics	www.eaiinfo.com	1	$230.00	$235.00
77 Material Ferrite Rod	Amindon	www.alltronics.com	3	$8.50	$42.47
Magnet Wire 26 Gauge AWG Enameled Copper Tesla Coil Winding 200C	Techfixx	www.ebay.com	2000 feet	$19.00 per 1300 feet	$44.00
LM 741 Op-amp	ECE Store	http://www.ece.illinois.edu/ecestores/	3	$0.25	$0.75
LM 6118 Op-Amp	Radio Shack	www.radioshack.com	3	$.50	$1.50
Rectifier Diode D1N/5817	ECE Store	http://www.ece.illinois.edu/ecestores/	1	$0.15	$0.15
Resistors (Values in Schematic)	ECE Store	http://www.ece.illinois.edu/ecestores/	25	$0.10	$2.50
Capacitors (Values in Schematic)	ECE Store	http://www.ece.illinois.edu/ecestores/	15	$0.10	$1.50
Arduino Nano-DEV-09218	ECE Store	http://www.ece.illinois.edu/ecestores/	1	$24.94	$24.94
Bread Board	ECE Store	http://www.ece.illinois.edu/ecestores/	1	$7.00	$7.00
EN 91- AA Battery	ECE Store	http://www.ece.illinois.edu/ecestores/	6	$0.34	$1.94
Sensory Module Holder	ECE Machine Shop	http://ece.illinois.edu - 66 Everitt Lab	1	$10.00	$10.00
Total Parts Cost of Project					$371.75

Total Cost of Project: $34,496.75

Schedule

Week	Date	Task	Person In Charge
1	2/6/2012	Write the Proposal	Gaurav Jaina
		Begin Evaluating Possible Amplifier Designs	Kuei-Cheng Hsiang
		Begin Evaluating Possible Filter Designs	Gaurav Jaina
		Begin Evaluating Microcontrollers	Bhaskar Vaidya
2	2/13/2012	Select Amplifier Design	Gaurav Jaina
		Select Filter Design	Kuei-Cheng Hsiang
		Antenna Core Evaluations	Bhaskar Vaidya
3	2/20/2012	Design Review, Complete Amplitude Detector Design	Gaurav Jaina
		Order Ferrite Rods, Magnet Wire, Microcontroller Complete Antenna Design, Run Simulations	Bhaskar Vaidya
		Complete Filter Design, Amplifier Design	Kuei-Cheng Hsiang
4	2/27/2012	Begin Building Sensory Module	Kuei-Cheng Hsiang
		Build and Test Amplifier,	Gaurav Jaina
		Build and Test Amplitude Detector	Bhaskar Vaidya
5	3/5/2012	Build and Test Filter	Gaurav Jaina
		Test Signal Pick Up Using Sensory Module, Build Helmholtz Coil	Kuei-Cheng Hsiang
		Order micro-transducer, Begin writing test scripts	Bhaskar Vaidya
6	3/12/2012	Complete Antenna Tests using Helmholtz Coil	Kuei-Cheng Hsiang
		Test Transducer	Bhaskar Vaidya
		Test Combination of Amplifier, Filter, and Amplitude Detector	Gaurav Jaina
8	3/19/2012	Spring Break	
9	3/26/2012	Mock Up Demo	Gaurav Jaina
		Work On Transducer Placement	Kuei-Cheng Hsiang
		Financial Assessment, Improvements	Bhaskar Vaidya
10	4/2/2012	Mock Presentation	Kuei-Cheng Hsiang
		Construct Holder for Sensory Module	Gaurav Jaina
		Begin Complete System Testing	Bhaskar Vaidya
11	4/9/2012	Tweak Design, Check for Possible Improvements	Gaurav Jaina
		Debug If any errors	Kuei-Cheng Hsiang
		Resolve if any problem remains	Bhaskar Vaidya
12	4/16/2012	Prepare Presentation	Kuei-Cheng Hsiang
		Create Assembly from all modules	Gaurav Jaina
		Prepare Final Paper	Bhaskar Vaidya

13	4/23/2012	Presentation	Kuei-Cheng Hsiang
		Test assembly completely	Gaurav Jaina
		Demo	Bhaskar Vaidya
14	4/30/2012	Final Paper	Kuei-Cheng Hsiang
		Last-Minute Changes	Gaurav Jaina
		Last-Minute Changes	Bhaskar Vaidya

Citations

[1] Kazimierczuk, Marian K. High-Frequency Magnetic Components. pp27-29 2011.

[2] Milligan, Thomas A. Modern Antenna Design. pp 259-262. 2005.

[3] Seran, H.C. and Fergeau, P. An optimized low-frequency three-axis search coil magnetometer for space research. AIP: Review of Scientific Instruments. 76, 044502 (2005).