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PULSED ELECTROMAGNETIC

FIELD DEVICE

(PEMF)

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PULSED ELECTROMAGNETIC FIELD DEVICE

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Entidad Colaboradora: Introtech.

RESUMEN DEL PROYECTO

El objetivo de este proyecto es desarrollar y analizar un dispositivo electrónico de campos electromagnéticos pulsantes que sirva de fuente de investigación para la empresa Introtech, consultora tecnológica establecida en San Diego que esponsoriza este Proyecto Fin de Carrera.

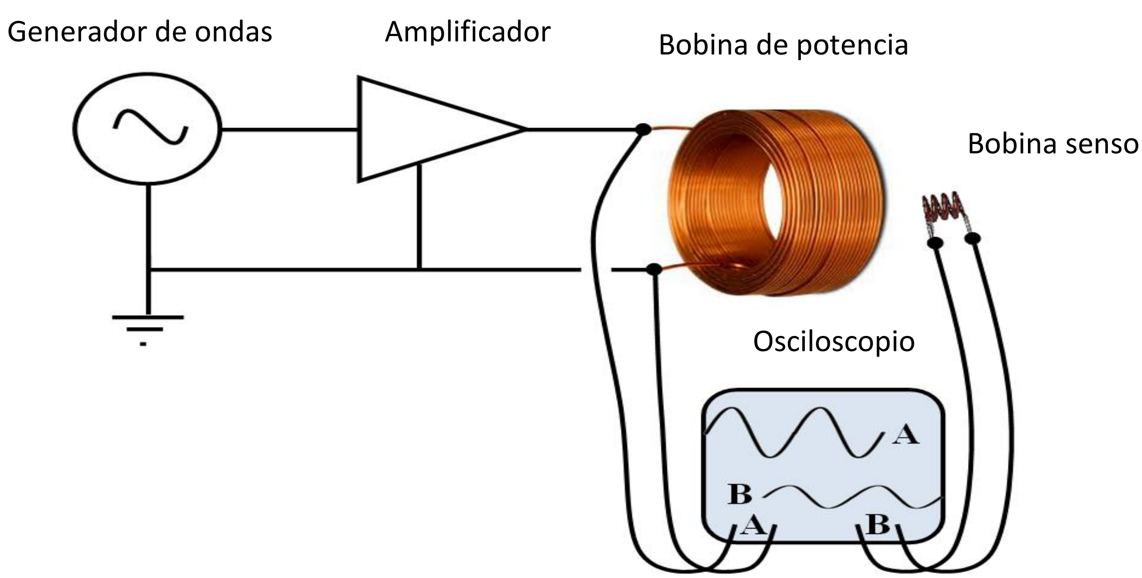
El uso de dispositivos electrónicos de campos electromagnéticos pulsantes nace a raíz de la necesidad de tratar de forma eficaz e innovadora tejidos y articulaciones del cuerpo humano a través del electromagnetismo. Los campos electromagnéticos pulsantes se producen a partir de una bobina eléctrica que recibe un pulso eléctrico, con el cual se genera un campo electromagnético. Las distintas frecuencias de trabajo son la base de la tecnología de los campos electromagnéticos pulsantes, aunque también influye la amplitud de estos pulsos eléctricos así como el tipo de onda de estos pulsos. La eficacia de este dispositivo de campos electromagnéticos pulsantes, no sólo depende de la cantidad de energía transferida en el cuerpo, sino también de la forma de onda aplicada durante los impulsos. La forma de onda refleja la capacidad de absorber la energía dentro del cuerpo y la eficacia del dispositivo es altamente dependiente de esta variable en combinación con las frecuencias y amplitudes de los pulsos.

Actualmente, existen numerosos dispositivos cuyo funcionamiento se basa en el electromagnetismo con aplicaciones muy diversas en la medicina. La terapia con campos electromagnéticos pulsantes es hoy una posibilidad avalada por un número creciente de estudios que recogen sus beneficiosos y sorprendentes efectos sobre el cuerpo humano. Los campos magnéticos pulsantes tienen una gran influencia biológica ya que influyen en el cuerpo, general o localmente, estimulando las funciones celulares y acelerando los propósitos terapéuticos. Actúan como un regenerador celular restituyendo el sistema biológico alterado a consecuencia de traumatismos, infecciones y otras patologías que producen la pérdida de

energía en las células. La magnetoterapia a baja frecuencia recarga las células permitiendo que el organismo se defienda eficazmente de forma natural, aliviando el dolor y acelerando los tiempos de curación y recuperación.

Las soluciones actuales en el mercado presentan un rango de frecuencias que oscila entre 1 Hz y 100 Hz, dependiendo del efecto curativo que se quiera conseguir en función de las necesidades. El dispositivo de campos electromagnéticos pulsantes que se desarrolla en este Proyecto Fin de Carrera no solo abarca el rango de frecuencia descrito anteriormente, sino que además genera pulsos eléctricos de hasta 500 Hz de frecuencia, que producen un campo magnético más leve que se utiliza para terapias menos agresivas.

El propósito de este proyecto es crear un dispositivo dedicado a la investigación sobre la interacción entre campos electromagnéticos pulsantes y los tejidos biológicos, aplicando diferentes formas de onda, frecuencias y amplitudes. Esto se consigue a partir de cuatro subsistemas perfectamente acoplados entre sí: un generador de ondas, un amplificador, dos bobinas electromagnéticas y un voltímetro digital. El generador de ondas produce una señal de tensión que es amplificada por un amplificador de potencia. La señal llega a la bobina de potencia, la cual genera un flujo electromagnético que induce una tensión en una segunda bobina que actúa como sensor. Finalmente, la tensión inducida en la bobina-sensor es medida y analizada a partir de un voltímetro digital. A continuación se muestra el circuito utilizado.



Circuito del dispositivo

El generador de ondas se comunica directamente con el amplificador de potencia, necesario para amplificar la señal de tensión que acto seguido se transmite a la bobina de potencia que produce el campo electromagnético. Por otro lado, la bobina-sensor se acopla a la bobina de potencia induciéndose en la primera de ellas una señal de tensión de menor amplitud pero misma fase. Ambas señales se muestran en el osciloscopio, como se observa en la figura anterior. La amplitud de la señal de tensión inducida varía dependiendo de la distancia a la bobina de potencia de manera que a mayor distancia entre las bobinas, menor será la amplitud que tendrá la señal de tensión inducida. La fase entre ambas señales varía ligeramente debido a la distorsión electromagnética.

Debido a la numerosa oferta de productos que utilizan este método terapéutico, el objetivo de este dispositivo ha sido construir un sistema generador de campos electromagnéticos que sea fiable, económico, y versátil.

En cuanto a la fiabilidad, numerosos estudios han observado que la magnetoterapia se ha utilizado con éxito para estimular la regeneración del tejido dañado y enfermo. El precio de los dispositivos que actualmente están en el mercado rondan los 3.000-12.000 dólares, a diferencia del dispositivo desarrollado cuyo presupuesto aproximado es de 650 dólares. Por último, la versatilidad y alta funcionalidad de este aparato es innegable. En primer lugar, se ha comprobado que la magnetoterapia alivia la sensación de dolor de manera casi inmediata. En segundo lugar, ejerce una acción regenerativa sobre las células del cuerpo ya que transporta energía a cada célula. La terapia de campos electromagnéticos pulsantes está indicada para pacientes de cualquier edad, pues no genera efectos secundarios nocivos ni tampoco es invasiva. Se usa también para aliviar los dolores musculares de atletas de alto rendimiento con el objetivo de regenerar su tejido celular.

Numerosos estudios médicos afianzan la fiabilidad y rentabilidad de este método terapéutico así como sus múltiples aplicaciones en la medicina actual como por ejemplo esguinces, artritis, osteoporosis, lumbalgias, fracturas con problemas para cicatrizar, etcétera.

Por ello, el desarrollo de este dispositivo avalado por la entidad colaboradora Introtech es objeto de investigación y cumple con las aspiraciones de Introtech de crear un sistema fiable, económico y versátil que estudie la interacción entre campos electromagnéticos pulsantes y tejido biológico. Se ha obtenido el diseño y desarrollo completo de un equipo electrónico que abre un hueco en el mercado a un coste muy reducido comparado con la competencia.

PULSED ELECTROMAGNETIC FIELD DEVICE

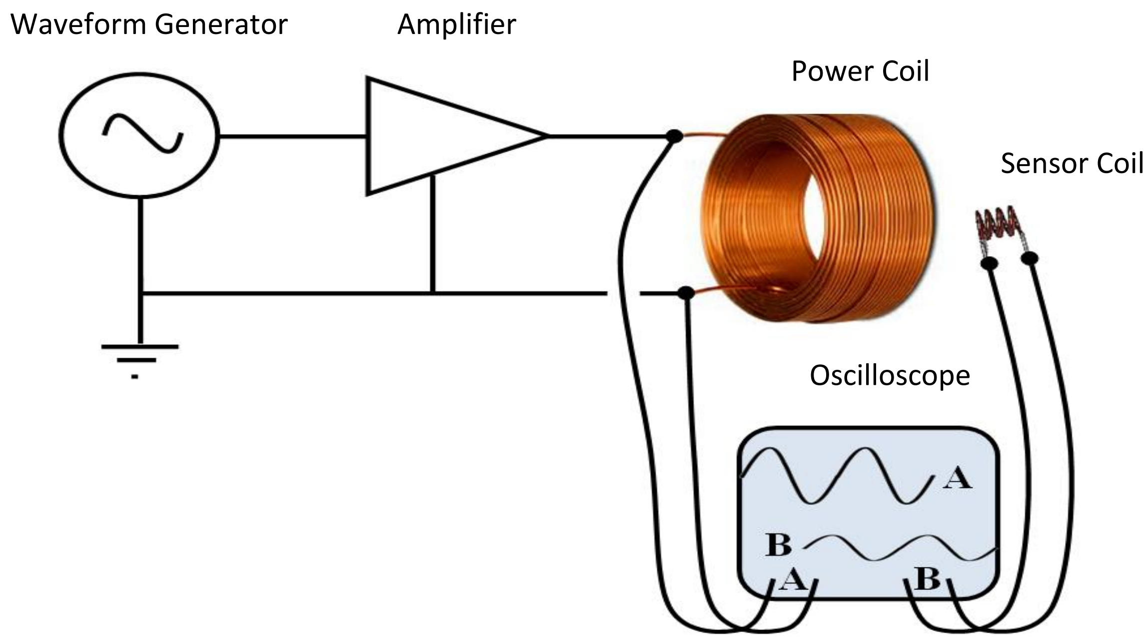
The goal of this project is to develop and analyze an electronic device of pulsed electromagnetic fields as research source for the company Introtech which is a technological consultancy established in San Diego that sponsors this project.

The use of pulsed electromagnetic field devices (PEMF) started as a result of the need to treat in an effective and innovative way tissues and joints of the human body through electromagnetism. Pulsed electromagnetic fields are produced from an electrical coil that receives an electrical pulse, which generates an electromagnetic field. Different working frequencies are based on the technology of pulsed electromagnetic fields, but also influence the extent of these electrical pulses as well as the waveform of these pulses. The efficacy of a PEMF device not only depends on the amount of energy transferred into the body, but also on the waveform applied during the individual pulses. The waveform reflects the ability to absorb the energy inside the body and the efficacy of the device is highly dependent on which waveforms are used in combination with the pulsing frequencies.

There are currently numerous devices whose performances are based on electromagnetism with different applications in medicine. Today, pulsed electromagnetic field therapy is a reality supported by a growing number of studies that collect their surprising and positive effects on the human body. Pulsed electromagnetic fields have a great biological influence since they influence the body, general or locally, stimulating the cellular functions and accelerating therapeutic purposes. They act as a cell regenerator restoring the biological system altered due to injuries, infections, and other diseases that cause loss of energy in the cells. Low-frequency magnetotherapy recharges the cells allowing the organism to effectively and naturally defend itself, relieving pain and accelerating healing and recovery times.

Current solutions on the market have a range of frequency between 1 Hz and 100 Hz, depending on the healing effect according to the needs. The device of pulsed electromagnetic fields developed in this project not only covers the frequency range described above, but also generates electrical pulses up to 500 Hz of frequency producing a slighter magnetic field that could be used in less aggressive therapies.

The purpose of this project is to create a device dedicated to research on the interaction between pulsed electromagnetic fields and biological tissues, applying different waveforms, frequencies and amplitudes. This is achieved through four subsystems perfectly coupled together: a waveform generator, an amplifier, two electromagnetic coils and a digital voltmeter. The waveform generator produces a voltage signal which is amplified by a power amplifier. The signal reaches the power coil, generating an electromagnetic flux and inducing a voltage in the second coil that acts as a sensor. Finally, the voltage induced in the sensor coil is measured and analyzed with a digital voltmeter. The circuit designed is shown below.



Circuit of the device

The waveform generator communicates directly with the power amplifier. The amplifier needs to amplify the voltage signal that later is transmitted to the power coil which produces the electromagnetic field. Furthermore, the sensor coil is coupled with the power coil by inducing in the first one a lower amplitude voltage signal but in-phase. Both signals are displayed on the oscilloscope as shown in the previous figure. The amplitude of the signal of induced voltage varies depending on the distance to the power coil, the greater distance between the coils, the lower the amplitude will be. The phase between both signals varies slightly due to electromagnetic distortion.

Due to the large range of products using this therapeutic method, the main goal of this device was to build a generator system of electromagnetic fields that is reliable, economic, and versatile.

In terms of reliability, a lot of studies have observed that magnetic therapy has been used successfully to stimulate the regeneration of damaged and diseased tissue. The range of the prices of the devices that are currently on the market goes from $3,000 to $12,000 in contrast to the developed device whose approximate budget is $650. In addition, the versatility and high functionality of this device is undeniable. First, it has been found that magnetic therapy relieves the sensation of pain almost immediately. Secondly, it exerts a regenerative action on cells of the body since it transports energy to every cell. Finally, pulsed electromagnetic field therapy is indicated for patients of any age because it does not generate harmful side effects nor it is invasive. Pulsed electromagnetic therapy is also used to relieve sore muscles of athletes of high performance in order to regenerate its cellular tissue.

Several medical studies reinforce the reliability and profitability of this therapeutic method as well as its multiple applications in the current medicine as sprains, arthritis, osteoporosis, back pain, fractures with problems to heal, etc.

For all the reasons above mentioned, the development of this device endorsed by the collaborating institution Introtech is under investigation and meets the aspirations of Introtech. The PEMF device designed is a reliable, economic, and versatile system that studies the interaction between pulsed electromagnetic fields and biological tissue. In addition, it was obtained the design and complete development of electronic equipment that opens a gap in the market at a very low cost compared to the competition.

ABSTRACT

A Pulsed Electro-Magnetic Field device (PEMF) is being designed and built for the client, Introtech. The device is being designed for research purposes. The goal is to design hardware and a method that will contribute to a better understanding of Pulsed Electro-Magnetic Fields (PEMF).

Pulsed Electromagnetic Field devices have been used commonly in the medical field for the treatment of non-union fractures, failed fusions and depression. A controllable Pulsed Electro-Magnetic Field (PEMF) can be used for medical and research purposes, as various combinations of frequency, amplitude, and waveform have different effects upon biological tissues. The project is composed of designing, fabrication and optimization of the PEMF device. The PEMF device consists of four subsystems: waveform generator, amplifier, coils, and digital display. The coils subsystem is the critical feature. The coils, integrated with the function generator, amplifier and digital voltmeter, will be utilized to research and determine the interaction between magnetic fields created by the PEMF generator and biological materials.

The project is divided into subsystems: the coils, waveform generator, amplifier and digital voltmeter. The coils, amplifier and digital voltmeter subsystems all have been designed and parts have been ordered to meet the technical requirements. The waveform generator has been purchased and tested to ensure it produces the desired waveforms. The next stage of the project was to conduct the test on each subsystem as well as the prototype.

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1. Introduction

1.1 Background of need

Osteoarthritis is a debilitating disease of the joint where the surface of cartilage degrades and is unable to repair itself through natural processes. As a result, the bones rub against each other resulting in pain, swelling and loss of motion in the joint. When cartilage is mechanically compressed, an electric field is induced across the tissue. These naturally occurring electric fields have been measured to be from 1 V/cm to 15 V/cm, depending upon physiological conditions [4]. Osteoarthritis affects 27 million people in the United States costing over $86.2 billion per year in health care.

PEMF therapy has been proposed to treat osteoarthritis. Clinical trials have been conducted on patients with osteoarthritis using coil systems that induce an electric field in the body. These studies reported an improvement in knee pain, function, flexion and active daily living following treatments with PEMF [5].

A controllable Pulsed Electromagnetic Field (PEMF) can be used for medical and research purposes, as various combinations of frequency, amplitude, and waveform have different effects upon biological tissues. This project will develop and characterize a new and simple Pulsed Electromagnetic Field generator, suitable for research. The system generates different waveforms (square, sine, and triangle) at varying amplitudes and frequencies (from 10 Hz to more than 10 kHz) to see which combination of the three variables (waveform, amplitude and frequency) creates the most significant interactions between magnetic fields and biological material. Integrating the hardware components (waveform generator, amplifier, coils and digital display) to achieve the desire result is a second challenge. From preliminary calculations the device uses about 15 to 20 W, so is necessary to build an appropriate amplifier. The amplifier’s output is routed to a coil, which requires an appropriate wire size and number of turns to achieve an AC impedance of about 4 - 8 Ω to match the amplifier.

Introtech has an aspiration for hardware and method that contributes to a better understanding of Pulsed Electromagnetic Fields (PEMF), so the focus is to develop a technically successful PEMF generator.

1.2 Purpose

The task is to develop a test system that produces electromagnetic fields that are controllable with respect to waveform, amplitude, and frequency, together with a means for monitoring changes. It is understood that the resulting test system is used by Introtech to define the relationship between such controlled magnetic fields and biological tissue.

A controllable Pulsed Electro-Magnetic Field (PEMF) can be used for research purposes, as various combinations of frequency, amplitude, and waveform have different effects upon biological tissues. This project develops and characterizes a new and simple PEMF generator, suitable for research.

The efficacy of a PEMF device not only depends on the amount of energy transferred into the body, but also on the waveform applied during the individual pulses. The waveform reflects the ability to absorb the energy inside the body and efficacy of the device is highly dependent on which waveforms are used in combination with the pulsing frequencies.

Once the problem of designing, building, and characterizing a PEMF generator is understood, the device is going to be created with the appropriate materials and devices. The purpose is to create a device which supports research in the interaction between electromagnetic fields and biological tissue, applying different waveforms, frequencies, and amplitudes.

1.3 Literature Review

1.3.1 Prior Work

Before tackling the project, there are some commercial PEMF devices that have been developed recently that should be reviewed. Since the turn of this century, a number of electrotherapeutic, magnetotherapeutic and electromagnetic medical devices have emerged for treating a broad spectrum of trauma, tumors and infections with PEMFs. There are some technologies and devices that are relevant for this project in order to learn from those appliances. There are some websites which provide useful information about PEMF [1-3]. Healthy.net [1] deals with the application of PEMF devices in pain management and PEMF therapy systems. Earthpulse.net [2] deals with PEMF therapy research. Pemft.com [3] explains the technology behind pulsed electromagnetic field devices.

1.3.2 Patents

There are some patents developed by companies including Electro-Biology, Inc. that manufacture and research therapeutic devices. These devices are very close to PEMF in terms of technology and performance so they constitute a very major source for this project. Main patents citations are described and compared with our device as shown below:

1. **Cited Patent**: US4266532
   Applicant: Electro-Biology, Inc.
   Title: An electromagnetic body-treatment device for surgically non-invasive modification of the growth, repair and maintenance behavior by a specific and selective change in electrical environment.
   Description and Comparison: Comprising two multi-turn electrical coils and body-adapting retaining means adapted to mount said coils in spaced relation on opposite sides of an afflicted body region to be treated. In this device, the power coil is generally rectangular in shape so as to define a "window" within the interior portion of the turns of the coil.

2. **Cited Patent:** US4501265

   Applicant: Electro-Biology, Inc.

   Title: Applicator head for electromagnetic treatment of an afflicted body region.

   Description and Comparison: Specific coil configuration adapted for use in treating a selected such region with pulsed electromagnetic signals which are induced within the body as electric voltage and attendant current signals which alter the growth, repair and maintenance behavior of living tissues and cells within the body region under treatment. This device is technically similar to the purposed device. It presents an overall U-shape wherein the afflicted body region may be laterally inserted through the open side of the U-shape.

3. **Cited Patent:** US4550714.

   Applicant: Electro-Biology, Inc.

   Title: Electromagnetic coil insert for an orthopedic cast or the like.

   Description and Comparison: Integration of electrical component into an orthopedic cast (main difference with regard to out device), using one or more multiple-twin coils which are essentially flat and thin and flexibly conformable to local curvature of the limb or other body feature to be subjected to electromagnetic therapy.

4. **Cited Patent:** US4561426

   Applicant: Stewart; David J.

   Title: Magnetic biological device.

   Description and Comparison: Electromagnetic device for modifying growth, repair or maintenance processes in a predetermined local area of a living body by utilizing a signal having a symmetric waveform to excite a coil and thereby induce a magnetic field and at the same time manually or mechanically manipulating the coil so as to cause time variations in the spatial-orientation of the induced magnetic field with respect to the local area. It consists of manipulating the coil instead of changing the waveforms.

5. **Cited Patent:** US6443883

   Applicant: Medical Bracing Systems, Ltd.

   Title: PEMF biophysical stimulation field generator device and method.

   Description and Comparison: A multi-functional, modular PEMF biophysical stimulation field generator device and healing system using small coils and a PEMF technique to create a high magnetic flux penetration into hard and soft tissues for treatment of a variety of conditions, including fractures and osteoporosis, to achieve an anticipated shorter healing and rehabilitation time. This device is similar to the purposed device.

1.3.3 Professional Codes and Standards

The relevant some codes and items are summarized below and more detailed information are provided in Appendix B.

The first standard, **HC Pub. 091029**, is a safety code that limits human exposure to radio frequency electromagnetic energy to a frequency range of 3 kHz to 300 GHz. The second standard, **OET Bulletin No. 56**, addresses questions about the biological effects and potential hazards of radio frequency electromagnetic fields. The last standard, **ISO 13485**, is a European rule that certifies PEMF devices are approved by health authorities for human applications.

2. Problem Definition

The goal of this project is to design and build a test apparatus that produces electromagnetic fields. It is required to build a device that is cheap yet reliable. This provides the test apparatus to be competitive in the market because the devices out there currently are extremely expensive.

The purpose of this project is to design, construct, and test an apparatus that produces controllable Pulsed Electromagnetic Fields (PEMF). The application of a

PEMF device is the experimental treatment of certain bone and joint problems, mainly osteoarthritis.

2.1 Project Requirements

The PEMF device must operate with high amplitude and low frequency waveforms applied to a helical coil, producing the desired fields. A means must be provided to measure changes in those fields when biological material is introduced into the core of the coil. It is going to use a gauss meter to measure these changes.

Functional requirements of the device are listed below:

R [1] Waveform generator: able to change the input wave to a sine, triangle, and pulse wave. Also, it has the capability of changing the amplitude and the frequency in a range between 10 Hz and 10 kHz.

R [2] Amplifier: output power of at least 15 W.

R [3] Power coil: big enough to fit a human finger inside.

R [4] Sensor coil: smaller coil to measure the voltage changes.

R [4] Digital display: must have an AC voltage range of 0 to 300 V.

R [5] Magnetic field: below 1 T, which must be measured with the gauss meter.

In terms of reliability, modulated magnetic fields have been successfully used to stimulate regrowth of damaged and diseased tissue. The efficacy of a PEMF device not only depends on the amount of energy transferred into the body but also on the waveform applied during the individual pulses. The waveform reflects the ability to absorb the energy inside the body and efficacy of the device is highly dependent on which waveforms are used in combination with the pulsing frequencies.

Physical requirements for this project are few. There are no limits on the aesthetics of the device, but there are some reasonable limits on the dimensions of the device, as the weight and length, and also medical requirements. According to these requirements, high-intensity magnetic fields at frequencies below 100 Hz are created, which are used for medical purposes. In terms of weight, a reasonable limit would be 15 lbs., which allows easy transporting of the device. Additionally, Introtech's requirement says that a human finger must fit inside the power coil.

2.2 Constraints

The following constraints applicable to the project are: safety, cost, deadline, codes, standards and regulations, and design complexity. All should be within the design capabilities.

- **Safety**

One of the main requirements of this device is safety. There are misperceptions regarding safety of PEMF. These devices only generate pulsing frequencies under 100 Hz which is classified as Extremely Low Frequencies (ELF). The frequency ranges specified for Pulsed Electromagnetic Field therapy devices range between 1 Hz to more than 1000 Hz. Many independent studies conducted the last 30 years clearly indicate that frequencies which are beneficial for human applications are mainly between 1 and 50 Hz. Electromagnetic pulsing frequencies above 100-200 Hz quickly lose the ability to contribute to the beneficial effects of PEMF on cells and bones. However, frequencies to be used in this system vary from 0 Hz to as high as 1 kHz. These frequency variations in combination with amplitude variations create significant interactions between magnetic fields and biological material.

- **Cost**

According to the project budget, it must be taken into account the essential components required for the PEMF device to operate with optimal efficiency and accuracy, but also the money invested in the device. The overall budget is $633.92 and is composed of a waveform generator, an amplifier, 482 m of stranded copper insulated wire necessary to make the power coil and the sensor coil, and the digital display are explained in page 67. Due to the complexity of the device, caution should be taken about the components and their performance. The budget boundary of this project is around $700 in case anything goes worse than expected.

- **Schedule**

The project construction time is divided into five parts. The first was “Research” which gave knowledge about magnetic fields and the means for generating them, before building a prototype. The “Preliminary Design/ Acquisition Components” stage began before intersession; a layout and design plan for the prototype of the PEMF device was done by December 10, 2013. The “Prototype” and “Integration of Components” began on January 27, 2014 and end on March 13, 2014. The “Testing and Troubleshooting” stage was approximately two weeks to test and adjust the prototype. Finally, from April 15, 2014 to May 1, 2014, it was entered the “Integration of Final Design” phase. It is done a fully constructed and working PEMF device. The main timing constraints that apply to this project are the need to have a working prototype by March 13, 2014 and the need to complete the effort by May 9, 2014. These constraints are motivations to be diligent and to complete tasks in a timely manner.

- **Regulatory**

Due to the obvious inability to create a medical device, the purpose is to create a device with the appropriate materials which support research in the interaction between electromagnetic fields and biological tissue, applying different waveforms, frequencies, and amplitudes. However, there are known which codes and standards must comply in case a real medical device would later be created. For example, in case a medical device is created in Europe, the rule ISO 13485 certificates that PEMF devices are approved by health authorities for human applications according to the EU Medical Device Directive 93/42 EEC and are manufactured according to Good Manufacturing Practice. In the U.S., U.S. FDA Medical Device Establishment Registration & Listing Requirements are responsible for regulating firms that manufacture, repackage, re-label, and/or import medical devices sold in the United States.

- **Design complexity**

Finally, the project design complexity must be within the capabilities of the design. It includes successful application of higher-level technical knowledge such as building and programming the amplifier of at least 15 W of power. The final amplifier has an average output power of 18 W. There was also a second amplifier built that has 35 W, but this amplifier is not going to be used because the efficiency was very low. Although it had a higher power and therefore higher magnetic field, the supply voltage was +/- 25 V and the amplifier created an excessive amount of heat especially compared to the final amplifier of 18 W. The building process of the power coils and identification and research of the specifications needed to achieve the correct impedance of the coils, and the complex programming and implementation of the digital voltmeter. The voltmeter required many hours of programming. It uses a PIC 16 that is connected to a LED screen. The complexity of the design was getting the LED to display the voltage of the power coil accurately. Also, it is good to be prudent about the device carried out because this project simulates a medical device even if this is working with non-live biological tissue.

3. Design Specifications

3.1 Design Overview and Deliverables

There is an expectation for the PEMF device, which is used as a test system, to show a relationship between controlled magnetic fields and biological tissue. In order for Introtech to be satisfied, it must be built a device capable of completing that task. The PEMF device requires a waveform generator with selectable waveforms, including sine, triangle, and square waveforms, where the input signals’s frequency and amplitude can be modified. The output of the waveform generator goes into an amplifier where the signal is outputted at a definable power level. This signal proceeds to a magnetic coil, which is where the magnetic field is created. There is a magnetic field sensor that indicates any interaction between the magnetic fields and the biological material, which is displayed on a digital volt meter. The final product is a device that can show an interaction between magnetic fields and biological tissue.

Shown in Figure 1 on the next page the subsystems for the PEMF device are the waveform generator, amplifier, coils and digital display. The project requires that the amplifier to be compatible with the changing frequencies and amplitudes of the waveform generator. The audio amplifier consists of an operational amplifier in the preamplifier stage, and then two transistors are located in the power amplifier stage. The output of the amplifier is sent to the magnetic coils, which are made of copper wiring. The hardware solution for the digital display involves integrating a microprocessor with a seven segment display. There is a smaller coil that is attached to the digital display, and this acts as the magnetic field sensor. The smaller coil has to be fixed near the bigger magnetic coil because any sort of movement will throw off the results being displayed on the digital display.

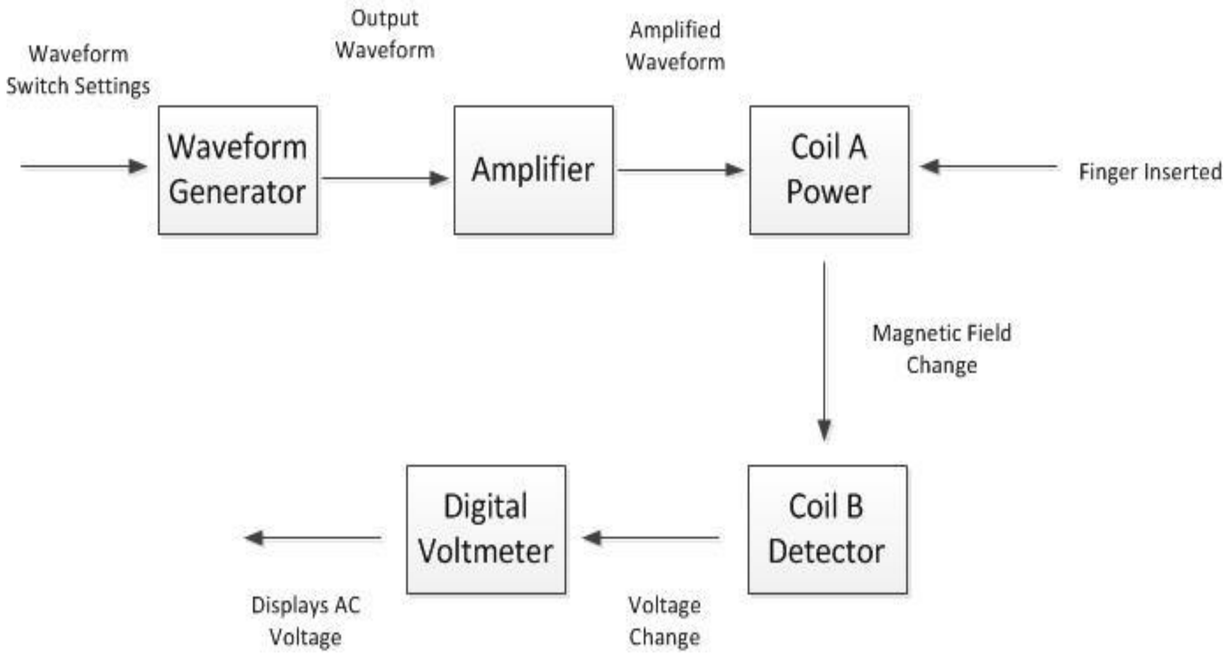

Figure 1: Block Diagram of the PEMF Device

Figure 2 on the next page, the concept diagram, shows the coil and digital display subsystem. Power coil A is attached to the amplifier and waveform generator (not shown in diagram). Power coil A is significantly larger than coil B because it is required to maximize the current and number of turns in order to maximize the magnetic field in coil A. Power coil B is smaller so it can be observed the different performance of the magnetic field in both coils. The digital display is constantly measuring the AC voltage of the power coil we use.

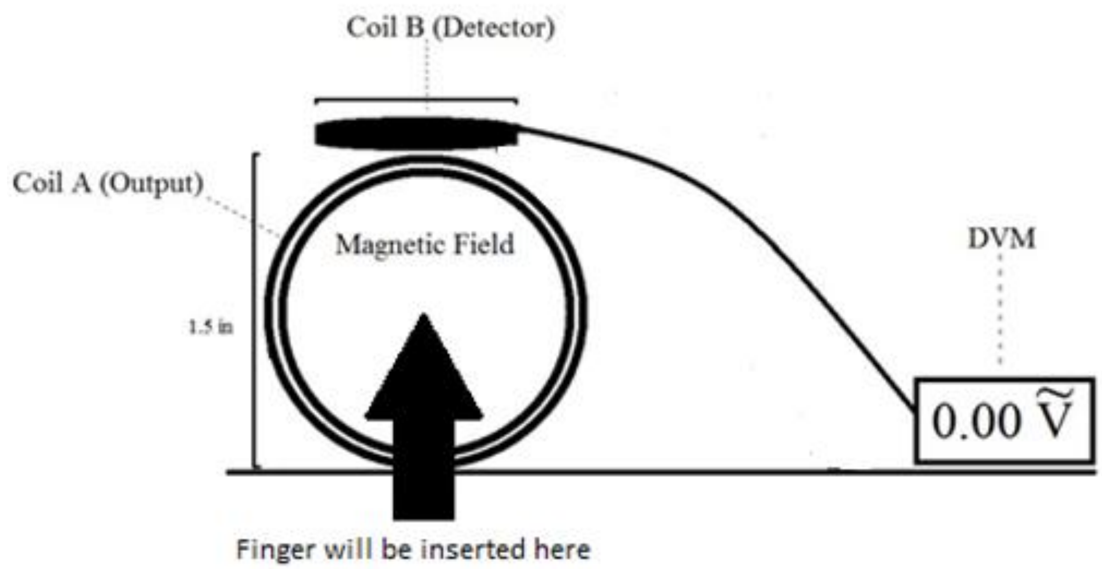

Figure 2: Coil and Fixed Arm Concept

Figure 3 below shows the concept diagram:

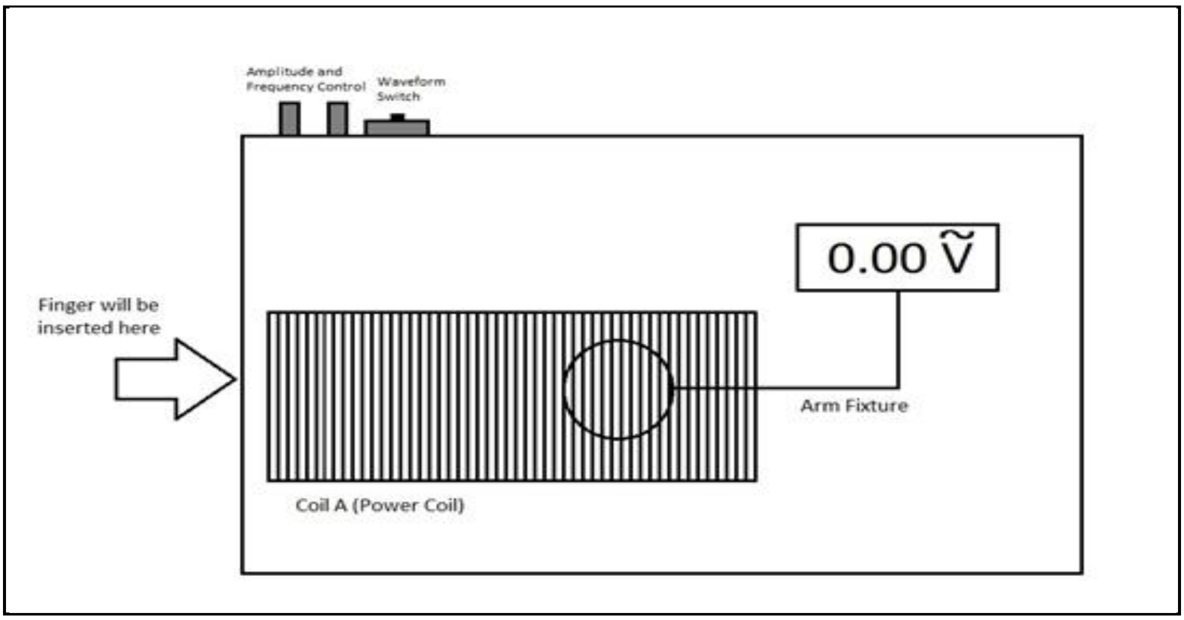

Figure 3: Concept Diagram (Top View)

3.2 Functional Specifications

- Waveform Generator:

  It should be able to change the input wave from a sine, triangle, and pulsed wave, and it must have adjustable frequencies from 10 Hz to 100 KHz meeting requirement 1.

- Amplifier:

  TDA2030 Amplifier has an output power of 18 W. The amplifier outputs the waveform at a higher voltage to create more current, meeting requirement 2.

- Power Coil A:

  Power coil A has 2000 turns, 14 gauges and a length of 241 m to achieve a strong magnetic field to meet requirement 5.

- Sensor Coil B:

  Coil B has 500 turns, 14 gauges and a length of 241 m to achieve a strong magnetic field to meet requirement 5.

- Digital Display:

  The AC voltage range goes from 0 to 300 V according to requirement 4.

The waveform generator should be able to change the signal's shape to see which combination gives the best results in electromagnetic field and biological tissue interaction. It is good to be conservative on the DC power to power the subsystems because if this product goes farther than PEMF research and reaches the market it is not good for the customers to use an excessive amount of batteries. The digital display gives the customer a great range of voltages to see if there is an interaction between the fields and biological tissue.

3.3 Physical Specifications

- Board dimensions:

  According to the size of the waveform generator, the board dimensions are 10 cm x 3 cm.

- Amplifier:

  The client has given freedom, within reason, regarding the physical requirements of the amplifier. With that in mind it has been chosen to design an 18W amplifier; refer to Table 3.

- Power Coil A:

  Power coil A diameter will be 3.81 cm and a length of 241 m using 14 gauge wire with 2000 turns.

- Sensor Coil B:

  Sensor coil B diameter will be 14.5 cm and a length of 241 m using 14 gauge wire with 500 turns.

- Area and weight of the device:

  The total area of the device must be less than 103.23 cm^2 and a reasonable limit of its weight would be 6.8 kg.

Table 1: Performance meeting requirements

Requirement	As Designed
Selectable Waveforms of sine and square waves	Waveform generator with sine, square, triangle waves.
Frequency range of 10 Hz to 1 kHz	Waveform generator frequency range of 10 Hz to 100 KHz

Amplitude range of -2 to 2 V	Amplitude range of -5 to 5 V
At least 15 Watt Amplifier	18 Watt Amplifier
Power coil able to fit human finger comfortably	Coils diameter of 3.81 cm and 14.5 cm
Safe and non-shocking	Coils are covered by a plastic housing
Digital Voltage Display with range of 0 to 100 AC V	AC voltage range of 0 to 300 V
Magnetic field below 1 T	Magnetic field around 0.1 T
Device to magnetic field density	Gauss meter
DC voltage source less than 40 V	DC voltage source of 30 V
Budget below $1000	Budget of $415.82
Max weight of 6.8 kg	Less than 6.8 kg
Max Size of 161 cm^2	Size of 103.23 cm^2

4. Design Results

4.1 System Design

4.1.1 Overview

The PEMF device is built, at first, as a research device where the goal is to make the device effective, inexpensive and portable. One key design tradeoff is that increasing the number of turns in our power coil creates a stronger magnetic field, but it would make the device significantly heavier and bulkier.

4.1.2 Detail Design

Introtech requested that the PEMF device is able to have a waveform generator where it can vary its waveform, frequency and amplitude. It has been decided that it can be either built or purchased a waveform generator. The device must be convenient for the user, so attaching an excessively large waveform generator would not meet requirements. The decision was to purchase a small waveform generator because building one would make the device larger. The Galak Waveform Generator purchased meets the customer's requirement of being able to adjust the waveform, frequency and amplitude.

Power coil A has around 3.81 cm in diameter and 241 m in length and 2000 turns. This design choice allows the user to be able to insert a finger into the coil, while keeping the product as compact as possible. Another option is making the diameter of 2 cm with a length of 700 m. Although this would technically be able to fit most fingers, so this is why we made a design choice of trading a compact coil size for compatibility. Sensor coil B will be around 14.5 cm in diameter and 241 m in length with 500 turns.

Introtech wanted the PEMF device to have a power output of the amplifier to be at least 15 W. The amplifier built has an estimated power output of 30 W. Figure 4 below shows the block diagram shows all the subsystems, waveform generator, amplifier, coil and digital display, that is described in the next section.

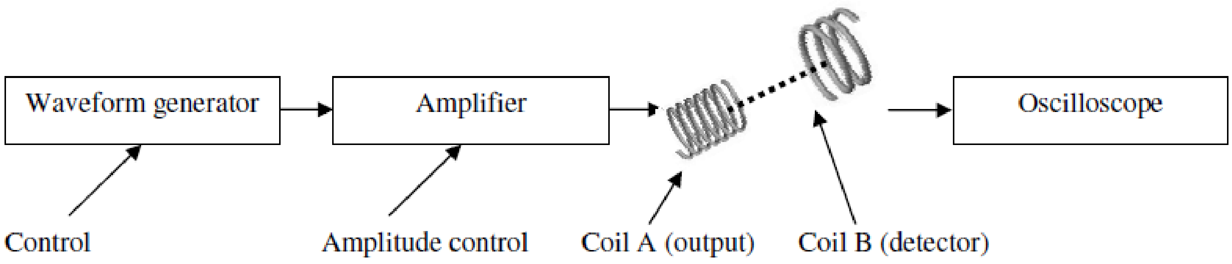

Figure 4: Block Diagram

4.1.3 Evaluation

The goals of the PEMF project include developing and building a device that can generate a pulsed electro-magnetic field (PEMF), and then determine the interaction between magnetic fields created by the PEMF generator and biological materials. The

PEMF device requires a waveform generator that permits selectable waveforms, including sine, triangle, saw tooth and square waveforms. The waveform generator is also able to vary frequency and amplitude. Output of the waveform generator is controlled to make it compatible with the selected amplifier, which outputs the signal at a definable power level. Once the signal is amplified to a range of 0-30 W it goes to a coil with AC impedance that is similar to that of the amplifier at about 4 to 8 Ω. Another coil is used as a sensor to sense the magnetic field when the coil is empty. When biological material is inserted into the coil, the coil indicates any interaction between the magnetic fields and the biological material. The detector coil should be built rigidly positioned close to the power coil. The detector must be rigid because any relative movement between the two coils can completely obscure the results on a digital display.

4.2 Waveform Generator Subsystem

4.2.1 Overview

The waveform generator has selectable waveforms of sine, square, triangle and pulse. The waveform is pretty simple to use. The waveform of the signal is controlled by a switch that clearly labels which switch position outputs a sine, square, triangle and pulse.

4.2.2 Detail Design

The frequency and amplitude of the signal is controlled by dials where clockwise increases the frequency and amplitude. All that is needed to power the waveform generator is a supply voltage of about 12-24 V DC. The output signal is clearly labeled on the printed circuit board (PCB), and is needed to solder a wire from the output and lead that to the amplifier subsystem.

It has been also decided to use an app called “Waveform Generator” that allows the phone to be used as a waveform generator. This allows the user to easily change frequency, amplitude and waveforms with just tapping the screen.

4.2.3 Evaluation

The next page shows the different types of waveforms produced by the waveform generator at different workable frequencies.

Figure 5: Galak Waveform Generator and Waveform Generator App

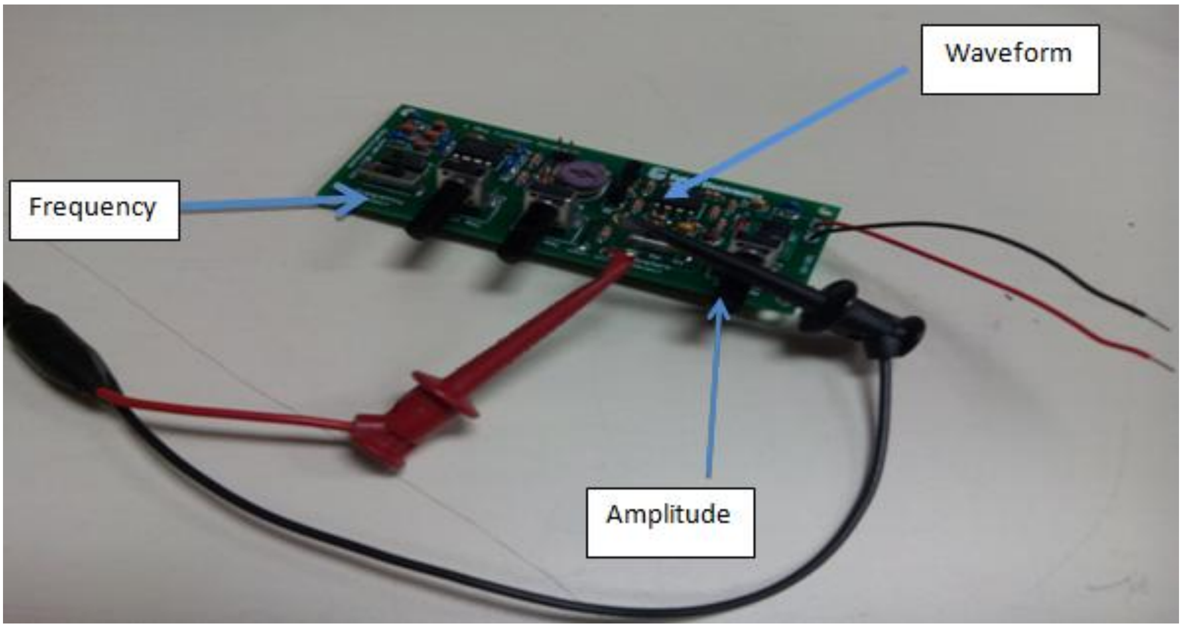

Figure 6. Galak Waveform Generator

10 Hz sine wave:

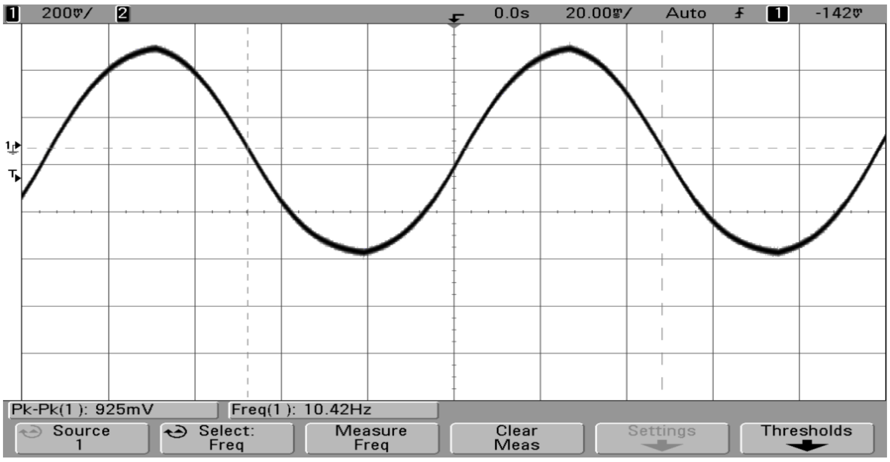

Figure 7: Sine wave at 10 Hz

100 Hz triangle wave:

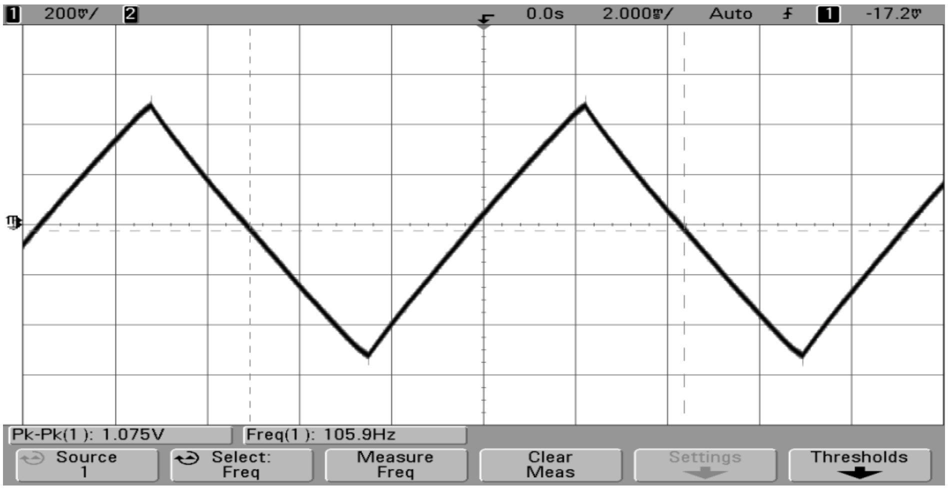

Figure 8: Triangle wave at 100 Hz

4.3 Amplifier Subsystem

4.3.1. Overview

The amplifier used has an output power of 18 W. This meets Introtech's power requirement of at least 15 W. As the main goal of wanting to make the PEMF device inexpensive and convenient, it builds a 18 W amplifier instead of a 15 W one. This allowed the design to have a higher power output therefore a higher magnetic flux density. The amplifier is connected to the waveform generator and then output to the power coil where the magnetic field is created. The function of the amplifier is to increase the power of the signal coming from the waveform generator. It essentially takes the energy from the DC power supply and modulates the output of the power supply. The amplifier is mounted on a custom printed circuit board. This subsystem involves controlling the power entering the power coil.

4.3.2 Detail Design

The particular amplifier uses a TD2030 IC chip. This amplifier uses 15 Volts symmetrical power supply. It can also work from 10 to 20,000 Hz with a maximum distortion of 0.5%. The signal to noise ratio is 80 dB.

Figure 5 below shows a schematic of the 18 W amplifier that is built. As shown, in the schematic the amplifier takes the output of the waveform generator and increases the power of the signal inputted into the amplifier. The output then sends to the power coil, where the magnetic field is created.

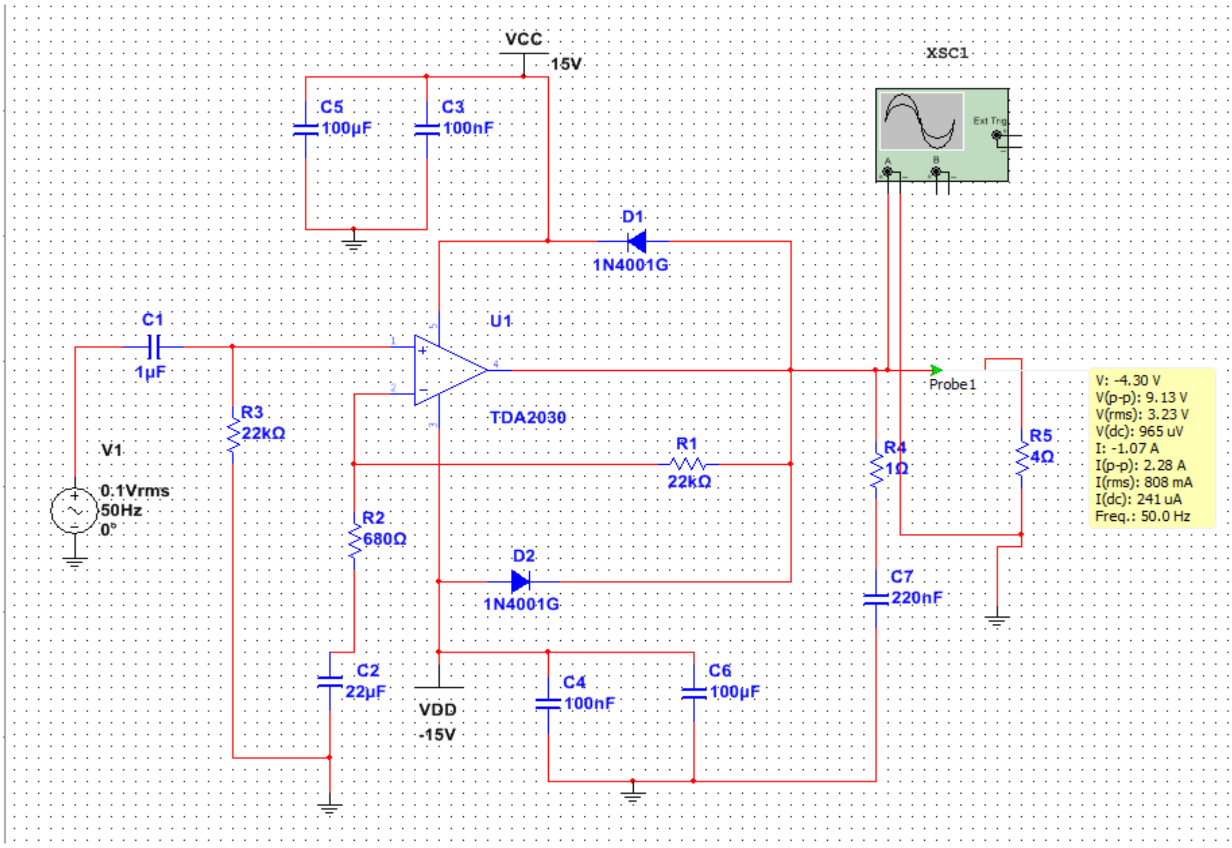

Figure 9: Schematic of the 18 W Amplifier

4.3.3 Evaluation

It is observed below how the amplifier performs by changing the input voltage and the frequency.

Table 2: Performance of the 18 W Amplifier

Input Voltage (Vrms)	Frequency	Output Voltage (Vpp)	Output Current (Ipp)
0.2	10	10.6	0.92
0.2	25	16.7	1.48
0.2	50	18.3	1.61
0.2	100	18.6	1.66
0.2	500	18.5	1.65
0.2	1000	18.6	1.66
Input Voltage (Vrms)	**Frequency**	**Output Voltage (Vpp)**	**Output Current (Ipp)**
0.3	10	15.8	1.39
0.3	25	25	2.21
0.3	50	26.9	2.42
0.3	100	27.4	2.48
0.3	500	27.5	2.49
0.3	1000	27.4	2.49
Input Voltage (Vrms)	**Frequency**	**Output Voltage (Vpp)**	**Output Current (Ipp)**
0.1	10	5.29	0.471
0.1	25	8.32	0.739
0.1	50	9.13	0.808
0.1	100	9.32	0.827
0.1	500	9.42	0.830
0.1	1000	9.38	0.831

The table above shows some results of the amplifier performing through various input voltages and frequencies. Any higher input voltages causes clipping of the output signal. As shown in the tables above, the amplifier handles small input voltages while still being able to have high output power. The maximum output power is 67.5 W, but the amplifier will only work at that state for around a second before the heats gets to damaging temperatures.

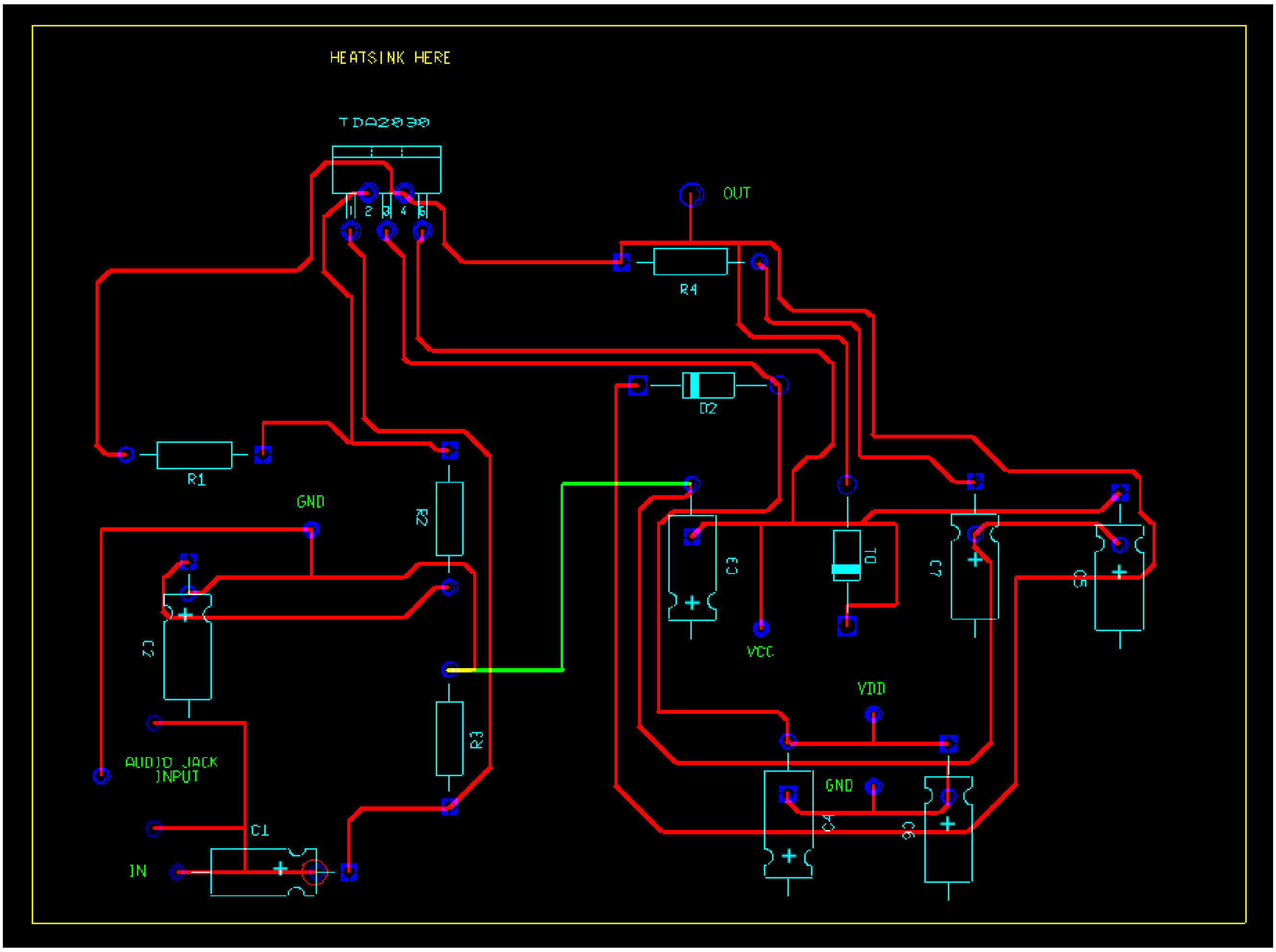

Figure 10: Printed Circuit Board (PCB) of amplifier

Figure 9 shows the PCB design of the amplifier. It also shows where the heatsink is located on the board that is used to dissipate heat from the IC chip. The amplifier also uses a 3mm audio jack input that will allow using the phone as a waveform generator.

4.4 Coil Subsystem

4.4.1 Overview

The amplifier's output will then be routed to a power coil. The experiment is done with two different coils to see the performance of the magnetic flux. First, it is going to be used power coil A (2000 turns) as the power coil and sensor coil B (500 turns) as the magnetic flux sensor. But it will be experienced the other way, coil A as the sensor and coil B as the power coil that produces the magnetic field. An appropriate wire size and number of turns are selected to achieve at least 4 Ω impedance knowing that the system must handle A and not mA. It will be used high-intensity magnetic fields at frequencies from below 10 Hz to as high as 1 kHz. Also it has to be taken into account that the number of turns of wire is directly related to the strength of the magnetic field. According to the estimates described below, the power coil A should have around 2000 turns of 14 gauge wire to achieve approximately 4 Ω of impedance. The power coil B has the same wire size of 14 gauge, 500 turns, and diameter of 14.5 cm and a length of 241m. Figure 6 below shows that highest flux configuration of a helical coil appears at its center, so the power coil must have a diameter that will permit the insertion of selected biological materials.

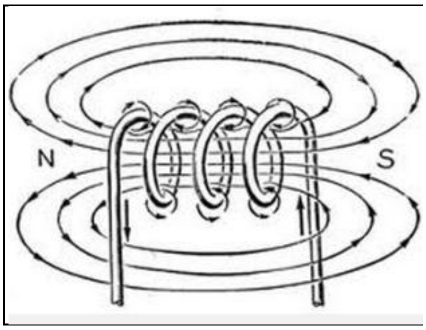

Figure 11: Flux Configuration of a Helical Coil[3]

Coil Calculations:

Coil A:

- Diameter of coil A: 1.5 in = 3.81 cm
- Perimeter of one turn: 3.14 * 1.5 = 4.6 inches = 11.68 cm
- Length of the wire: $\frac{2000 \text{ turns} * 4.6 \text{ inches/turn}}{12 \text{ inches/feet}}$ = 766.66 feet ≈ 791 feet = 241m
- Length of the coil: 7 ½ inches = 19.1 cm

[3] Taken from: http://encyclopedia2.thefreedictionary.com/Magnetism

Coil B:

- Diameter of coil B: 5.7 in = 14.5 cm
- External diameter of coil B: 6 in = 15.2 cm
- Perimeter of one turn: 3.14 * 5.7 = 17.9 inches = 45.46 cm
- Length of the wire: $\frac{500 \text{ turns} * 17.9 \text{ inches/turn}}{12 \text{ inches/feet}}$ = 745.83 feet ≈ 791 feet = 241m
- Length of the coil: 3 3/8 inches = 8.6 cm

The goal is 4 Ω impedance with 12 V of Source DC voltage which means that the load current will be 3 A. The number of AWG (American Wire Gauge) recommended by the Help Center of Bulk Wire[4] is 14 AWG, thus assuming a percentage of loss of about 74 %, so the output voltage will be around 3 V. With all of this in mind, it is created a power coil of 2000 turns, 14 gauge, and 241 m with 3.81 cm diameter. It is approaching this length due to the length of 241 m of one spool of 4.5 kg from TEMCo Industrial Power Supply. American wire gauge (AWG) is a standardized wire gauge system used for the diameters of round, solid, nonferrous, electrically conducting wire. For this project was chosen 14 gauge wire in order to work with a reasonable diameter of wire and also an assumable percentage of loss recommended by the Help Center of Bulk Wire. The cross-sectional area of each gauge is an important factor for determining its current-carrying capacity. Finally, with a coil winder of 3.81 cm created in the laboratory, it is achieved the desired power coil. Table 4 below shows the calculations. The second coil has the same length as coil A and also the same wire size of 14 gauge, but it is different from coil A because this second coil has 500 turns and 14.5 cm diameter, so it is more compact and the magnetic field it produces is slightly smaller.

Table 3: Calculations of the Coils

Load Current (Amps)	AWG	Diameter of the wire (mm)	Length of the one spool (m) (Coil A and B)	Diameter of the final power coil A (cm)	Diameter of the final power coil B (cm)
3	14	1.65	241	3.81	14.5

[4] Bulk Wire Help Center: http://www.bulkwire.com/wireresistance.asp

Table 4 below contains information on the copper wire used:

Table 4: Essex Copper Wire Product Specifications[5]

Model:	
TEMCo product ID	MW0515
Brand	Essex
Mfg part number	MW0515
Sizing Specifications:	
Wire gauge (AWG)	14
Wire diameter (with insulation) (in)	0.0675
Wire diameter (no insulation) (in)	0.0641
Spool weight	10 lb.
Length (ft)	791
Feet per pound	79.11
Mechanical Specifications:	
Conductor material	Copper
Wire format	Solid
Wire shape	Round
Wire build type	Double (heavy)
Insulation temp rating (deg C)	200
Insulation enamel (base coat)	Polyester
Insulation enamel (overcoat)	Polyamide-imide
Solder process	Remove insulation first

Figure 12 below is a picture of the wire used:

Figure 12: Picture of the Copper wire[3]

[5] http://www.temcoindustrialpower.com/products/Magnet_Wire/MW0515.html#

4.4.2 Detail Design

It is used an amplifier with an estimated power output of 12 W because one goal is to make a PEMF device that is inexpensive and convenient. With this amplifier the appropriate input power is 12 V DC. The output signal is sent to the coil to measure the effect frequency, the waveform selected and the amplitude of the waveform. These three variables are expected to create interactions between magnetic fields caused by the power coil and biological material. The calculations of the power coils are described in Appendix D2.

One constraint of the amplifier says that it can only handle 12 V of voltage. Another constraint is a load of at least 4 Ω of impedance. This functional constraint is imposed by the amplifier, so as the impedance of the power coil increases the load current that goes through the coil is decreasing following Ohm’s rule.

The measurement of the impedance of the coils has been carried out by following this circuit:

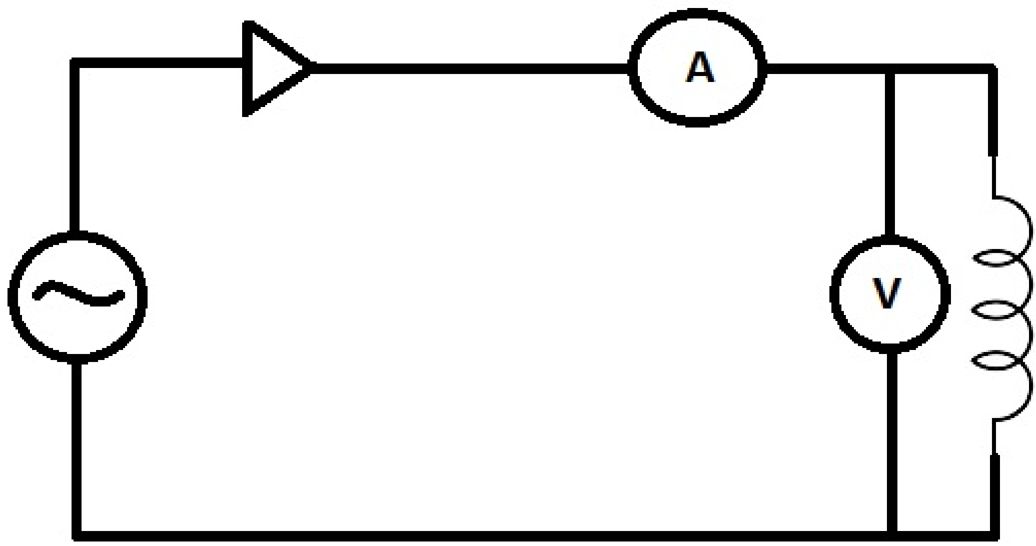

Figure 13: Circuit of our experiment.

4.4.3 Evaluation

The experiment to measure the impedance of the coils is based on the circuit of the figure above. The circuit consists of the waveform generator (on the left side of the circuit) connected to the amplifier. An ammeter is used to measure the load current that is going through the power coil. At the end of the circuit is located the power coil, and is used a voltmeter to measure the voltage across the coil. As the definition says, impedance is the complex ratio of the voltage to the current in an alternating current (AC) circuit. It is the measure of the opposition that a reactive circuit presents to current when an alternating-voltage is applied. Impedance extends the concept of resistance to AC circuits, and possesses both magnitude and phase, unlike resistance, which has only magnitude. Impedance can be written in this way too:

$$Z = R + jX$$

Where “R” is the real part of the impedance called resistance and “X” is the imaginary part of the impedance called inductive reactance.

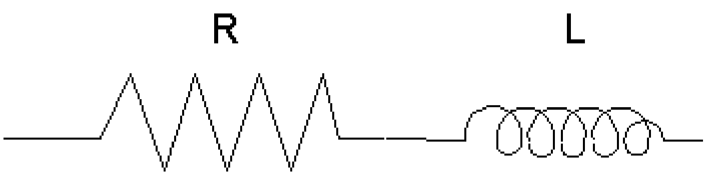

Figure 14: Model of an actual coil

In the circuit, the coils make the reactance to be inductive. The inductive reactance is formed by the frequency measured in radians multiplied by the inductance of the coil. So the inductive reactance (imaginary part of the impedance) is directly proportional to the working frequency. This linear relationship can be also observed in Figure 15.

$$X = \omega L$$

Through Ohm’s law and using the current and the voltage, both in AC, the impedance of the power coil is calculated. In the tables below it can be observed that increasing the working frequency decreases the load current that goes through the power coil so applying Ohm's law is estimated that the impedance of the power coils increases and therefore the its inductive reactance. First, with a digital multimeter the DC resistance of the coil is measured which is 5.25 Ω. Then, based on the circuit of Figure 12, the experiment continues by fixing a voltage value of approximately 10 V of alternating current (AC) and depending on the frequency of the waveform generator these load current data are collected:

Table 5: Values of coil A

Frequency (Hz)	Load current (A)	Impedance (Ω)	Inductive reactance (Ω)	Electromagnetic field (mT)
10	1.209	8.27	6.39	15.165696
50	0.9482	10.54	9.15	11.8942208
100	0.7102	14.08	13.06	8.9087488
200	0.4314	23.18	22.58	5.4114816
300	0.3186	31.39	30.95	3.9965184
400	0.204	49.02	48.75	2.558976
500	0.1564	63.94	63.72	1.9618816
1000	no value	very high	very high	no value

Table 6: Values of coil B

Frequency (Hz)	Load current (A)	Impedance (Ω)	Inductive reactance (Ω)	Electromagnetic field (mT)
10	1.1895	8.41	6.57	5.752422
50	0.9234	10.83	9.47	4.4655624
100	0.6833	14.63	13.65	3.3044388
200	0.4206	23.77	23.19	2.0340216
300	0.3051	32.77	32.35	1.4754636
400	0.1966	50.85	50.58	0.9507576
500	0.1509	66.27	66.06	0.7297524
1000	no value	very high	very high	no value

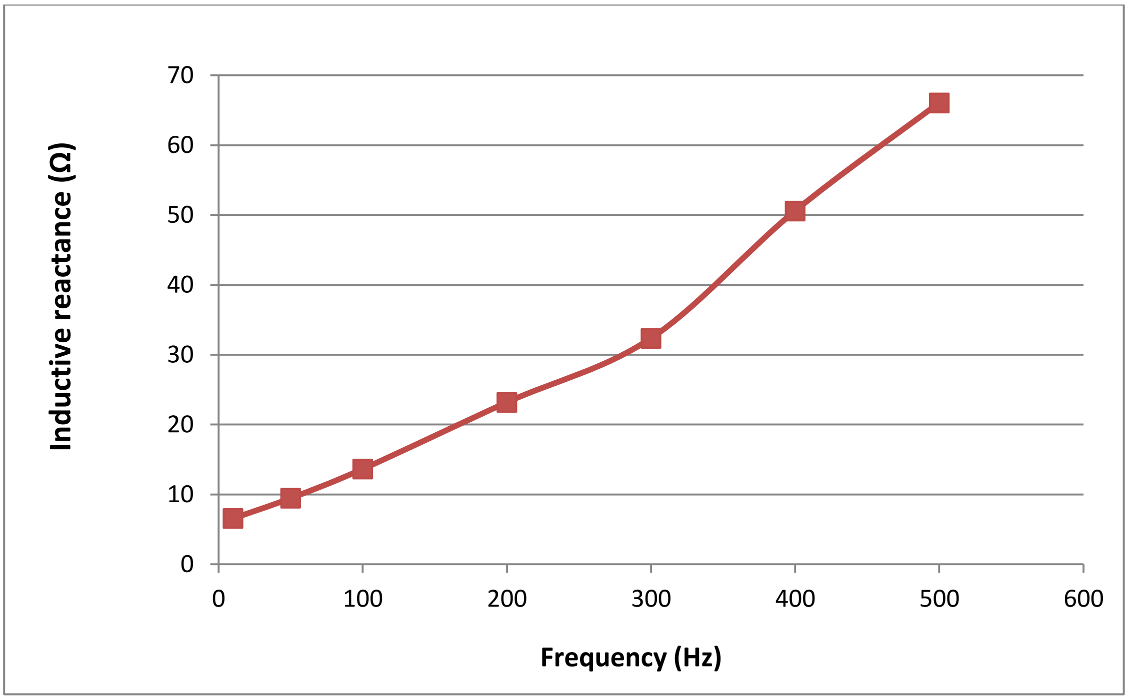

Figure 15: Frequency vs. Inductive reactance

As shown in Figure 15, increasing frequency increases the inductive reactance in an inductive circuit. These magnitudes are directly proportional, so their relationship is linear. Tables 5 and 6 show us that as current goes down then inductive impedance goes up. All the frequency values fulfill the requirement of the minimum impedance imposed upon the amplifier. Up to a certain frequency (perhaps 1000Hz) can be considered as model a series combination of ideal resistance and a perfect induction. From this value of frequency, it begins to increase the ohmic resistance due to the skin effect and the displacement of current between adjacent coils. As the frequency is increased, it appears capacitive effects which vary substantially the value of the apparent induction as well as resistance. That restricts the workable range of frequency from 0 Hz to 1 kHz. Also, it is important to comment that the magnitude of AC impedance cannot be lower than the DC resistance. AC impedance consists of a real component (DC resistance) and an imaginary component called inductance. It can be verified by looking at the impedance values obtained in the experiment. All of these are greater than the DC resistance value of 5.25 Ω. The two coils have slightly different impedance because coil A has a smaller radius and therefore has more turns so it has smaller impedance than coil B. However, the difference is small as is shown in tables 5 and 6.

4.5 Digital Display Subsystem

4.5.1 Overview

The digital display will be constantly measuring the AC voltage of the Sensor Coil. The output signal from the coil is the input of the digital display subsystem. The PIC microcontroller used in the display is PIC16F688 that has 12 I/O pins out of which 8 can serve as analog input channels for the in-built 10-bit ADC. The specifications for the PIC16F688 are located in Appendix C3. Since the PIC port cannot take 20V input directly, the input voltage is scaled down using a simple resistor divider network. The resistors R1 and R2 scale down the input voltage ranging from 0-20V to 0-5V before it is applied to PIC16F688’s analog input channel, AN2. A 5.1V zener diode connected in parallel between the port pin AN2 and the ground provides protection to the PIC pin in case the input voltage accidentally goes beyond 20V. The LCD display is connected in 4-bit mode, and the In Circuit Serial Programming (ICSP) makes the firmware development easier as you can reprogram and test the PIC while it is in circuit. The In Circuit Serial Programming (ICSP) is a method of directly programming PIC microcontrollers. Calculations for resistor and capacitor values are located in Appendix D1.

4.5.2 Detail Design

Figure 16 is the schematic of the digital voltmeter subsystem.

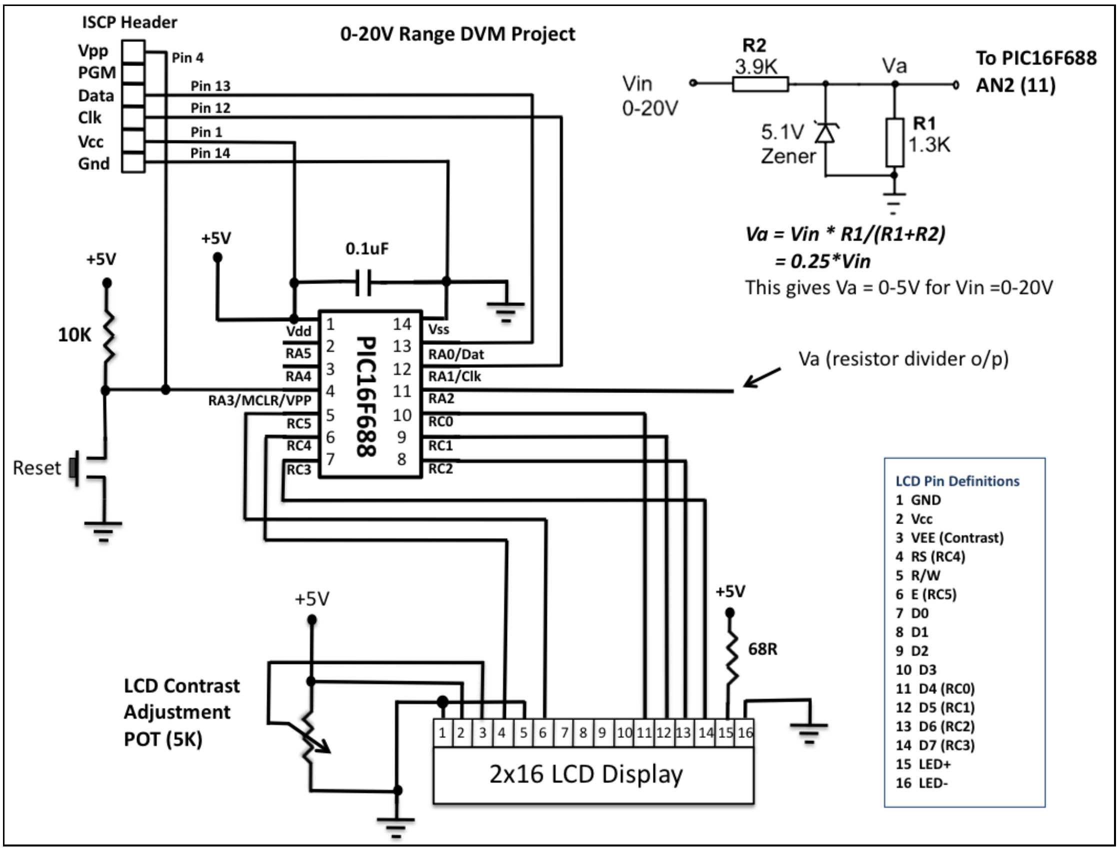

Figure 16: Schematic of Digital Voltmeter

The digital display uses a 2X16 LCD screen to display numerical values. The being used is the HD44780 2x16 1602 Character LCD Module Display with Black on Green screen display. Specifications for the HD44780 LCD Screen are located in Appendix C4.

5. Design Plan

5.1 Stage 1 – Research

Research about electromagnetic fields has already been completed. In addition, is necessary to conduct research on magnetic flux to aid in calculations for the coil subsystem. It is researched on different varieties of waveform generators; finally the decision was purchasing a waveform generator.

In terms of the coil subsystem, at the beginning of the project it was supposed to build one power coil to achieve high-intensity magnetic fields at frequencies from below 10 Hz to as high as 1 kHz. As state above, this coil has 2000 turns of 14 gauge wire to achieve approximately 4 Ω of impedance. This constraint comes from the amplifier, which can only handle 12 V of voltage so if the purpose is to work with high-intensity magnetic field as 3 A the coils must have at least 4 Ω of impedance. Another power coil (B) is used with the same wire size of 14 gauge, diameter of 14.5 cm, 500 turns and it has a length of 241 m as coil A. This second coil helps to observe the performance of the magnetic field due to the different configurations of the coils and it is also a Sensor Coil.

In researching digital displays the first design found was the standalone digital voltmeter. The design is based on the Atmel ATmega8-16AC microcontroller and the Maxim MAX1230 12-bit ADC. Although the microcontroller has an internal 10-bit ADC, it's more efficient to use an external multichannel ADC than to multiplex more analog channels to the ATmega8-16AC differential ADC inputs. It was decided to search to see if there is a more efficient and easier to build digital voltmeter. Finally, the decision was to go with a digital voltmeter using a PIC microcontroller. A HD44780 based character LCD is used to display the measured voltage. The PIC microcontroller used in this project is PIC16F688 that has 12 I/O pins out of which 8 can serve as analog input channels for the in-built 10-bit ADC. In addition, it was researched different sensor options that can be implemented into the design to detect the magnetic field. Instructables.com [6] has specifications and information about the Arduino EMF (Electromagnetic Field) Detector. Elechouse.com [7] has specifications and information about the Electromagnetic Wave Detection Sensor. The Arduino EMF seems very involved and complex. As a result, it was found a reliable gaussmeter to measure the magnetic field produced by the coils. This measuring device is called Gaussmeter M-test LL and its specifications are shown in Appendix C5.

5.2 Stage 2 – Design

This phase consists of applying the research knowledge, and then using that knowledge to create a solution. In this stage, a conceptual diagram is created to have an awareness of each subsystem. A waveform generator is chosen that has selectable waveforms, frequencies and amplitudes. Then the next step is to create circuits for the electrical subsystems such as the amplifier and digital display. The amplifier is simulated and checked using an oscilloscope to see that it was working appropriately. These are the goals that have been completed so far:

- Created a conceptual diagram.
- Choose an appropriate waveform generator.
- Created circuit diagrams for amplifier and digital display.
- Made final decision on hardware components.
- Obtained hardware components.

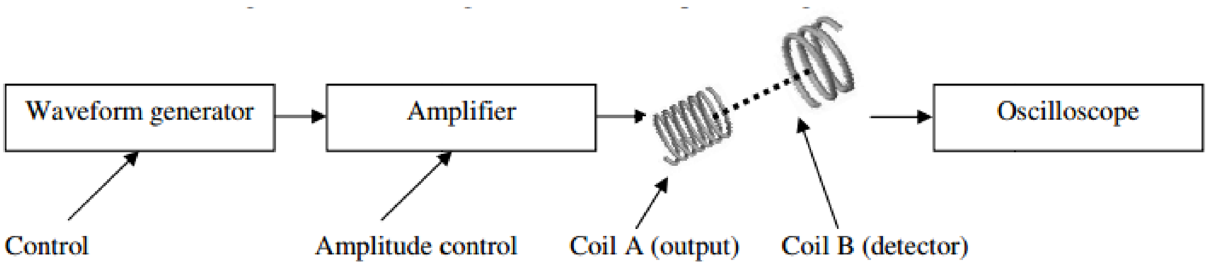

Figure 17. Conceptual Diagram

5.3 Stage 3 - Prototype Construction

In the initial prototype stage the device was made by combining the four main parts of the device. The first part is using a waveform generator as the control and input to the device. The waveform generator has selectable waveforms, including sine, triangle, saw tooth and square waveforms. The amplifier used has an output power of 12 W. The amplifier was connected to the waveform generator and then output to the power coil where the magnetic field is created. The particular amplifier uses an op amp, the IC TL081, which acts as the preamplifier. Then are used NPN and PNP transistors, specifically TIP125 and TIP120, for the power amplifier stage. The output for the power coil was taken from the collector junction of the two transistors. It is included an amplification circuit because connecting the Arduino directly to the coils can damage the board. The LM386 audio amplifier is used in the amplification circuit because of its ability to change the gain of the amplifier easily. The waveform generator is a component that is already built, so it is not arduous to integrate this component into the PEMF device. The most challenging part of the project is creating two coils that have an impedance of 4 to 8 Ω across the frequency range of the system. The plan for these coils is to use the initial estimates of using 14 gauge wire on one coil with 3.81 cm average diameter, 241 m length with 2000 turns, which has an estimated impedance of 4 Ω, and another coil (used at first as a sensor coil but is going to be used also as a power coil to see the different performance of the magnetic field) of 14 gauge wire, 14.5 cm average diameter, 241 m length with 500 turns. The power used is up to 20 W. Then is time to implement a digital voltmeter attached to one of the power coils to see if introducing biological tissue is affected by the magnetic fields. The plan is to use the MAXIM IC L7106 along with common anode seven segment displays. The IC L7106 is chosen because it can measure a wide range of AC/DC voltages. The prototype was anticipated by early December.

5.4 Stage 4 – Testing

Once each subsystem was successfully designed and constructed, it begins testing of the four subsystems. The subsystems consist of the coils, the function generator, the amplifier and the digital display. Once each subsystem was tested the team began constructing the prototype for testing. The following is the breakdown of the subsystems and testing:

5.4.1 Waveform Generator Subsystem

It was decided that it would be more efficient to purchase a function generator. The projected outcome of the testing on the waveform generator was to produce waveforms. Specifications for the function generator are in Appendix C2 on page 40.

5.4.2 Digital Display Subsystem

The design of the digital voltmeter subsystem is completed. All parts required for construction were ordered and testing of the subsystem will be started. The projected outcome of the testing of the digital voltmeter subsystem is to produce an accurate well calibrated digital display that accurately displays values on the LCD screen. Calculations of the digital display subsystem are in Appendix D1 on page 43.

5.4.3 Coil Subsystem

All calculations required for the coil subsystem were completed. All parts required for construction were ordered and the subsystem was tested. The projected outcome is to have the coils produce the proper AC impedance as shown in the Evaluation of the Coil Subsystem. Calculations of the coil subsystem are in Appendix D2 on page 43.

5.4.4 Amplifier Subsystem

All components required for construction to the amplifier subsystem were purchased. The design and construction of the subsystems is completed, so is time to start testing. The projected outcome of the amplifier is to accurately output power between 15-18 W.

5.4.5 Prototype

Once testing of the subsystems is completed, it is time to construct and conduct meticulous tests on the prototype. The projected outcome of the prototype testing was to produce an electromagnetic field and have the field interact with biological tissue. Once the electromagnetic field is produced and due to the properties of conducting metals, inserting a metal clip (built by steel) shows the client that there is a strong magnetic field produced by the load current that goes through the power coil. This power coil induces an electromotive force (voltage) in the sensor coil that produces an inductive current due to the fact that the sensor coil is conductor. The load current that goes through the power coil can be controlled through the working frequency as is shown in the design results of the coil subsystem and also in the next tables. In addition to magnetic field, the potential differences also created electric field; there is also a small capacity between loops that significantly hinders the modeling of actual coil. Up to a certain frequency (perhaps 1000Hz) can be considered as model a series combination of ideal resistance and a perfect induction. From this value of frequency, it begins to increase the ohmic resistance due to the skin effect and the displacement of current between adjacent coils. As the frequency is increased, it appears capacitive effects which vary substantially the value of the apparent induction as well as resistance. For our purposes, and low-frequency electrical effects, will consider as basic model described above, which means an ideal element only presenting autoinduction L_s in series with another ideal element which only presents ohmic resistance R_s as can be seen in the following figure:

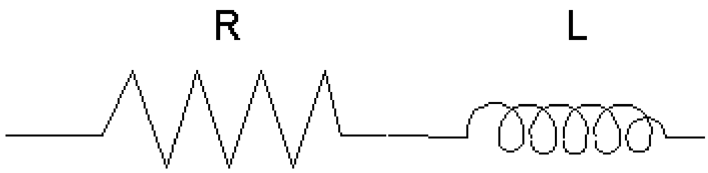

Figure 18: Model of an actual coil

The magnetic field in the center of a coil is calculated this way:

$$dB = \frac{\mu i a^2}{2\left(\sqrt{x^2 + a^2}\right)^3} \frac{N}{L}\, dx$$

$$B = \frac{\mu i N}{2L} \left(\cos \theta 2 - \cos \theta 1\right)$$

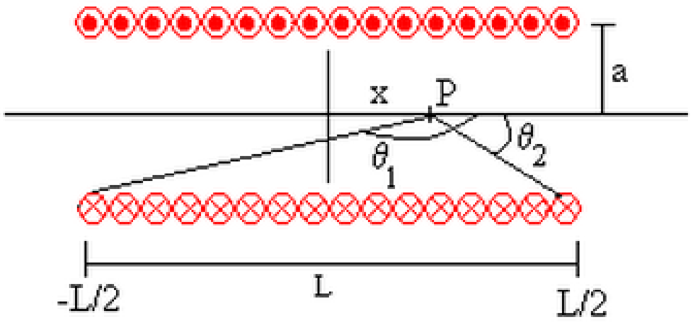

Figure 19. Point P at a distance x from the center of the solenoid

The magnetic field is calculated in the center of the power coil, so the value of x is going to be x=0 m:

$$\cos\theta 2 = \frac{\frac{L}{2} - x}{\sqrt{\left(\frac{L}{2} - x\right)^2 + a^2}} \qquad \cos\theta 1 = \frac{-\frac{L}{2} - x}{\sqrt{\left(-\frac{L}{2} - x\right)^2 + a^2}}$$

The parameters needed to calculate the magnetic field produce by the two coils are:

μ = magnetic permeability in the air ($4\pi 10^{-7}$ TmA^{-1})

i = load current that goes through the power coil

N = number of turns of the power coil

L = length of the power coil

Therefore, applying the equation of the magnetic field and substituting for the corresponding variables and parameters is obtained:

$$B = \frac{\mu i N}{2L}\left(\cos\theta 2 - \cos\theta 1\right)$$

Coil A as the power coil:

Table 7. Values of coil A

Frequency (Hz)	Load current (A)	Impedance (Ω)	Inductive reactance (Ω)	Electromagnetic field (mT)
10	1.209	8.27	6.39	15.165696
50	0.9482	10.54	9.15	11.8942208
100	0.7102	14.08	13.06	8.9087488
200	0.4314	23.18	22.58	5.4114816
300	0.3186	31.39	30.95	3.9965184
400	0.204	49.02	48.75	2.558976
500	0.1564	63.94	63.72	1.9618816
1000	no value	very high	very high	no value

Coil B as the power coil:

Table 8. Values of coil B

Frequency (Hz)	Load current (A)	Impedance (Ω)	Inductive reactance (Ω)	Electromagnetic field (mT)
10	1.1895	8.41	6.57	5.752422
50	0.9234	10.83	9.47	4.4655624
100	0.6833	14.63	13.65	3.3044388
200	0.4206	23.77	23.19	2.0340216
300	0.3051	32.77	32.35	1.4754636
400	0.1966	50.85	50.58	0.9507576
500	0.1509	66.27	66.06	0.7297524
1000	no value	very high	very high	no value

As shown in the tables above, having coil A as the power coil produces higher magnetic field than coil B. This occurs because coil A has more turns and is more compact than coil B as shown below:

Figure 20. Coil A

Figure 21. Coil B

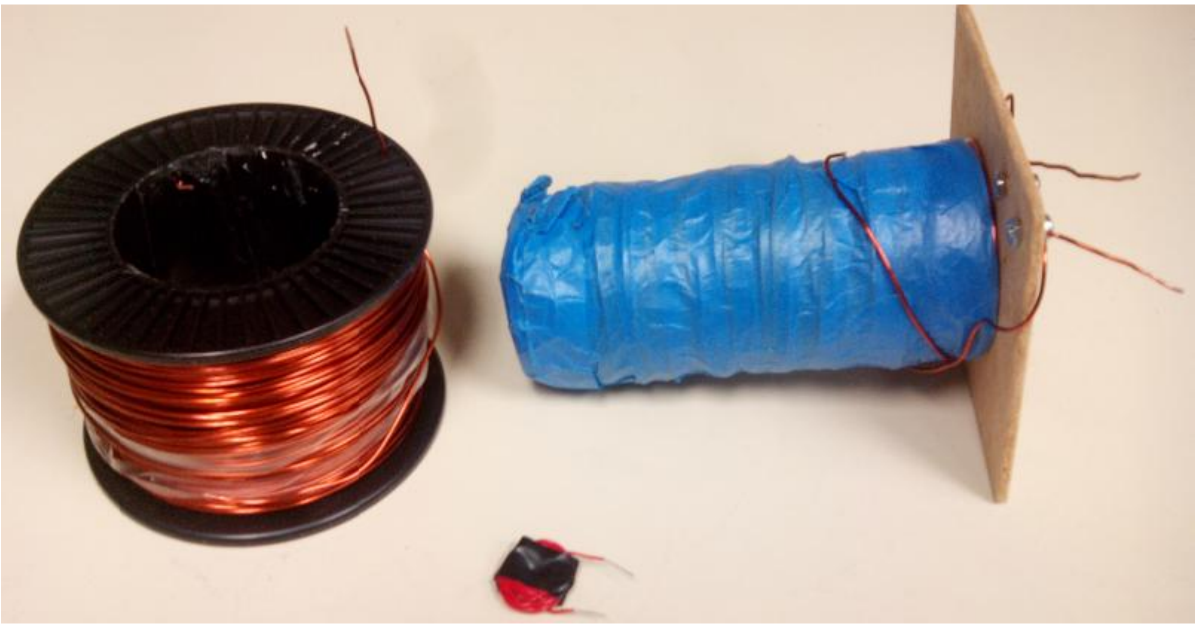

Figure 22. Coil A, coil B, and another detector coil

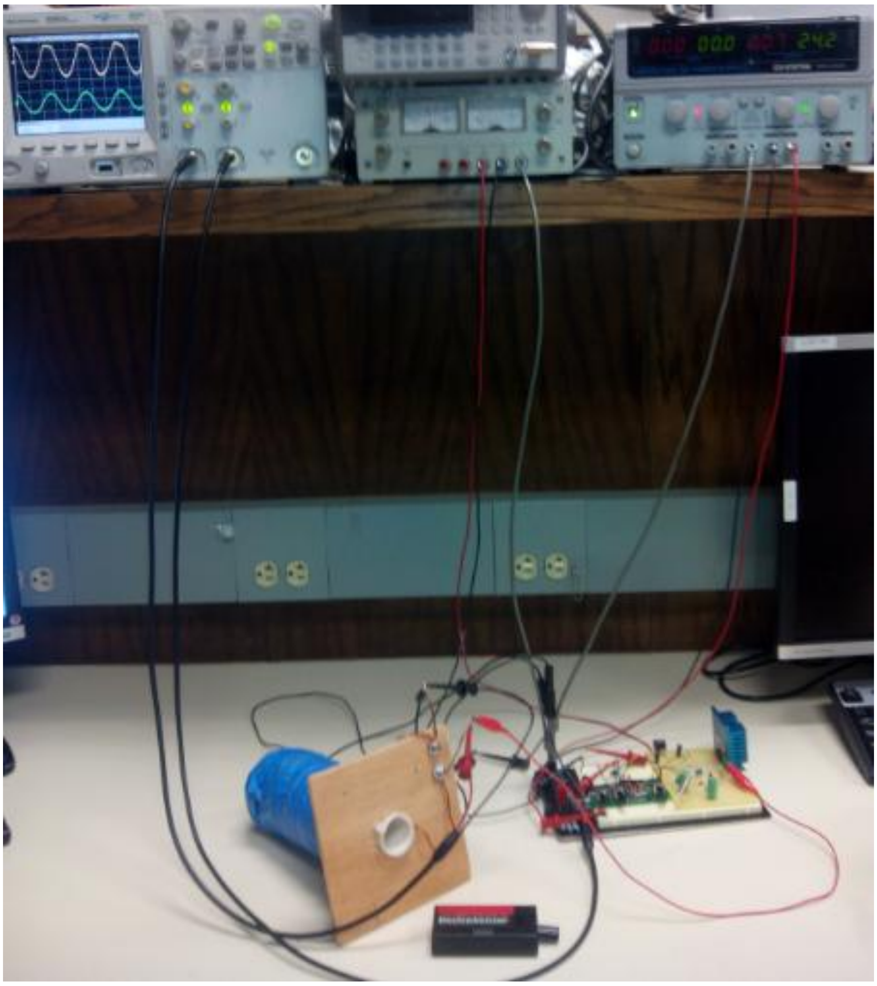

Figure 23. Real circuit of the device

It is observed that from 1000Hz of frequency, it begins to increase the ohmic resistance and the autoinduction due to the skin effect and the displacement of current between adjacent coils so is not possible to measure the load current that goes through the coil and the magnetic field either. This fact restricts the workable range of frequency up to 1 kHz.

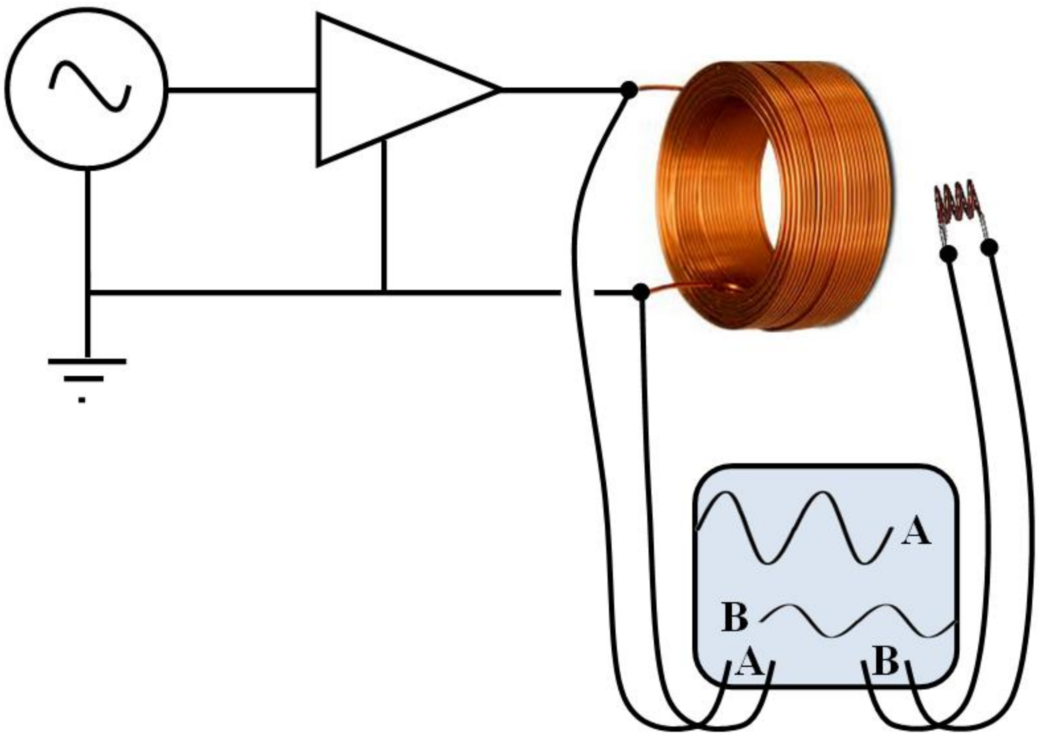

Figure 24. Circuit of the device

This circuit represents the purposed device. The signal at A is the output of the amplifier. The signal at B is the output of sensor coil. The large coil does not generate a voltage output. It produces only a magnetic field - its "output" is magnetic flux. Due to the magnetic induction produced by the power coil, a voltage is induced in the sensor coil. The phase of that induced voltage lags the original voltage and its amplitude is lower, though frequency is identical. Proximity to the large coil affects amplitude, but does not change phase or frequency. As farther as the sensor coil is located from the power coil, less amplitude will have the signal of the sensor coil (B) as is shown in the following examples.

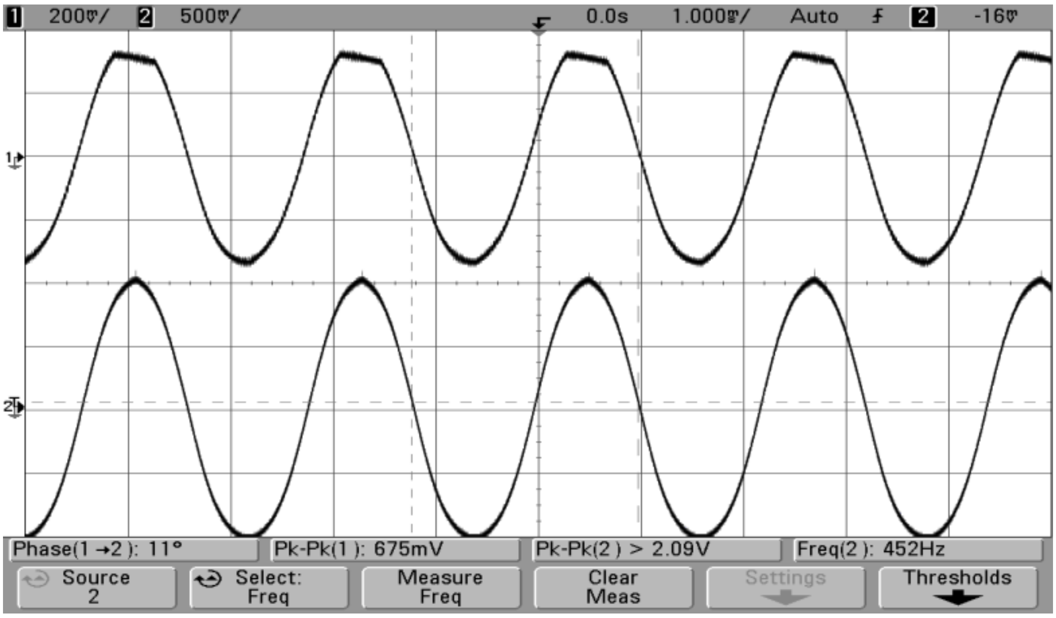

Figure 25. Sine waves at high frequencies

As shown in Figure 25, there is a distortion in the voltage signal of coil B (the induced signal) due to the bad performance of the system at high frequencies.

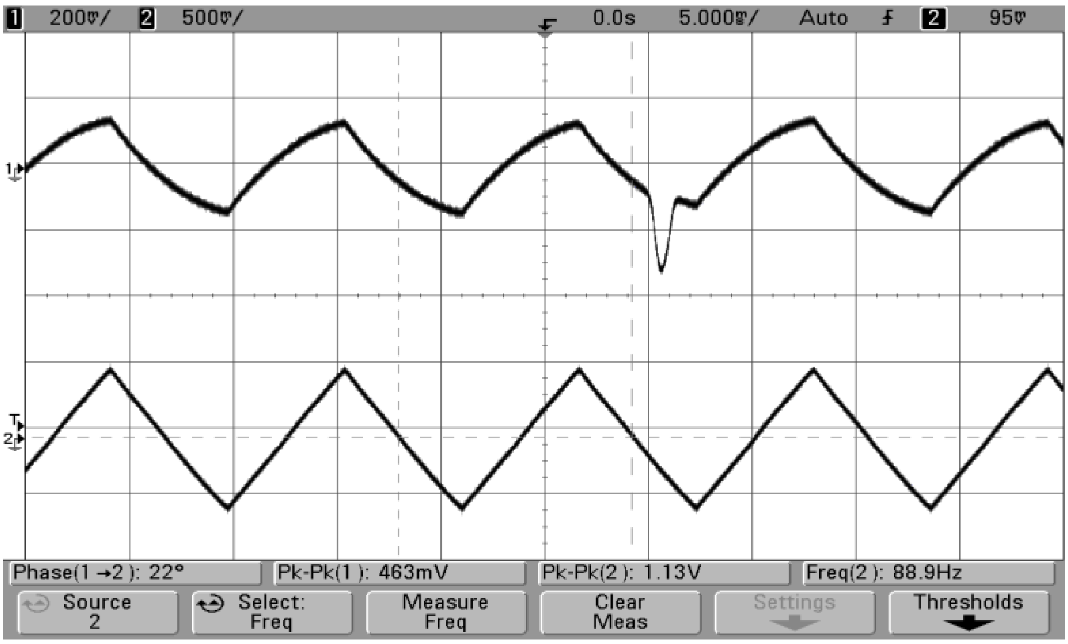

Figure 26. Triangle waves at 100 Hz

As shown, there is a small lag between signals 1 and 2 due to the distortion at high frequencies. Signal 1 is the signal above that represents the voltage induced in the sensor coil, and signal 2 is the input of the power coil. It clearly shows a change of amplitude between the signals. The output signal (sensor coil B) has less amplitude than the input signal (power coil A). Amplitude varies depending upon coupling between the two coils, number of turns, etc. Phase, however, is slightly delayed due to the distortion at high frequencies.

Table 9: Testing Plan

Requirement	Testing
Selectable Waveforms of sine, square, triangle and sawtooth waveforms	Use oscilloscope to display if signal generator is outputting sine, square, or triangle waveforms
Frequency range of 10 Hz to 1 kHz	Use oscilloscope to measure the frequency of the waveforms
Amplitude range of -5 to 5 V	Use oscilloscope to check the amplitude of the waveform
30 Watt Amplifier	Attach equivalent impedance of the coil to amplifier, and measure voltage across to calculate power
Power coil with diameter of 4 cm and 15 cm	Use caliper to measure diameter of coils
Digital Voltage Display with range of 0 to 300 AC V	Attach function generator, and vary frequencies and amplitudes. Replace built digital voltage display with actual DVM to test accuracy, and compare numbers between out built digital voltage display and actual DVM
Magnetic field below 1 T	Magnetic field from 1-15 mT
Detector Coil to measure magnetic flux	Use gauss meter to test accuracy of the detector coil
DC voltage source of 30 V	Use digital volt meter to measure DC voltage
Weight less than 15 lbs	Use scale

5.5 Stage 5 – Documentation

Once the prototype is tested, a user manual for the completed device is created. The user manual includes a list of each part and subsystem functions. All the useful documentation and specifications of the subsystems can be founded in Appendices C and D.

5.6 Schedule

The Gantt chart shows the timeline of the PEMF project in an organized manner. The "Preliminary Design/ Acquire Components" stage was completed before intersession break, and a layout was made and also design plans for the prototype PEMF device by December 10, 2013. In addition, the coils were built and a working magnetic field sensor was able to display for the Engineering Expo in December.

Furthermore, a working prototype was planned to be finished by January 27, 2014. This required each subsystem to be constructed and tested. The "Testing and Troubleshooting" stage required more than two weeks to test and adjust the prototype. Starting April 15, 2014 and ending May 9, 2014, "Integration of Final Design" is a fully constructed and working PEMF device.

Figure 27 below is an organization chart that needs to be fulfilled in order to progress with efficiency to accomplish the client’s needs by all deadlines:

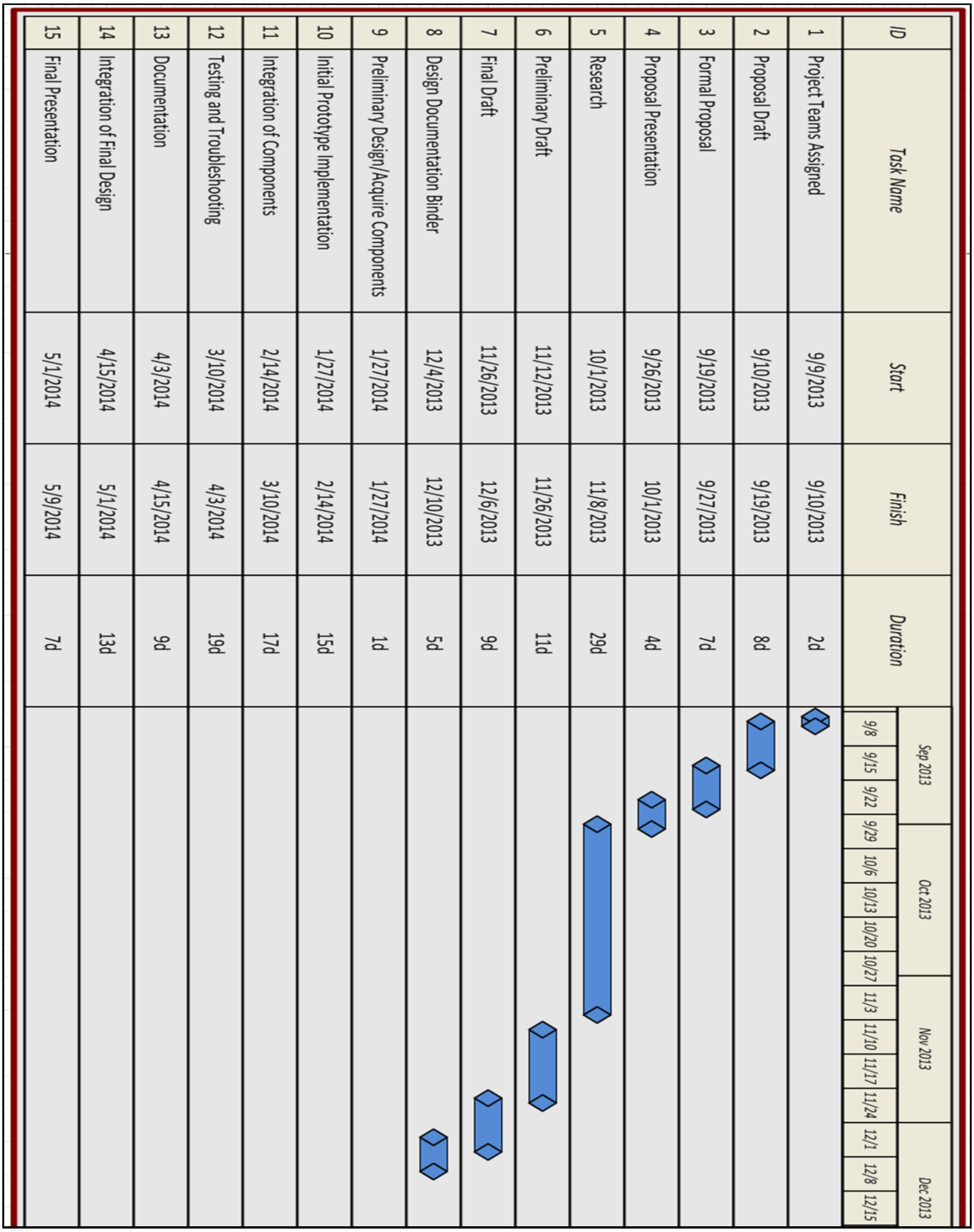

Figure 27: Gantt Chart

5.7 Budget

Careful consideration was taken when planning the budget. It has to be taken into account the essential components required for the PEMF device to operate with efficiency as well as accuracy. The device components include a waveform generator, amplifier, two coils and a digital display. The budget incorporates a margin of $100 in case any additional parts are required**.** Table 8 below outlines the estimated budget.

Table 10: Estimated Budget

Part/Material	Supplier	Cost ($)	Quantity	Subtotal ($)
Waveform Generator	Amazon.com	17.00	1	17.00
Standard Insulated Copper wire	TEMCO	236.81	1	236.81
Seven Segment Display	Maxim Integrated Products	3.79	1	3.79
IC L7106 Circuit for digital display	Maxim Integrated Products	5.90	1	5.90
LM 386 OpAmp	Parts Express	1.58	1	1.58
Arduino Amplifier	Besram-Tech	29.85	1	29.85
PCB	Coughlin Companies INC	5.95	2	11.90
Casing(sheet metal)	Zorotools.com	8.99	1	8.99
Gaussmeter M-test LL	Maurermagnetic AG	210	1	210
Misc.		100.00	1	100.00
			Total:	633.92

6. References

[1] W. Pawluk. (2013, September 12) *Pain Management with Pulsed Electromagnetic Field (PEMF) Treatment* [Online]. Available: http://www.healthy.net

[2] L. Taylor. (2013, September 12) *Pulsed Electromagnetic Field; a research bibliography* [Online]. Available: http://www.earthpulse.net

[3] B. Philipson. (2013, September 12) *PEMF Technology, what is it actually?* [Online]. Available: http://www.pemft.com

[4] P. G. Chao, "Chondrocyte Translocation Response to Direct Current Electric Fields," *Journal of Biomechanical Engineering*, vol. 122, pp. 261-67, 2000.

[5] D. H. Trock, "The Effect of PEMF in the Treatment of OA of the Knee and Cervical Spine. Report of Randomized, Double Blind, Placebo Controlled Trials," *Journal of Rheumatology*, vol. 21, pp. 1903-11, 1994.

[6] Computer Geek. (2013, September 16) *Arduino EMF (Electromagnetic Field) Detector* [Online].
Available: http://www.instructables.com

[7] ELECHOUSE. (2013, September 16) *Electromagnetic Wave Detection Sensor* [Online].
Available: http://www.elechouse.com

7. Improvements and recommendations

In order to save some money and time for future applications of this device, some improvements and recommendations are listed below, based on the knowledge gained throughout the course of this project:

- Research on digital display subsystems in order to improve the programming of the PIC microcontroller or use of an oscilloscope to save costs and complexity of the project.
- PCB board bigger to avoid overlapping wires in the circuit implementation.
- Use of Waveform Generator App to save costs instead of buying the Galak Waveform Generator.
- Create a database of the displayed values to show all the changes of amplitude, frequency, and types of waveforms.
- Increasing the portability of the system.

8. Appendices

Appendix A: Lucía Romero Tejera's Resume

Lucía ROMERO TEJERA

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Born: October 17th, 1991

EDUCATION

2013-2014 **University of San Diego** — **San Diego, USA**

Industrial Engineering

- Major in Electrical Engineering
- Course in Operations and Supply Chain Management

2009-2013 **Escuela Técnica Superior de Ingeniería (ICAI)** at Universidad Pontificia de Comillas — **Madrid, Spain**

- Major in Electrical Engineering

WORK EXPERIENCE

2013 (Jul-Aug) **Fullgas S.A.**, Project Management and Commercial Department — **Madrid, Spain**

- Calculation and design features of electric motors, gas facilities, and security systems in the oil industry
- Optimization of oil station supply facilities and security systems

2012 (Jul-Aug) **NGO Jóvenes y Desarrollo**, Volunteering — **Cochabamba, Bolivia**

Guardianship tasks in a village of the Andean area of about 40 children inside and outside the educational framework

2011 (Jul-Aug) **Etmar S.A.**, Commercial Department — **Madrid, Spain**

Checking certifications and telephone services to customers and suppliers in real estate

2009 (July) **Vinuesa Camp**, Nuestra Señora del Recuerdo School — **Soria, Spain**

Monitor selflessly taking responsibility of 34 children over 350 during 25 days

LANGUAGES

Spanish	**Native**
English	**Fluent**
French	**Intermediate Level** (B1) Diplôme d'Etudes en Langue Française (DELF)

COMPUTER SKILLS

Excellent command of Microsoft Office (Word, Excel, Powerpoint, Visio) and Scientific & Engineering Software (Matlab, Derive, Autocad, RStudio, Programming in C)

INTERESTS AND ACTIVITIES

Sports

- Basketball: autonomic competition during 10 seasons, trainer of lower categories unselfishly
- Horse riding: Participant in autonomic competitions
- Swimming: Participant in autonomic competitions

Social Job	School reinforcement to children with school problems due to difficult home environments in los Jesuitas de Maldonado
Others	Monitor course (300h), travel and read

Appendix B. Professional Codes and Standards

- **HC Pub. 091029** Limits of Human Exposure to Radio Frequency Electromagnetic Energy in the Frequency Range from 3 kHz to 300 GHz – Safety Code 6 (2009).
  - ⇨ Standard from Health Canada which is the federal department responsible for helping the people of Canada maintain and improve their health. This safety code published in 2009 specifies the requirements for the safe use of, or exposure to, radiation emitting devices. The safety limits in this code are based on an ongoing review of published scientific studies on the health impacts of radiofrequency electromagnetic energy.

- **OET Bulletin No. 56** Questions and Answers about Biological Effects Potential Hazards of Radio Frequency Electromagnetic Fields (Fourth Edition, August 1999).
  - ⇨ This is an informative bulletin written as a result of increasing interest and concern of the public with respect to this issue. The expanding use of radio frequency technology has resulted in speculation concerning the alleged "electromagnetic pollution" of the environment and the potential dangers of exposure to non-ionizing radiation. This publication is designed to provide factual information to the public by answering some of the most commonly asked questions.

- **ISO 13485** European rule which certificates that PEMF devices are approved by health authorities for human applications according to the EU Medical Device Directive 93/42 EEC and are manufactured according Good Manufacturing Practice.

Appendix C. Other Devices and PEMF Subsystems Specifications

Appendix C1: Various PEMF Devices

Next, there is some data sheet of PEMF units that can be useful to be familiar with these devices.

1) PMT-100 Office/Home model

Height: 15.9"
Width: 9.5"
Depth: 4.7"
weight: 16.5 lbs
VOLTAGES:
120 vac 2amp • 240 vac 1amp
Gauss: 19,200G per pulse
TESLA: 1.92T per pulse
Frequency: 1Hz to 50Hz

2) PMT-100P Portable

Height: 21.7"
Width: 14.1"
Depth: 8.9"
Weight: 23 lbs
VOLTAGES:
120 vac 2amp • 240 vac 1amp
Gauss: 19,200G per pulse

TESLA: 1.92T per pulse

Frequency: 1Hz to 50Hz

3) PMT-100AT

Height: 40"

Width: 20"

Depth: 9"

Weight: 25 lbs

VOLTAGES:

120 vac 2amp • 240 vac 1amp

Gauss: 19,200G per pulse

TESLA: 1.92T per pulse

Frequency: 1Hz to 50Hz

Appendix C2: Waveform Generator Specifications

Features:

User selectable frequency from 2 Hz to 1 MHz* with 4 frequency ranges and coarse and fine adjustment controls.

Square wave, sine wave and triangle wave selectable via 3 position slide switch

- Operates from a single +12V supply thanks to onboard ±5V regulated supplies.
- Adjustable amplitude from ±0.5V to ±3V with separate logic output** for external triggering or clocking.

Wide input supply voltage from 12 VDC to 24 VDC and a maximum supply current of only 25mA

Specifications:

- Supply Voltage: 12VDC to 24VDC @ 25mA
- Frequency Range: 2 Hz to 1 MHz (User selectable with slide switch and 2 potentiometers)
- Waveform Functions: Sine, Square and Triangle (User selectable with slide switch)
- Output Amplitude: ±0.5V (1V p-p) to ±3V (6V p-p) @ 300kHz; ±0.25V (0.5V p-p) to ±1.5V (3V p-p) @ 1Mhz (1kΩ load)
- Output Current: 20mA @ 6 VDC peak-peak (100 mW max @ 25 degrees C)
- Waveform Distortion: <2% error @ 250 kHz; >10% @ 500 kHz or greater
- Board Dimensions: 3.95" x 1.57" (10.0 cm x 4.0 cm)
- Board Material: 0.062" (1.6 mm) FR-4, with green solder mask and top layer silk screen
- Finished Weight: 0.9 ounces (26 grams)

Appendix C3: PIC16F688 Specifications PIC16F688

14.0 ELECTRICAL SPECIFICATIONS

Absolute Maximum Ratings (†)

Ambient temperature under bias..-40° to +125°C

Storage temperature …….. -65°C to +150°C

Voltage on VDD with respect to VSS .... -0.3V to +6.5V

Voltage on MCLR with respect to Vss... -0.3V to +13.5V

Voltage on all other pins with respect to VSS........................ -0.3V to (VDD + 0.3V)

Total power dissipation (1)... 800 mW

Maximum current out of VSS pin... 300 mA

Maximum current into VDD pin.. 250 mA

Input clamp current, IIK (VI < 0 or VI > VDD)... 20 mA

Output clamp current, IOK (Vo < 0 or Vo >VDD)...20 mA

Maximum output current sunk by any I/O pin... 25 mA

Maximum output current sourced by any I/O pin …....................................... 25 mA

Maximum current sunk by PORTA and PORTC (combined)....................... 200 mA

Maximum current sourced PORTA and PORTC (combined)....................... 200 mA

Note 1: Power dissipation is calculated as follows: PDIS = VDD x {IDD - Σ IOH} + Σ {(VDD - VOH) x IOH} + Σ(VOL x IOL).

† NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at those or any other conditions above those indicated in

the operation listings of this specification is not implied. Exposure to maximum rating conditions for extended periods may affect device reliability.

Note: Voltage spikes below VSS at the MCLR pin, inducing currents greater than 80 mA, may cause latch-up.

Thus, a series resistor of 50-100 Ω should be used when applying a “low” level to the MCLR pin, rather than

Appendix C4: LCD Display Specifications

FEATURES
***** HIGH CONTRAST LCD SUPERTWIST DISPLAY
***** EA DIP162-DNLED: YELLOW/GREEN WITH LED BACKLIGHT
***** EA DIP162-DN3LW AND DIP162J-DN3LW WITH WHITE LED B/L., LOW POWER
***** INCL. HD 44780 OR COMPATIBLE CONTROLLER
***** INTERFACE FOR 4- AND 8-BIT DATA BUS
***** POWER SUPPLY +5V OR ±2.7V OR ±3.3V
***** OPERATING TEMPERATURE 0~+50°C (-DN3LW, -DHNLED: -20~+70°C)
***** LED BACKLIGHT Y/G max. 150mA@+25°C
***** LED BACKLIGHT WHITE max. 45mA@+25°C
***** SOME MORE MODULES WITH SAME MECHANIC AND SAME PINOUT:
-DOTMATRIX 1x8, 4x20
-GRAPHIC 122x32
***** NO SCREWS REQUIRED: SOLDER ON IN PCB ONLY
***** DETACHABLE VIA 9-PIN SOCKET EA B200-9 (2 PCS. REQUIRED)

Pinout

Pin Symbol Level Function Pin Symbol Level Function

1 VSS L Power Supply 0V (GND) 10 D3 H / L Display Data

2 VDD H Power Supply +5V 11 D4 (D0) H / L Display Data

3 VEE - Contrast adjust. (About 0V) 12 D5 (D1) H / L Display Data

4 RS H / L H=Command, L=Data 13 D6 (D2) H / L Display Data

5 R/W H / L H=Read, L=Write 14 D7 (D3) H / L Display Data, MSB

6 E H Enable (falling edge) 15 - - NC (see EA DIP122-5N)

7 D0 H / L Display Data, LSB 16 - - NC (see EA DIP122-5N)

8 D1 H / L Display Data 17 A - LED B/L+ Resistor required

9 D2 H / L Display Data 18 C - LED B/L -

Appendix C5: Gaussmeter M-Test LL Specifications

The datasheet of the gaussmeter used can be found through this link:

http://www.maurermagnetic.ch/PDF/Mess_Brochure_Gaussmeter_M-Test_LL.pdf

Appendix D. Code and Calculations

Appendix D1: Calculations for Digital Display

The accuracy depends upon the accuracy of the resistors at the input end and the stability of reference voltage:
$Vdd\ = 5Volts$

Given Vdd to be 5 Volts, R1 is measured to be 1267Ω and R2 is measured to be 3890Ω. So this gives the following:

For Digital Count: 1023

$$Resolution\ = \frac{5.02\ -\ 0}{1023 - 0}$$

$$Resolution\ =\ 0.004907\frac{V}{Count}$$

$$Va = 1267\Omega * \left(\frac{Vin}{1267\Omega + 3890\Omega}\right)$$

This simplifies to:

$$Va =\ 0.2457 * \mathrm{Vin}$$

$$I/P\ voltage\ =\ 4.07 * Va\ =\ 4.07 *\ Digital\ Count\ *\ 0.004907$$
$$I/P\ voltage\ \ =\ 0.01997\ *\ Digital\ Count$$
$$I/P\ voltage\ \ =\ 0.02 * Digital\ Count\ (Approx.)$$

Example, suppose Vin = 7.6V. Then,

$$Va\ =\ 0.2457 * Vin\ =\ 1.87V$$

=> $Digital\ Count\ = \frac{1.87}{0.004907} =\ 381$

=> $Calculated\ I/P\ Voltage\ =\ 2 * 381\ =\ 0762\ =\ 07.6V$

Appendix D2: Calculations of Coils

Coil Calculations:

Coil 1:

- Diameter of coil A: 1.5 in = 3.81 cm
- Perimeter of one turn: 3.14 * 1.5 = 4.6 inches = 11.68 cm
- Length of the wire: $\frac{2000 \text{ turns} * 4.6 \text{ inches/turn}}{12 \text{ inches/feet}}$ = 766.66 feet ≈ 791 feet = 241m
- Length of the coil: 7 ½ inches = 19.1 cm

Coil 2:

- Diameter of coil B: 5.7 in = 14.5 cm
- External diameter of coil B: 6 in = 15.2 cm
- Perimeter of one turn: 3.14 * 5.7 = 17.9 inches = 45.46 cm
- Length of the wire: $\frac{500 \text{ turns} * 17.9 \text{ inches/turn}}{12 \text{ inches/feet}}$ = 745.83 feet ≈ 791 feet = 241m
- Length of the coil: 3 3/8 inches = 8.6 cm

Appendix D3: Program 7segment voltmeter

```
#include <xc.h>

//#include <adc.h>

//#include <cmsis.h>

//#include <pinmap.h>

//#include <error.h>


unsigned int adc_rd0,tlong;

unsigned short shifter, porta_index;

unsigned int digit, number;

unsigned short porta_array[4];

void interruptaaa(void);

void display(void);


void main(void)

{

  // port initialization...

  TRISA = 0x00; // Set PORTB direction to be output

  PORTA = 0xff;    // Turn OFF LEDs on PORTB

  TRISC= 0x00; // Set PORTB direction to be output

  PORTC = 0x00;
```

```
 TRISA = 0xFF; // all input


digit = 0;

porta_index = 0;

shifter = 1;

number = 0;                    //initial value;



ADCON1 = 0x00;

// tiemr0 settings...

OPTION_REG = 0x80;             // Set timer TMR0;

TMR0 = 0;

INTCON = 0xA0;                 // Disable interrupt PEIE,INTE,RBIE,T0IE




while(1)

 {

   // Read Battery  voltage

   ADCON0 = 0b00000001;

   adc_rd0 = ADC_read0(0);     // A/D conversion. Pin RA2 is an input.
```

```
    tlong = (float)adc_rd0 *1.96078431372549; // Convert the result in millivolts
    number = tlong;
    display();
  }//Endless loop;
}//End;
unsigned short mask(int num){
 switch (num)
 {
   case 0 : return 0xC0;
   case 1 : return 0xF9;
   case 2 : return 0xA4;
   case 3 : return 0xB0;
   case 4 : return 0x99;
   case 5 : return 0x92;
   case 6 : return 0x82;
   case 7 : return 0xD8;
   case 8 : return 0x80;
   case 9 : return 0x90;
   case 10: return 0x40;
   case 11: return 0x79;
   case 12: return 0x24;
```

```
   case 13: return 0x30;
   case 14: return 0x19;
   case 15: return 0x12;
   case 16: return 0x02;
   case 17: return 0x78;
   case 18: return 0x00;
   case 19: return 0x10;
 }
}

void interruptaaa(void){
  PORTC = 0;
  PORTA = porta_array[porta_index];
  PORTC = shifter;

  shifter <<= 1;
  if(shifter > 8u)
  shifter = 1;

  porta_index ++ ;
  if (porta_index > 3u)
```

```
 porta_index = 0;
 TMR0 = 0;
 INTCON = 0x20;
}
void display()
{
  digit = number % 10u;
  porta_array[0] = mask(digit);
  digit = (number / 10u) % 10u;
  porta_array[1] = mask(digit);
  digit = (number / 100u) % 10u+10;
  porta_array[2] = mask(digit);
  digit = number / 1000u;
  porta_array[3] = mask(digit);
}
```