Original Research Article

DESIGN AND CONSTRUCTION OF ELECTRONIC MUSCLE STIMULATOR

Abstract

The project is titled Design and Construction of Electronic Muscle Stimulator (EMS) with embedded time Display unit and Dual Source of Powering. The EMS is a type of electrotherapy device that functions by stimulating muscle contraction using electrical impulses to strengthen weak muscles, reduce swelling, aid in blood circulations that helps to heal wounds. These impulses are generated by the device and deliver through electrode pads over the area that requires stimulation. The impulses from EMS mimic the action potential (the stimulus required to contract the muscle) that naturally comes from central nervous system (CNS). Proteus, software simulation Library was used to simulate the components and to understand the behaviour of the output stage. After that, hardware components were assembled together that gave rise to this EMS apparatus. Designing of the device was completed with different modes tagged Press, Thump, Rub, and vibrate with frequencies 40Hz, 20Hz, 10Hz, and 3Hz respectively. The project was completed and human experiment was carried and result showed that decrease in impedances brings increase in current intensity.

Keywords: electrical impulses, muscle contractions, impedances

1. Introduction

Electrical stimulation started from ancient Egypt (around 2500 BC) which was involved using electric shocks produced by fish to relieve pains [1]. Electronic Muscle Stimulator (EMS) is an electrotherapy device which can be used to generate electrical impulses and send to human body through electrode pads that stick on the skin to stimulate skeletal muscle contraction. The electrical impulses mimic what occurs when someone contracts and releases muscle naturally. Physical therapists and doctors use electrical muscle stimulation to strengthen weak muscles, improve blood circulation in the body and heal injured muscles. The physical inactivity and aging cause losses of muscular mass (sarcopenia). World Health Organization and other institutions, as well as various publications support the benefits generated by physical activity to counteract sarcopenia. This fact led to generate new technologies for muscular strengthening which one of them is electronic muscle stimulator (EMS). EMS consists of the involuntary muscle contraction through the direct application of low intensity electric current that is enough to contract the muscle without causing harm. In the year 1976, Dr. Yakov Kotz , a Soviet Union researcher, developed the first localized external muscle stimulation. He trained Russian athletes for the Montreal Olympic Games. Dr. Kotz claimed that within 20 sessions, athletes increased strength by 40%. Initially his idea was to treat injured muscles, but he saw how efficient it was in producing strength as well [2]. To have in-depth knowledge on how human body functions and how biomedical devices like EMS can be designed for therapeutic purposes in our country Nigeria is a challenge and concern. This is because depending on imported hospital equipment's for our country discourages our indigenous engineers from going into designing and inventions of biomedical equipment's like other industrialized nations. To have knowledge to maintain even the imported biomedical equipment's is big challenge to our health section. This challenge is the reason our government do spend heavy amount of money in importing engineers to service our hospital equipment's. To maintain physical fitness as one becomes advanced in age or as people go about their daily business, is a big challenge in the whole world and particularly in our country Nigeria. Also, poor economy in the country has made it that only few rich and educated ones know about gymnastic center where people can go for sports activities or exercise for their physical fitness.Few families can afford having gymnastic apparatus like Electrical Muscle Stimulator (EMS) for family use due to high cost of the imported ones.

11. Literature

With the knowledge of biology and medical sciences combine with engineering principle and design concept, appropriate electrical and electronic components and biomaterials can be assembled to build up an EMS device. The parameters that the device supposed to operate with should be body friendly parameters. Parameters such as voltage, frequency, pulse-width, current and so on. [3] as a study assistance consultant at the American Council on Exercise said to keep muscle safe and healthy, we need to have a good understanding structural components and how they work together as this knowledge provides the foundation for effective exercise instruction. [4] designed an electronic muscular stimulator which comprises two units as muscular stimulator and Timer. In the system, IC7555 was wired as astable multivibrator to generate about 80Hz pulses. The timer circuit used IC NE555 wired in monostable mode. According to the design, when you press switch S2, the monostable triggers an and its output goes high for 10 minutes, thereafter, its output goes low to give a beep sound from piezobuzzer and light up the red LED2 indicating that stimulation time is over. **[5]**, carried out a study on the area of utilizing the EMS, the frequency pulse width, ramp time, operation cycle and amplitude are among the vital parameters of EMS that will be reviewed in this research work. Frequency refers as the pulses produced per second during stimulation and in the units of Hertz. Most clinical regiments use frequency between 20 to 50Hz to obtain optimum results, although, it also differs accordingly to the intervention, intention, or objectives at that time. [6] wrote on the process of muscular contraction which occurs over a number of key steps including: Depolarization and calcium ion release. Actin and myosin cross-bridge formation. Sliding mechanism of actin and myosin filaments. [7], muscle fibers are composed of bundles of myofibrils and composed of contractile unit, the sarcomeres. These sarcomers are positioned adjacent to one another and that contains alternating thick and thin filaments arranged in a specific order. The filament are name myosin and actin Myosin anchored to the middle line in the in the sarcomeres called the M-Line. [8], explained how electrical stimulation involves sending electrical impulses through electrode pads on the skin to help repair tissues, strengthens muscles aid in the circulation of blood. This process is to mimic action potential occurs when one releases muscle naturally [9] emphasized on the importance of muscle contraction precisely to the middle-age older people who don't to engage in physical exercise to avoid the risk of sarcopenia. According to pressbooks.com 2020, the sequence of events that brings about contraction of muscle fibers begins as result of interactions between proteins known as myosin and actin. In [10], proposal short-term propulsion of EMS was introduced accompanied by a functional leg-cycling task to patient with stroke. They hypothesized that this intervention can reduce the spasticity of the affected leg muscle. [11], explained the importance of having knowledge spindle behaviors. In the article explain the length of spindle as 3-10μm and the annul spiral endings which is the primary which is the center of intra-fusal fibers which come from thickly myelinated (type 1a) nerves that response rapidly, transmitting information on velocity of change as well as length (dynamic responses) The velocity of impulses is 70-120m/s. [12], study of functional electrical stimulation (FES) is a technique that has been successfully employed in rehabilitation treatment to mitigate problems after spinal cord injury (SCI). One of the more relevant modules in a typical FES system is the power or output amplifier stage which is responsible for the application of voltage or current pulses of proper intensity to biological tissue, applied noninvasively via electrodes, placed on skin surface or inside the muscular tissue closer to the nervous fibers.[13],design of circuitry for a wearable current stimulator, it was explain in the review that the device needs to be sufficiently compact and lightweight so that it can be worn in every day circumstances. The system was designed to be able to operate continuously for at least 10 hours without the need for recharging or replacing batteries. However, study reviewed based on four planks; Fundamental concept, Theoretical framework, Theoretical study and summary of related literature. The study was based on biological and medical sciences combined with engineering principle and design concept. The study was based on understanding the reason muscle needs to be contracted, the need to understand to keep muscle safe and healthy and also to have good understanding of the body's most basic structural components and how they work together. Several studies were done on different electrical components and biomaterials that were assembled to build EMS for therapeutic use.In this Research work, there is need for wireless EMS systems and body weight and fat content measurement unit. There is need to upgrade EMS with embedded system that can help to obtain data real time from any part of the world as Medical Internet of Things

III Methodology

This is approach taken after running the feasibility study of the project The project was first analyzed on a paper with a block diagram. Proteus Lite, software simulator from Lab center Electronics Ltd, was used to simulate the behavior of the output stage. Active and semiconductor discrete components in the circuits were picked from the software library or modified from the suitable in the library. Passive components were created using parameters from component datasheets. This signal of the different output stages are viewed using the software digital oscilloscope. Also, the simulator was used to monitor the responses of the LED indicators, the alarm circuitry and the display. The transformer for generating the high voltage pulses for the electrodes and the transformer switching circuitry were not implemented in the simulator

Block diagram

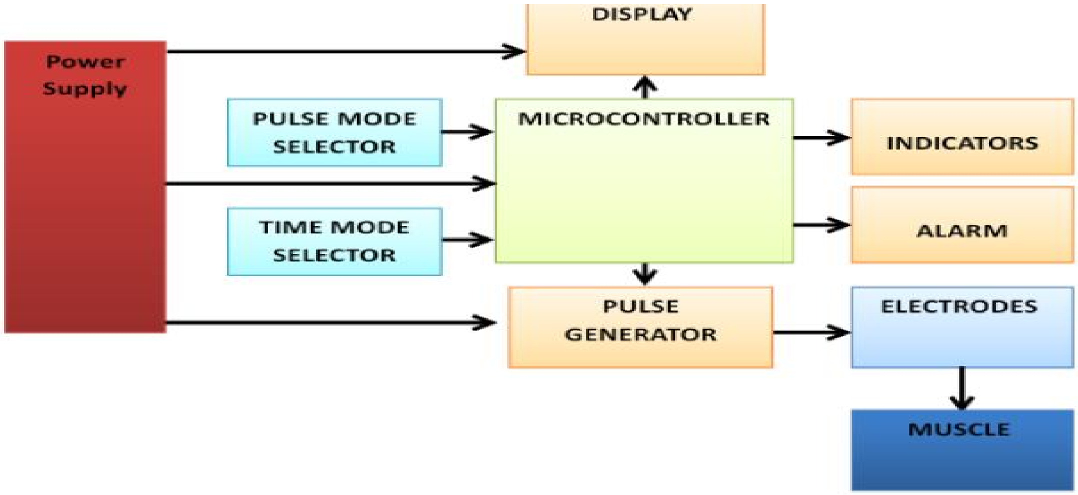


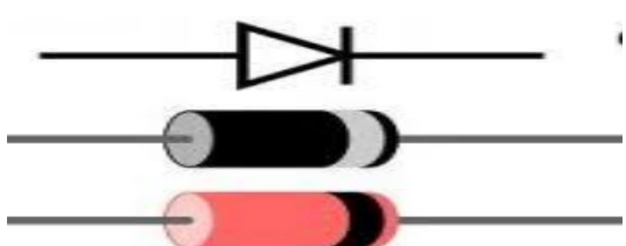
Figure 1 Block diagram of EMS

V Description of Hardware components

Hardware components for the system were selected after observing their behaviors on proteus simulator. The EMS was first created, designed and tested on breadboard and later transfer to Vero-board. All the components chosen for this project were briefly described separately to acquaint the reader with their principle of operation.

a. **Step-Up Transformer:** The final output comes from the step-up transformer. 3volt from transformer gave max output of 60volt which was fed into the electrodes.

b. Diodes: D3 diode bridges collector Q2 Transistor which enters directly to the transformer, R4 resistor controls the flow for current that flows through D2 (LED) that indicates the output is at work



Anode (+) Cathode(-)

Figure 2: diodes

c. **Capacitors:** The two capacitors C2 connected at both sides of voltage regulator 7085 U1 are to allow current and voltage of specific frequency pass through the circuit.

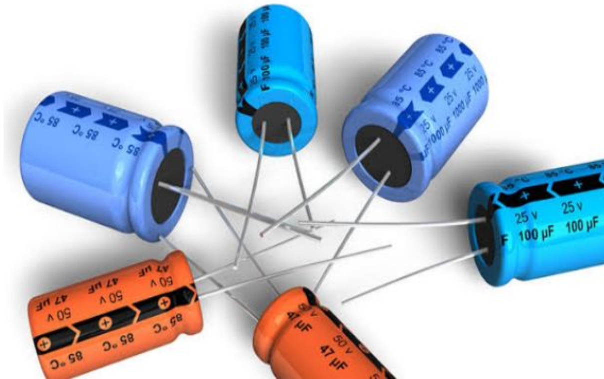


Figure 3 capacitor

d. Relay: The switching relay brings about the tussling between the two sources of power supply (public power supply AC and 12volts 7Amp battery DC). S1 switch ass current from the relay to the circuit when it is closed. R1 resistor controls the flow of current that moves into Light Emitting Diode (LED) which indicates when circuit is ON

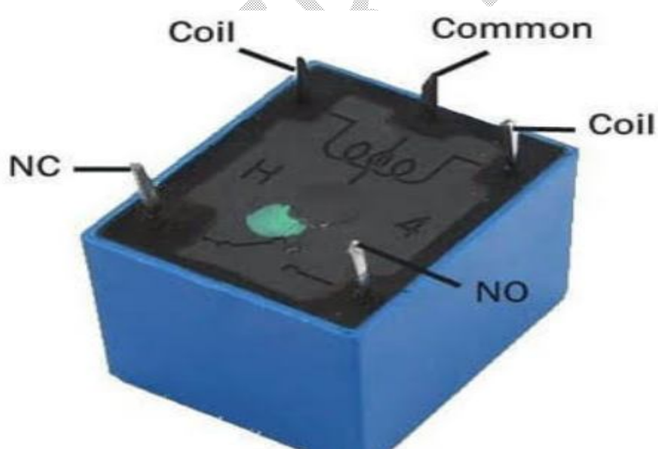


Figure 4 Relay

e. Transistor and Piezouzzer: The C1815 NPN transistor is a high voltage current NPN transistor. A transistor can normally be used as a switch or amplifier, but this transistor is commonly used only for audio frequency amplifier application since it has very high DC current giant values of 120-700D dB (logarithm decibel). Piezobuzzer is a type of electronic device that is used to produce a tone, alarm, or sound. Transistor TR triggers on the piezobuzzer to beep sound as an alarm that the time set for machine operation has ended.

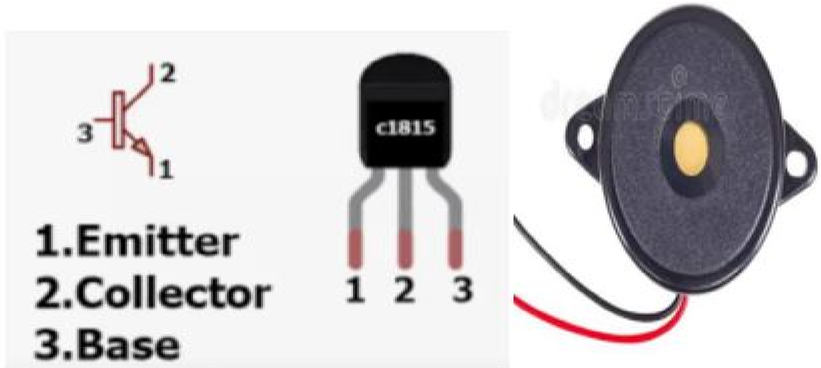


Figure 5 Transistor and Piezouzzer

f. Variable Resistor RV1 (5Kohm): Variable resistor is a component that used in the system to tune the pulse strength of the EMS from minimum pulse strength to maximum pulse strength. RV5k was connected to relay 12v while the second terminal was connected to transistor base

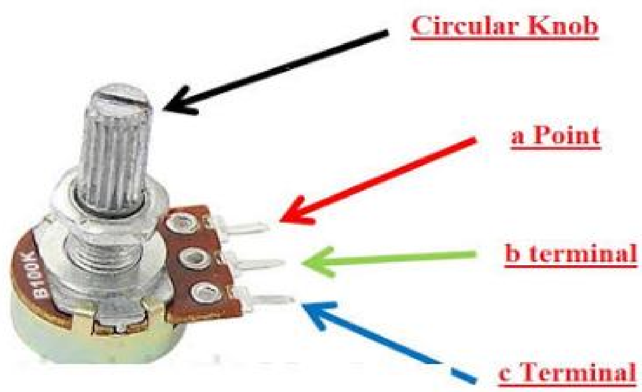


Figure 6 Variable Resistor

g. **Voltage Regulator U 7805:** The voltage regulator sets the voltage at 5volts which is fed into the microcontroller. The output signals come from microcontroller in form of modulated signals with different modes. The final output comes from the output of the step-up transformer via Q1 (pulse) and Q4 (pulse PWR).

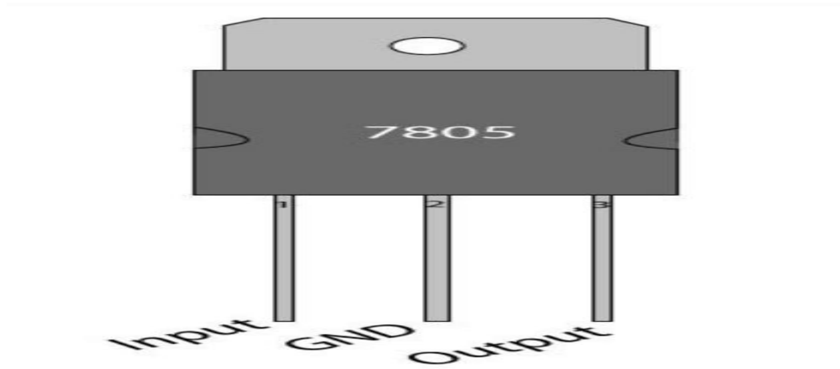


Figure 7 Voltage Regulator U 7805

h. **Electrode Pads Plugged Into Two Interface Sockets:** These electrode pads are the interface between the EMS device and subject skin for therapeutic transduction.**Electrode Gel (hydro gel):**This is a 99.06% water based and highly conductive solution that facilitates better skin-to-device contact. This adhesive gel is to adhere the electrodes to the skin as well as provide transcutaneous electrolyte between the skin and the device. The gel reduces the impedance at the point of contact with the skin to avoid attenuation of the signal.

a. **16 by4 Liquid Crystal Liquid (LCD):** This is a type of flat panel display which uses liquid crystals in its primary form of operation

VI Implementation and Results

The voltage regulator regulates and gives 5volts DC as input which the microcontroller works with as modulated signals that gives different modes as Press, Thump, Rub and Vibrate. In this project, PIC 18F2550 microcontroller is the heart of the system. It coordinates the functioning of the components 16 by 4 LCD, the alarm, the buttons, the LEDs indicators and the different pulses as mentioned above. It controls the alarm through the pin 22 of the microcontroller (RB1), which goes high to beep the alarm at the end of each stimulation cycle period. The microcontroller is programmed not see the 5volts but triggers input with the pull-up resistors R6, R7 and R8 as the system is programmed to work with low voltage. These three buttons are source of inputs to the PIC microcontroller which it uses to control the behavior of the output of the system. The four output pulses tagged Press, Thump, Rub, and Vibrate move with different frequencies as 40Hz, 20Hz, 10Hz and 3Hz respectively. This output comes as 3volts via the transformer that steps it up to 60volts and feed the electrode.

Hardware Designing

This stage of creating, designing and testing EMS circuit on breadboard (figure 8) below.

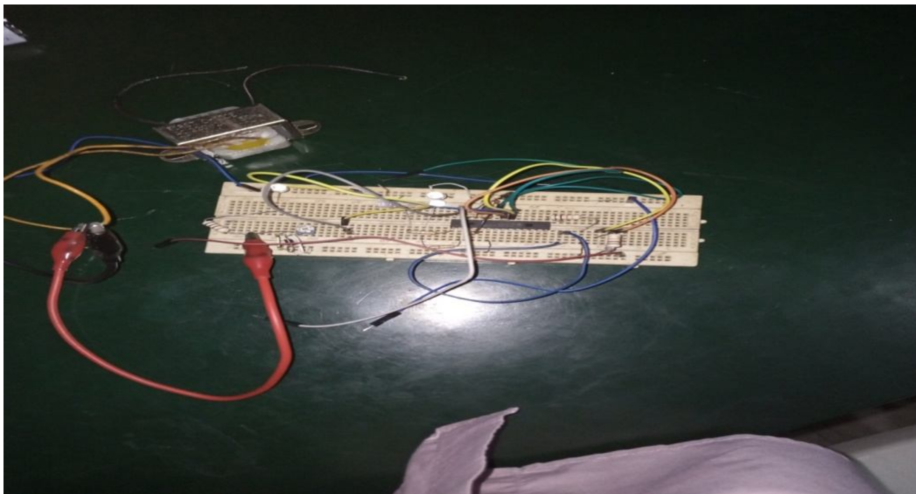


Figure 8 cerating, designing and testing EMS circuit on breadboard

The stage of transfering EMS circuit to veroboard

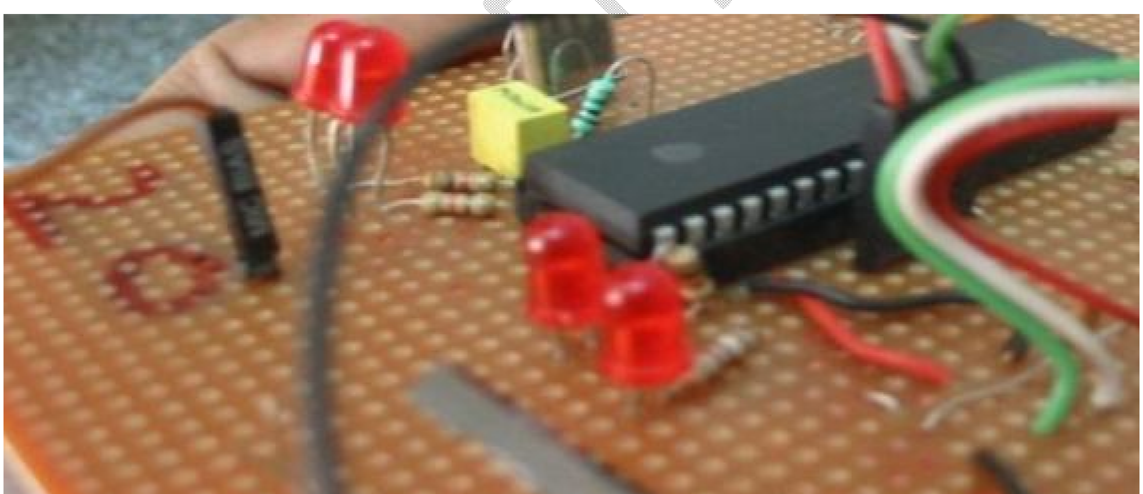


Figure9: EMS circuit transfering to veroboard

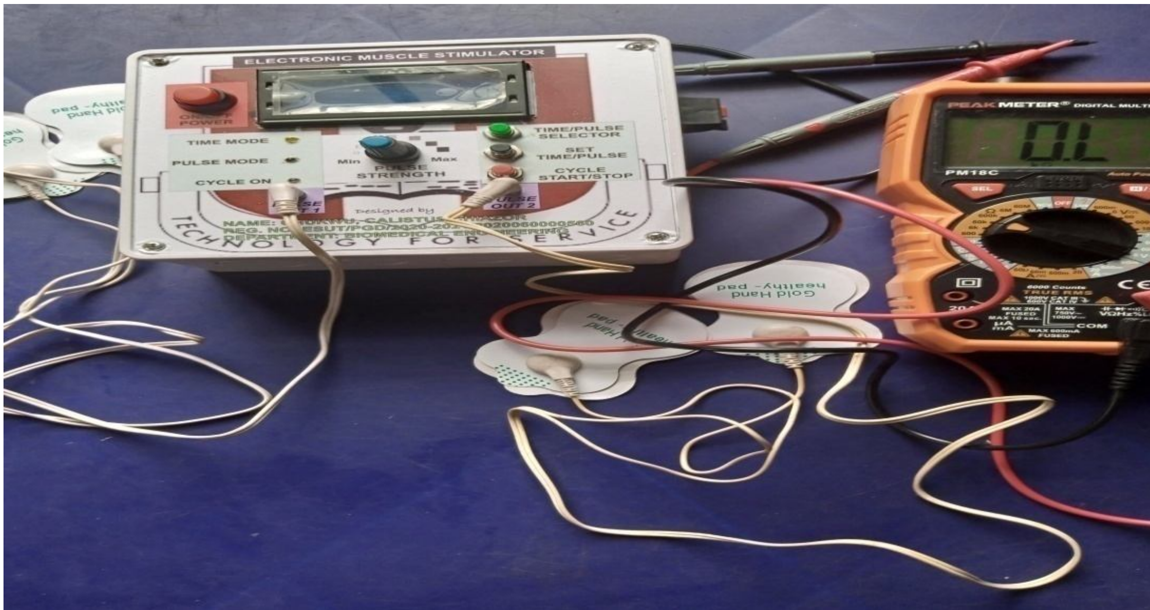


Figure 10: EMS System and Digital-multimeter

The purpose of this experiment was to compute the skin impedance of one subject as the stimulation intensity increased. To design well regulated stimulator drive stage, it is important to know the load impedance changes with respect to the intensity of the stimulus. Subject B participated in this experiment which involved higher intensity setting with the Electronic Muscle Stimulator (EMS). The EMS was used to stimulate and measured the output currents of to the subject.

The maximum impedance of the skin for each setting was determined by stimulating subject B. The relation between the increased in intensity and impedance values were determined.

VII Results and Evaluation

Skin Impedance vs. Intensity

The output voltage and current data collected from the varying intensity in experiment performed on subject.

Table 1: Impedances vs current level on subject B under settings 1 to 4 of the EMS

Setting	Ave. Current (mA)	Impedance (ohms)
1	20	7890
2	40	4205
3	60	2050
4	80	1550

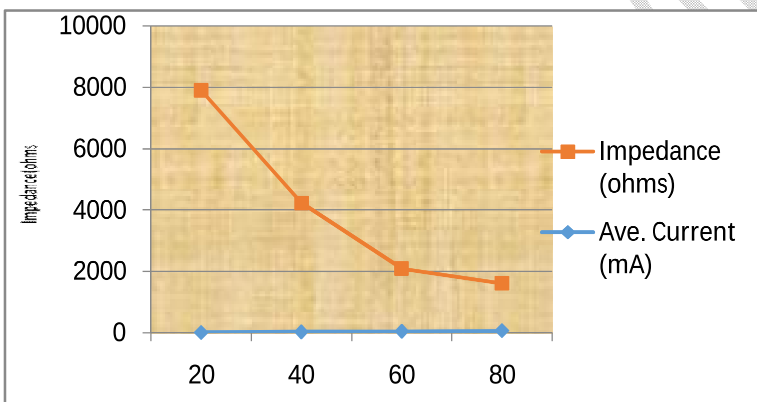


Figure11: Graph of impedance vs. current levels on subject B

Setting 1 resulted in impedance 7890 ohms. The impedance at setting 4 was 1550 ohms while the intensity was 80mA. Previously published work has shown that the impedance values of the skin decrease with increasing stimulus intensities.

Table 2: Minimum and maximum impedances over subjects

Muscle	Electrode Type	Minimum Impedance (ohms)	Maximum (ohms)
Bicep	Oval	2032	4811
Bicep	*Rectangular*	*1269*	*3082*
Quadriceps	Oval	2216	5966
Quadriceps	Rectangular	1565	3824
Tibialis Anterior (TA)	Oval	2450	5469

Tbials Anterior(TA)	Rectangular	1740	3602

Table 2: Minimum and maximum impedances over subject using PEA METER Digital millimeter by setting the meter on 60kilo ohms and using oval electrodes on Bicep, Quadriceps, and Tibialis anterior.The highest value in the table 2 was 5966Ω that occurred for the oval electrodes stimulating the quadriceps. The smallest value was 1269Ω for the rectangular electrodes on the bicep.

Results

The purpose of this experiment was to determine how the stimulations matched the hardware when applying pulses to four types of passive loads. Each of the intensity settings of the stimulator was tested. Different frequency and the four stimulation modes were tested with Digital Multimeter and found to be as follows: Press, Thump, Rub, and Vibrate are 40HZ, 20Hz, 10Hz, and 3Hz respectively. The minimum and maximum impedances for the subject were taken with digital millimeter and the results are shown on the table 2 above: The impedance of the subject decreases with increase in the intensity of the stimulation.

Conclusion and Research Gap

The research was based on electrophysiological and electrochemical circuit of human system and also the study of therapeutic interaction between the body and EMS. During the study, I found components that I assembled to have this apparatus. The design was completed and human experiment was carried with results computed.

Increasing the area of stimulation with large electrode pads was found to decrease the impedance as experience in the output of the stimulator drive circuitry.

The basic trend of decreasing resistance by increasing electrode pads area was observed.This project was designed to have 4 by 16 matrix Liquid Crystal Display (LCD) unit that displays how the time mode counts down and buzzer that beep at the end of every operational cycle. This feature will help healthcare providers to use the device on a patient while attending to other cases as the display on the screen can be seen from distance it can help the healthcare provider to monitor how the set time counts. This feature was not found in other people's work I saw during my research work.

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