Palestine Polytechnic University

College of Engineering and Technology

Electrical and Computer Engineering Department

Graduation Project

Design and Implementation of a Functional Electrical Stimulator

Project Team

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Project Supervisors

Dr. Ghandi Manasrah **Eng. Abdullah Irman**

Hebron – Palestine
June , 2009

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Graduation Project Report

Submitted to the Department of Electrical and Computer Engineering in the College of Engineering and Technology

Palestine Polytechnic University

Approved by ______________________________________

Chairperson of Supervisory Committee

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Date ______________________________________

جامعة بوليتكنك فلسطين

الخليل-فلسطين

كلية الهندسة و التكنولوجيا

دائرة الهندسة الكهربائية والحاسوب

اسم المشروع

Design and Implementation of a Functional Electrical Stimulator

أسماء الطلبة

محمد عمر أبوسنينة .... **نورشريف حمارشة**

بناءً على نظام كلية الهندسة والتكنولوجيا وإشراف ومتابعة المشرف المباشر على المشروع وموافقة أعضاء اللجنة الممتحنة تم تقديم هذا المشروع إلى دائرة الهندسة الكهربائية والحاسوب، وذلك للوفاء بمتطلبات درجة البكالوريوس في الهندسة تخصص هندسة الأجهزة الطبية.

توقيع المشرف

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توقيع اللجنة الممتحنة

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توقيع رئيس الدائرة

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ABSTRACT

In this project thanks to God, there had been accomplished a design and a study of an Electrical Stimulation Device, which is used to compensate for Nerves Signal when it suffers from a partial or complete paralysis, so as to get the electrical activity of muscles to prevent shrinking using special electrodes that is fastened on the patient skin.

The project gives the capability of adjustment of frequency, current amount, electrical voltage and the type of electrical stimulation in a way to fit the sensitivity, place and degree of paralysis that the patient suffers from, and it is usually used in the cases of Physiotherapy in clinics and hospitals.

This documentation includes the detailed design of the project and the stages which were followed in order to reach to the desired goals of the project, those are represented as designing and studying each partial stage of whole project's stages each one aside, then to collect or assemble these stages as a one integrated unit.

ملخص المشروع

في هذا المشروع تم بحمد ا دراسة وتصميم جهاز التحفيز الكهربائي ،الذي يستخدم للتعويض عن اشارة الأعصاب (السيال العصبي)، عندما يحدث لها شلل كلي اوجزئي ، لكي نحصل على النشاط الكهربائي للعضلات لمنع ضمورها باستخدام الكترودات خاصة تثبت على سطح جلد المريض.

المشروع يمكننا من ضبط التردد وكمية التيار والجهد الكهربائي ونوع التحفيز الكهربائي، بما يناسب حساسية و مكان ودرجة الشلل عند المريض، و يستخدم في العلاج الطبيعي في العيادات والمستشفيات.

يحتوي هذا التقرير على التصميم التفصيلي للمشروع والمراحل التي تم اتباعها من أجل الوصول إلى الأهداف المرجوة من هذا المشروع والتي تتمثل في تصميم ودراسة كل مرحلة جزئية من مراحل المشروع على حدة، ثم تجميع هذه المراحل كوحدة واحدة.

DEDICATION الإهداء

.... إلى روح الحبيب المصطفى ....

محمد صلى الله عليه وسلم

إلى نبع الحب والأمان ....أمي الحبيبة

إلى رمز العطاء و الحنان...أبي العزيز

إلى من هم أغلى من الماس ....أخوتي الأحبة

إلى عناوين الطموح والتفاني...أساتذتي الكرام

إلى من هم أكرم منا جميعا............... عناوين التضحية والفداء.................. شهداؤنا الأبرار

إلى كل من ساهم في إنجاز هذا المشروع

نهدي إليكم هذا العمل المتواضع

فريق العمل

ACKNOWLEDGMENT

Firstly, we thank our God for helping us in completing our project, and specially for helping us in constructing our different project circuits.

Here, we thank Dr. Ghandi Manasrah and Eng. Abdullah Irman for their supervision, taking care of our project, and their very useful advices in each step of our work; also we want to thank Eng. Fidaa’ Al-Jaafrah for helping us when we need her.

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Introduction

Chapter One
Introduction

1.1 Overview

Today, as the development of science & modern technology, which treat those who are unable to move parts of their body Breathing, blood circulation, bladder and bowel functions such as electric pulse stimulation; the physiotherapy instrument state to be one of the most important devices that give treatment for many chronic and cute diseases and pains of human muscles.

This project "Design and Implementation of a Functional Electrical Stimulation" is used in physiotherapy clinics or hospitals. This technique is used to treat different cases of muscular system and nerve system diseases, to prevent the muscles atrophy and to get strong muscles and good blood circulation in that treated part of the body.

Electrical stimulation is applied on patients who have a problem of loss in the action potential pulse that generated by the brain to muscles through the motor nerve, the problem may be in the brain, the motor nerve or the muscles, in the case that any part has been exposed to partial or overall paralysis.

The pulses that are to be generated from this device should have the same function and replaces the signal of that pulse comes from the brain naturally.

This project aims to design and implement a functional electrical stimulation with different modes; the device will be designed in such a way easily to have different modes and different frequencies of treatment.

1.2 Literature Review

No graduation projects could be used as previous studies for this project “Design & Implementing of a functional electrical stimulator”.

1.3 Scheduling Table

The time management will divide the system hierarchy according to the actions as follows:

T1*: Preparing to the project*: this stage of the project primarily aims at identifying the contents of it, discussing the initial information, and evaluating the project tasks and levels.

T2: *The project analysis*: the analysis process includes extensive study for all possible design options of the project.

T3: *The project requirements analysis*: tasks have to be implemented, equipments will be needed to be provided, and data should be processed.

T4: *Conceptual Design:* project objectives, design block diagram will be done with representing how the system works.

T5: *Studying project component and schematic analysis*: it is necessary to study the datasheet of the chipsets to ensure that it will meet the requirements of the project.

T6: *Writing the documentation*: the writing began from the first phase to the last one in parallel.

Table (1.1): The Task Duration

Task	Duration(weeks)	Dependencies
T1	3	-----
T2	3	-----
T3	4	T1,T2
T4	5	T3
T5	2	T3
T6	15	T4, T5

Task / Week (1st semester)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Preparing to the project	■	■	■													
Project analysis				■	■	■										
Project requirement analysis						■	■	■	■							
Conceptual design										■	■	■	■	■		
Studding project component and schematic analysis														■	■	
Writing documentation	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Task / Week (2nd semester)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
buying components	■	■	■	■	■	■										
Implementation					■	■	■	■	■							
testing					■	■	■	■	■	■						
Writing documentation					■	■	■	■	■	■	■	■	■	■		

Table (1.2): Time plan

1.4 Estimated Cost

This section lists the overall cost of the components that is considered in implementing the system.

According to the Hardware Components, there are many electrical Chips and equipments have to be provided as in table below:

Table (1.3): Hardware Costs

Component	Cost ($)
NE555	5.00
Step-up transformer	70.00
Step-down transformer	10.00
Resistors and Capacitors	25.00
Electronic board	5.00
Total Sum	115.00

1.5 Project Risk Management

The project may avoid some problems to work as a high efficiency, there are a lot of risks that occur and they should be declared when designing and manipulating the project. When the problem is founded, it should be solved without affecting the whole project.

1.5.1 Hardware Risks:

The most important hardware parts in the project are the NE555 timer and step up transformer. The predicted risks are:

- The NE555 timer does not generate pulses.

- One of the transistors (BJT and MOSFET) may be damaged.
- Applying voltage more than +16v may damage the NE555.

1.5.2 Group Risks:

- Illness of one or more of group members.
- Group meeting difficulties.

1.5.3 Project Risks:

- Inaccurate schedule.
- Insufficient budget.
- Delay of devices arrival.

1.5.4 Risk Avoidance Methodology:

- Demand device at earlier time.
- Start working on the implementation earlier.
- Use alternative devices with the same functionality and less cost.

1.6 Human Development Resources:

The team is composed entirely of two Biomedical Engineering undergraduate students who are interested in physiotherapy field.

The project Team: Mohammad Abu Snan and Noor Hamarsheh.

Supervisors: Dr. Ghandi Manasrah & Eng. Abdullah Irman.

1.7 Report Road-Map:

The documentation of this project is divided into six chapters. The following explains briefly the contents of each chapter:

Chapter 1: Introduction

This chapter presents overview, literature review, project scheduling, estimated costs, project risks and human development resources.

Chapter 2: Theoretical Background

This chapter discusses the Muscular - Nervous systems anatomy, theory of the project (main idea), hardware related to the project components.

Chapter 3: Project Conceptual Design

This chapter explains the project objectives, project design block diagram, how the system works and contraindications.

Chapter 4: Detailed Technical Project Design

This chapter includes project phases, subsystem detailed design.

Chapter 5: System Implementation and Test

This chapter includes testing of the design which has been done in this semester.

Chapter 6: Conclusion and Future Work

This chapter includes expected results of the intended design which has been achieved in this semester.

2

Theoretical Background

2.1 The Nervous System Physiological Anatomy

2.2 Muscle Physiological Structure

2.3 Project Theory

2.4 Project Components

Chapter Two
Theoretical Background

2.1 The Nervous System Physiological Anatomy:

In this section, the physiological structure of the nervous system will be discussed, mentioning the categories of neurons, nerve impulse propagation, the resting membrane potential and the action potential of nerves will be explained.

2.1.1 The Nervous System Structure:

The nervous system is a network of specialized cells that communicate information about human's surroundings and themselves. It processes this information and causes reactions in other parts of the body.

The nervous system is divided broadly into two categories; the Peripheral Nervous System (PNS) and the Central Nervous System (CNS). Neurons generate and conduct impulses between the two systems.

PNS is composed of sensory neurons and the neurons that connect them to CNS which composed from the spinal cord and brain. In response to stimuli, sensory neurons generate and propagate signals to the CNS which then processes and conducts signals back to the muscles and glands through the motor neurons as shown in Fig (2.1).

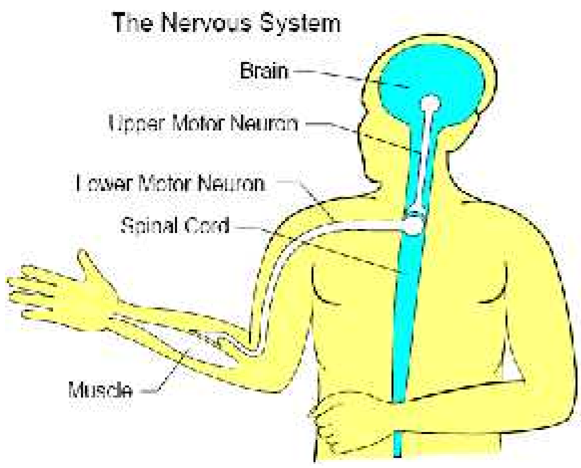

Fig (2.1): The Nervous System

The neurons of the nervous systems of humans are interconnected in complex arrangements and use electrochemical signals and neurotransmitters to transmit impulses from one neuron to the next.

2.1.2 Neurons Categories:

There are three types of neurons in the body:

1. ***Sensory neurons****:* As shown in Fig (2.2) have long axons and transmit nerve impulses from sensory receptors overall the body to the central nervous system.

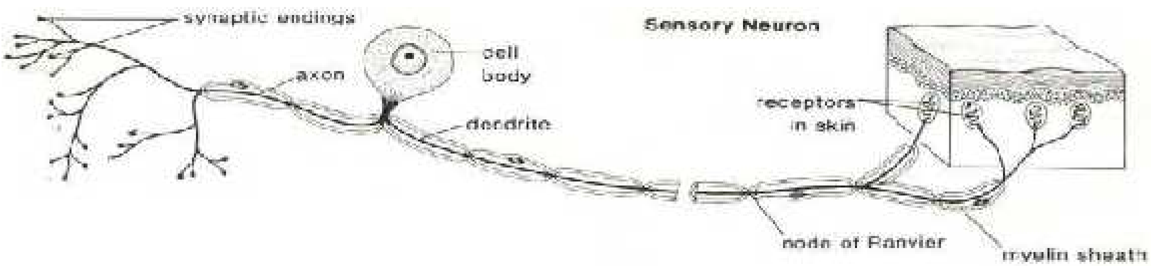

Fig (2.2): Sensory neuron

2. ***Motor neurons****:* As shown in Fig (2.3) also have long axons and transmit nerve impulses from the central nervous system to affected parts (muscles and glands) overall the body.

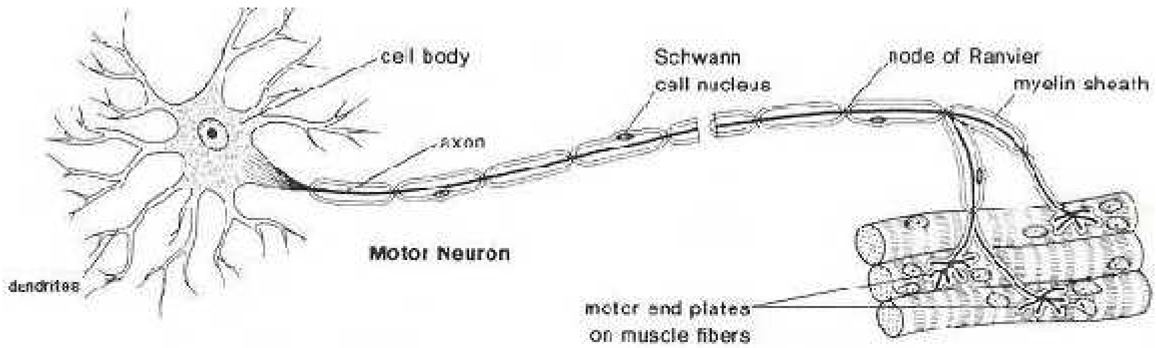

Fig (2.3): Motor neurons.

3. ***Inter-neurons****:* (also called connector neurons or relay neurons) are usually much smaller cells, with many interconnections as shown in Fig (2.4).

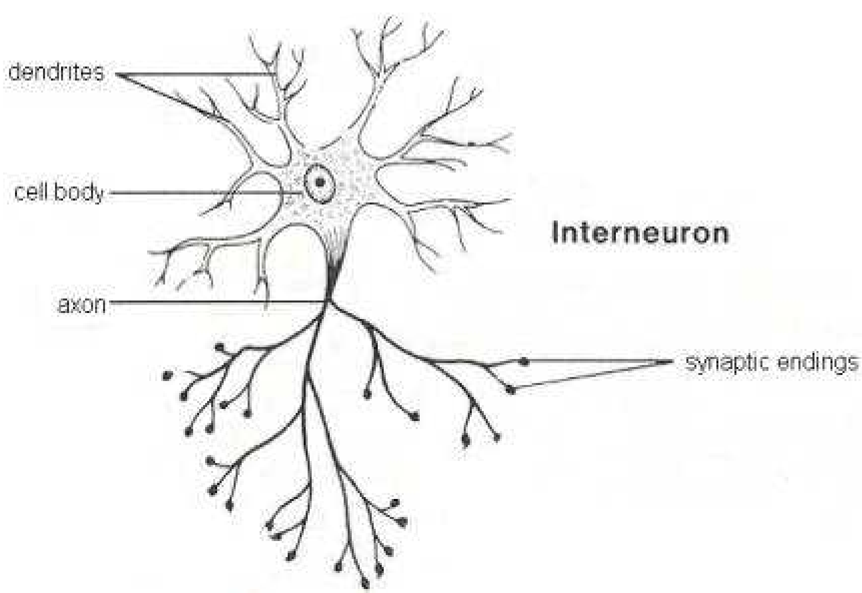

Fig (2.4): Inter-neuron

Neurons are similar to other cells in the body by a cell membrane, have a nucleus that contains genes, contain cytoplasm, mitochondria and other organelles and neurons carry out basic cellular processes such as protein synthesis and energy production.

Neurons differ from other cells in the body by having specialized extensions called dendrites and axons. Dendrites bring information to the cell body and axons take information away from the cell body, neurons communicate with each other through an electrochemical process, neurons contain some specialized structures (for example, synapses) and chemicals (for example, neurotransmitters).

2.1.3 Nerve Impulse:

Nerve impulses are propagated once an action potential has started it is moved (propagated) along an axon automatically. The local reversal of the membrane potential is detected by the surrounding voltage-gated ion channels, which open when the potential changes enough.

The ion channels have two other features that help the nerve impulse work effectively. For an action potential to begin, then the depolarization of the neuron must reach the threshold value; all or nothing.

After an ion channel has been opened, it needs a “rest period” before it can open again. This is called the refractory period, and lasts for about two ms; this means that, although the action potential affects all other ion channels nearby, the upstream ion channels cannot open again since they are in their refractory period, so only the downstream channels open, causing the action potential to move one-way along the axon as shown in Fig (2.5).

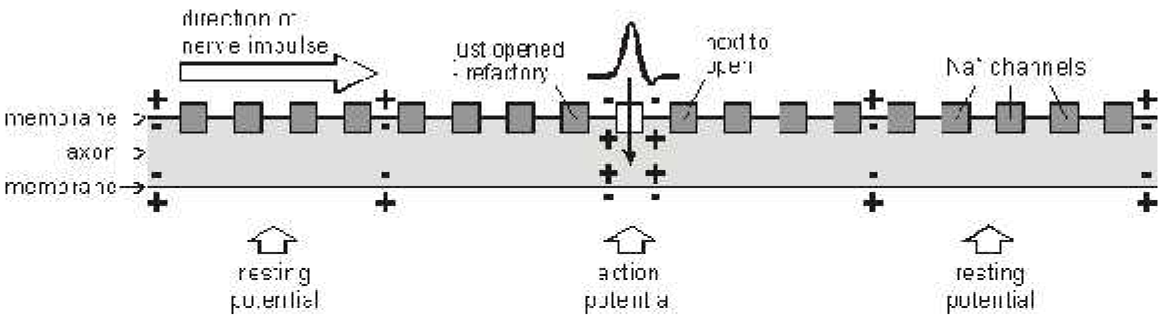

Fig (2.5): Direction of nerve impulse

The refractory period is necessary as it allows the proteins of voltage sensitive ion channels to restore to their original polarity.

The absolute refractory period means that during the action potential, a second stimulus will not cause a new action potential.

There is an interval in which a second action potential can be produced but only if the stimulus is considerably greater than the threshold, which means that the relative refractory period can limit the number of action potentials in a given time; with an average of about 100 action potentials per second.

2.1.4 The Resting Membrane Potential:

When a neuron is not sending a signal, it is at ‘rest’, the membrane is responsible for the different events that occur in a neuron. The membrane contains a protein pump called the sodium-potassium pump (Na + K + ATP) as shown in Fig (2.6). This uses the energy from ATP splitting to simultaneously pump three sodium ions out of the cell and two potassium ions in.

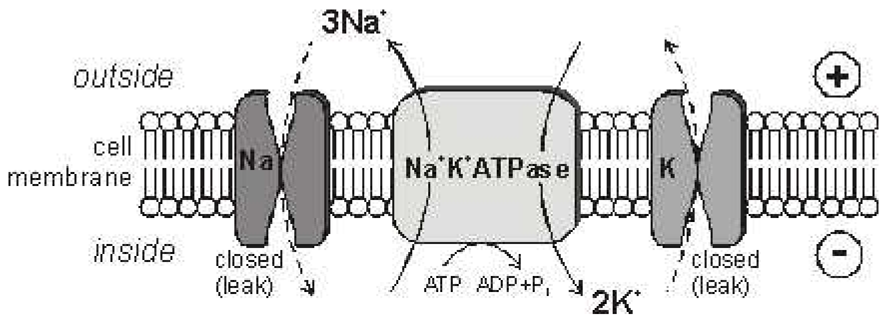

Fig (2.6): The Resting Membrane Potential

The combination of the Na +K + ATP pump and the leak channels cause a stable imbalance of Na+ and K+ ions across the membrane. This imbalance of ions causes a potential difference (or voltage) between the inside of the neuron and it's surroundings, called the resting membrane potential. The membrane potential is always negative inside the cell which equals –70mV. The Na +K + ATP is thought to have evolved as an Osmo-regulator to keep the internal water potential high and so stop water entering human cells and bursting them.

2.1.5 The Action Potential:

The resting potential tells about what happens when a neuron is at rest. An action potential occurs when a neuron sends information down an axon. When the nerve and muscle cells resting membrane potential changes this causes an explosion of electrical activity.

In nerve and muscle cells the membranes are electrically excitable, this means they can change their membrane potential, and this is the basis of the nerve impulse. The sodium and potassium channels in these cells are voltage-gated, which means that they can open and close depending on the voltage across the membrane.

The normal membrane potential inside the axon of nerve cells is –70mV, and since this potential can change in nerve cells, it is called the resting potential. When a stimulus is applied a brief reversal of the membrane potential, lasting about a millisecond, occurs. This brief reversal is called the action potential. An action potential has two main phases called depolarization (rising phase) and re-polarization (falling phase) as shown in Fig (2.7).

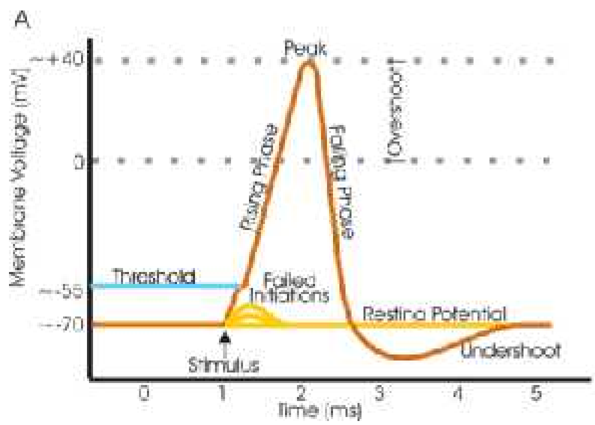

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Fig (2.7): phases of Action Potential

Depolarization:

When stimulated past threshold (about –30mV in humans), sodium channels open and sodium rush into the axon causing a region of positive charge within the axon.

Re-polarization:

The region of positive charge causes nearby voltage gated sodium channels to close. Just after the sodium channels close, the potassium channels open wide, and potassium exits the axon, so the charge across the membrane is brought back to its resting potential.

2.2 The Muscular System Physiological Anatomy:

In this section, the physiological structure of the muscle will be discussed, mentioning the categories of muscles, also the contraction process of muscle will be explained.

2.2.1 The Muscular System Structure:

Muscles are a sort of soft tissues that possess specific contractile properties and function as flexible shortening actuators on the different components of the organism. They also convert chemical energy into force. The muscular system is composed of specialized cells called muscle fibers. Their predominant function is contractibility. Muscles, where attached to bones or internal organs and blood vessels, are responsible for movement. Nearly all movement in the body is the result of muscle contraction.

Each muscle fiber ("muscle cell") is covered by a plasma membrane which is called the sarcolemma. Tunnel-like extensions from the sarcolemma pass through the muscle fiber from one side to the other one in transverse sections through the diameter of the fiber, these tunnel-like extensions are known as transverse tubules. The nuclei of muscle fiber are located at the edges of the diameter of the fiber, adjacent to the sarcolemma, noting that muscle fiber may have many nuclei.

Cytoplasm is present in all living cells, and the one present in muscle fibers is called sarcoplasm. The sarcoplasm present in muscle fibers contains many mitochondria, which are the energy-producing units within the cell. These mitochondria produce large amounts of a chemical called "Adenosine Tri-phosphate", which as usually referred to in abbreviated form as "ATP", this chemical substance is necessary for contracting muscles, transporting substances across the cell membranes and moving structures within the cell. These Components are the major components inside the muscle fiber needed to be mentioned.

2.2.2 Muscle Categories:

There are three types of muscle in the body, and they are as follows:

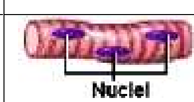
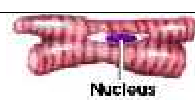
1. Skeletal muscle: By definition is muscle which is involved in movement of the skeleton. Skeletal muscle is composed of cells that have specialized functions. They are called muscle fibers, due to their appearance as a long cylindrical shape plus numerous nuclei. Their lengths range from 0.1 cm to 30 cm with a diameter from 0.001 cm to 0.01 cm. It is also called striated muscle as the fibers, which are made up of many cells, are composed of alternating light and dark stripes, or striations. Skeletal muscle can be contracted without conscious control, for example in sudden involuntary movement.

2. Smooth muscle: This tissue is so called because it does not have striations and therefore appears smooth under a microscope, noting that the smooth cell is

spindle-shape and has one nucleus. It is also called involuntary because it is controlled by the autonomic nervous system. Unlike skeletal muscle, it is not attached to bone. It is found within various systems within the human body, for example the circulatory, the digestive and respiratory. Its main difference from skeletal muscle is that its contraction and relaxation are slower. Also, it has a rhythmic action which makes it ideal for the gastro-intestinal system. The rhythmic action pushes food along the stomach and intestines.

3. Cardiac muscle: is a specialized kind of muscle found only within the heart. Cardiac muscle can't be controlled consciously so it is an involuntary muscle. The cardiac muscle has one central nucleus, like smooth muscle, but it also striated like skeletal muscle. The cardiac muscle cell is rectangular in shape, while its contraction is strong, and rhythmical.

Table (2.1): Comparison between different types of muscles

	Skeletal Muscle Cell	Cardiac Muscle Cell	Smooth Muscle Cell
Shape	Elongated Cells	Branching Cells	Spindle-Shaped Cell
Nuclei Type	Multiple Peripheral Nuclei	Single Central Nucleus	Single Central Nucleus
Striations Existence	Visible Striations	Visible Striations	Lack Visible Striations
Movement Type	Voluntary	Involuntary	Involuntary
Normal picture	 [8]	 [8]	 [8]

2.2.3 Structure of Skeletal Muscles:

Because this project is related to the skeletal muscle, construction of this type is to be explained widely. At the high level, skeletal muscles consist of muscle cells and fibrous connective tissues. The cells, which are elongated and shaped like cylinders, are called muscle fibers. A group of muscle fibers forms a bundle (also called fasciculi), and many fascicles (bundles) together form a muscle head. Finally, one or more heads constitute a complete muscle belly.

From Fig.(2.8) at the low level, a muscle can be defined as a combination of many strands of tissue called fascicles. Each fascicle is composed of fasciculi which are bundles of fibers, themselves composed of parallel bundles of myofibrils. The myofibril is the basic fiber of muscle and can contract, relax, and elongate (lengthen). It consists of series of contractile units, named sarcomeres, composed of arrays of actin protein ("which is thinner and therefore more transparent") and myosin protein ("which is thicker and responsible for the darker bands") myofilaments, arranged so as to form the contractile mechanism of muscle.

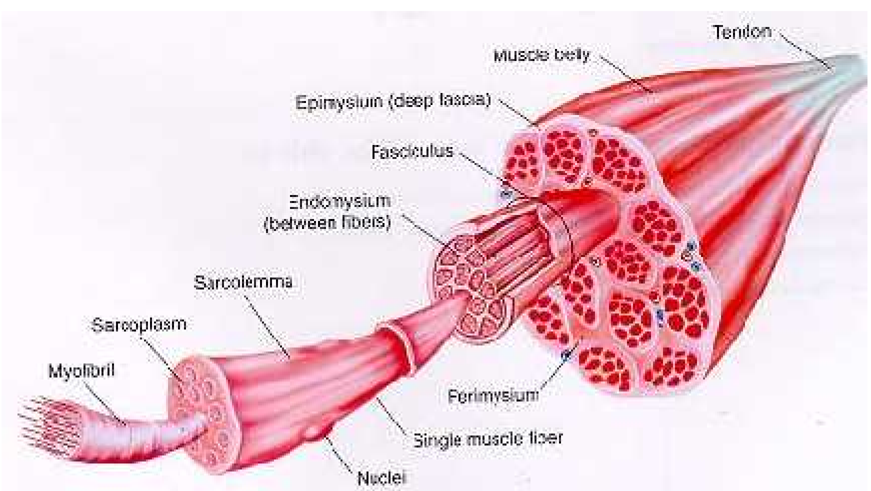


Fig (2.8): Skeletal muscle

The connective tissue in a muscle can be divided into three structural entities, the epimysium, which surrounds the center part of the muscle (also called “belly”), the perimysium, which binds bundles of muscle fibers into individual fasciculi, and the endomysium, which surrounds each muscle fiber individually. The whole of these tissue sheaths called the fascia. It encloses the muscles, separates them into layers, and ultimately connects them at their ends by the tendons.

2.2.4 Mechanism of Contraction of Muscle:

Cell membrane situation at rest conditions is shown in Fig. (2.9). Muscles are connected to the spine by nerves. The connection between these two structures is called neuromuscular junction.

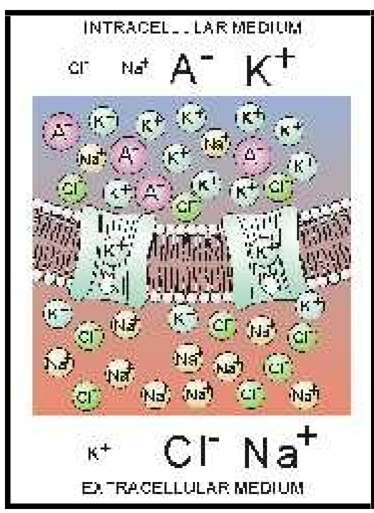


Fig (2.9): Cell membrane at rest condition

A muscle has an all or none phenomenon. In order for it to contract, it has to receive a stimulus of a certain threshold. Below this threshold, muscle will not contract; above this threshold muscle will contract but the intensity of contraction will not be greater than that produced by the threshold stimulus.

The mechanism of contraction can be explained with reference to Fig. (2.10). A nerve impulse travels down the nerve to the motor end plate. Calcium diffuses into the end of the nerve. This releases a neuron transmitter called acetylcholine - neural transmitter.

Acetylcholine travels across the small gap between the end of the nerve and the muscle membrane. Once the acetylcholine reaches the membrane, the permeability of the muscle to sodium (Na^+) and potassium (K^+) ions increases, and hence; both ions are positively charged. However, there is a difference between permeabilities for the two ions. (Na^+) enters the fiber at a faster rate than the (K^+) ions leave the fiber. This results in a positive charge inside the fiber. This change in charge initiates the contraction of the muscle fiber.

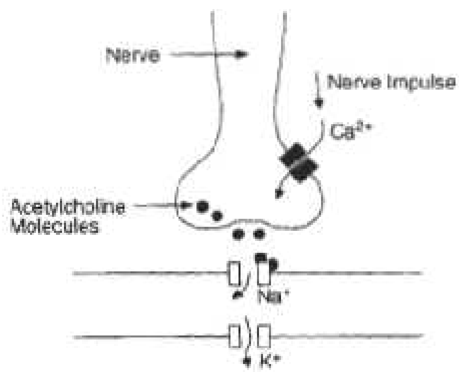


Fig (2.10): Neuromuscular junction

The mechanism of contraction involves the actin and myosin filaments which, in a relaxed muscle, are held together by small cross bridges see Fig (2.11). The introduction of calcium breaks these cross bridges and allows the actin to move using ATP as a fuel. Relaxation of a muscle occurs via the opposite mechanism. The calcium breaks free from the actin and myosin and enables the cross bridges to reform.

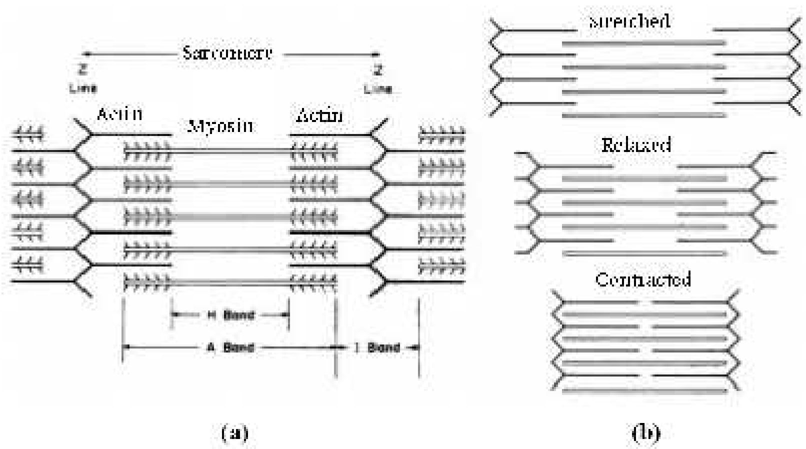


Fig (2.11): Muscle Sarcomere: (a) Striating bands of the sarcomere crossing the filaments; (b) appearance of a sarcomere within stretched, relaxed and contracted muscle

2.3 Project Theory

The project depends mainly on applying pulses - of special characteristics that comfort the sensitivity of patient response - to the patient skin through a conductive rubber electrodes, these pulses will generate a rearrangement of the ions of the motor nerve cell around its semi-permeable membrane causing an active potential similar to that comes from the brain which finally reaches the muscles fibers causing contraction of muscles.

2.3.1 Main Idea

The effects on the body of applied electric charges depend on the intensity and nature of the resulting current in the tissues. They can be rather simply summarized as having three basic effects, each of which may have various complex physiological and therapeutic consequences.

Chemical changes occur in the tissues as a result of the application of unidirectional or direct current. If the current is sufficiently great; tissue destruction will occur.

Excitable tissues, nerve and muscles, can be stimulated by currents that vary at a suitable rate. The change in current has to be quick enough to unbalance the ions around cell membranes, but not so quickly that they do not allow time for the cell to respond. This may lead to many effects such as muscle contraction and altered pain perception. significant heating can be generated in the body tissues if high-frequency evenly alternating currents are applied; because the rate of change is too high to allow time for excitable cells to respond and the polar or chemical effects are insignificant due to the alternation, so that; relatively high current intensities can be applied.

High currents cause significant heating in the tissues because they dissipate much more energy than low current intensities. The heating will actually depend on the square of the current intensity, according to the following formula (Joule's Law):

$H \sim I^2 * R * T$ …………………………………...……(2.1)

Where:

H: Heat (Joules).

I: Current Intensity (Amperes).

R: Resistance (Ohms).

T: Time (Seconds).

2.4 Project Components:

Here in this section, provided the theoretical background of each component of project.

The design consists of the following components:

- DC power supply.
- Multi-frequency generator circuit.
- Time control circuit.
- Mode circuit.
- Driving transistors circuit (BJT & MOSFET).
- Step-up transformer.
- Voltage regulators.
- Current and Voltage control circuit.
- Leads and Electrodes.

2.4.1 The Power Supply:

In the proposed design, many integrated circuits (IC's) and transistors are to be used, the 12 volt dc power supply is used to bias transistors and to provide the required dc voltage for IC's till the subsystems can be operated within the overall system.

The main components of the DC power supply can be listed as follows:

- Step down transformer.
- Bridge rectifier.
- Capacitor.
- Regulator.

Note:

Before talking about Multi-frequency generator, time control and mode circuits; the NE555 operation, features and applications should be known and understood.

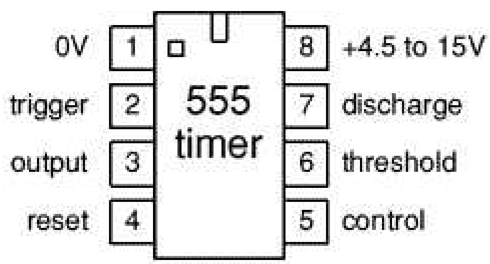


Fig (2.12): PIN Configuration of the NE555 IC

Operation:

The 555 timer consists basically of two comparators, a flip-flop, a discharge transistor, and a resistive voltage divider, as shown in Fig (2.13). The flip-flop is a two-state device whose output can be at either a high voltage level (set, S) or a low voltage level (reset, R). The state of the output can be change with proper input signals.

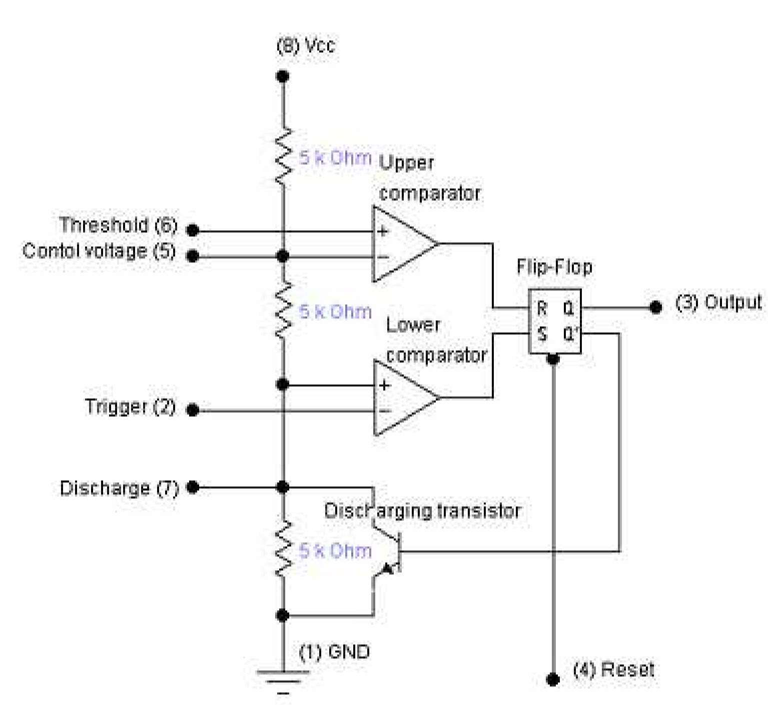


Fig (2.13): Internal Configuration of the NE555 IC

The resistive voltage divider is used to set the voltage comparator levels. All three resistors are of equal; therefore, the upper comparator has a reference of ⅔ Vcc, and the lower comparator has a reference of ⅓ Vcc.

The comparator's outputs control the state of the flip-flop, when the trigger voltage goes below ⅓ Vcc, the flip-flop sets and the output jumps to its high level. The threshold input is normally connected to an external RC timing circuit.

When the external capacitor voltage exceeds ⅔ Vcc, the upper comparator resets the flip-flop, which in turn switches the output back to its low level. When the device output is low, the discharging transistor is turned on and provides a path for rapid discharge of the external timing capacitor. This basic operation allows the timer to be configured with external components as an oscillator.

Features:

- Direct replacement for SE555/LM555.
- Timing from microseconds through hours.
- Operates in both ***Astable*** and ***Monostable*** modes.
- Adjustable duty cycle.
- Output can source or sink 200 mA.
- Output and supply TTL compatible.
- Temperature stability better than 0.005% per °C.
- Normally on and normally off output.

Applications:

- Precision timing.
- Pulse generation.
- Sequential timing.
- Time delay generation.
- Pulse width modulation.
- Pulse position modulation.
- Linear ramp generator.

2.4.2 Multi-Frequency Generator Circuit:

The NE555 IC has been used, to be operated in the ASTABLE mode oscillator that enables the generation of continuous pulses at variable four frequency values around 2, 40, 80 and 130 Hz of a square waveform, which can be selected one by one.

2.4.3 Time Control Circuit:

The NE555 IC has been used, to be operated in the Mono-stable mode that generates a pulse according to the input on its trigger pin, and here the duty cycle of the pulse resulted at the output (Pin 3) can be controlled.

2.4.4 Mode Circuit:

The NE555 IC had been used, to be operated in the ASTABLE mode oscillator and enables the generation of continuous pulses at fixed frequency value of 0.07 Hz, this circuit provides to select the operating mode of the system.

2.4.5 Driving Transistors Circuits (BJT & MOSFET):

There had been used a sequence of a PNP and an NPN transistors to interface the output of the mono-stable circuit with the input Gate of the power MOSFET type “p” which drives the primary of the step-up transformer in the next step. As the voltage varies at the Gate pin of the MOSFET, the direct proportional current passes from the source pin to the drain pin.

2.4.6 Step-up Transformer:

The step-up transformer, which transforms low AC voltage (12v) at the primary terminal of the transformer to a higher voltage (120v-130v) at the secondary terminal.

2.4.7 Voltage Regulators:

Here, the final form of the wave that is divided into the positive phase at 100 volt and the negative phase at -33 volt is to be resulted. To get these voltages, a 100 and 33 volts ZENER diodes are to be used respectively.

2.4.8 Current and Voltage Control Circuit:

After the voltage regulators in series, a constant resistor and variable resistor are to be used. The fixed one is for limiting the voltage and current. The maximum voltage can be applied to the patient skin when the variable resistance is at zero value, the variable resistance at the beginning of the applied system on the patient skin, should be at it's maximum value, then by decreasing it's value we alter the current and the voltage till have to be altered, it will be appropriate to the sensitivity of the patient and the position of the electrodes.

2.4.9 Leads and Electrodes:

Electrodes are connected to a stimulator by insulated wires called leads. The stimulator sends electrical pulses through the leads and to the electrodes where the electrical charge is delivered to the nerve, muscle or other tissues.

Two types of electrodes are used; ***Implemented electrodes*** are located inside the body and avoid the need for daily application. They provide selective stimulation of particular muscles with lower current levels. But, a drawback is the need for surgery to place the electrodes or replace them if necessary, ***Surface electrodes*** have some drawbacks. Because they are separated by skin and fat from the underlying muscles and nerves, surface electrodes can’t make individual muscles active.

3

Project Conceptual Design

Chapter Three
Project Conceptual Design

In this chapter, the main objectives of the project, the general block diagram and how the overall system works are to be explained.

3.1 Project Objectives:

The project contains and implements many ideas and objectives that can be summarized in the following points:

1. To design and implement a functional electrical stimulator.
2. To simulate the same idea of a functional electrical stimulator device.
3. To be applicable for applications in studying as a model.
4. Can be used in clinical and hospital physiotherapy units.

3.2 General Block Diagram :

The following figure shows the block diagram of the project.

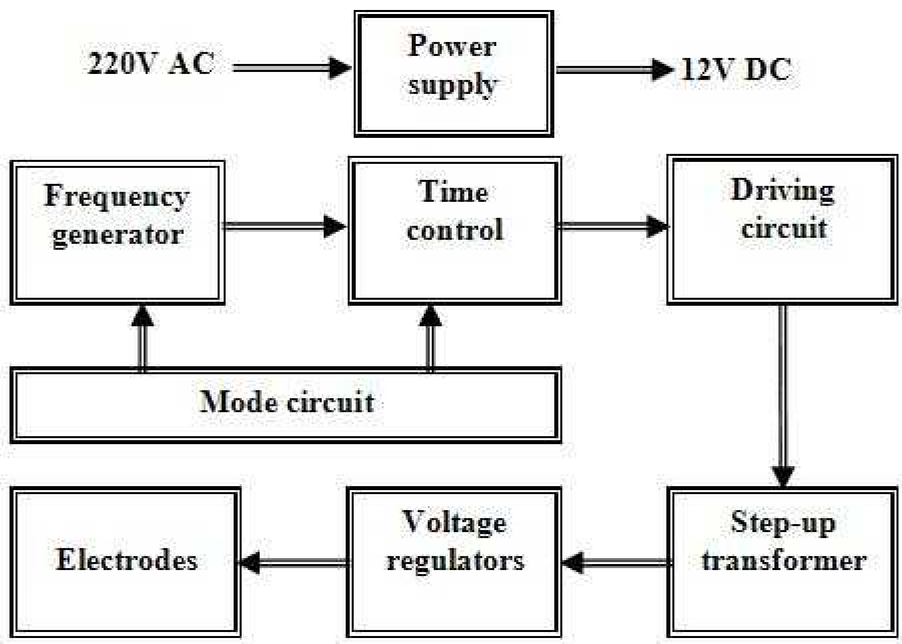


Fig (3.1): General block diagram

It is clear here that each individual block has its own function, and by summing those functions, and integrating with each other; the functional electrical stimulator system will be accomplished.

Here is the explanation of the individual units:

3.2.1 DC Power Supply Block Diagram:

In the design, it is needed to use a DC power supply to provide the necessary (+ve) voltage supply for the ICs used in the project. The following Fig (3.2) shows the block diagram for the DC power supply:

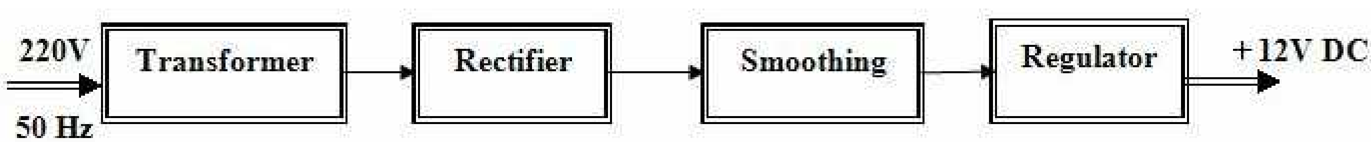


Fig (3.2): DC power supply block diagram

1. **Transformer**: it is used for reducing voltage and to perform the isolation process too.

2. **Rectifier:** this stage is used for converting form AC to DC voltage using a bridge full wave rectifier.

3. **Smoothing:** here, the ripple voltage will be reduced.

4. **Regulator:** the output of this stage is a pure DC line voltage as needed.

3.2.2 Multi-frequency generator circuit:

This is the first pulse generator stage with four variable selected frequencies, it consists of the selecting value and the generator of the required pulses as Astable mode of the NE555 and its output is a square wave signal with a value near to the supply voltage (12v), and by Ra, Rb and C, the on time, off time, pulse time and duty cycle can be controlled.

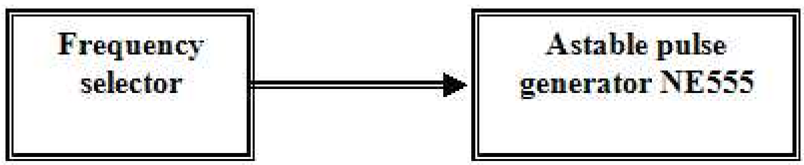


Fig (3.3): Multi-frequency generator block diagram

Frequency selector:

It consists from a constant resistor Ra and another four variable resistors as Rbs that had been connected with Ra by DIP switches. and one of them each time not all at the same time as shown in Fig (4.3) chapter four.

Astable pulse generator circuit:

This IC1 has been used as Astable mode by connecting its pin 2 and pin 6 with each other by a jumper, then connecting this jumper between Rb and the polar capacitor ,and its pin 7 connected between Ra and Rb as shown in Fig (4.3) chapter four to generate a train of square pulses with a frequency as selected in the frequency selector.

3.2.3 Mode circuit:

NE555 IC3 has been used as Astable mode by connecting its pin 2 and pin 6 with each other by a jumper then connecting this jumper between R_B and the polar capacitor and its pin 7 connected between Ra and Rb as shown in fig (4.6) chapter four to generate a train of square pulses with a frequency of 0.07 Hz.

This circuit will provide multi-modes such as:

1. Mode 1: Continuous pulses (all DIP 6, 7 & 8 are opened).
2. Mode 2: Rest-continuous (DIP6).
3. Mode 3: Time mode (DIP7).
4. Mode 4: Voltage mode (DIP8).

3.2.4 Time control circuit:

NE555 IC2 has been used as Monostable mode by connecting its pin 6 and pin 7 with each other by a jumper then connecting this jumper between a Resistor (R-constant +R-variable) and the polar capacitor, and its pin 2 connected to the frequency generator of the previous stage as shown in Fig (4.4) chapter four and its output is taken from pin3, this mode concerns the positive time length of the pulse.

3.2.5 Driving transistors circuit (BJT & MOSFET):

The BJT transistors in a specific configuration are to be used to interface the output of the Monostable stage with the power MOSFET type “p” at gate pin, the signal had been amplified and inverted through the BJT transistors, the MOSFET gate voltage controls the source drain current directly proportional, and this current is used to drive the step-up transformer.

3.2.6 Step-up Transformer:

The step-up transformer transforms low AC voltage at the primary terminal of the transformer to higher voltage at its secondary terminal. The low voltage constructed from the MOSFET current at the primary terminal.

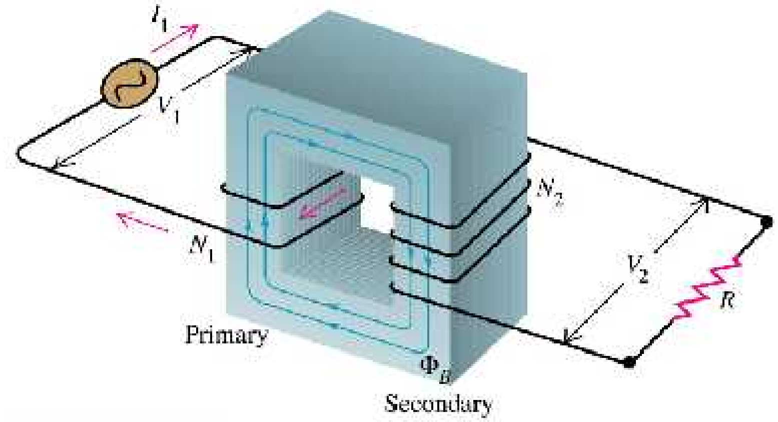


Fig (3.4): Step-up transformer

3.2.7 Voltage Regulators:

As mentioned before (chapter 2), two ZENER Diodes (33 and 100 volt) were used to limit the peaks of the resulted waveforms, positive and negative phases respectively.

3.2.8 Leads and Electrodes:

As stated in chapter 2, there are two main types of electrodes, implemented and surface electrodes. In this project, the second type was used.

The electrodes are usually supplied with an adhesive back that allows them to be easily attached to the skin. If the adhesive dries out, a smear of personal lubricant will be helpful.

The electrodes can then be attached to the skin using any of the variety of tapes or bandages used to secure wound dressings. Attach the electrodes in position on either side of the pain source or possibly on the back for pains in the leg / foot – to confuse the nerves.

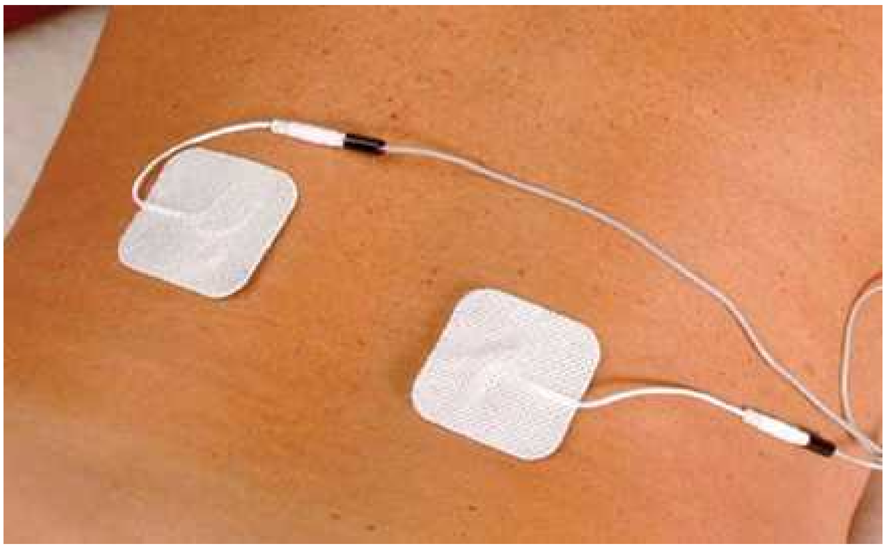


Fig (3.5): Leads and Electrodes

There are three common used types of surface electrodes as follows:

1. A ***malleable metal electrode*** such as tinplate or aluminum coupled to the skin, with water retained in a pad of lint, cotton gauze or some form of sponge material, e.g. spontex. The water provides the uniform ion-containing low resistance pathway for current while the absorbent material simply service to keep the water in place.

2. The second system involves electrodes that will conform to the body surface more easily than metal electrode described above. These are made of ***carbon-impregnated silicone rubber***. They may be used with sponge pads or coupled to the skin a thin layer of conducting gel and fixed in place either with a strap or adhesive tape.

3. The third system is by ***means of water bath or baths*** in which the body part is immersed with an electrode. Current is passed from electrode to tissue through the water.

3.3 How System Works:

The following steps explain how the project works, and what steps should be taken, to give pulses waveforms by system modes. Those modes are:

- Choose one of the frequencies by the frequency selector, which will be applied to the Astable NE555 (frequency generator), that generates the pulses.

- Then those pulses applied to the trigger pin on the next NE555 that is used in Monostable mode, the on time of the generated pulses can be changed by the variable resistor.

- Then the time controlled pulse applied to the primary of the step-up transformer through driving and interfacing circuit that makes the required amplification of power and the inverting of signal.

- The step-up transformer elevates the primary voltage in 1-to-10 ratio on the secondary; the voltage in this stage will be nearly +120v and -36v by the free weeling diods.

- Now by using Zenor diodes, the form and amplitude of the required waveform in the final form (+100v and -33v) are resulted.

- Then the constant resistor that works as current limiter with another variable resistor to control the current and voltage (according to the patient and place sensitivity) that to be applied to the patient through Leeds and electrodes.

3.4 Modes of work:

Mode 1 Continuous Pulses (DIP 6, 7 & 8 are opened):

All jumpers are opened; the generated pulses are continuous with the selected frequency with voltage source amplitude.

Mode 2: Rest-Continuous (DIP6 is closed, DIP7 & DIP8 are opened)**:**

The difference from the Mode 1 is that the output of the Mode circuit (pin 3) here provides the reset pin 4 of the Astable IC1 in the **Astable pulse generator** through DIP6, this will stop pulse generating only when the coming signal is low from the Mode circuit output.

Mode 3: Time mode (DIP7 is closed, DIP6 & DIP8 are opened)**:**

In this mode the emitter of the PNP transistor in the mode circuit is connected with the pin 5 of the **Astable pulse generator** circuit via DIP7**,** to create a variation in the duty cycle at it's output (pin 3), which will be varied in fixed range from minimum to maximum in an oscillation according to the frequency of the mode circuit.

Mode 4: Voltage mode (DIP8 is closed, DIP6 & DIP7 are opened)**:**

This mode results in amplitude variation from 1/3 to 2/3 of the supply voltage on the output of the time control circuit, by connecting pin5 of it's Monostable IC with the emitter of the PNP transistor in the mode circuit in an oscillation according to its the frequency via DIP8 .

Note: more modes can be generated by more selecting of the DIP switches with each other at the same time.

3.5 Contraindications:

Contraindications to electrical stimulation may be summarized as circumstances in which:

1. Strong muscle contraction might cause joint or muscle damage, detachment of a thrombus, spread of infection, and haemorrhage.

2. Stimulation of autonomic nerves might cause altered cardiac rhythm or other autonomic effects.

3. Currents might be unduly localized due to open wounds or skin lesions, e.g. eczema.

4. Currents might provoke undesirable metabolic activity in neoplasms or in healed tuberculous infections.

5. Current is not evenly biphasic, leading to possible skin damage or irritation, especially if there is loss of sensation.

4

Detailed Technical Project Design

4.1 Detailed Description of the Project Phases

4.2 Overall System Design

4.3 Total Practical Circuit to be Implemented

Chapter Four
Detailed Technical Project design

The necessity of this chapter takes a place in order to explain the detailed design for each unit in this project. Also to clarify the main characteristics that will make this project to operate as planned, after viewing the theoretical background, and the general block diagram that explain how the system works in the previous chapters.

4.1 Detailed Description of the Project Phases

The project is divided mainly into the following phases:

- Pulse generating with four variable frequencies by using NE555 in the Astable mode configuration (IC1) to give a train of pulses.

- Controlling the positive phase time of the pulse using NE555 in the Monostable mode configuration (IC2) till getting the required on/off pulse time that will be used as in the stimulation principle.

- Interfacing the signal from the Monostable (IC2) with a MOSFET transistor where amplification and inverting should be done on the signal in this stage, to be around the required final form of the stimuli wave.

- Elevating the signal that produced from the MOSFET transistor by a step-up transformer that elevates with a ratio of (1:10) and using the free wheeling diode idea.

- Regulation done on the signal that produced from the second terminal of the step-up transformer to +100 volt in the positive phase and -33 volt in the negative phase, by using forward 100 volt and reverse 33 volt ZANER diodes having those values.

- Intensity control should be founded, by controlling the current and voltage of the signal that is applied through the lead and electrodes to the patient, to get the comfort intensity to the patient's skin and his pain place sensitivity.

4.2 Overall System Design

Here the project aim is to particularize the characteristics, and specifications for each circuit, also to view the schematics, and features of those subsystems.

4.2.1 Power Supply Subsystem

The following figure - Fig (4.1) – shows main components of the power supply that will be used.

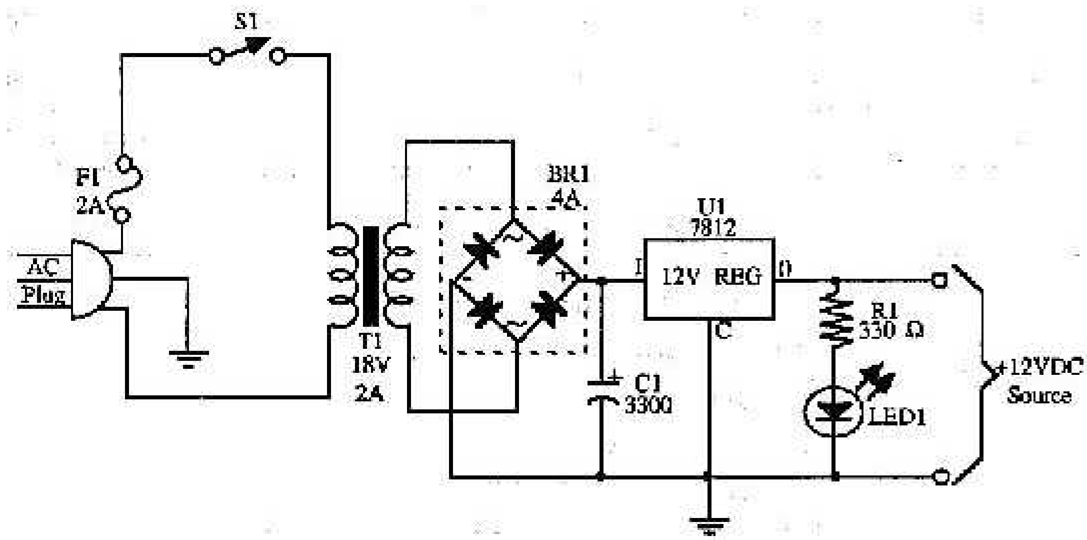


Fig (4.1): DC power supply circuit

The above DC power supply circuit will convert the 220V/50Hz AC voltage to 12V DC voltage, the circuit is composed of:

1- Step-down transformer: The secondary provides the ground output, and provides a 20:1 voltage reduction ratio.

2- Regulator: 7812 is available to have (+ve) 12 VDC output.

3- Bridge Rectifier: this part is available and easy to use, for those reasons it is to be used in the design as shown in Fig (4.1).

The following Fig (4.2) shows the block diagram and the output waveform from each block of the DC power supply:

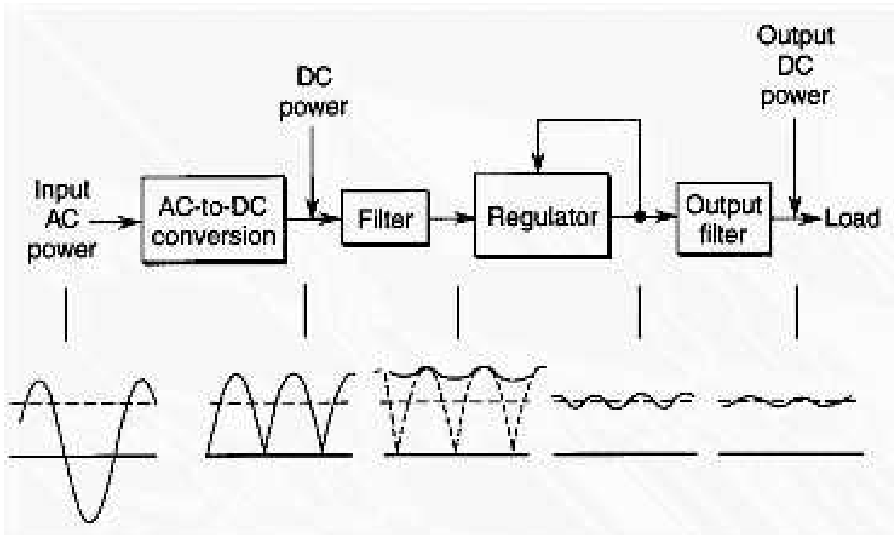


Fig (4.2): block diagram and the Output waves from DC supply

4.2.2 Multi-frequency generator circuit

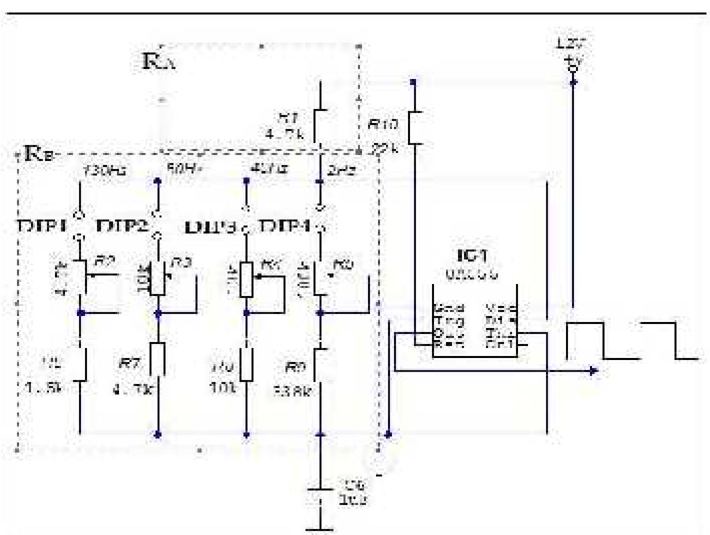


Fig (4.3): Multi-frequency generator circuit

The frequency of the operation of the Astable circuit is dependent on the values of R_A, R_B and C. In the Astable mode, the circuit will keep re-triggering itself, resulting in a pulse train.

In this case, the capacitor charges and discharges between 1/3 VCC and 2/3 VCC. The 555's output will be high while charging and low while discharging. The capacitor charges and discharges at different rates, it has to charge through R_A and R_B, but it only discharges through R_B.

The circuit's equations and calculations:

$$f = \frac{1}{0.693 * C * (R_A + 2 * R_B)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.1)$$

Let

R_A=4.7kΩ,

C=1μf

To get the following frequencies R_B values as have been calculated are shown in the following table:

Table (4.1): The adjustable values of Rb

R_B (KΩ)			FREQUENCY (Hz)	
Min	Mean	Max		
		438	1.6	Min
	357.65		2	Mean
338			2.1	Max
		20	32.3	Min
	15.65		40	Mean
10			58.4	Max
		14.7	42.3	Min
	6.4		80	Mean
4.7			102.3	Max
		6.2	84.4	Min
	3.2		130	Mean
1.5			187.4	Max

4.2.3 Time Control Circuit

The positive phase time T_{ON} can be controlled here by using the Monostable mode for the NE555 as shown in Fig (4.4).

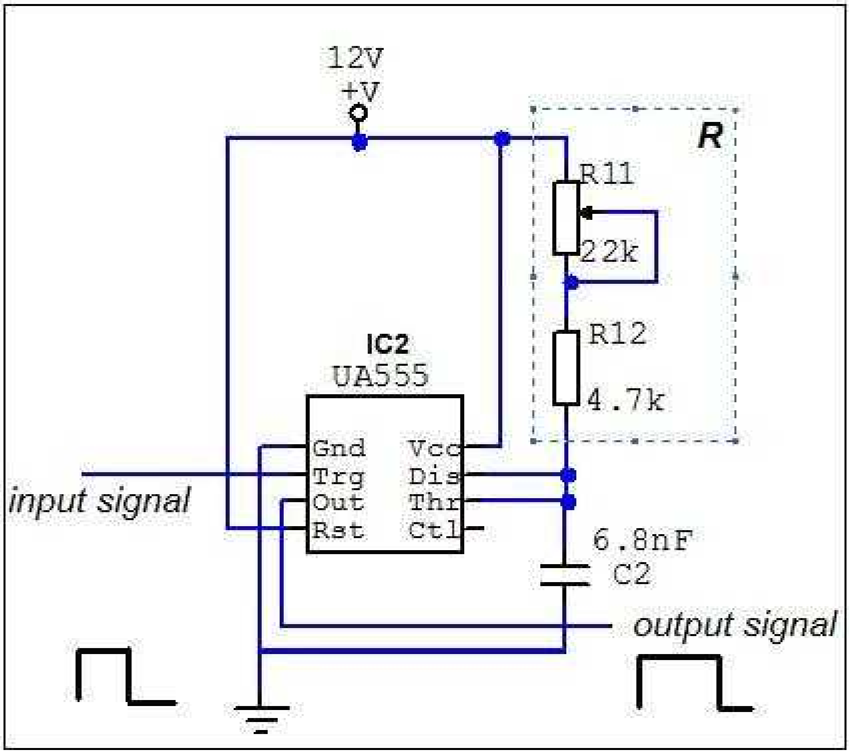


Fig (4.4): Time Control Circuit

The circuit operates as follows:

1. In this circuit's initial condition, the capacitor C is held discharged through the discharge pin, which is grounded through the flip-flop in the timer. The threshold voltage is equal to the voltage across the capacitor.

2. When the trigger pin receives a negative trigger pulse less than 1/3 VCC, the flip-flop sets the output to high and disconnects the discharge pin from the ground. This allows the capacitor to charge until the voltage across it reaches 2/3

VCC, which takes about T=1.1*R*C seconds. If the trigger receives a signal while the output is still high, there is no effect.

3. When the threshold voltage reaches 2/3 VCC, the flip-flop resets, connecting discharge pin to the ground and setting output to low. It is now backing in the initial state, and waits another trigger pulse.

According to the Time Out Delay (**seconds**) equation:

T = 1.1 *R *C ……………………………..…(4.2)

T (min) = 1.1 * 4.7k * 6.8nf = 35.16 ms

T (max) = 1.1 * 26.7k * 6.8nf = 199.72 ms

The following figure shows the timing diagram in mode one at three frequencies 130Hz, 80Hz and 40Hz at T (min):

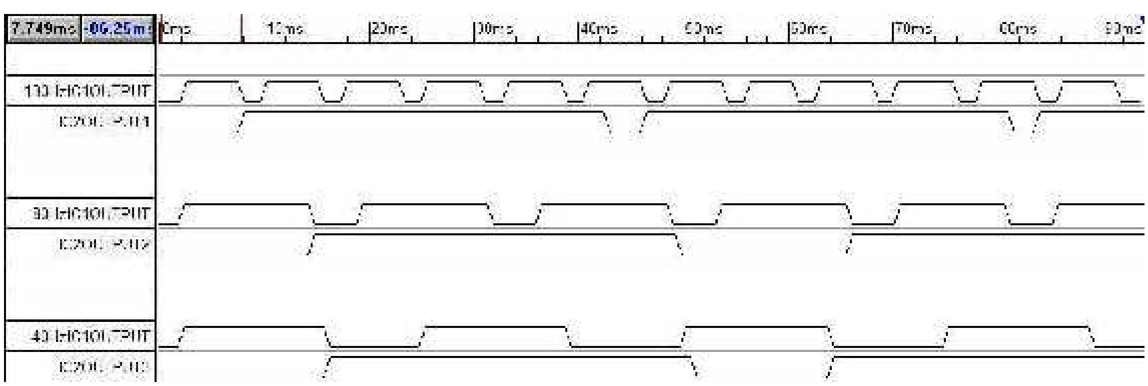


Fig (4.5): Mode one timing diagram

4.2.4 Mode circuit

This circuit as shown in Fig (4.6) Astable mode of NE555, which to be used in the modes explained earlier.

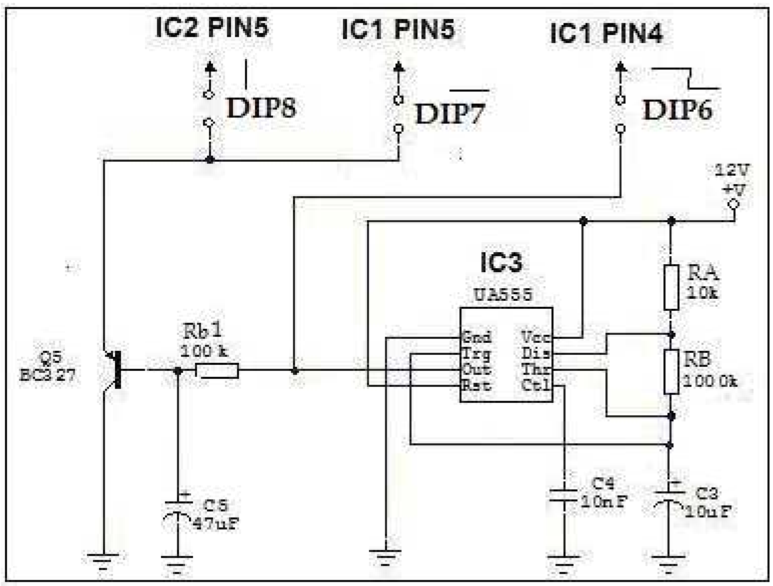


Fig (4.6): Mode circuit

This circuit gives a fixed frequency according to equation (4.1):

$$f = \frac{1}{0.693 * C * (R_A + 2 * R_B)}$$

$$f = \frac{1}{0.693 * 10\mu f * (10\ k\Omega + 2 * 1000\ k\Omega)}$$

$$f = 0.07Hz$$

$$T = \frac{1}{f}$$

$$T = \frac{1}{0.07Hz} = 14.29\ sec.$$

At low output of mode circuit (IC3), PNP transistor works as a switch, the following calculations are done for the design, The internal three resistors inside the NE555 of the Multi-frequency generator circuit or Time Control Circuit is 5kΩ at control voltage (pin5), the upper one connected to the supply voltage and to the emitter of the transistor in mode circuit through control voltage (pin 5) as shown in fig(4.7), this creates a small circuit consists from 12 volt and resistor 5kΩ and earth, the project calculations:

$$I_E \approx I_C = \frac{V_{CC} - V_{(GND)}}{R} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.3)$$

$$I_E = \frac{12 - 0.0}{5k} = 2.4\ mA$$

Where:

I_E: emitter current

I_C: collector current

R: NE555 internal resistor

$$I_B = \frac{I_C}{\beta} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.4)$$

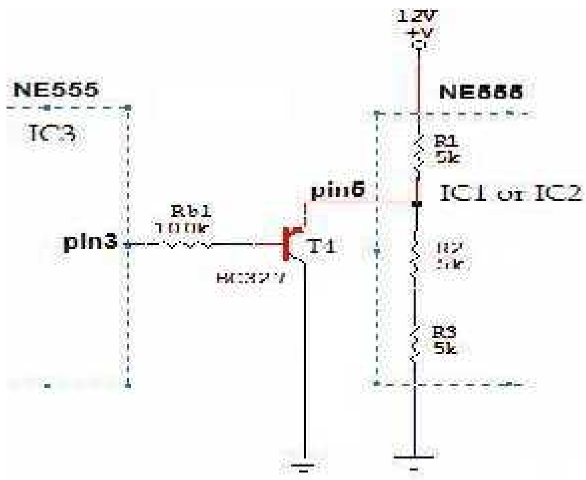
$$I_{b1} = \frac{2.4mA}{250} = 9.6\mu A$$

Where:

I_{b1}: base current

Ic: collector current

β : DC current gain



Fig(4.7): Rb1 calculation

To maintain the biasing of the transistor, a resistor between base and the output of the (IC3) is put, and its value calculated as:

$$R_B = \frac{V_{BE}}{I_B} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.5)$$

R_B : Base Resistor

$$R_{b1\,(min)} = \frac{V_{BE}}{I_{b1(max)}}$$

$$R_{b1\,(min)} = \frac{0.7V}{9.6\mu A} = 72.92\ K\Omega$$

Or more (R_{b1}= 100KΩ resistor is chosen).

4.2.5 Driving transistors circuit (BJT & MOSFET)

This circuit will invert the output of the previous stages; the positive into negative and the negative into positive and make the required amplification.

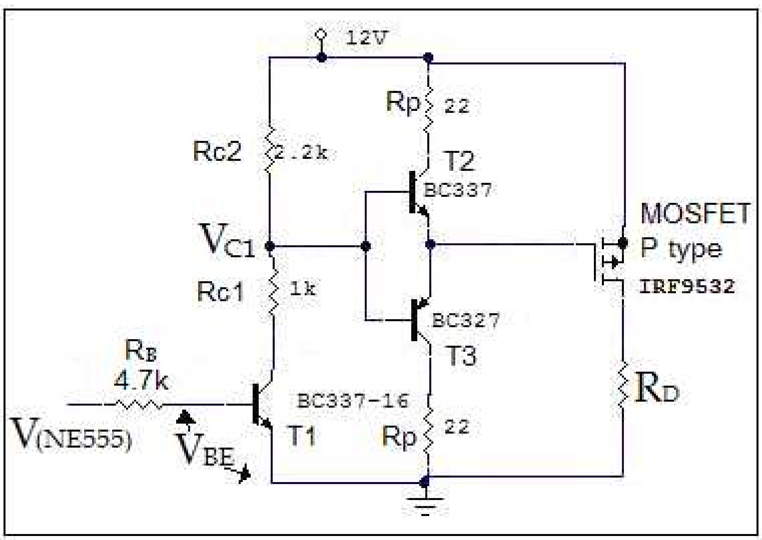


Fig (4.8): Driving transistors circuit (BJT & MOSFET)

As the project aims to elevate the Monostable signal to that required range (-33V- to- 100V), but it could not be made without step-up transformer with ratio of 1:10, it is not possible to connect the output of the NE555 on the Monostable directly to the primary of the step-up transformer which have a relatively small resistance. This means it will drain a high current, while that maximum current can be drained from the NE555 is 200 mA, it is not enough.

So that in the project it is planned to use an enhancement MOSEFET P-type, that supplies the step-up transformer with the required current and voltage to work as switch, and as it is a control voltage component, that means it works on more than 3.75 volt at it’s gate (threshold voltage) at this voltage the current is zero, and the operating voltage more than this value, the current at it’s output is directly proportional with the input voltage and it’s output can be loaded with low impedance as that for primary of the transformer and it’s input impedance is very high (thousands of mega ohm) this means the required current at the gate of MOSFET approaches to zero.

Now, there should be a new matching circuit between the MOSFET and the output on the NE555, here has been made an implementation of a driving circuit design to the MOSFET, that consists from common emitter circuit that will invert the voltage as the required form and to make all the signal in the positive phase, and push-pull circuit that will be as a voltage follower where it’s infinity output impedance will match that input impedance of the MOSFET.

It is aimed to make the zero output of the NE555 to be 12 volt and the 12 volt to 3.75 volt, so that; the NPN transistor T1 (BC337) with the following calculations is to be used, so that two resistors are to be used at the collector Rc1 equal 2.2 kΩ and Rc2 equal 1 kΩ. So that:

When T1 is off:

$V_{c1}=V_{cc}=12volt$

When T1 is on:

$$I_c=\frac{V_{cc}}{R_{c1}+R_{c2}} \quad \text{……………..(4.6)}$$

$$I_c=\frac{12volt}{(2.2+1)K\Omega}=3.75mA$$

Where:

Ic: collector current of the transistor T1.

Vcc: the power source.

Rc1 & Rc2: two resistors on the collector of transistor T1.

$$V_{c1}=V_{(th)}=I_c * R_{c1} \quad \text{…………………..….(4.7)}$$

$V_{c1}= 3.75mA * 1K\Omega = 3.75$ volt

Where:

Vc1=V(th): collector voltage between the two Rc resistors, threshold voltage is the least required to the gate of the MOSFET.

Ic: collector current of the transistor T1.

Rc1: collector resistor.

Where $I_{b\,(max)}$= 100 mA for the transistor so that the base resistor can be calculated as follows:

According to equation (4.4):

$$I_{b(min)}=\frac{Ic}{\beta}$$

$$I_{b(min)}=\frac{3.75mA}{250}=15\mu A$$

According to equation (4.5):

$$R_{b(min)}=\frac{V_{(NE555)}-V_{BE}}{I_{b(max)}}$$

$$R_{b(min)}=\frac{12-0.7}{100mA}=113\Omega$$

$$R_{b(max)}=\frac{V_{(NE555)}-V_{BE}}{I_{b(min)}}$$

$$R_{b(max)}=\frac{12-0.7}{15\mu A}=753.33k\Omega$$

And so; $113\Omega \langle R_b \langle 753.33k\Omega$

In the project it is chosen as (R_b=4.7 kΩ)

These voltages will be applied to the input of the push-pull emitter follower that will increase the current only, and the voltage will be the same of the input in the same phase. In the case that push-pull load is zero (if the MOSFET is damaged) we can protect the push-pull transistors by a minimum collector resistor (Rp) that can be calculated as:

$$R_{b(min)} = \frac{V_p}{I_{p(max)}} = \frac{12}{800mA} = 15\Omega$$

$R_p \geq 15\Omega$, it has been chosen as (R_p=22Ω)

R_D : Will be explained in the step-up transformer and Voltage regulators circuit.

4.2.6 Step-up transformer and Voltage regulators circuit

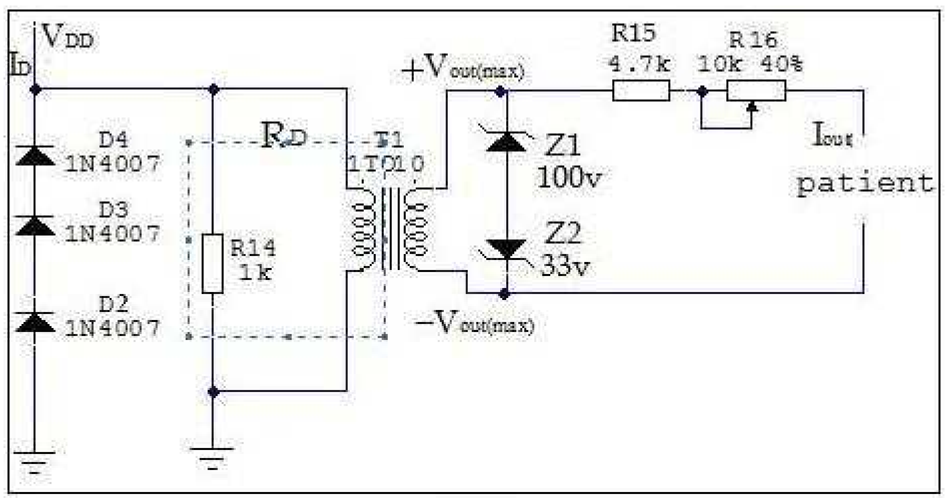


Fig (4.9): Elevator transformer and Voltage regulators circuit

First, the drain resistor should be chosen of a value that is more than the minimum limit $R_{D(min)}$ according to the following equation:

$$R_{D(min)} = \frac{V_{GS(on)} - V_{DD}}{I_{D(on)}} \text{……………………..…(4.8)}$$

$$R_{D(min)} = \frac{(11.3 - 0.0) \text{ volt}}{10 \text{ Amper}} = 1.13\Omega$$

So R_D should be more than 1.13 Ω ($R_D \geq 1.13\Omega$), this resistor will appear in the design as a combination of resistors, it should be known that the maximum current and voltage that can be applied to the patient's skin is 100 mA, 100 volt. That data will be used in the calculation; R_D will be actually as according to the following calculations at the maximum power:

$$S_{in} = S_{out} \text{………………………………..…….(4.9)}$$

Where:

S: complex power.

S=I*V………………………..……..(4.10)

$$I_{in} * V_{in} = I_{out} * V_{Tout}$$

Where:

$I_{in} = I_D$

$V_{in} = V_{DD} = 12$ volt

$I_{out} = 100$ mA

$V_{Tout} = 120$ volt

Then the equation will be:

$$I_D * V_{DD} = I_{out} * V_{Tout}$$

$$I_D = \frac{I_{out} * V_{Tout}}{V_{DD}}$$

$$I_{D(max)} = \frac{100\ mA*120\ volt}{12volt} = 1Amper$$

$$R_D = \frac{12volt}{1Amper} = 12\ \Omega$$

It is an acceptable value since R_D grater than 1.13Ω, now if a resistor of 1kΩ (R14) was used in parallel for safety aims, this value (RD) will not change.

The negative part of the final wave comes by a free wheeling diode; the drained current continuity into the primary is provided by free-wheeling diodes. These diodes allow recapture of the energy stored in the in inductor (the primary) during off-times of switching process. Thus, when the MOSFET transistor switch goes into its non-conductive state, the sudden collapse of the magnetic field in the inductor induces a back-EMF which is so polarized as to continue the current circulating through the primary part; in order to do so, the current must complete its path through the wheeling diodes, which provides the final wave form with its negative phase.

At the secondary of the transformer, the value and wave form of the final signal that have the range of (-33 to +100volt) is needed, for this ZENER diodes are used to cut the voltage that exceeds its value.

Now the Voltage regulators circuit; maximum current is 100mA **without effect on the ventilation and heart**, and the safe limit and maximum voltage is +100VAC in the positive phase and -33VAC in the negative phase, so two Zenor diodes (Z1, Z2) are put in the shown combination [Fig (4.9)]; this means no more voltage can reach the patient circuit than these voltages.

The voltage necessary for electrocution depends on the current through the body and the duration of the current. Using Ohm's law, Voltage equal Current multiplied by Resistance, the current drawn depends on the resistance of the body. The resistance of human skin varies from person to another, and fluctuates between different times of the day. In general, dry skin is a poor conductor that may have a resistance of around 100 kΩ, while broken or wet skin may have a resistance of around 1 kΩ.

The patient skin resistance R_{body} and protection resistor 4.7kΩ (R15) in series combination put at the end of the circuit, where the effect of the current starts from 5mA, so maximum current in this case that the body resistance approaches to minimum value (1kΩ) and (4.7kΩ) as a constant resistor, assume the adjustable current and voltage variable resistor (R16) is zero, which is also connected in series with those mentioned before.

The safety calculations according to equation (4.11) Ohms' law:

$$V = I * R \quad \text{……………………………………} (4.11)$$

The maximum current:

$$I_{(max)} = \frac{V_{out\,(max)}}{R_{15} + R_{body(min)}}$$

$$I_{(max)} = \frac{100\ \text{volt}}{(4.7+1)k\Omega} = 17.5mA$$

Then the minimum voltage across the skin will be:

$$V_{out(min)} = I_{(max)} * R_{body(min)}$$

$$V_{out(min)} = 17.5mA * 1\ k\Omega = 17.5\ volt$$

Where

The minimum current:

$$I_{(min)} = \frac{V_{out(max)}}{R_{15} + R_{body(max)}}$$

$$I_{(min)} = \frac{100\ volt}{(4.7+100)k\Omega} = 955\text{«}A$$

Then the voltage across the skin will be:

$$V_{out(max)} = I_{(min)} * R_{body(max)}$$

$$V_{out(max)} = 995\text{«}A * 100k\Omega = 95.51\ volt$$

So as shown in the calculations, all the project’s values are in the range of patient’s safety.

4.3 Total Practical Circuit to be implemented

The following Fig (4.10) represents the total practical circuit that is to be implemented within the second semester.

In the matching activity between IC1 and IC2, R13 and C1 are used to maintain the required triggering waveform to form and to match the charging and discharging of the mentioned capacitor.

The time constant (τ) can be calculated according to equation (4.12):

^{2} = R * C ……………………………….…..(4.12)

^{2} = R13 * C1

^{2} = 22k * 1n = 22 «sec.

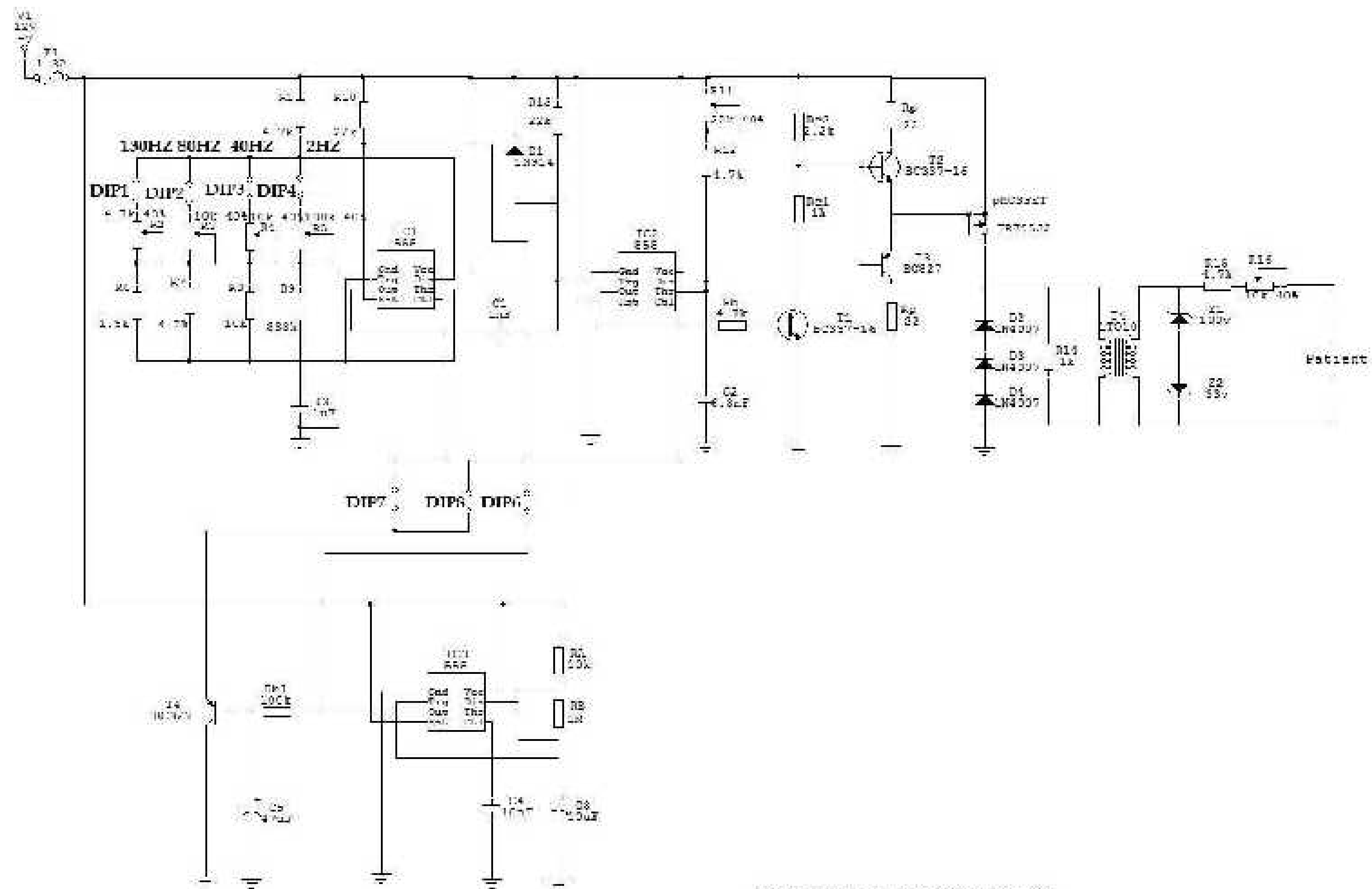
Where:

^{2} : is the constant time

$\tau = T_{total} = T_{on} + T_{off}$.

D1 is a free wheeling diode that is used here in parallel with R13 for protection of reverse currents.

The capacitor C4 is a bypass capacitor connected to pin 5 of the IC3, and is usually inserted according to instructions available in data sheets. And its value is equal to 10nF or more.



Fig(4.10):Total Practical Circuit

5

System Implementation and Testing

5.1 Actual Project Implementation

5.2 Testing & Results

Chapter Five

System Implementation and Testing

5.1 Actual Project Implementation

Practical implementation of the project have been done in the second semester, and this implementation started by implementing each individual subsystem and after completing this implementation, the individual subsystems are connected together to accomplish the project as one unit.

5.1.1 Multi-frequency generator circuit

The Multi-frequency generator circuit as it was shown in Fig (4.3) has been connected as the first component in the project, shown as implemented practically in its final state.

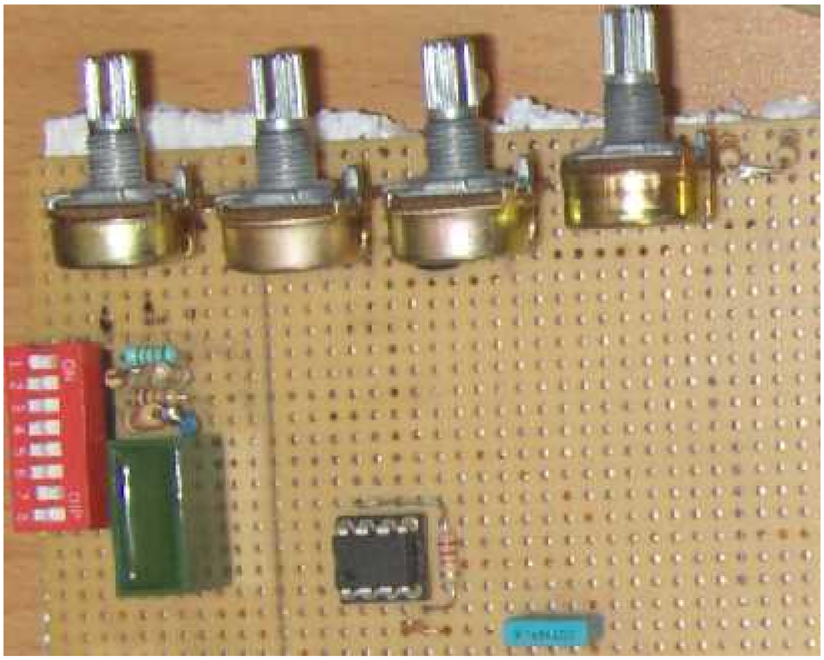


Fig (5.1): Multi-frequency generator figure

Practically R_2 =4.7 kΩ not found as a variable resistance as so it is replaced by 5 kΩ, the result differ slightly (not affect) from calculated but in the safely range. And many resisters made in series to get the required value.

5.1.2 Time Control Circuit

The Time Control Circuit had been connected as the second component in the project which takes it input signal from the Multi-frequency generator circuit output.

Fig (5.2): Time Control Circuit figure

The capacitor C_2 = 6.8nf replaced by two capacitors 3.3 in parallel the values differ slightly:

T=1.1*R*C, the T(min) =35.16ms→=34.12ms & T(max) =199.72ms→193.84ms.

5.1.3 Driving transistors circuit (BJT & MOSFET)

The Driving transistors circuit had been connected as the third component in the project which takes it input signal from the Time Control Circuit output.

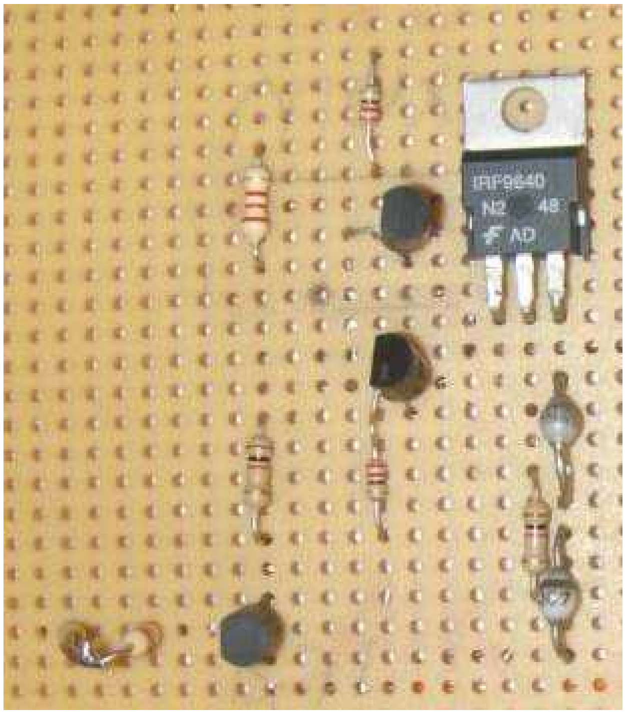


Fig (5.3): Driving transistors figure

The MOSFET need 3.75V to start its work at high frequency, this made by voltage divider, and matched with the previous circuit by push-pull circuit (voltage follower).

5.1.4 Step-up transformer and Voltage regulators circuit

The Step-up transformer and Voltage regulators circuit had been connected as the fourth component in the project which takes it input signal from the Driving transistors circuit output.

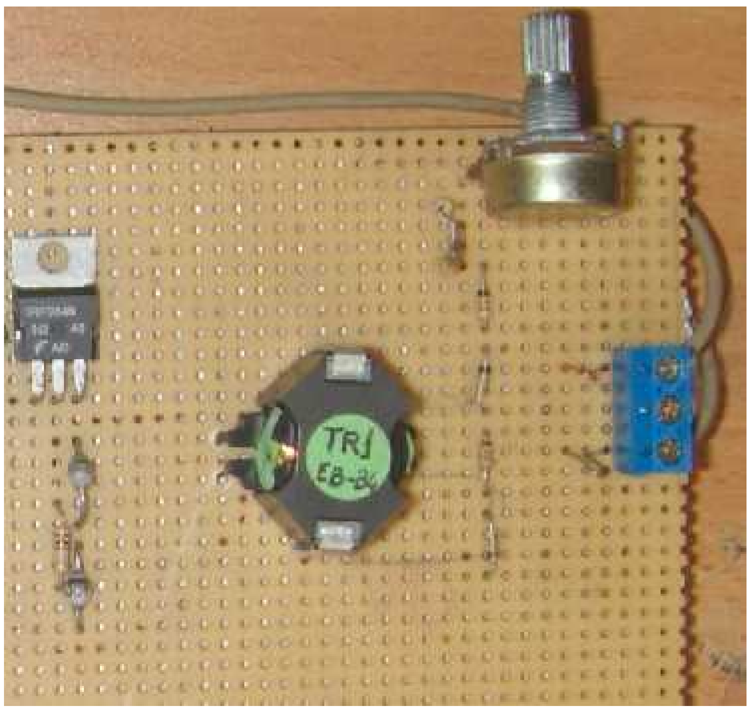


Fig (5.4): Step-up transformer and Voltage regulators figure

The free-wheeling diodes (1N4007) practically for more safety aim is implemented two not three (3.3V→ 2.2V) at the primary side of the transformer. The 100V ZENER diode not found in the local markets so replaced by three diode of 33V in series.

5.1.5 Mode circuit

The Mode circuit had been connected as the fifth component in the project as seen in Fig (5.5).

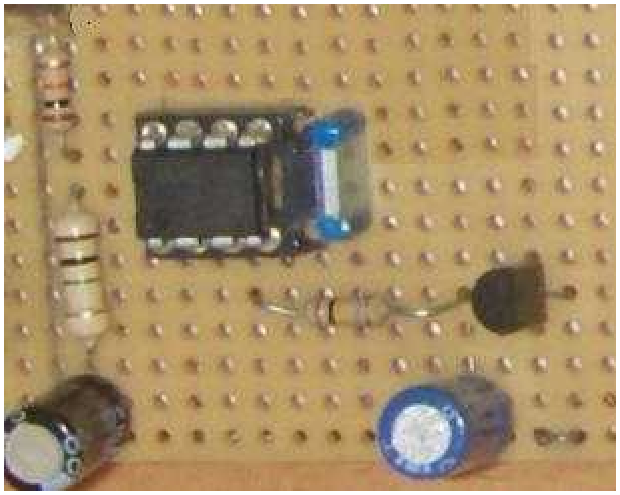


Fig (5.5): Mode circuit figure

which its output in the **continuous pulses mode** not connected to the system, and in the other three modes connected to the system, with the Multi-frequency generator circuit at its pin 4 to get **rest mode** and at its pin 5 **voltage mode**, and with the Time Control Circuit at its pin 5 **variable duty cycle mode (Time mode).**

5.1.6 Total Practical Circuit implemented

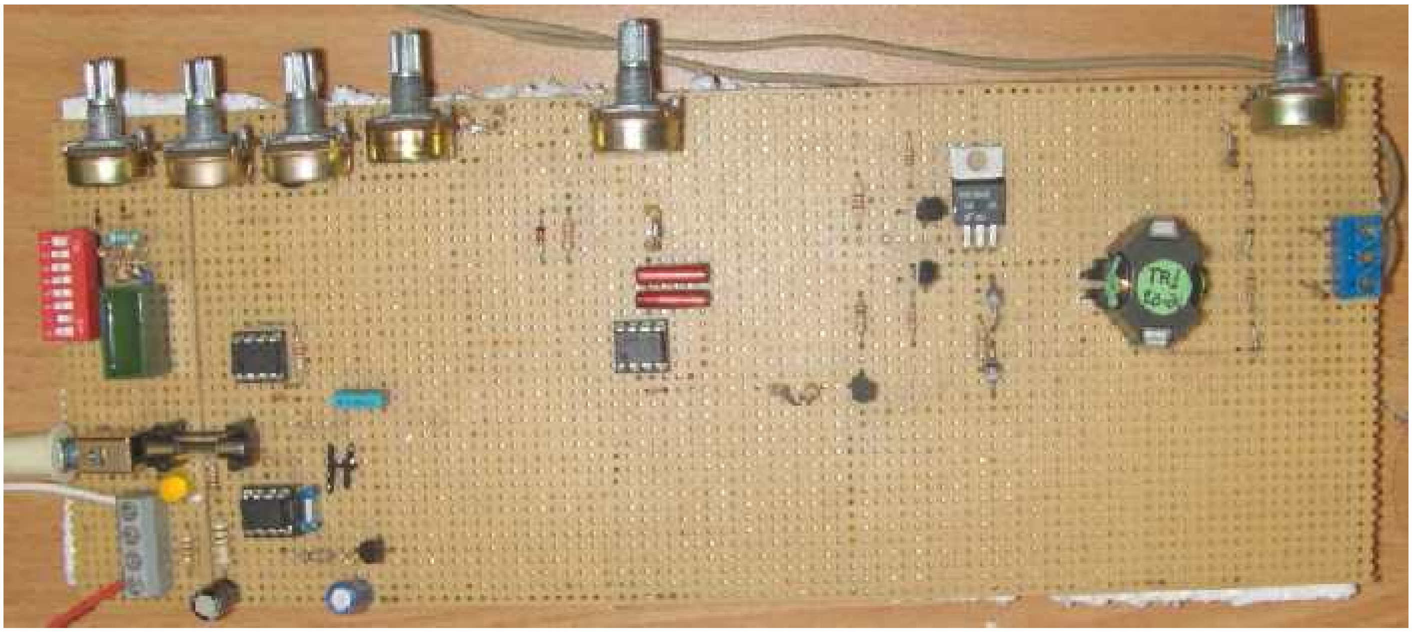


Fig (5.6): Total Practical project figure implementation

The dip switches practically still but its function taken by new practical switches

5.2 Testing & Results

After implementing all individual subsystems and connecting them together, testing operation is done to get the results of each effective subsystem and the following results appear as follows:

5.2.1 Multi-frequency generator circuit

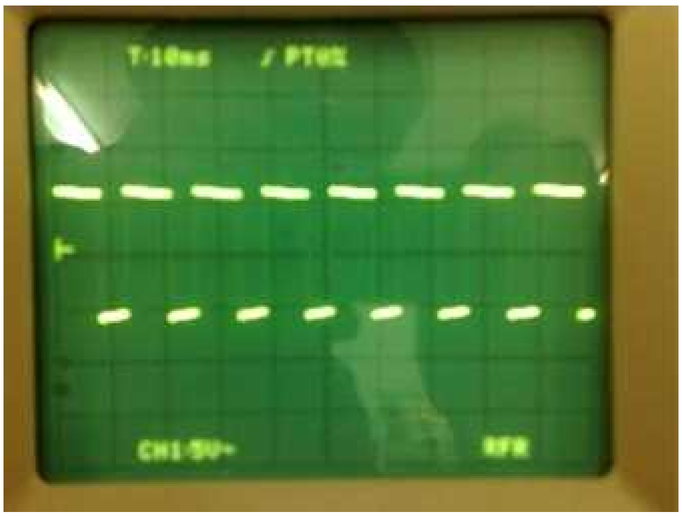


Fig (5.7): Multi-frequency generator signal

The shown square pulses signal taken randomly for the circuit that follow the equation (4.1): $f = \frac{1}{0.693 * C * (R_A + 2 * R_B)}$, R_A=4.7kΩ, R_B=R_{FIXED}+$R_{VARIABLE}$, C=1μf

5.2.2 Time Control Circuit

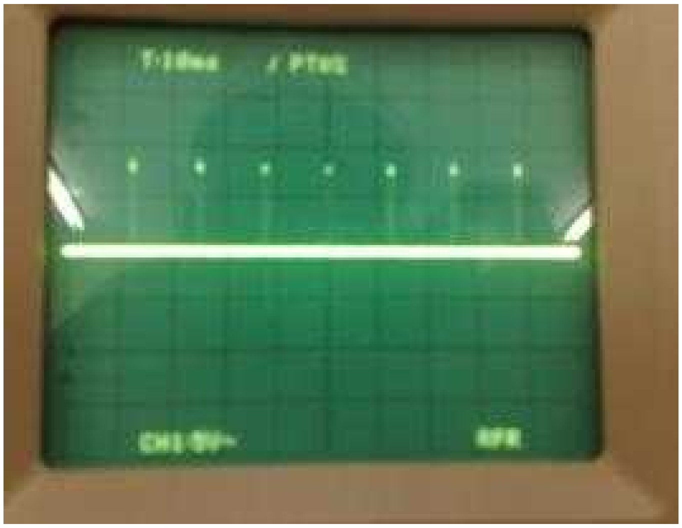


Fig (5.8): Time Control Circuit signal

In this signal time varies as R11 adjusted according to equation (4.2):-

T = 1.1 *R *C ; T (min) = 34.12 ms, T (max) = 193.94 ms

5.2.3 Driving transistors circuit (BJT & MOSFET)

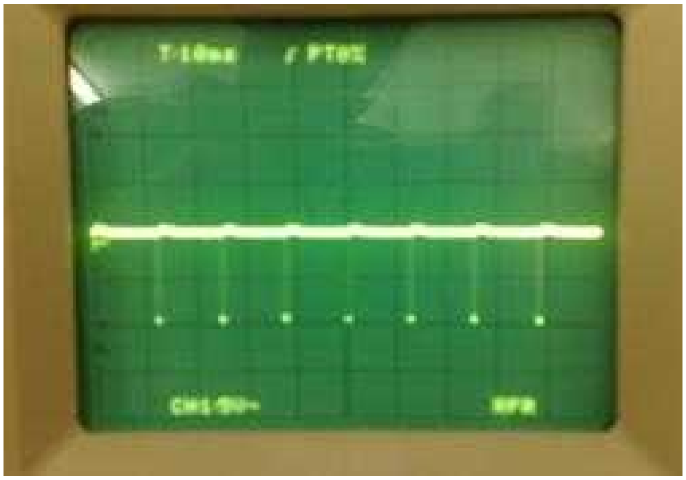


Fig (5.9): Driving transistors circuit signal

5.2.4 Step-up transformer and Voltage regulators circuit

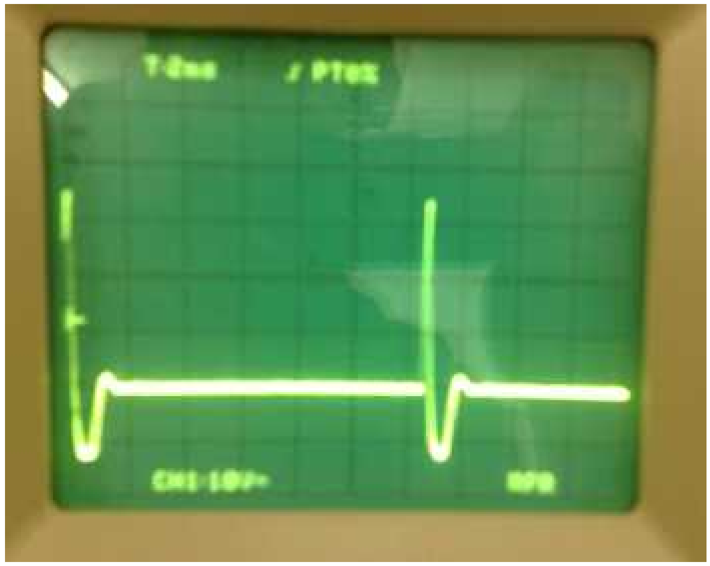


Fig (5. 10): step up transformer and Voltage regulators signal

This signal is the final signal of the project and it is taken when it was applied at the body skin (peripherals).

High peak voltage applied=100V- I*[R15+R16 (variable)]

Low peak voltage applied =22v - I*[R15+R16 (variable)]

The variable resistor 10 kΩ adjusted according the sensitivity of the body place.

6

Conclusion and Future Work

Chapter Six
Conclusion and Future Work

6.1 Conclusion

In this project thanks to God, there had been accomplished a design and implementation of an Functional Electrical Stimulation Device (FES), which is used to compensate for Nerves Signal when it suffers from a partial or complete paralysis, so as to get the electrical activity of muscles to prevent shrinking using special electrodes that is fastened on the patient skin.

The project gives the capability of adjustment of frequency, current amount, electrical voltage and the type of electrical stimulation in a way to fit the sensitivity, place and degree of paralysis that the patient suffers from, and it is usually used in the cases of Physiotherapy in clinics and hospitals.

This documentation includes the detailed design of the project and the stages which were followed in order to reach to the desired goals of the project, those are represented as designing and studying each partial stage of whole project's stages each one aside, then to collect or assemble these stages as a one integrated unit.

The project contains several results, namely:

The project shows that FES gives signal that can be used to activate the damaged muscles and to prevent muscle atrophy, and this idea is very useful in the physiotherapy.

555 IC, easy used device. So we recommend using it in graduated projects, and also focusing on it in some under graduated courses.

To use this device of the project, first step the EMG signal can be taken and analyzed to diagnose many muscle disorders, according to the electrical activity of those muscles.

FES signal changed in its values (voltage and current) according to sensitivity that depends on the type and the place of the muscle, and it also depends on the situation of the muscle.

FES signal is a very critical signal in amplitude and frequency, so we must be very accurate when dealing with this signal, because it needs very high safety system of correct and safe values of voltage and current.

6.2 Future Work

The project main idea is a very interesting one, and also open many doors in the medical field to help special needs people even it is not a new idea.

The researches about this idea must be developed, to get more opportunities about the ways of controlling and many other things depending on this idea.

The project can be developed in the future to be digital, by taking its setting values and converting it to a digital values.

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6. *http://www.dinf.ne.jp/doc/english/Us_Eu/conf/resna96/page109.html#main*
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APPENDECIES

1. Appendix A (Definitions).

2. Appendix B (Used Programs).

3. Appendix C (Data Sheets).

Appendix A (Definitions)

Term	*Meaning or Definition*
Functional Electrical Stimulation (FES)	**Technique of generating electrical pulses, that in the place of the central nervous system to get the activity for the muscles.**
Paralysis	**Partially or completely nerve damage**
Sarcolemma	**A plasma membrane covering the muscle cell.**
Transverse Tubules	**Tunnel-like extensions pass through the muscle fiber from one side to the other one in transverse sections through the diameter of the fiber.**
Sarcoplasm	**Cytoplasm is present inside the muscle cell.**
Mitochondria	**The part of the muscle cell that is responsible for generating or producing energy inside cell.**
ATP "*A*denosine *TriP*hosphate"**	**chemical substance used for contracting muscles, transporting substances across the cell membranes, and moving structures within the cell**

Appendix B (Used Programs)

1. Microsoft Word: this program was used for writing the documentation of our project. It is a very easy program to deal with; also gives many opportunities for controlling the options of writing.

2. Microsoft Project: this program was used for generating the scheduling table, and also producing the timing plan. It is an important program and every body must have even little information about this program.

3. Microsoft Visio: this program was used for generating the block diagrams implemented inside this project. This program gives also excellent choices to draw and generate block diagrams.

4. Circuit-maker: this program was use for drawing the schematic diagrams of the subsystems in our design

5. Math Type: is an intelligent mathematical equation editor designed for personal computers running Microsoft Windows.

6. 555 Timer PRO: provides an array of design wizards, circuit blocks and information panels that facilitate the use of the 555 timer. Component value calculations for the 555 take into account the supply voltage, timer fabrication (CMOS or Bipolar), and, where appropriate, load currents.

Appendix C (Data Sheets)