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Microcontroller based Muscle Stimulator

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Abstract: Muscle stimulation devices are used to restore or maintain the muscle activity of paralyzed patients who suffer from musculoskeletal injuries for several decades. In this paper, a portable and low-cost versatile muscle stimulator for two channel TES applications is described. The microcontroller-based programmable stimulator with two bipolar output channels send arbitrarily specified electrical pulses to the element in the electrode array for enabling the complex schemes of muscles. The amplitude and phase of each pulse in the stimulus sequence are in-dependently variable, and the two channels are independently programmable, al-lowing a wide variety of stimulus patterns. We also designed an output circuit that can provide bi-phasic, voltage-regulated, charge-balanced outputs while avoiding the electrochemical erosion of electrode due to charge accumulation, the electrodes are electrically isolated from one another to effect regional (Selective) stimulation. Selective stimulation offers greater control over the spatial pattern of muscle stimulation and may allow for increased muscle efficiency. The proposed stimulator has provided an opportunity for further study of a potential novel electrical stimulator with closed-loop stimulation paradigm suitable for a variety of FES (Functional electrical stimulation) applications, both for experimental and clinical studies.

Keywords: Muscle stimulation; microcontroller; medical device; FES applications.

I. INTRODUCTION

TES with non-invasive is often applied in the rehabilitation of stroke subjects or spinal cord injured subjects or for supporting tasks of daily living. In recent years, research has been focused on active wrist joint stabilization in C4 and C5 individuals by FES. Conventional TES is usually performed by using an indifferent and a different electrode or through pair of electrodes of the same size per channel to accomplish the stimulation. Traditionally electro-motor stimulation (EMS) has been utilized by therapists as an ancillary tool in the restoration of function in innervated weak or emaciated musculature and after enervation injuries or pathology.

Once patients are capable of voluntary muscular control the strengthening programs usually continue with voluntary exercise. Resisted voluntary exercise has been the traditional method of muscle training in muscles functioning at normal and reduced strength levels.

In transcutaneous electrical stimulation (TES), pair of surface electrodes is placed on the skin in order to stimulate motor nerves clinically. Common to all applications of surface electrodes for stimulation is that it requires a great deal of skill and patience of the user or the therapist to place the electrodes at the optimal position for the function to be performed.

It is very difficult to envisage accurately which anatomic structures will be activated for any given position and electrode configuration. For all these reasons a non-optimal electrode position and electrode size are often preferred for stimulation sessions. With this fixed spatial electrode configuration however stable reproducibility of the movements on a day-per-day base and also through electrode shifts caused by movements is a big challenge.

To solve this predicament, investigators focus their efforts on the improvement of surface FES systems with multi-electrode arrays for rehabilitation of the SCI and stroke individuals. Recently array electrodes were proposed to improve the efficiency of such TES systems. Array electrodes consist of multiple elements which can be individually activated to form a virtual electrode of random size and position. The location and dimension of the activated region (virtual electrode) can be dynamically changed. The dynamic version of electrode size and position helps to simplify the use of electrical stimulation systems and to increase their clinical efficiency [1].

Electrical stimulators are essential in FES for eliciting electrical stimulation. Many electrical stimulators have been developed for various FES applications from the simplest stimulators with a single channel to the most multifaceted ones with programmable multichannel. Computer-controlled or microcontroller-based programmable stimulators with multi-channel outputs are necessary to develop complex schemes of muscles. In recent years portable stimulators have played a significant role in clinical studies for improved patient acceptance.

Neuro stimulation Stimulators are designed to direct either current or voltage. With voltage-regulated stimulation the stimulator output is a voltage and therefore the magnitude of current delivers to the tissue is dependent on the impedance at the electrode interface. With the apply of surface electrodes the impedance at the electrode-skin interface increases as the electrode dries or loses contact with the skin. As electrode impedance increases the current delivered with a voltage-regulated stimulator decreases therefore possibility of skin burns due to high current densities minimizes. Therefore voltage-regulated

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stimulation is frequently used for surface stimulation applications. Besides during reversible (non-faradic) reactions at the electrode-tissue interface electrode capacitance influences the electric field transmitted to the tissue during voltage-regulated stimulation and conversely tissue capacitance bring to bear an influence during current-controlled stimulation. In recent studies complex waveforms such as quasi trapezoidal waveforms are considered for selective stimulation of nerve fibers for more specific activation of muscles. A voltage-regulated source should then be flexible to generate complex electrical waveforms. In this paper, we describe a multi-channel programmable stimulator that allows programmed pulse patterns to be sent to four isolated electrode elements in the fixed electrode array which enable a dynamic change of the stimulated target. The parameters of each pulse including pulse-shape amplitude and inter-channel phase are independently programmable.

II. BASIC PRINCIPLE OF REHABILITATION STIMULATOR

In general physiology nerves carry messages from the brain to the muscles and they as well carry messages from sensors back to the brain. They are the 'wires' of the body. Nerves are similar to an extended bag of salty water. The outer surface of the nerve is positively charged or In other words it is polarized. That charge is vanished when the top end of a nerve cell is stimulated. This is called depolarization. The wave of depolarization runs from the brain to the muscle. The nerve swells out close to the muscle at the neuro-muscular junction. The nerves cell releases a special chemical called Acetyl-choline into the gap between the nerves and the muscles. Muscles have a polarized membrane nearby them that is very similar to nerves. There are particular receptors built into this membrane. When Acetyl-chorine attaches to a receptor the membrane is depolarized. The wave of depolarization runs over the muscle fiber and causes it to contract. A neuromuscular junction (NMJ) is the synapse or junction of the axon terminal of a motor neuron with the motor end plate, the highly-excitable region of muscle fiber plasma membrane accountable for initiation of action potentials across the muscle's surface ultimately causing the muscle to contract. Stimulation of nerve impulse can be initiate by an electrical stimulus. To achieve this varying current of adequate intensity should be applied. The plasma membrane of the nerve fiber form a resistance which lies in series with the order tissues therefore a potential difference is establish across it as the current flows. The surface of the membrane nearer to cathode becomes negative relative to other surface. On the side of the nerve closer to anode this increases the resting potential difference across the membrane but on the side of the nerve closer to cathode the additional charges are of opposite polarity to those present on the resting membrane and so reduces the potential difference across it. If the potential difference falls lower the level at which the membrane becomes permeable to sodium ions these ions start to enter the axon and initiate series of events therefore a nerve impulse is initiated. A nerve stimulator supplies electrons to depolarize a nerve. The number of electrons supplied per stimulus is equal to the current. To make sure that the nerve is completely depolarized we keep winding up the stimulating current until the muscular response does not increase and then we add another 10%. This is called the supra-maximal stimulus. At this point we assume that the nerve supplying the muscle is completely depolarized. As a result the muscle must be maximally stimulated by the nerve. The muscle contraction that results must also be maximal. The muscle response to the stimulus is called a twitch. The amount or strength of movement is called the twitch height. To allow comparison of twitches it is necessary that this current remains constant to ensure this nerve is always completely depolarized. Fig.1 shows the generalized block diagram for stimulator.

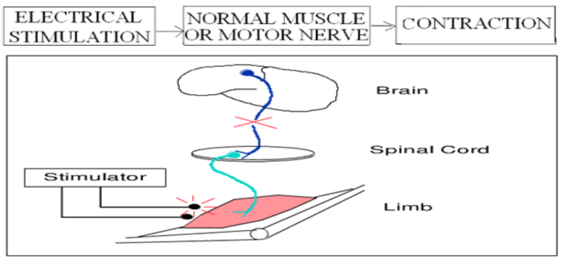

Figure 1: General principle of stimulation

III. HARDWARE DESCRIPTION

Figure 2 illustrates the basic block diagram of Microcontroller based rehabilitation stimulator. The fundamental components are the microcontroller, Square and Triangular generator, LCD Display, transformer, pulse selector switch, potentiometer. Microcontroller is the most important board which controls timer circuit and the time for which circuit gets ON. Using the selector switch, we can select type of current to be applied. Then we can select the frequency and duration of the pulses. LCD display will indicate the frequency or duration of the pulses. The potentiometer is used to control the intensity of the current. This intensity varies from patient to patient. The current thus generated will be given to patient using suitable electrodes.

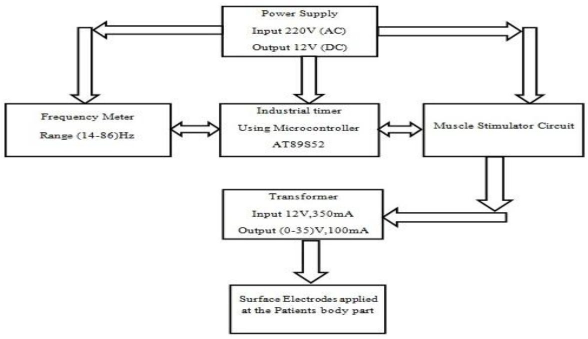

Figure 2: Functional Block Diagram of Rehabilitation Muscle Stimulator

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IV. INDUSTRIAL TIMER

Industrial timers can be constructed using discrete components including up or down counters and timers. However to incorporate different facilities like setting the count, start, stop, reset and display these circuits would require too many ICs and discrete components. A detail of industrial timer design can be seen from reference [19]. On the other hand, a microcontroller-based industrial timer can be programmed and it is used as a timer, counterand time totalizer. Here is a simple design based on 40-pin Atmel AT89S52 microcontroller that performs countdown operation up to 9999 minutes/second with four 7-segment displays showing the actual time left. The relay energizes as you press the start switch and remains on till the countdown reaches '0000.' Four tactile push-to-on switches are used to start or stop and tochoose either minutes or seconds and set the initial value for count-down operation.

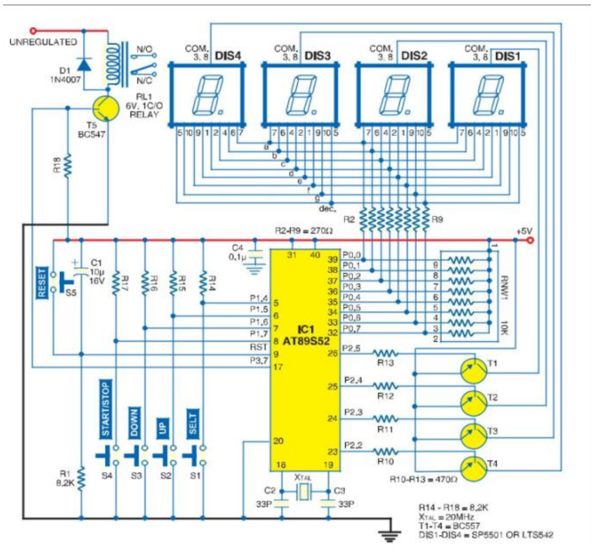

Figure 3:Circuit Diagram of Industrial Timer

A. Operation

Switch on the circuit using ON/ OFF switch S6. The microcontroller is reset by power-on-reset and then timer is in seconds mode. The 'select' key selects the mode between 'seconds' and 'minutes.' This is displayed as '0' for seconds and '1' for minutes on the hundreds digit display (DIS3) respectively. 'Up' key increments the time setting in seconds and minutes. 'Down' key decrements the time setting in seconds and minutes. After setting the desired time with the help of 'up' and 'down' keys press 'start' key. This energises the relay. The timer counts down for the set time and once the display becomes zero the relay deenergizes. The timer will stop before preset time by pressing 'start' key again.

B. Microcontroller AT89S52

The AT89S52 is a low-power, high-performance CMOS 8-bit microcontroller with 8K bytes programmable Flash memory. The device is manufactured using Atmel's high-density nonvolatile memory technology. The detailed pin diagram, architecture and other relevant details of AT89S52 can be seen from reference [20].

V. MUSCLE STIMULATOR

Fig.4 shows the circuit diagram of Muscle stimulator.

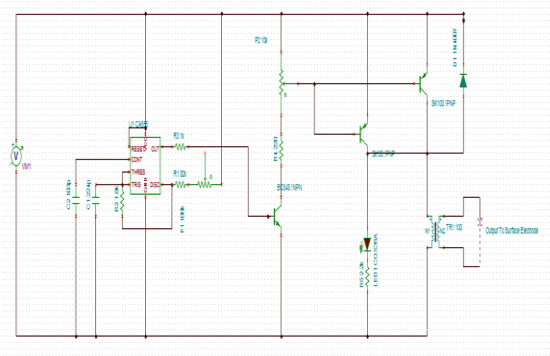

Figure 4:Muscle Stimulator Circuit Diagram

As we press 'start' key red colour LED on industrial timer circuit glows which indicates that Timer has started. This energises the relay and when relay is energized muscle stimulator circuit gets ON. The timer counts down for the set time.

As the muscle stimulator circuit gets ON we select which pulse(Square or triangular) is to be given for stimulation by 'Selector switch'. Square or triangular pulsed is fed to base of transistor BC548 which is N-P-N transistor whose emitter is connected to negative supply(see fig.8).When signal is high transistor gets ON and then when we start increasing intensity by tuning potentiometer, then this negative voltage is fed to base of transistor SK100 whose emitter is connected to V_{cc} and collecter is connected to output transformer.

Since SK100 is P-N-P transistor so it gets ON as negative voltage is fed at its base.SK100 is connected to the driver stage so when it gets ON it drives the output transformer and output transformer given this signal to the Surface electrodes connected at the output. This surface electrode is applied to the patients muscle and hence the muscle gets stimulated. Output voltage is controlled by intensity control knob.

VI. RESULT

The benefit of Neuromuscular Stimulator is the application of an electrical stimulus for use in muscle rehabilitation. A wide range of neurological and orthopedic diagnoses will benefit from the use of Rehabilitation Stimulator.

This muscle stimulator is applied for Rehabilitation purpose usually therapeutic purpose and applied only externally. Result is obtained when the surface electrodes are applied to the arm is given in following table.

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TABLE I
OUTPUT SPECIFICATION

Input Voltage to output transformer	0V-12V
Output Voltage	0V-35V
Output Current	120mA-155Ma
Output Frequency	14Hz-86Hz

VII. ANALYSIS OF OUTPUT ON CRO

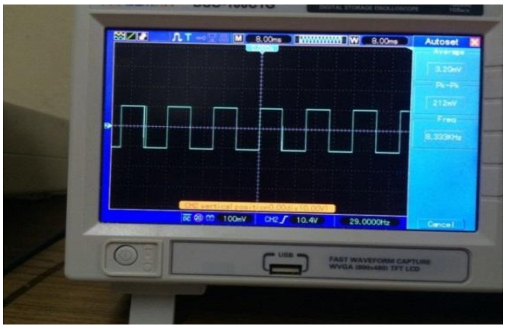

Figure 5(a)

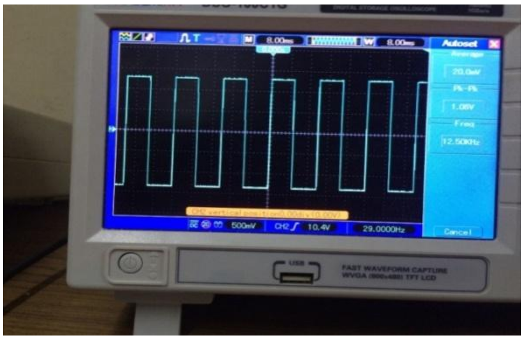

Figure 5(b)

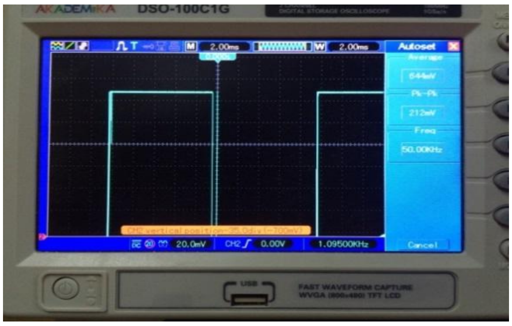

Figure 5(c)

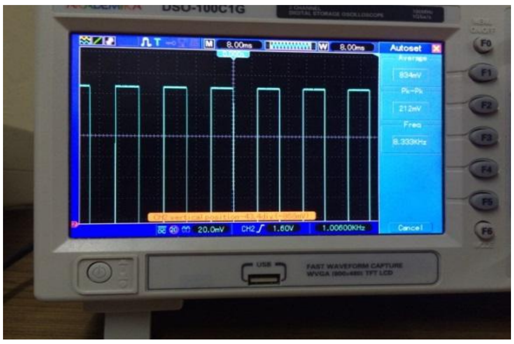

Figure 5(d)

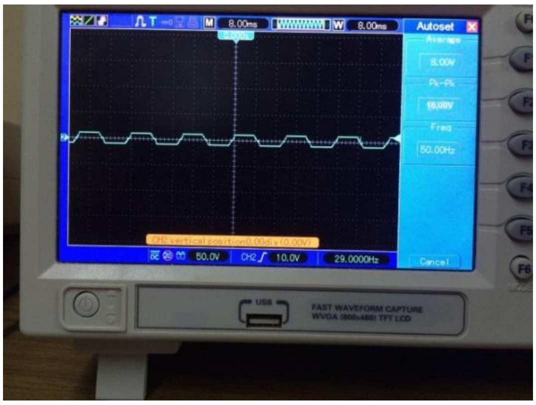

Figure 5(e)

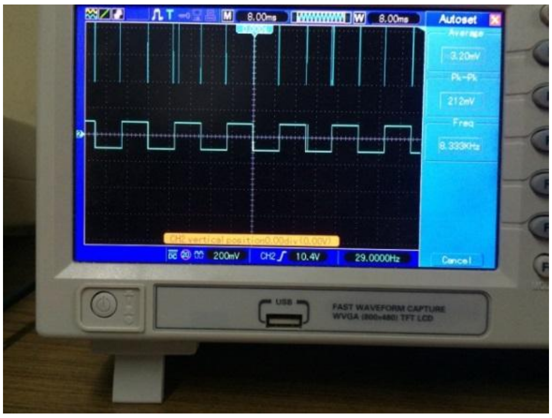

Figure 5(f)

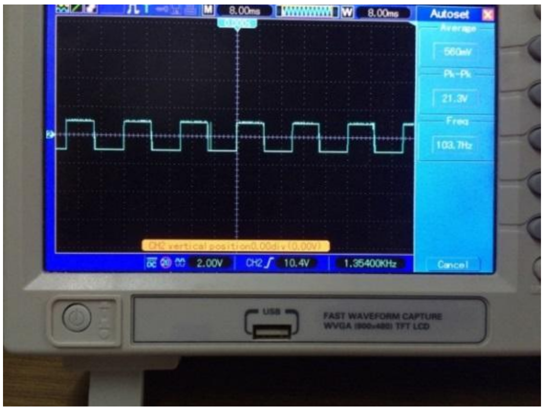

Figure 5(g)

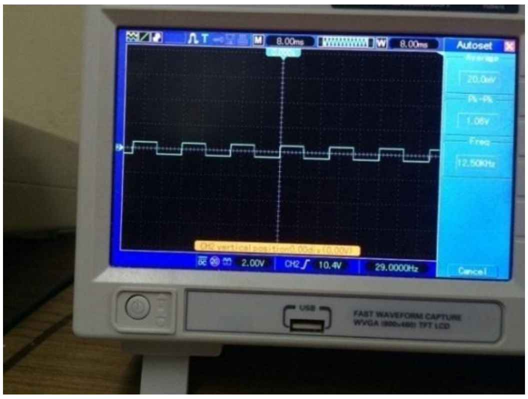

Figure 5(h)

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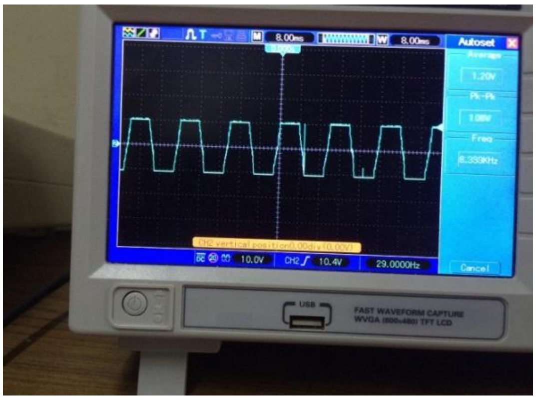

Figure 5(i)

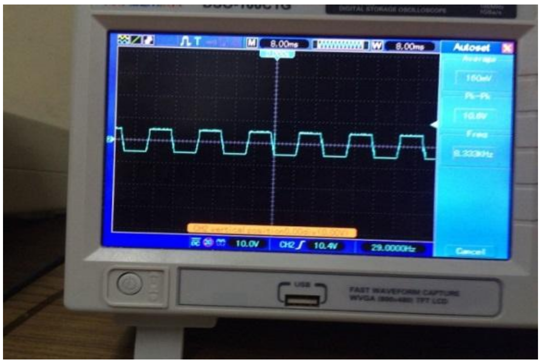

Figure 5(j)

Figure 5:Pulsed Output:(a)V=3.20mv,(b) V=20.0mV, (c) V=644mV, (d)V=834mV,(e) V=8.00V, (f) V=3.20mV,(g) V=560mV, (h) V=20.0mV, (i)V=1.20V, (j)V=160mV

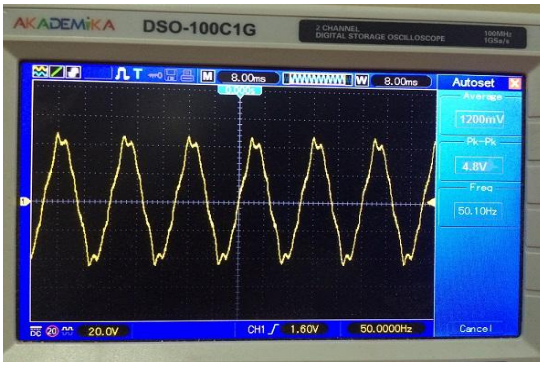

Figure 6(a)

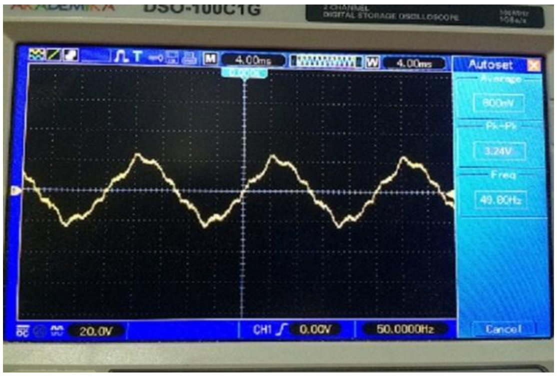

Figure 6(b)

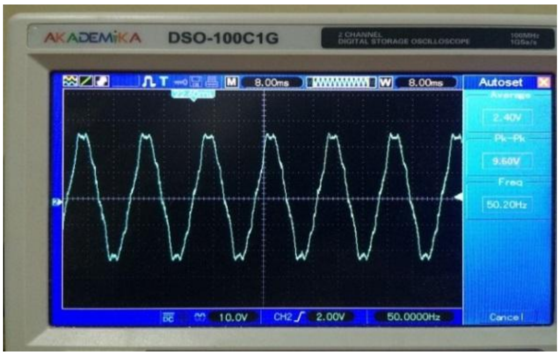

Figure 6(c)

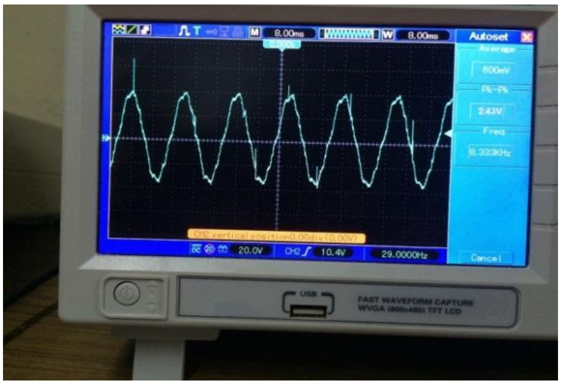

Figure 6(d)

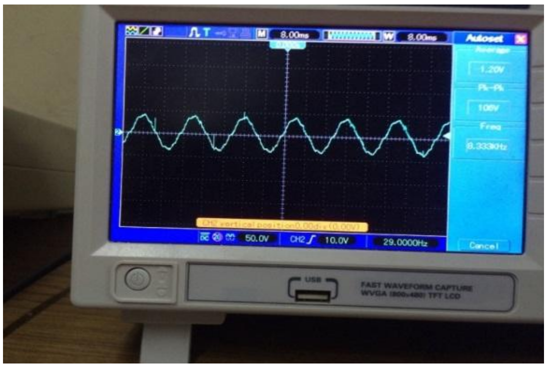

Figure 6(e)

Figure 6(f)

Figure 6: Triangular Output: (a) V=1200mV, (b) V=800mV, (c) V=2.40V, (d) V=600mV, (e) V=1.20V (f) V=9.10

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The output voltage of 555 timer electro muscular stimulator circuit is 0-35 volts positive and but the output current is very small and there is no electric shock danger. Rehabilitation stimulator generally considered safe, but improper application can cause problems. It should not used near wet areas. It should be avoided or used with caution by the following population:

1. People who had medical implants such as pacemakers or spinal cord stimulators, unless approved by a physician.
2. People with certain heart conditions. It may alter the heart rate of some people.
3. People with epilepsy or other seizure disorders. It may increase the risk of seizures in some cases, such as if the electrodes are to be used on scalp or face.
4. Women who are pregnant, unless strictly supervised by physician. Pregnant women are especially advised not to use stimulator over abdomen or pelvic region. The effect ofstimulator on fetal health is unknown and has not been studied.

Additionally, Stimulator should not use in the following areas of the body:

1. Over the carotid sinus which is a large blood vessel in the neck just below the jaw.
Application of stimulator there could cause blood pressure to drop.
2. Over throat. Application of it there could cause laryngeal muscle to spasm.
3. On broken or damaged skin and over the eyes or mouth.

VIII. CONCLUSION

A programmable two-channel stimulator in TES applications has been developed in this work. The developed device stimulates nerves, muscles and cells via surface skin by low electricity. The most important technical features of the stimulator are low power consumption, comfort and simple programming with pushbuttons.

Although the proposed design of FES system made it possible to provide some mobility and functions to the partially paralyzed patients but it inherent multiple limitations. To restore the lost function safely, completely and efficaciously, further research is needed. There are multiple challenges that need to be met before it can be utilized by the fully paralyzed population on a regular basis.

In future, experimental models of FES systems with implantable electrical stimulators and portable microprocessors can be investigated for better results. Central Pattern Generators (CPG), Hybrid Neuro-prosthetics are few other fields that need exploration. These and other further improvements in the FES technology would help augment its role as a valuable therapeutic and rehabilitative technique.

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