

# Design of Functional Electrical Stimulation System

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**Abstract:** Functional electric stimulator (FES) is a device which is used to apply electric pulses to a muscle to trigger the movement. FES is most effective in treating conditions like foot drop, Spinal cord injury and rehabilitation. FES helps to restore mobility by applying electrical pulses to the paralyzed muscles so as to enhance that person's ability to function and live independently. Existing FES is of high cost thus not affordable by most of the people in India. FES thus designed is cost effective and is focused on rehabilitation. It has both current and voltage regulated stimulation system. It has dual microcontrollers. Arduino due is used as the master controller. It takes various parameters from the slave devices and triggers the device accordingly. It also controls the device by mapping input on to the output. Arduino Uno is used solely for the generation of the stimulation signal. Serial peripheral interface (SPI) and I2C protocols are used to communicate between master and slaves. Due to its cost effectiveness it will be of great use for middle class community.

**Keywords:** FES, NMES, Stimulation, voltage regulated, current regulated.

## Introduction

Neuromuscular Electrical Stimulation or NMES is the phenomenon of invigorating the motor neurons, to actuate immobilized muscles. [1]

FES includes the utilization of NMES to actuate muscles in a particular request and extent to finish a practical errand. [1] FES includes applying an electrical current, with electric discharge on or near by the nerve filaments, to evoke an activity, creating a tissue constriction that can be adjusted by altering stimulating values, keeping in mind the end goal to help re-establish functional movements.[2] [3]

The fundamental plan of surface FES framework comprises of three essential segments: incitement console unit, electrical Incitement unit and cathodes. The consoler sends impulse signals to incitement unit, producing electric pulses and conveys the signal to the target site by means of cathode and anode, utilizing a fitting incitement band. Ordinary FES gadgets comprise of compact invigorating unit, pedal tuner & 2 external electrodes with associated connections. Late reviews have demonstrated FES frameworks with incitement console unit that depend on electromyography (EMG) criticism and electric incitement unit in light of simple envelopes (trapezoidal/rectangular) are better than traditional FES gadgets.[4]

External incitement is one of the oldest form of electro-therapy. In the 18<sup>th</sup> & 19<sup>th</sup> hundreds of years, external electrical incitement was connected to mitigate different diseases, strengthening weakened muscles, etc. Electrodes connected to the target area is in the form of flat surface made out of metal aided with gel to support contact. Among usually used materials are stainless steel, silver-silver chloride, Pt or Au coated plate. The terminals are of different geometries, complying with the body contour. Numerous cathodes and anodes are self-glue or are tied directly onto the target area. Suction terminal, like ECG terminal is additionally utilized. Adaptable cathodes which constitutes of elastic containing carbon and silicon or any other suitable polymer is additionally accessible.

Transformation of external states of skin and contrasts in situating of incitement plate might prompt changeability in attributes. For non-prying transitory electric therapy, the electrode give simplicity of utilization and don't require broad administrator abilities. [5]

External FES: The placement of impulse inducing plates plays a very pivotal role in order to achieve required movement. Popularly followed method is to use external electrodes on target area. The patient experiences a sensation similar to sharp tiny points being touched against the skin as soon as the impulse passes by, but later on, with gradual use of it, people get accustomed to this sensation.

Insinuate/Internal FES: Here the electrodes are lodged inside the body onto the required site. The FES gadget enacts the embed via a remote radio wire which lies outside the body.

Lodged gadgets expel the exigency to connect and place incitement plates every time the device is used. They additionally essentially lessen/take out the prickle that occur in case of external incitement.

## Background

**Neuromuscular node:** A neuromuscular node (or myoneural node) is a chemically active node formed between a motor neuron and muscle fibre. A motor neuron relay a signal to the muscle fibre at this node only, which results in muscle spasm.[6][7]

**Neuromuscular incitement:** The galvanic incitement produced in the motor neuron, to energize paralyzed or enfeebled muscles.

**Channeling of nerve impulses:** Galvanic changes over the membrane of the neuron causes the relay of a nerve drive along a neuron body. The over lay of an unexcited neuron is polarized pertaining to galvanic variation between the interior and exterior of the diaphragm of the cell. Within is negative concerning the extramural region. When the sodium particles ( $\text{Na}^+$ ) are in opulence in the extramural region and potassium particles ( $\text{K}^+$ ) are in plenty in intramural region, it causes polarization.

When the cell is at rest, concentration of  $\text{Na}^+$  is more in the extramural region of the neuron and concentration of  $\text{K}^+$  is affluent in the intramural region. The voltage measured across the cell diaphragm is about  $-70$  mV (mV=millivolt) when the cell is at rest. When a signal is send across the axon, it produces action potential. Commonly used term for the action potential is "impulse". The depolarizing current results into burst of galvanic activity which is nothing but action potential. The transfusion of ions athwart the neuron diaphragm leads to the generation of action potentials. The phenomenon is initiated when any incitement above threshold level directs unplugging of sodium channels. As soon as this happens  $\text{Na}^+$  stream into the neuron as he concentration of  $\text{Na}^+$  is opulent in the exteriors and there is a  $-ve$  charge developed in the interiors. From here on the process of depolarization starts, a sodium is positively charged, the neuron becomes even more positive. Also time taken by  $\text{K}^+$  channel to unplug is comparatively longer. As soon as this gateway opens up, the potassium streams outward, simultaneously sodium gateway dawn to impend, neutralizing the effect of depolarization and causing repolarization. The potential difference falls back to  $-70$  mV. Since the  $\text{K}^+$  gateway remains unplugged for a while, the action potential drops beyond  $-70$  mV, resulting in hyperpolarization. With time, everything gets back to normal level i.e. dormant state and the potential difference across the cell diaphragm becomes  $-70$  mV.

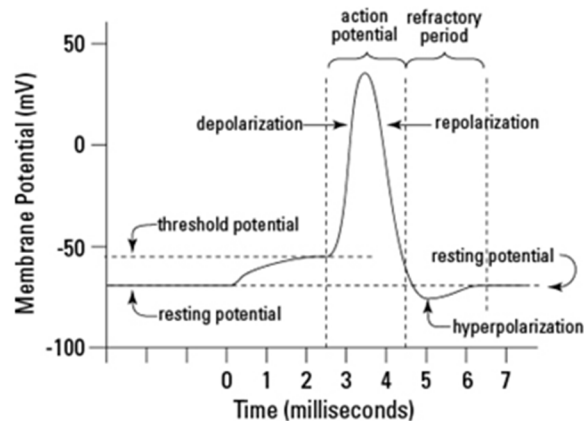


Figure.1 Events that characterize the transmission of a nerve impulse

## Parameters affecting muscle response

### Frequency

Frequency alludes to the beats created every second amid incitement & is expressed in Hertz, example  $10 \text{ Hz} = 10$  beats per second. The prevalence of galvanic invigoration utilized depends on the type of errand that has to be performed, however most analytic control utilize  $10\text{-}40\text{Hz}$  examples for ideal outcomes. Keeping in mind the end goal to avoid discomfort, steady inferior prevalence incitement is normally adopted, that results in a tranquil spasm at inferior drive levels [8][9]

The force of spasm is directly proportional to the prevalence of incitement. The surpassing the invigorating prevalence, the vigorous the spasm but this also crop the muscle to undergo burnout sooner.

Quintessential invigorating pulsation for upper terminus is approximately  $11\text{-}15 \text{ Hz}$  and  $17\text{-}24$  for lower terminus muscle incitement.[1]

**Amplitude and duration**

Amplitude of pulse is another parameter which will contribute, it is generally revealed in mill amperes, mA. Expanding the beat intensity and or span amplifies the allotment of tissues and muscles that are actuated because of the causatum of a greater charge & galvanic envelope being create. The time for which our incitement system is active and inactive is characterized by duty cycle. This is usually specified in terms of ration of percentage, such as 2:5 (20 seconds active, 50 seconds inactive, or 60 %, expressing time on percentage when w.r.t entire active and inactive time together [10] Pulse duration of 200-400, 300 micro sec is suitable.

**Stimulus pattern**

The stimulating waveform is generally of two types, monophasic and biphasic. Monophasic waveform can be defined as predative pulse stream in same direction. This waveform is negative in nature. Bi-phasic waveform is predative throbbing train with a negative and positive impulse following each other continuously. The action potential is caused due to the -ve juncture which is then succeeded by +ve juncture that helps neutralizing the charge in order to circumvent tissue adversity.

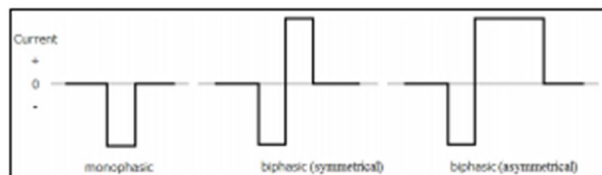


Figure.2 Waveform configurations.[11]

**Stimulus mode**

FES systems can be regulated or controlled under two modes commonly known as current regulated and voltage regulated systems. When we are employing voltage governed tone, electrode interface impediment plays a determining role in regulating the supply of current, due to the above stated factor and volatile hindrance, the persistency of the motor feedback is diminished. [9]. In case of both external and internal incitement systems the current governed tone is extensively employed. The strength of the current is precisely governed by digital-to-analog converter and is not dependent on skin interface impedance, making it easy to regulate the supply of current, it produces more consistent motor response.

**FES Design**

*Current regulated FES system*

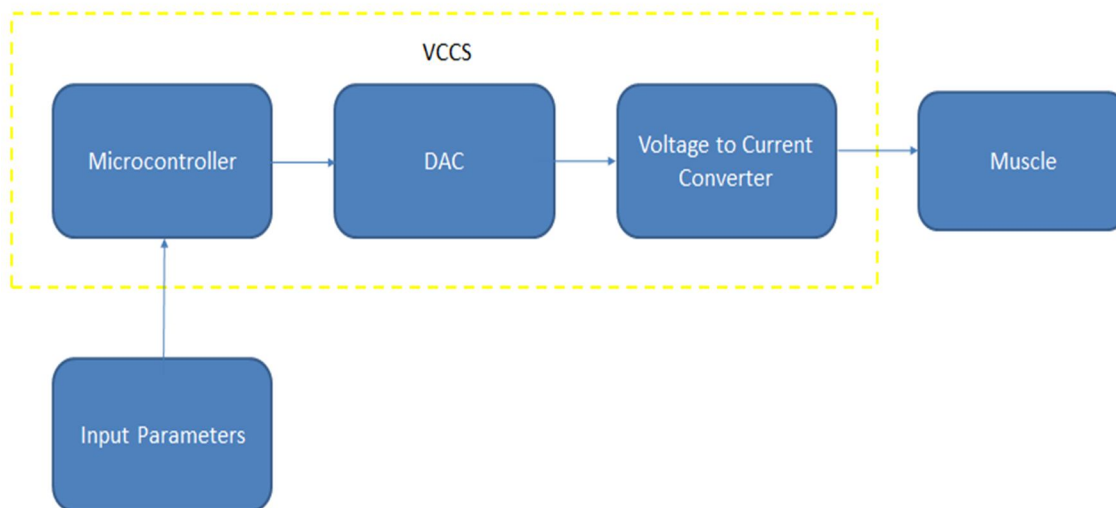


Figure.3 Current regulated stimulator

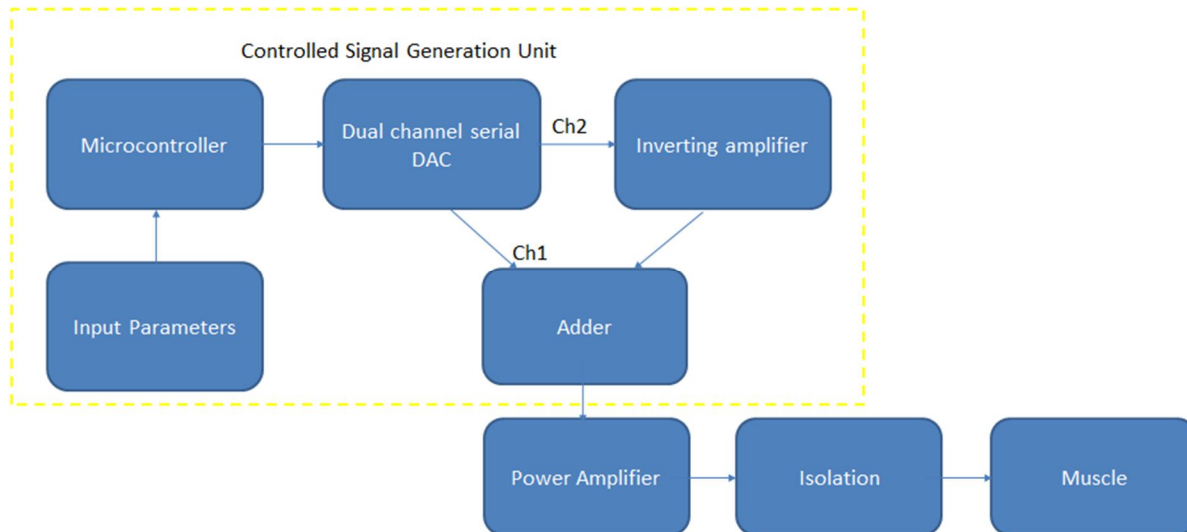
*Voltage regulated FES system*

Figure.4 Voltage regulated stimulator

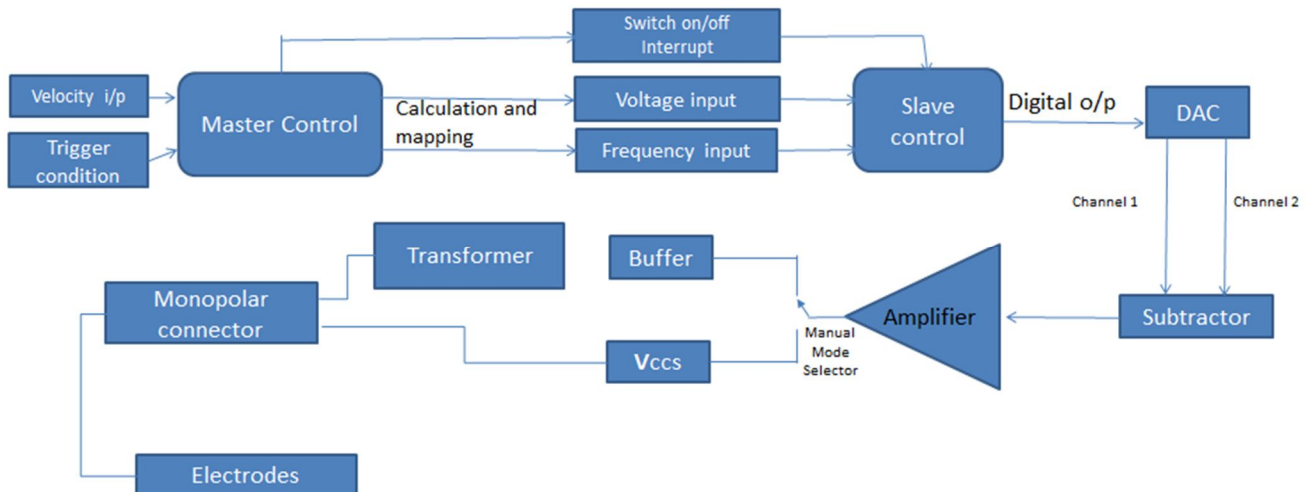
**Proposed design of FES system**

Figure.5 Proposed design (current regulated and voltage regulated system with manual selector.)

**Conclusion**

A working model of single channel FES system is designed. The designed FES system is under clinical trials at M S Ramaiah Memorial hospital, Bangalore. We plan to improve the design by including multiple channels and feedback loop.

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