Multichannel Programmable Functional Electrical Stimulator using Atmega Controller.

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Abstract - FES is a method of applying low level electrical pulses to the body to restore or improve daily routine of patients suffering from Spinal Cord Injury. Biphasic electrical pulse ensures least tissue damage with higher torque generation. Level of Muscle contraction force depends on combination of pulse frequency, pulse intensity and pulse width, which is function of muscle morphological data. Activation of limited number of muscles around a joint restricts torque generated about a joint axis. In this paper, we are proposing a fully programmable multichannel FES with biphasic output in terms of adjustable frequency, adjustable pulse width and adjustable intensity. The functionality & circuit performance of the circuits is presented in this paper.

Keywords — FES, Multichannel, Adjustable pulse width, Adjustable frequency, Adjustable Intensity, Biphasic.

I. INTRODUCTION

Muscles are used to control movement of bony lever around joint axis, helping to stabilize joint movement and mobility in human structure. When Central Nervous System (CNS) is damaged due to Spinal Cord Injury (SCI), path of natural electrical signals between CNS and Peripheral Nervous System (PNS) gets impaired. If Muscle and nerve supply are still healthy to function, there are chances of restoration of few normal daily activities. A muscle tissue possesses the properties of contractibility and irritability. Contractibility is related to ability of muscle to develop tension and Irritability is related to ability of muscles to respond to stimuli like Chemical, Electrical or Mechanical [1]. Frequency of electrical stimulation will decide the force of contraction [2]. The muscle contraction is a function of total charge transferred to the muscle which depends on pulse amplitude, pulse width and pulse frequency [3].

In general, muscle fibers respond to frequencies at 20 Hz (slow-twitch fibers) to 80-150 Hz (fast-twitch fibers) [4]. Muscles stimulated between 10 Hz to 30 Hz will produce lower force but consistent frequency of 30 Hz will help preserve force better. Less than 16Hz frequency is not useful in producing notable force. Fast twitch fibers are recruited by applying higher frequency hence they are fatigued easily but force response is smooth and has only tingling effect rather than low frequency tapping effect [5]. FES recruits fast twitch fibers first rather than slow twitch fibers first which is non-physiological recruitment of fibers and so muscle gets fatigued [3]. To avoid fatigue and produce more torque in muscle when applying electrical stimulation, Biphasic pulse (a positive pulse combined with negative pulse) is normally used, which ensures immediate reversal of induced charge.

It is found that wider pulse width produces stronger contraction and reduced fatigue due to its higher penetration power, recruitment of more fibers and impact on secondary tissue layers [5]. Pulse amplitude is linear function of muscle contraction. Constant current sources are used due to variations in tissue impedance resulting in more predictable responses [6]. Functional Electrical stimulator (FES) with adjustable frequency, pulse width and intensity will help restore the normal functioning of paralysed patient and increase life expectancy.

A fully programmable biphasic pulse generator for FES with 8 channels was developed by us [7], so that variable frequency, variable pulse width/duration, Duty cycle, pulse pattern can be generated depending on patient requirement. The circuit is modified and updated to fully programmable FES with added parameter of variable intensity/ amplitude from 1 mA to 100mA.

II. MATERIALS & METHODS

Block diagram of FES is shown in Fig. 1. The block diagram is divided in two parts first Mother Board and second Driver Circuit Board. Mother board generates pulses with variable frequency and variable pulse width for eight channels which are fed to Driver Circuit board. Driver circuit board converts these pulses into biphasic with help of MOSFET H bridge circuit. Both Mother board and Driver circuit board are controlled by two different microcontrollers Atmega 328/p. The output current is sensed by feedback resistor and given to PID to modify PWM pulses making it truly current output device.

A. Mother Board Description

Mother Board shown in Fig. 2, is designed using Atmega 328/p AVR series 8-bit microcontroller family with 23 programmable I/O pins, 32Kbytes in- system self programmable flash program memory, 1k Bytes EEPROM and 2Kbytes Internal SRAM [7]. Microcontroller outputs serial pulses on pins 14 and 15 which are connected through Serial Peripheral Interface protocol with 74HC595, an 8-bit serial in/parallel out shift register. The shift out frequency from 74HC595 is 100 MHz. Two 74HC595 are used to generate 16 pulses in total, which are sent in pair to Driver circuit board, which converts them into Biphasic pulse for all 8 channels. The pulses are inputted to Driver circuit board through eight pairs of optocouplers PC817 for providing isolation to Mother board from high currents. Two main variables, pulse width and pulse frequency can be configured using four key keyboard connected to microcontroller. Duty Cycle of 1:3 is fixed for all channels. A 16 * 8 LCD is used to select and display channel number, variable frequency and variable Pulse width parameters [7].

B. Driver Circuit Board description

Driver Circuit Board shown in Fig. 3 uses another Atmega 328/p microcontroller; the board layout can be broadly bifurcated into three parts. First part consists of software for PID and PWM, second part consists of driver circuit for transistors and MOSFET H-Bridge configuration and third with load current sensing to be used as feedback to compare with set point value set through 10K potentiometer. Pulses generated in pair A_x and B_x from output block of Mother Board are fed into MOSFET driver circuit. Each pair A_x and B_x is first given to pair of AND gates, along with PWM pulses from pin 11 of port D. 1 KHz PWM frequency generated by microcontroller is used to switch MOSFETS ON and OFF for controlling current as per set point value. Biphasic pulses are generated when MOSFET pair's switch alternately using a single positive 100 V DC power supply. The variation in output pulse current is sensed by current sense resistance 47Ω, which is feedback though inbuilt ADC in Atmega controller to achieve closed loop control. This feedback voltage is fed to error detector in PID and is sampled by microcontroller. PID controller output varies PWM pulse width from 0% to 100% to control load current. Current set point is given to controller using precise 10 turn trim potentiometer which is calibrated from 1mA to 100 mA. A fuse is kept to limit maximum current to 100 mA for patient's safety.

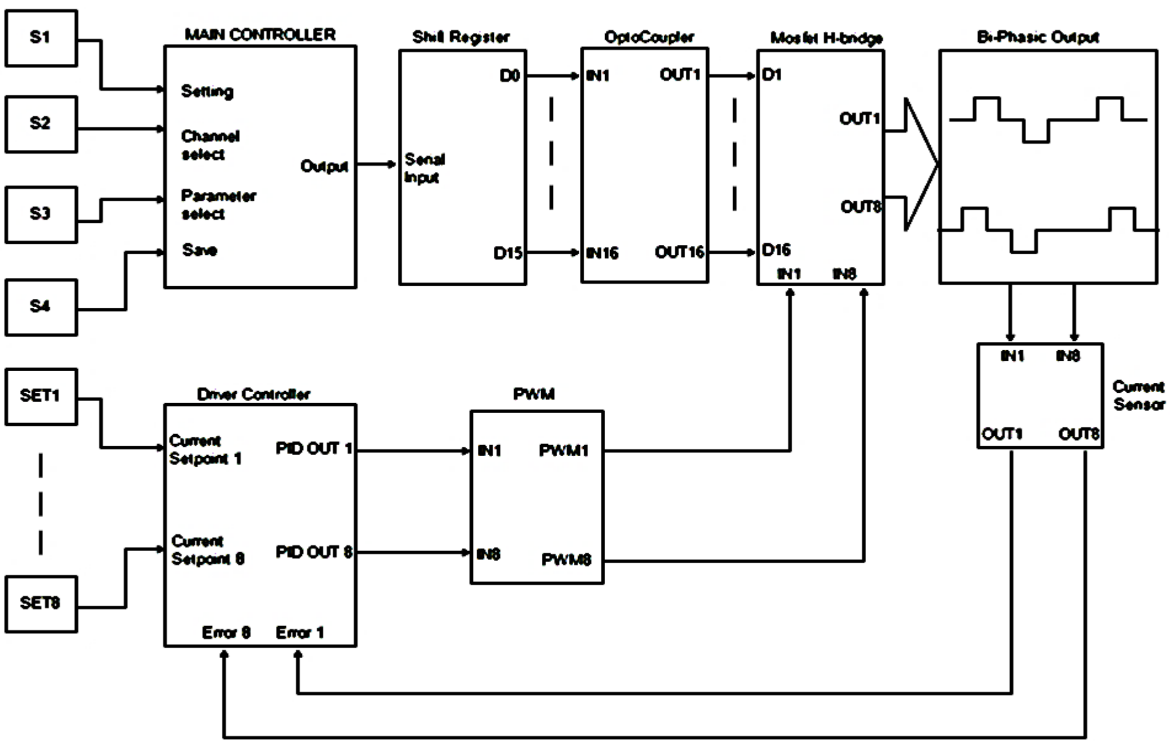

Fig. 1 Block Diagram of FES System

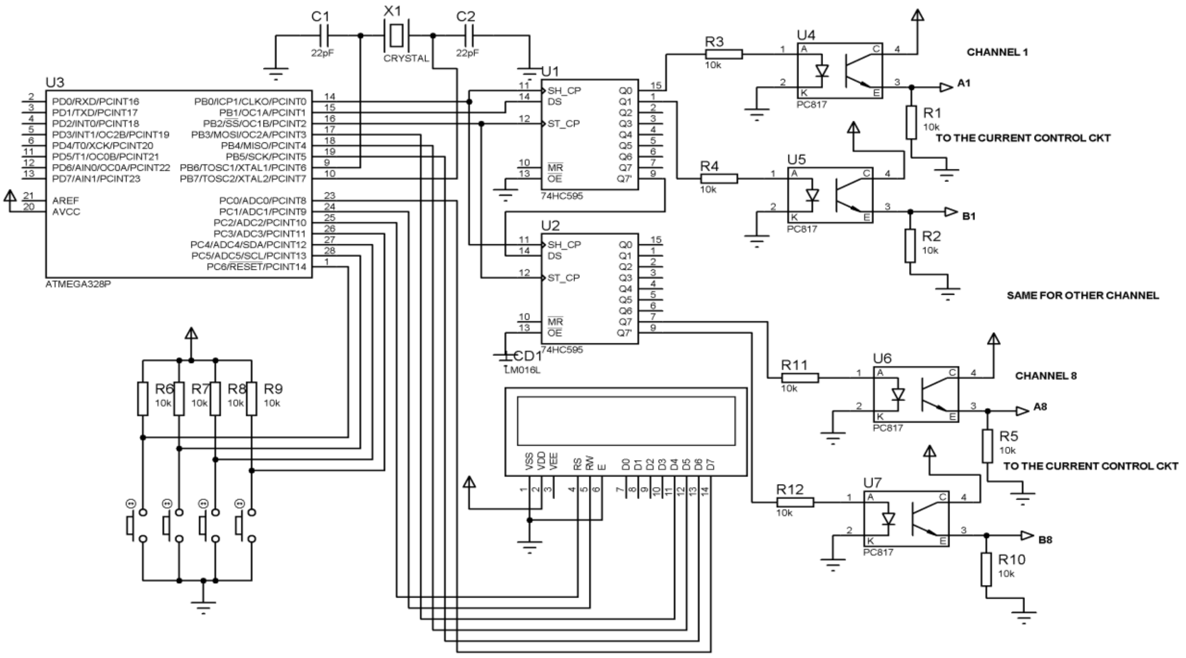

Fig. 2 Mother Board

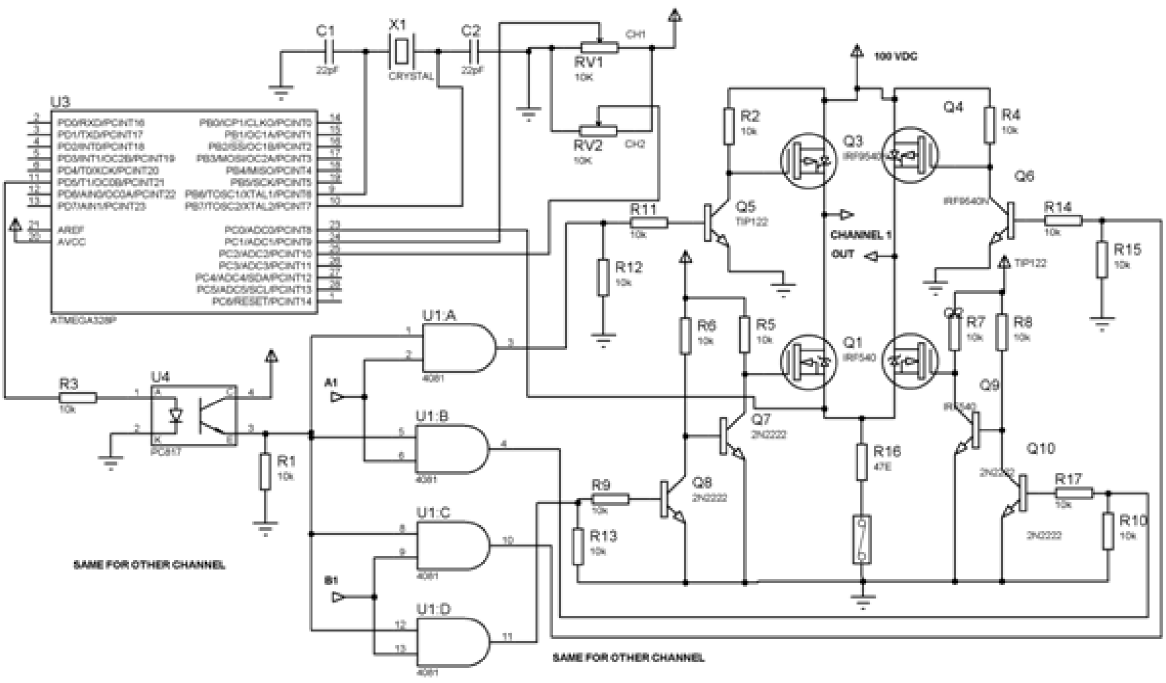

Fig. 3 Driver Circuit Board

C. Experimental Waveforms

The multichannel FES is designed to generate biphasic signal with variable pulse frequency from 16 Hz to 100 Hz and variable pulse width from 50 µS to 3000 µs. Combined effect is seen in two channels shown in Fig. 4.

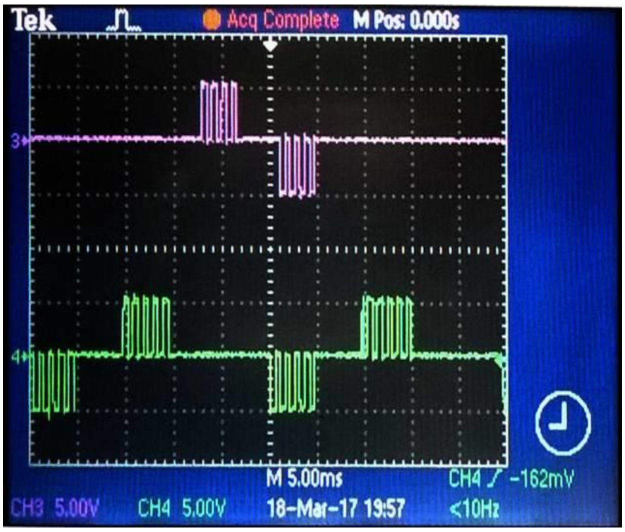

Fig. 4 Variable pulse frequency and pulse width

This FES is also designed to generate 1:3 duty cycle, which is used to train patient's muscle without getting fatigue (Fig. 5). During ON time burst of biphasic pulse, will be generated, and during OFF time there will be no output, relaxing the muscle.

Fig. 5 Duty Cycle 1:3

III. CONCLUSION

In this circuit, single power supply of 100 VDC is used to generate biphasic pulse using alternate switching of MOSFET H bridge circuit. Darlington pair TIP 122 is used to provide high current gate pulse for MOSFET firing. All eight channels are software programmable in terms of frequency and pulse width [7]. The current is manually adjustable through 10 turn 10 K potentiometer reducing chances of manual errors. 100 mA fuse is kept in output circuit to ensure patients safety. In each Biphasic current output pulse, pulsing effect is seen which is due to 1 KHz PWM & MOSFET switching effect. Only two channels are shown in waveform.

IV. FUTURE SCOPE

In future, this FES can be used in closed loop where controller will decide frequency, pulse width and intensity based on type of muscle based on Fuzzy rules, so that individual muscles can be activated to produce voluntary forces needed to create joint movements to complete desired daily tasks.

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