Development of Programmable Multichannel Biphasic Pulse Generator for FES

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Abstract* - Functional Electro stimulation (FES) is a device delivering electric impulses to restore normal functioning of patients suffering from stroke or spinal cord injury Biphasic electrical impulse ensures least tissue damage and skin reaction due to bipolar action. Portable FES device commercially available are having limited number of channels. In this paper, we are proposing a circuit for FES which gives fully programmable biphasic output in terms of adjustable frequency and adjustable pulse width simultaneously for eight channels. The functionality & circuit performance of the circuits are presented in this paper.

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

I. INTRODUCTION

The word Functional Electrical Stimulation (FES) is probably the most commonly used in the literature and is well known through decades for restoration of upper and lower limb muscle activities of patients who are paralysed due to stroke, spinal cord injury, Multiple Sclerosis or other related neural impairments [1]. FES is not a permanent cure but is an assistive device [2]. Therapeutically FES is a low-level electrical current applied to restore the normal function of paralysed muscles of person with incomplete spinal lesion [3]. It is reported that FES can be programmed for the upper extremity of persons with stroke that consisted of initial stimulation of the anterior and posterior deltoid, followed by triceps brachii stimulation [4]. This resulted in flexion of the shoulder and elbow extension to produce a forward reaching motion for function. By modulating frequency, pulse width and amplitude of stimulation the angle of a joint, or, alternatively, the torque produced about a joint, can be regulated by varying the tension produced in the flexor and extensor muscles of the joint [5].

In clinical settings, electrical stimulation can be used for improving muscle strength, increasing range of motion, reducing edema, decreasing atrophy, healing tissue, and decreasing pain. Neuromuscular Electrical Stimulation (NMES), used interchangeably with Electrical Stimulation (ES), is typically provided at higher frequencies (20-50 Hz) that can be used for “functional” purposes [6]. Transcutaneus Electrical Nerve Stimulation (TENS) is another conventional form of electrical stimulation that uses high frequencies for pain relief based on pain gate mechanism [7]. Normally TENS are bifurcated into sensory TENS and motor TENS depending on frequency of operation. Sensory TENS are operated at very low frequencies 2-10 Hz and motor TENS above 50Hz [8]. Sensory TENS propagates along smaller afferent sensory fibers specifically to override pain impulses. When very low frequencies are used, TENS specifically targets sensory nerve fibers and does not activate motor fibers; therefore, no discernible muscle contraction is produced [6]. Functionally both types of TENS are applied for different purpose.

It is reported that biphasic waveform (a positive phase combined with a negative) creates a reversible charge transfer process which stops tissue damage. Biphasic pulse stimulus produces more torque [5]. Pulse widths 300µs-600µs are commonly used for quadriceps extension [9-11]. Some investigators have suggested that low frequency stimulation with short pulse durations (500µs-1000µs) will exhibit a lower fatigue index [6, 12]. However, even shorter pulse widths (10µs-50µs) have been shown to affect the recruitment of muscle fibers and can generate a larger maximum torque in a smaller number of fibers before causing a contraction in another muscle fascicle [13]. Increase in pulse width will recruit more fibres and reduce fatigue chances.

A full understanding of the settings that govern the Stimulation is vital for the safety of the patient and the success of the intervention. Consideration should be given to the frequency, pulse width/duration, duty cycle, intensity/ amplitude, ramp time, pulse pattern, program duration, program frequency, and muscle group activated [6]. Various commercially available

FES have limitations with respect to number of channels, and individual channel programmability. This paper presents a Biphasic pulse generator for FES which is fully programmable in terms of adjustable frequency (1Hz to 60Hz (Programmable up to 100 Hz)) and adjustable pulse width (4µs to 1ms (Programmable up to 9.9ms)) with option for number of channels to activate muscles in group either simultaneously or synchronously.

II. MATERIALS & METHODS

FES Circuit is designed using an atmega 328/p AVR series 8-bit microcontroller family with 23 programmable I/O pins, 32Kbytes in- system self programmable flash program memory and 1kBytes EEPROM and 2Kbytes Internal SRAM.74HC595 8bit serial in/parallel out shift register with 100 MHz shift out frequency is used to generate pulses for LM 358 Op-amp.

A. *Circuit Description*

Fig.1 shows the schematic diagram of the circuit. First part consists of atmega 328/p microcontroller with 74HC595 SI/PO shift register, where the pulses are generated serially from microcontroller and fed to shift register. Parallel output pulses are given to second stage which consists of set of inverting and non-inverting op-amp. The output of both operational amplifier is then added to generate biphasic signal with varying pulse width and frequency as per the settings done using functional keyboard for each channel separately. The circuit is designed to generate biphasic signal for 8 channels simultaneously. Separate channel for each muscle. The pulse width for biphasic signal can be varied from 4µs to 1ms (programmable up to 9.9ms)

and frequency from 1 to 60 Hz (programmable up to100Hz). An LCD panel with 4-bit nibble mode is used to display the different parameters like channel number, current pulse width and frequency.

B. *Program Flow Chart*

Fig. 2 shows the flow chart of programming and function of circuit. Biphasic pulses for 8 channels are simultaneously generated by timer interrupt of atmega328p microcontroller. Individual counter is used to generate variable pulse width for biphasic pulse in term of 1µs timer interrupt for each channel separately. For biphasic pulse generation two shifted pulses are used, both shifted pulses are then summed using one non-inverting and one inverting Op-amps LM358. Every 1us timer generates interrupt which is used to increment the current counter. Separate counter is set by Keyboard & pulse is generated by comparing the set count & current count. Eight different counters are defined for frequency of biphasic pulses. Parameters of all channels can be set through keyboard.

C. *Experimental Waveforms*

The multichannel FES is designed to generate biphasic signal with variable pulse width (Fig.3) and variable frequency (Fig.4). There is 0.5 µs resolution in 4 µs pulse width. It will be very high for 9.9 ms pulse width.

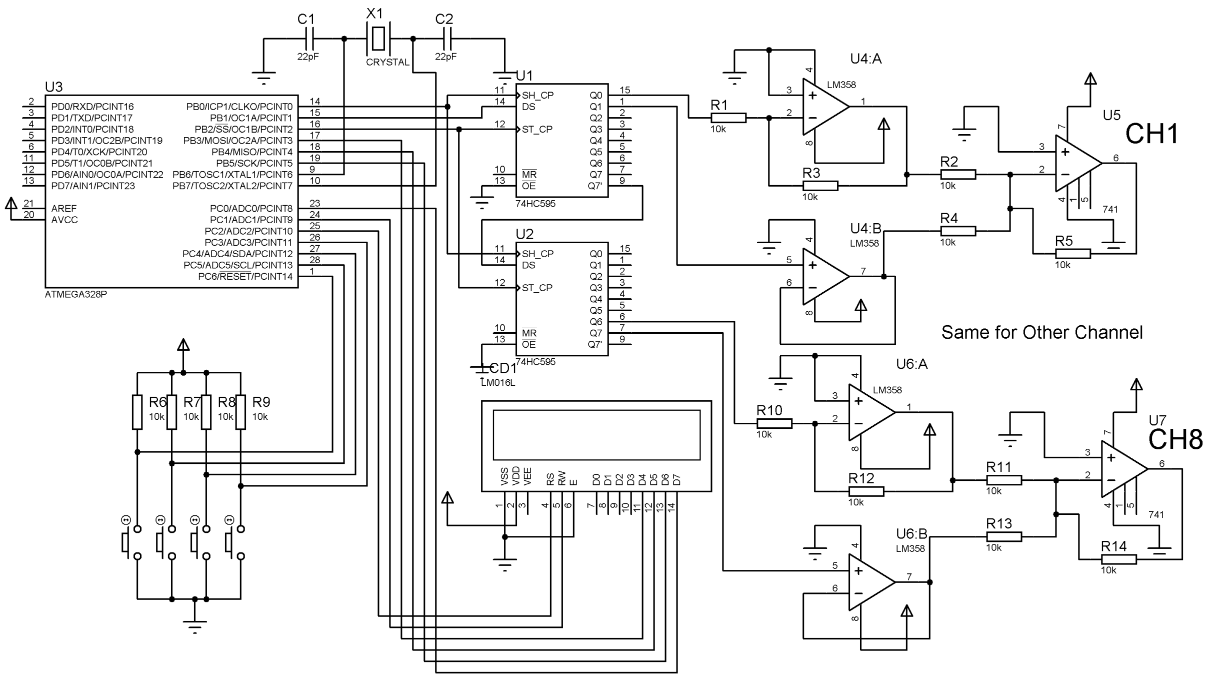

Figure 1 Circuit Layout

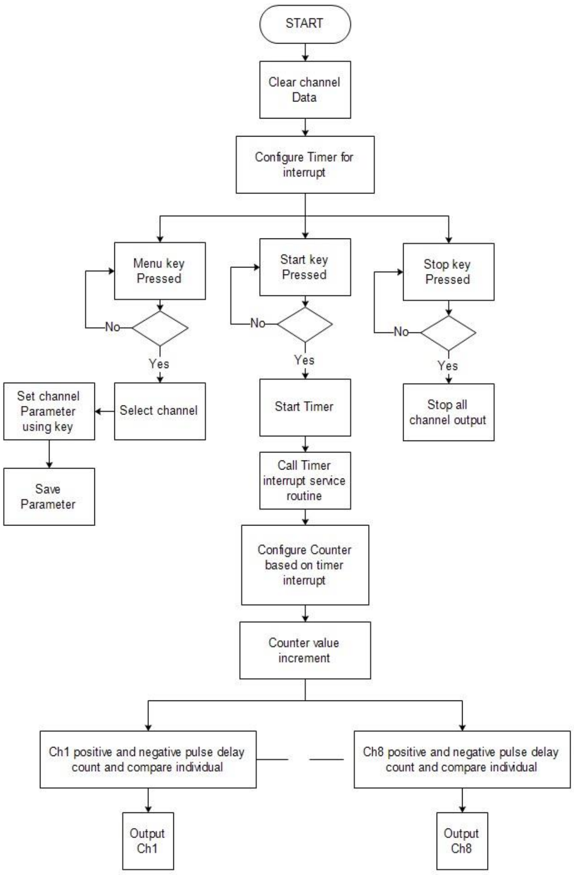

Fig. 2 Program Flow Chart

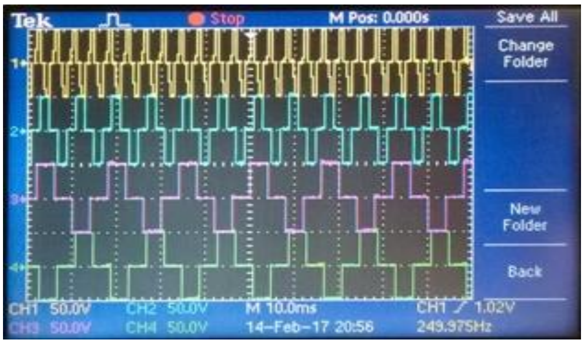

Fig.3 Variable Pulse Widths

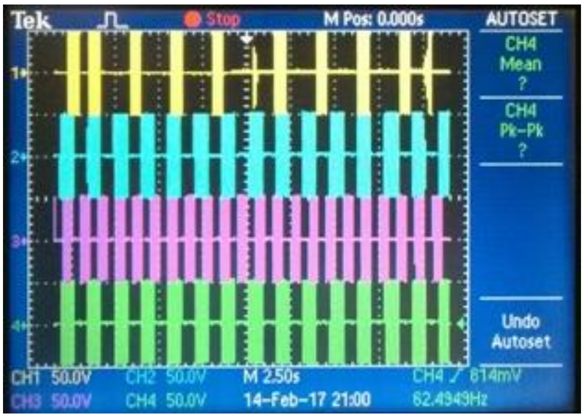

Fig. 4 Variable Frequency

III. CONCLUSION

The advantage of this circuit is all the 8 channels are individually programmable with capability of deciding range of frequency and pulse width along with the type of pulse, i.e. Uniphasic, Biphasic, or Polyphasic. This is desirable when the stimulus is to be applied to stimulate different muscles as per their morphometric requirements sequentially or simultaneously.

IV. FUTURE SCOPE OF WORK

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

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