A Multi-frequency Electrical Stimulation Waveform Generator[§]

Ya-Hsin Hsueh[†], Wei-Cheng Hong
Department and Institute of Electronic Engineering
National Yunlin University of Science and Technology
Douliou, Yunlin, Taiwan, R.O.C

Abstract: - The design of multi-frequency electrical stimulation waveform generator contains low-frequency module, medium-frequency module, and ON/OFF percentage module. Meanwhile, this generator includes seven kinds of low-frequency and three kinds of medium-frequency for producing different electrical stimulation output waveform. The stimulation duration is from 10 to 630 μs. The proposed multi-frequency electrical stimulation waveform generator is implemented on Altera EP1K100FC484-3 device.

Key-Words: multi-frequency, electrical stimulation waveform generator

1 Introduction

In the rehabilitation field, the electrical stimulation is one of the major instruments. Bionic-eye [2], ladder leakage control [1], interrupt of pains, shaking syndromes of Parkinson's disease [3], muscle nerve stimulation, and Cochlear implants [4], all are the eminent electrical stimulation applications. However, most of the electrical stimulators are designed only for few stimulation waveform output; therefore, this paper would like to propose a flexible electrical stimulation waveform generator with six parameters, which can be adjustable.

Low-frequency electrical current means the current pulse frequency below 1000 Hz for nerve and muscle stimulation. 1 kHz to 10 kHz is called medium-frequency electrical current for deeper part and pain relief. The electrical stimulation contains three main physiological functions. First, it can make muscular tissue system be exciting. Then, it can increase blood circulation. Also it can release the pain. Therefore, all the different applications of electrical stimulator are based on these three major physiologies. Different parts and applications meet different "frequency", "duration", the "pulse interval", the "pulse wave quiescent interval", and the "ON/OFF percentage". In the other hand, the electrical stimulation waveform generator must design to be changeable for these parameters.

The goal of this design is intensively focused on the flexible electrical stimulation waveform generator, which can generate low frequency and medium frequency pulse. The waveform generator includes of seven low-frequency types, three medium-frequency stimulation types, and adjustable duration.

2 Multi-frequency Electrical Stimulation Waveform Generator

The waveform generator generates different output by setup individual parameter value in each module. The generator contains 3 major modules, as the "duration selection module", the "ON/OFF percentage module", and "medium-frequency module". The block diagram of the entire electrical stimulation waveform generator is showed as Fig. 1.

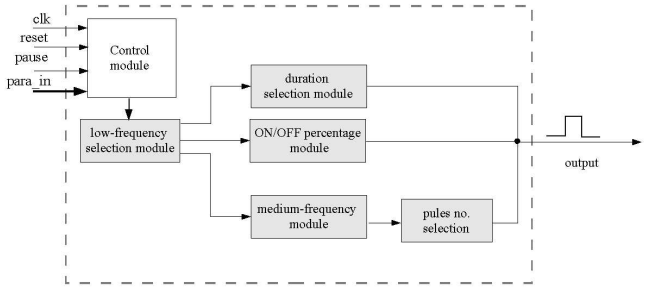

Fig. 1. The block diagram of the electrical stimulation waveform generator

2.1 Control module

In addition to the control module receives signals as the system clock (clk), reset and pause for entire

[§] This research was partially supported by National Science Council under grant NSC 95-2221-E-224-002

[†] The contact author.

waveform generator. The module and frequency parameters input also pass through control module. The electrical stimulation waveform generator I/O pins list in Table 1.

Table 1. The I/O Pins of the waveform generator

I/O		*description*
clk		system clock pulse: 1 MHz
reset		reset signal
pause		pause signal
para_in	freq_sel	low-frequency type selection
	module_sel	module selection
	duration_set	duration selection
	on_off_set	ON/OFF percentage
	medium_freq	medium-frequency type selection
	pulse_no	select pulse number of the medium-frequency stimulation
output		electrical stimulation waveform generator

2.2 Low-frequency selection module

The low-frequency selection module is focus on generate the low-frequency stimulation pulse for most applications. There are total seven low-frequency stimulation pulses in this module, including 50 Hz, 80 Hz, 100 Hz, 125 Hz, 160 Hz, 200 Hz, and 250 Hz.

2.3 Duration selection module

The duration is from 0 to 630 μs. The input "duration_set" is a 6-bit signal. As soon as the input value increases 1, the stimulation duration will increase 10 μs. The waveform definition is showed as Fig. 2.

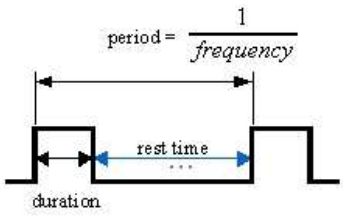

Fig. 2. The definition of electrical stimulation waveform

2.4 ON/OFF percentage module

ON/OFF percentage module also provide another way to adjust the duration. The "on_off_set" uses to setup the duration for each low frequency. Each low frequency owns seven duration time, as the following Table 2 shows. For safety issue, the limitation of duration is below 640 μs.

Table 2. ON/OFF percentage

Frequency selection	duration		
	on_off_set =*0*	…	on_off_set =*7*
50 Hz	200 μs	…	600 μs
80 Hz	125 μs	…	625 μs
100 Hz	100 μs	…	600 μs
125 Hz	80 μs	…	640 μs
160 Hz	62 μs	…	500 μs
200 Hz	50 μs	…	400 μs
250 Hz	40 μs	…	320 μs

2.5 Medium-frequency module

Medium-frequency, as showed in Fig. 3, is widely using on rehabilitation and treatment. Users can select three kinds of medium-frequency. Options of pulse number for each medium-frequency are listed in Table 3. It also considers about safety issue, therefore, the stimulation duration needs to below 640 μs. Fig.3 is an example of a 100 Hz stimulation waveform having three pulses 4K Hz medium-frequency.

Table 3. Medium-frequency Mode with carry number

Medium-frequency	*min. pulse #*	*max.. pulse #*
2K (Hz)	1	2
4K (Hz)	1	5
8K (Hz)	1	10

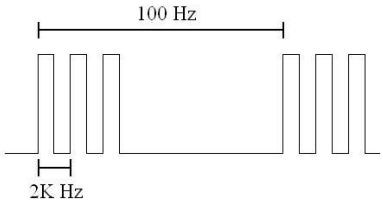

Fig. 3. 100 Hz stimulation waveform having three pulses 4K Hz medium-frequency

3 Simulation and Implementation

The electrical stimulation waveform generator is implemented by Altera EP1K100FC484-3 device for function verification. The Fig. 4 is the block diagram for test system of the electrical stimulation waveform generator, and Fig. 5 is the physical implementation board. It includes two DIP switch, a button, an oscillator and an Altera device.

- DIP switch: It is using to input the "para-in" and "reset" signals.
- Button: It is the "pause" signal
- Oscillator: It is using to input the clock pulse.
- Altera EP1K100FC484-3: It is using Verilog hardware language to achieve the entire electrical stimulation waveform generator. Then, the Verilog code of the generator circuit is compiled and programmed to EP1K100FC484-3 by Altera Quartus 5.0.

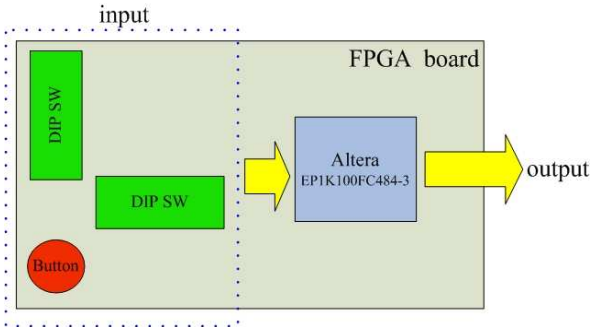

Fig. 4. The implementation and test system of the electrical stimulation waveform generator

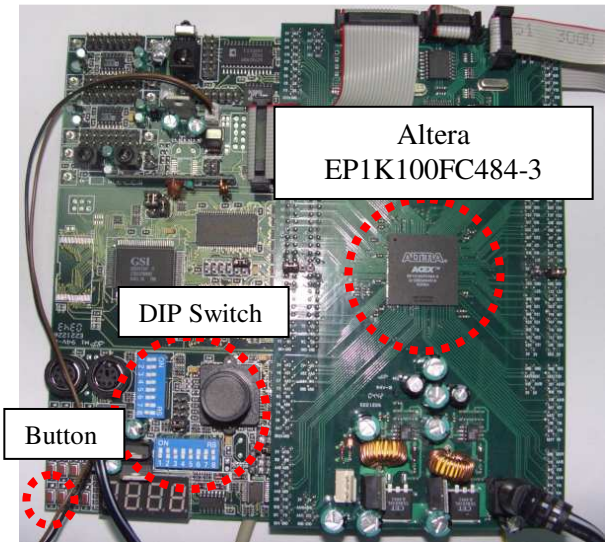

Fig. 5. The physical implementation board

The principle of this action is described as following.

Step 1: Turn ON the reset signal

Step 2: Turn OFF the reset signal, and setup the "para-in" value by using DIP switches.

Step 3: Start output the electrical stimulation waveform.

The Fig.6 is the snapshot generated by Agilent 3102a when the system is under test.

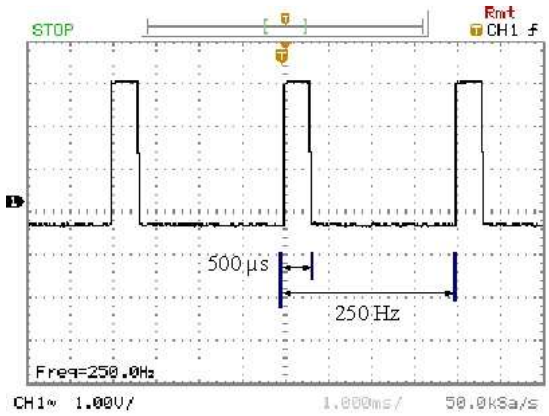

Fig. 6. The electrical stimulation waveform generator output

4 Conclusion

A solution for multi-frequency electrical stimulation waveform generator is present. The proposed design can generate different frequency and duration, it also including the medium-frequency mode with pulse number selection. The physical measurement results verify the correct functionality as well as the impressive performance.

References:

[1] J. S. Walter, J. S. Wheeler, W. Cai, W. W. King, and R. D. Wurster, "Evaluation of a suture electrode for direct bladder stimulation in a lower motor neuron lesioned animal mode," *IEEE Trans. on Rehabilation Engineering*, Vol. 7, No. 2, 1999, pp. 159-166.

[2] V. Chowdhury, J.M. Morley, and M.T. Coroneo. "An *in-vivo* paradigm for the evaluation of stimulating electrodes for use with a visual prosthesis," *ANZ Journal of Surgery,* Vol. 74, No. 5, ,2004, pp. 372-378.

[3] M Tinazzi, C Del Vesco, E Fincati, S Ottaviani, N Smania, G Moretto, A Fiaschi, D Martino, and G Defazio, "Pain and motor complications in Parkinson's disease," *J. Neurol. Neurosurg. Psychiatry*, Vol. 77, No. 7, 2006, pp. 822 – 825..

[4]R. E. Isaacs, D. J. Weber, and A. B. Schwartz,``Work toward real-time control of a cortical neural prosthesis," *IEEE Trans. Rehab. Eng.*, Vol. 8, No. 2, 2000, pp. 196-198.