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Design of Low-Cost General Purpose Microcontroller Based Neuromuscular Stimulator

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In this study, a general purpose, low-cost, programmable, portable and high performance stimulator is designed and implemented. For this purpose, a microcontroller is used in the design of the stimulator. The duty cycle and amplitude of the designed system can be controlled using a keyboard. The performance test of the system has shown that the results are reliable. The overall system can be used as the neuromuscular stimulator under safe conditions.

KEY WORDS: neuromuscular stimulator; microcontroller.

INTRODUCTION

Stimulators are the system which can generate pulses whose amplitude, frequency, and duration (duty cycle) can be adjusted.(1–3) Today, microcontroller based electronic stimulator applications are being widely used.(4,5) Stimulators play an important role in stimulating the nerves and muscles of the human body over the last three decades, neuromuscular stimulators have offered new possibilities for the treatment of many organ failures. The majority of commercially available stimulators have some significant limitations. These limitations are: (1) an independent multichannel implant, (2) a wide range of programmable parameters, (3) a high degree of efficiency in energy and data transmission, (4) a user-friendly interface, (5) high frequency stimulus generation, and (6) wave form flexibility (monophasic, biphasic).

This paper presents a low-cost, general purpose, programable neuromuscular stimulator for use in the clinical environment. The pulse repetition rate of the designed stimulator can be adjusted. In addition to this, pulse widths are also changeable.

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HARDWARE

A microcontroller based programmable stimulator was designed and implemented. All parameters of the stimulator such as amplitude, pulse duration, duty cycle, and frequency can be adjusted. For this purpose the microcontroller (89S53) is used in the design of the stimulator.

The specifications of the designed stimulator system are: Output frequency: 0-300 Hz; Pulse duration: 0,02-99 ms; Output voltage: 0–120 V.

The block diagram of the stimulator is shown in Fig. 1.

Frequency, pulse duration, and amplitude of pulses are entered using the keyboard. Frequency can be entered as a 2-digit (00–99) or as a 3-digit (100–300) decimal number. If you prefer to enter a 3-digit decimal number, there is no need to press the "enter" key. If you prefer to enter a 2-digit decimal number, you must press the "enter" key to signal that entry is over. The same procedure is applied for the voltage. Only the pulse duration is a 1- or 2-digit decimal number, so if you prefer to enter only a 1-digit decimal number you must again press the "enter" key. The keyboard encoder chip that is used can output hexadecimal numbers. So, the decimal number keys (0–9) on the keyboard are used for number entries and the remaining keys (A to F) are used for special purpose entries. Special purpose entries are dedicated as pulse duration selection menu key (A), pulse frequency selection menu key (B), enter key (C), start key (D), clear key (E), and pulse amplitude selection menu key (F).

The display is a 16×80 dot matrix LCD display with an intelligence controller which can show both numeric and alphanumeric characters. Display is two rows wide because there is a need to show many messages simultaneously on it. When the frequency key is pressed, the "enter the frequency" message is displayed on the LCD display. In a similar manner, when the pulse duration menu key is pressed, the "enter the amplitude" is displayed, and when the time key is pressed the "enter the operation time" message is displayed. After one of every parameter is entered, all of them are displayed on the LCD simultaneously. Timer supplies a 1-sec timing information to the microcontroller which is needed for time keeping functions. After all the start keys are pressed, the operation begins and a clock shows the time elapsed (00:00:00) starting from zero. In addition, the remaining time is displayed on the LCD display.

By using a DC/DC converter, 120V peak value is obtained. DC/DC converter maintains an isolation between human body and ground. This device also has current and voltage limiting functions. The device does not send any output signal which exceeds the preset limits of current and voltage. The output voltage can be adjustable via the digital power supply which is controlled by the microcontroller. The output voltage in digital power supply is controlled via an adjustable analog regulator by converting digital data to analog data using a D/A converter.

The blocks of the designed hardware are explained as the following.

89S53 Microcontroller

89S53 is an 8-bit microcontroller which can operate with a clock frequency (24 MHz). 89S53 chip contains a 12-Kbyte flash memory with a 1000 erase-write cycle,

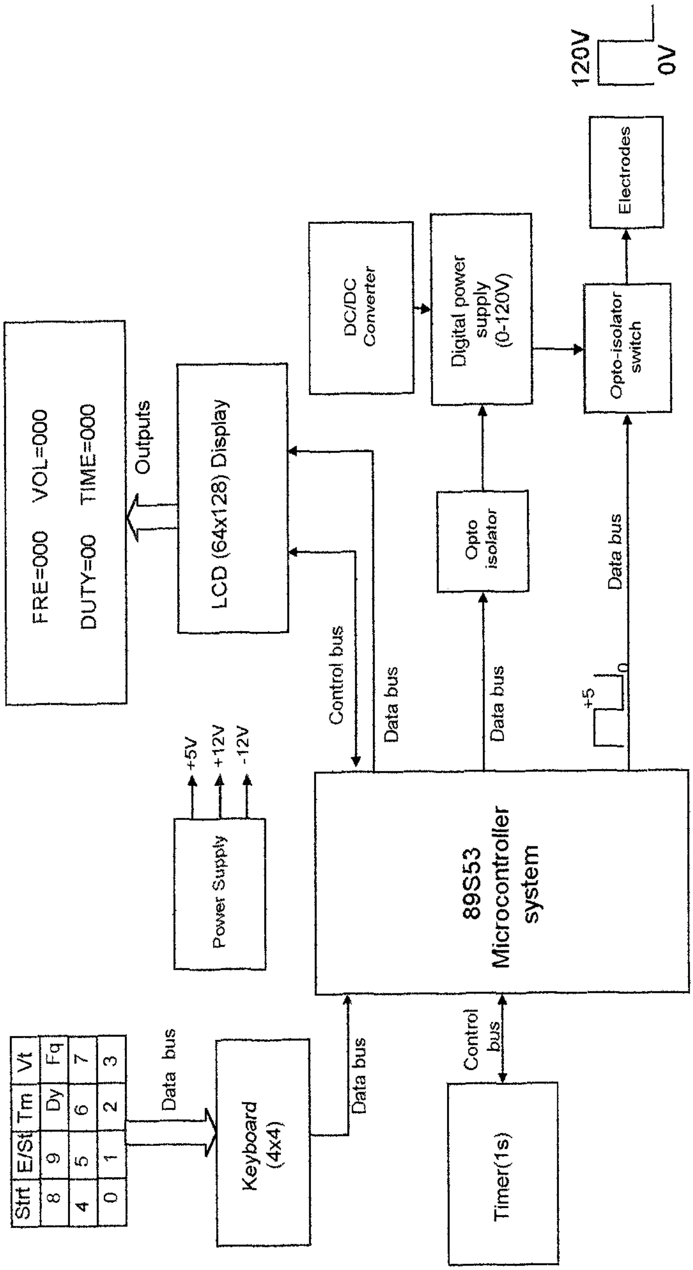


Fig. 1. Block diagram of stimulator.

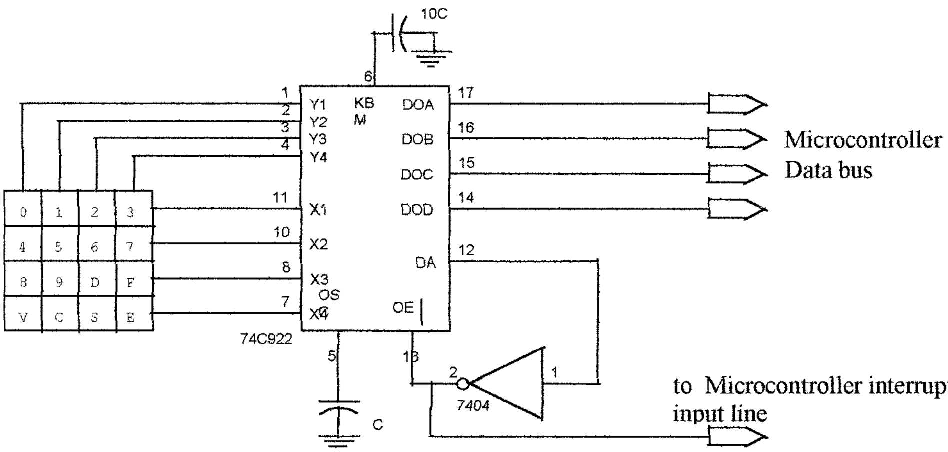


Fig. 2. Keyboard driver circuit.

a 256 × 8 bit internal RAM, 32 programmable I/O line, 8 interrupt source input and a programmable serial output. 89S53 chip also has a three level program memory lock function.

Keyboard Driver Circuit

The keyboard driver circuit is shown in Fig. 2. This circuit utilizes a hexadecimal keyboard encoders chip which encodes a 4 × 4 matrix keyboard keys to a 4-bit

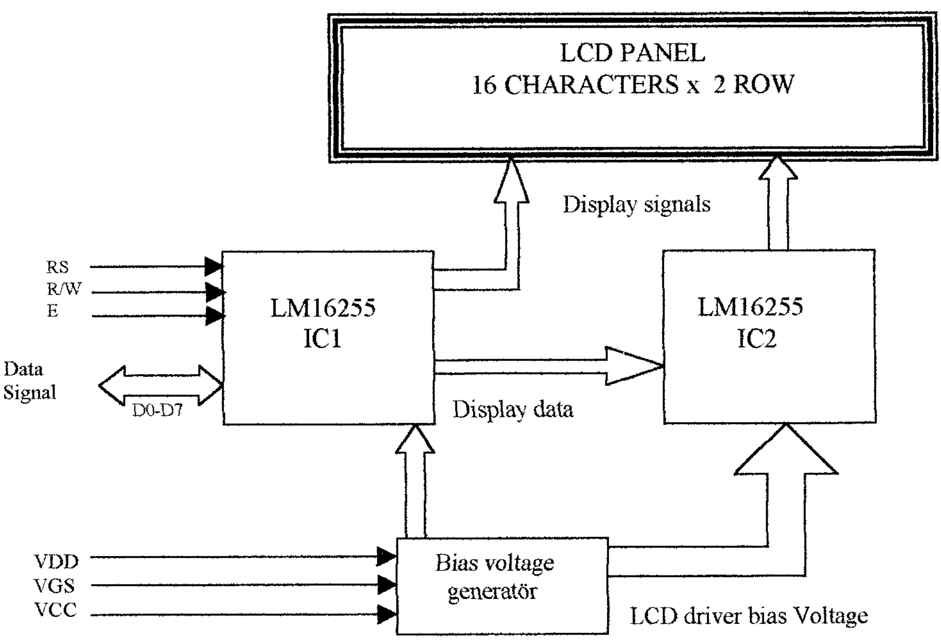


Fig. 3. LCD driver circuit.

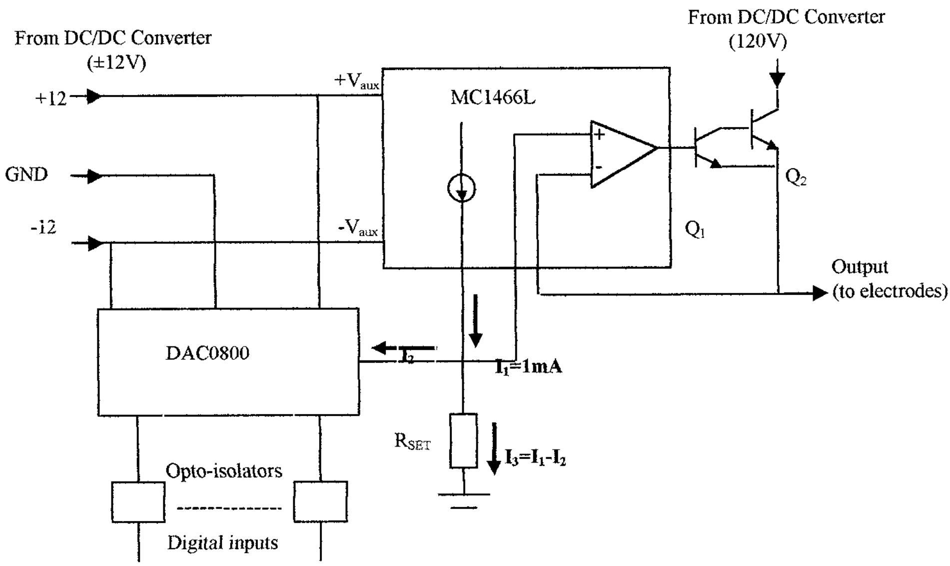


Fig. 4. Block diagram of digital power supply.

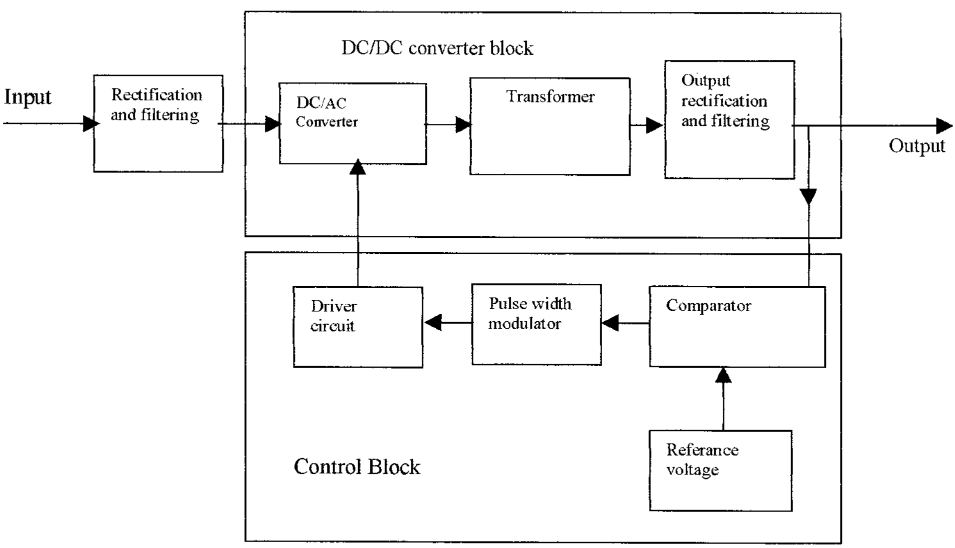


Fig. 5. Block diagram of switch mode power supply.

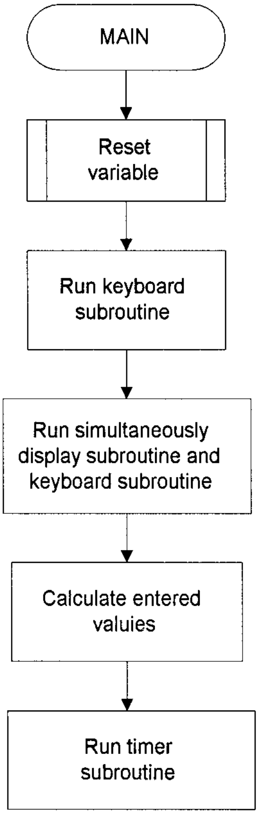
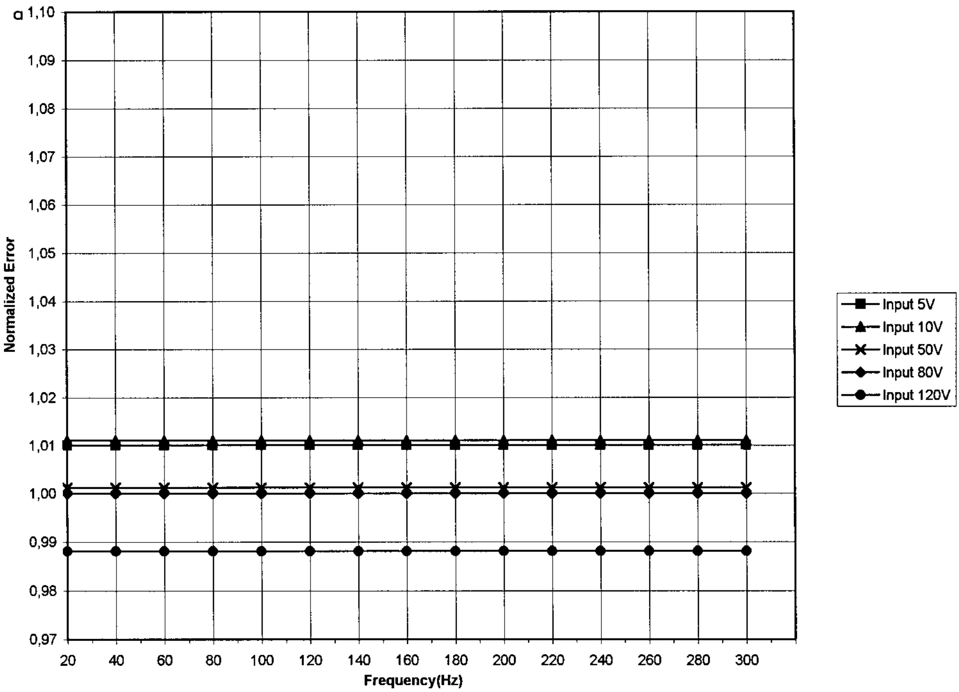


Fig. 6. The flowchart of main program.

data bus. The Data Available (DA) line gets logic high when a key is pressed and its encoding is over. This is inverted by a logic gate and then applied to the Output Enable (OE) input of the encoder chip and the interrupt input of the microcontroller. This chip can encode up to 20 keys.

LCD Driver Circuit

The advantages of using a dot-matrix intelligent LCD display are dissipation of very low power. It is compact and can also be interfaced to a microcontroller very easily. The LCD driver circuit, which consists of IC1, IC2, and LCD displays, is shown in Fig. 3. This intelligent LCD module can show 160 different characters, which are stored in its character ROM. Some functions, such as clearing the display, shifting the cursor, and display the ON/ OFF functions exist. The module itself is automatically reseated after power-off. The entire system is supplied with a 5-V power supply. Each character is generated by switching some of dots in a 5×7 matrix. RS, R/W, and E inputs are used for control purposes. Data are entered via the data line (D0–D7).



A

Fig. 7a. Normalized input-output of voltage (V) (Duty cycle = 10%).

Digital Power Supply

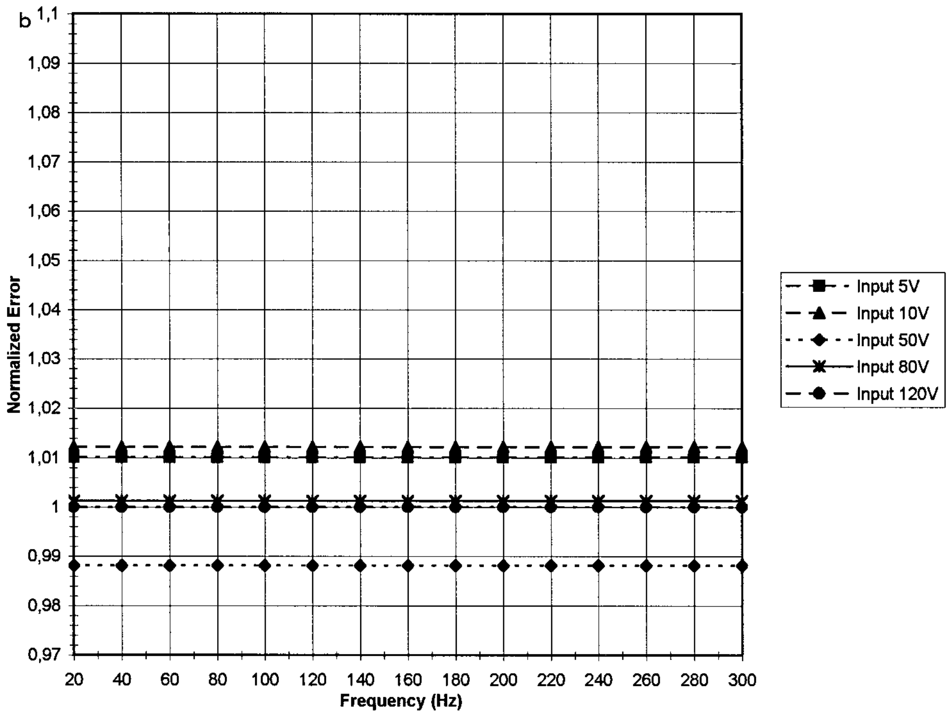
Power supplies used in the stimulator must be isolated from mains and have a limited current and voltage output in order to protect the patient. The designed stimulator device has a power supply which has all the safety features (shown in Fig. 4). MC 1466L is a floating regulator chip which gives us the capability to adjust the output voltage in a broad range. Output voltage depends on the Rset value. Regulation is 0.03% and short circuit protection exists.

Auxiliary supply voltage Vaux is isolated from the output high potential. Output voltage can be adjusted digitally by using a D/A converter which is constructed using DAC0800.

Digital data are transferred from microcontroller via an opto-coupler.

Switch Mode Power Supply

The block diagram of the switch mode power supply is shown in Fig. 5. This power supply contains a rectifier, a DC/DC converter, and a switching circuit. Switch mode power supply provides further advantages for the isolation between the mains and human body. DC/DC converter is chopped and switched the DC voltage. This chopped voltage is then boasted and rectified. Since the switching is



B

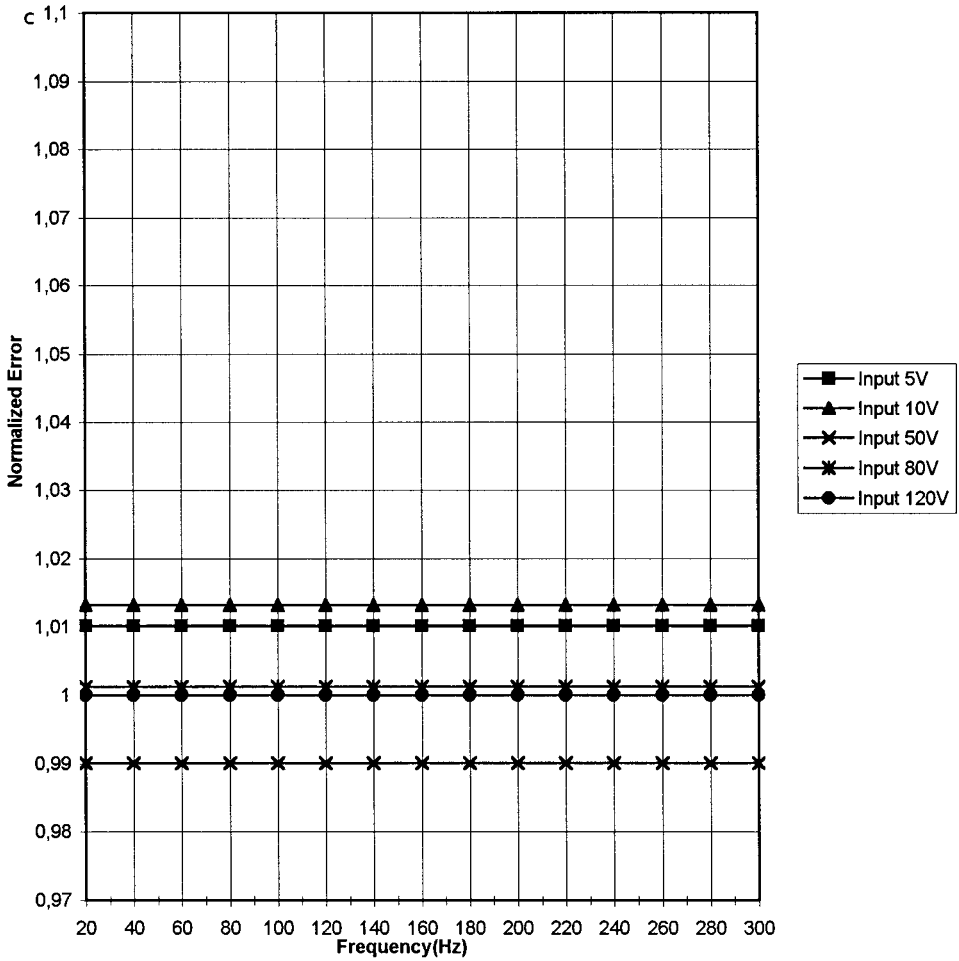
Fig. 7b. Normalized input-output of voltage (V) (Duty cycle = 50%).

in very high speed, high frequency spikes are present at the output. These spikes are suppressed and the regulated voltage is obtained at the output.

The regulation is sustained by comparing the output with the reference voltage. This comparison gives an error signal. This error signal is then used to control the pulse width of switching waveform. So the voltage swings at the output due to the changes in line and load are suppressed. Boost type regulators regulate the output voltage without the aid of a transformer. A transistor is used to obtain the power switching function and their efficiency is high.

SOFTWARE

The flowchart of the main program is shown in Fig. 6. The microcontroller jumps to the memory location INIT(0040) when it is reset in the block named INIT. In the keyboard pulse routine, the entered variables such as frequency duration and amplitude are stored at proper RAM locations. "Display" subroutine is used for displaying the characters which are pressed. When all the variables are entered and the start key is pressed "calculation" routine runs. Just after the calculation on the entered data is over, timer routine runs in order to use these calculated



C

Fig. 7c. Normalized input-output of voltage (V) (Duty cycle = 90%).

data. When the system is powered up, then the main menu is displayed on the LCD. When the pulse frequency menu key is displayed on the LCD, the system waits for us to enter a proper number. When a number key is pressed, it is displayed on the second row of the LCD. If the entered number is correct then we can proceed with another number. The menu can be ended by pressing the enter key after the second digit or third digit. After that, the display returns to the main menu again.

When we press the pulse amplitude menu key, the system waits for us to enter a proper number for this menu. At this time a 1- 2- or 3-digit number can be entered. After that, the display returns to the main menu again.

When we press the pulse duration menu, a proper number should be entered

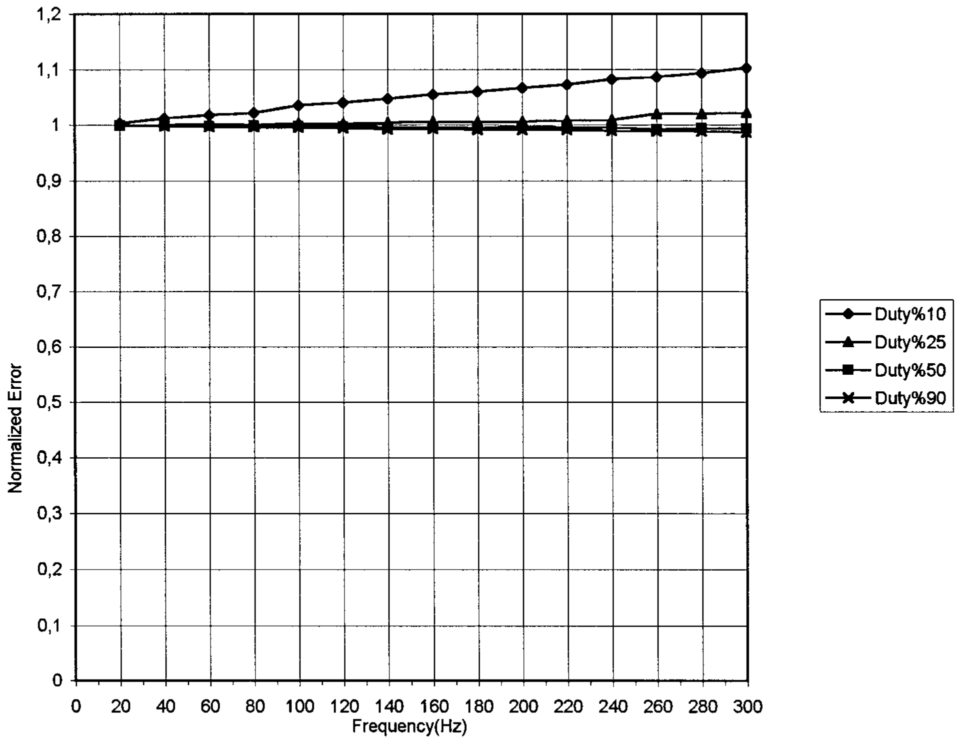


Fig. 8. Normalized input-output of duty cycle (%) (Voltage = 50 V).

by pressing the time menu key out of the main menu display. When we press the time menu key, a proper value should be entered. If we enter a wrong value by mistake then the "clear" key should be used. If we enter any of the menus explained above we can see and check the values entered before.

RESULTS AND DISCUSSION

A microcontroller based low-cost general purpose stimulator device has been designed and implemented. It is possible to obtain a square wave at the desired frequency, duration, and amplitude from the output of the device. The output parameters of the device are summarized in Table I.

Atmels 89S53 was chip selected because it has an E^2PROM program memory which makes it flexible and easy to use. This feature of the chip provides flexibility in the design of the main program. The pulse duration entered is specified as percentage because there may be situations where an improper value leads to malfunction. For example, if pulse frequency is entered as 100 Hz, minimum pulse duration entered can be 1 ms and maximum pulse duration entered can be 9 ms.

Performance analysis of the device are given below.

Table I. The Output Parameters of Devices

Parameters	Minimum	Maximum	Increment
Pulse period	3.3 ms	50 ms	0.01 ms
Pulse duration (can be applied)	0.0336 ms (%1)	49 ms (%99)	0.379 ms
(Durable)	0.037 ms (%10)	45 ms (%90)	
Pulse amplitude	5 V	120 V	1 V

(a) Pulse duration is constant; pulse amplitude and frequency are variable. The normalized graphics are shown in Fig. 7a–c.

(b) Amplitude is constant; pulse duration and frequency are variable. The normalized graphics are shown in Fig. 8.

As a result, current controlled voltage IC (MC1466L) is found to be sensitive to the ambient temperature changes as stated its data sheet, and this sensitivity is observed as 0.001V/0.1°C.

As seen from Figs. 7 and 8, when pulse duration is kept constant and the other parameters are variable, there is a linearity in the case of the input and output voltages. A little diversion results from MC1466L. For the maximum current, a minimum voltage is obtained. For the maximum voltage, a minimum current is obtained. At minimum current (adjusting using R_{set}), the entered voltage (120 V) is measured as 123 V. At maximum current, the entered voltage (5 V) is measured as 4.95 V. These results show that the performance of the stimulator is linear. This means that the system is reliable and also can be used with safety standards.

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