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Design of Waveform Generator for wearable Intermediate Frequency Therapy Apparatus

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ABSTRACT: Medium frequency electrotherapy increasingly applied today. However, many therapy products have the weaknesses of humdrum treatment, large size, large power consumption, heavy and wired devices. According to the above situations, this paper designs a waveform generator for wearable intermediate frequency therapy apparatus, which can be connected with the electrodes directly on parts of the body. It is based on low-power controller chip STM32F103VET6 internal timer and DAC programmed to generate waveforms, and the audio amplifier chip named PAM8403 is composed to achieve power amplifier circuit that can amplify waveform power. Then the waveform voltage is boosted through a safety isolating transformer. Finally, the output signal is suitable modulated medium frequency current for therapy. The experiments show that our waveform generator achieves technic index. The output voltage peak-to-peak value is 0-99V, the output voltage peak-to-peak value is 0-26mA , the modulation frequency ranges from 1Hz to 150Hz, the intermediate carrier frequency ranges from 1kHz to 5kHz and it can generate kinds of pulse waveforms. The developed therapy apparatus' size is 10cm*7cm*4.8cm, which can be worn on human arm or stomach. Its actual endurance can reach 24h.

Keywords: intermediate frequency therapy apparatus; waveform generator; modulated medium frequency current; Wearable

I. INTRODUCTION

Electrotherapy is now commonly used in medicine. The process involves no pain and it is very effective in some diseases[1], so it has a wide range of applications, like muscular pain treatment [2, 3], muscular spasms [4], arthritis, hair loss, anxiety control, acne, weight loss [5], cellulite treatments, and skin rejuvenation [6, 7].

Besides the long known, low-frequency currents (galvanization, impulse galvanization, diadynamic currents, TENS), medium-frequency currents (interference current) are increasingly applied today, as they cause patients to a far lesser degree to experience the often unpleasant sensation of current[8].

Medium frequency current is modulated by low frequency current and its amplitude and frequency alter with the modulating amplitude and frequency. The therapy using the modulated medium frequency current to treat disease or reduce pain is called Medium Frequency Electrotherapy (MFE). The medium frequency current used always ranges from 1kHz to 100kHz. MFE is according to gate control theory of pain[9] and many studies indicate that MFE can work to noninvasively increase the release of endogenous opioids from pain management regions of the brain[4, 10, 11, 12]. MFE is proved to be as effective as Transcutaneous Electrical Nerve Stimulation (TENS) in increasing pain thresholds in healthy subjects. In addition, it has been shown to be more comfortable than TENS and is likely to be better accepted and tolerated by patients[13].

There are many MFE products [14, 15, 16, 17]. However, these products have some weaknesses. The waveform types and treatment of the electrotherapy device is humdrum. In addition, these products are large size, large power consumption, heavy and wired , which can't meet the need of wearable electronics now.

So this paper proposes methods to improve the performance of intermediate frequency therapy apparatus and have designed the waveform generator which can be adopted in the devices. The waveform generator has the following advanced technical characteristics:

1. The stimulation parameter is rich and controllable. It has been shown that different stimulation parameter, including wave shape, amplitude, frequency and duration will strongly affect the therapy result [18, 19, 20, 21, 22]. So the waveform generator need to provide these parameters and can change them easily.

2. The stimulation waveform uses medium frequency current modulated by low frequency current. The modulation frequency ranges from 1Hz to 150Hz and the intermediate carrier frequency ranges from 1kHz to 5kHz. The therapy is more effective and tolerated by patients.

3. Portable, safety, low power consumption. The waveform generator uses rechargeable lithium battery and adopts portable design; uses low power safety isolating transformer and the output current is less than 26mA, which is safety to human; uses audio amplifier to increase power, which avoids power consumption in DC-DC

transformation using switching power-supply technology[16]; uses low power CPU to reduce the power consumption of controller.

II. SYSTEM DESIGN

2.1 Overall Design

The design of the system is based on STM32F103VET6 as the main control chip. Micro Controller Unit (MCU) output therapy signal by Digital to Analog Converter (DAC) channel. Lithium battery provide power supply to MCU and power amplifier by voltage regulators. The therapy signal will pass a RC high-pass filter and the power amplifier circuit composed by PAM8403 chip to amplify power. Then the signal will pass E130 pulse transformer to boost voltage. The overall composition of the system is shown in Figure 1.

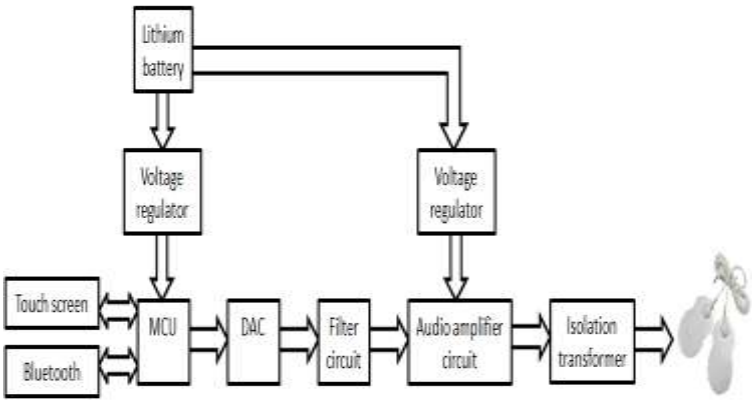

Fig.1 System structure

2.2 Master Chip

The controller uses STM32F103VET6 as the control chip. STM32F103VET6 is a 32 bit high performance and low power stmicroelectronics production of the micro controller, which can meet the low power consumption requirementof the apparatus; has many handle interrupts and programmable timers, which can meet the control requirement; is able to drive touch-sensitive displays and DAC, which can meet the system design requirement.

2.3 Waveform Generation Method

The waveform generator uses the 12 bits digital input, voltage ouput DAC of the MCU, which can cooperate with Direct Memory Access (DMA) controller. DAC data can be set left or right align. DAC has two output channels and each channel has individual converter. DAC can get more precise converted result by the reference voltage VREF+ input pin.

In this system, low frequency modulation wave is generated by DAC. Under the control of DMA and MCU's timer for trigger source, MCU puts the voltage data of the waveform division point to the DAC register. In this way, DAC can generate the base waveform including trapezoidal wave, triangular wave, triangular wave and sinusoidal wave. And when we want to change the wave frequency, we just need to change the controller timer's frequency. The waveform generator uses DMA to carry data from memory to device, DAC register directly without CPU control, which can improve the system efficiency greatly.

At the same time, in order to generate intermediate frequency carrier, we use MCU's timer to control DAC output pin on-off according to the carrier frequency, which can simplify hardware design.

2.4 Power Amplifier Module

Power amplifier module's is responsible to increase MCU output low voltage signal to therapy high voltage signal. It consists in filter circuit, audio amplifier circuit and pulse isolation transformer. The circuits are shown in Figure 2.

The signal coming from MCU DAC channel will first pass a RC high-pass filter. The filter cut-off frequency is:

$$f(x) = \frac{1}{2\pi \mathrm{RC}} = \frac{1}{2\pi * 180k\Omega * 1\mu f} = 0.88HZ$$

After filter, the signal will get through the audio amplifier circuit composed by PAM8403 chip. PAM8403 is a 3W, class-D audio amplifier. It offers low THD+N, allowing it to achieve high quality sound reproduction. The new filterless architecture allows the device to drive the speaker, requiring no low-pass output

filters, thus to save the and PCB area. With the same numbers of external components, the efficiency of the PAM8403 is much better than that of class-AB cousins. It can extend the battery life, ideal for portable applications.

After class-D audio amplifier, the signal's peak voltage and current reach 10V, 320mA. Then the signal will get through the custom pulse transformer to boost voltage to suitable therapy voltage. After the transformer, the peak voltage will reach 99V and the waveform properties keep stable in an especial range of deformation. In addition, we put the resistive load in the transformer secondary to realize impedance matching. At last, the output waveform will be connected with the electrodes on parts of the human body.

We assume the output waveform duty ratio is 1. The maximum output voltage is 99 V. The load resistance is human body's impedance, about 3kΩ. Then the output power is:

$$P_{max} = \frac{V_{max}{}^2}{R} = \frac{99^2}{3000} = 3.27W$$

In fact, therapy apparatus' output waveform duty ratio is always less than 1, so the output power of PAM8403 (3W) meets the system design requirement.

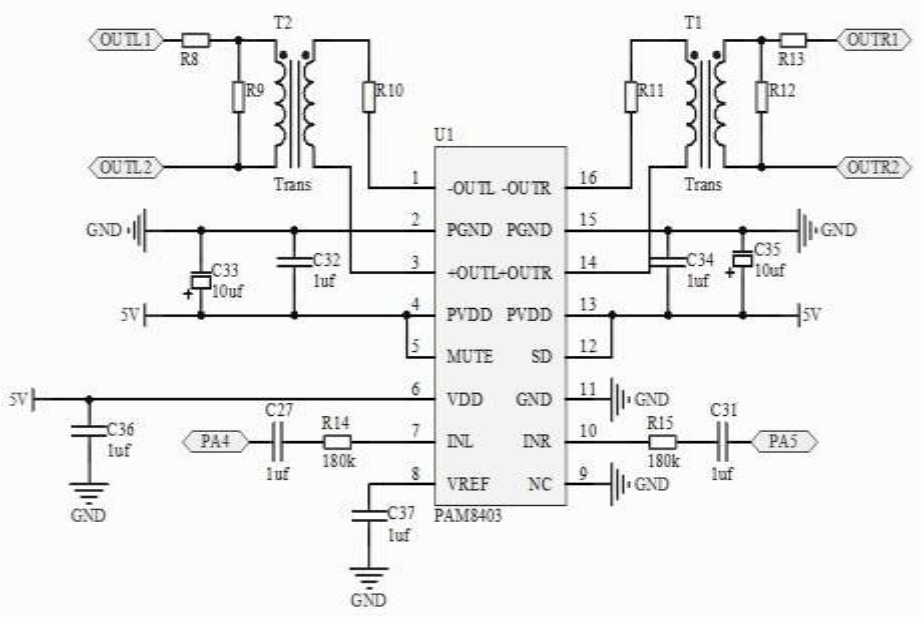

Fig.2 Power amplifier module

2.5 Power Supply Module

The waveform generator uses 7.4V rechargeable lithium battery for power supply and the battery capacity is 1000mAh. The power supply provides 5V to power amplifier module through 7805 voltage regulator circuit. The circuit is shown in Figure 3. The output voltage of 7805 voltage regulator circuit rages from 4.8V to 5.2V. The line regulation is 4.0mV. The maximum output current reach 2.2A.

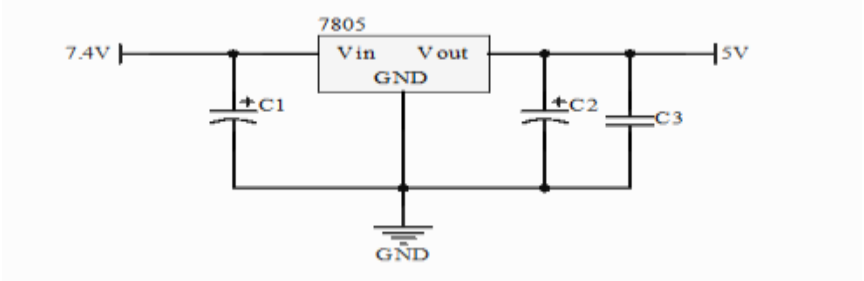

Fig.3 7805 voltage regulator circuit

The power supply provides 3.3V to master chip through AMS1117 voltage regulator circuit. The circuit is shown in Figure 4. AMS1117 voltage regulator is designed to provide 3V fixed voltage and the maximum output current reach 1A. When work on maximum output, AMS1117's dropout voltage is less than 1.3V, which will gradually decrease along with the decrease of load current.

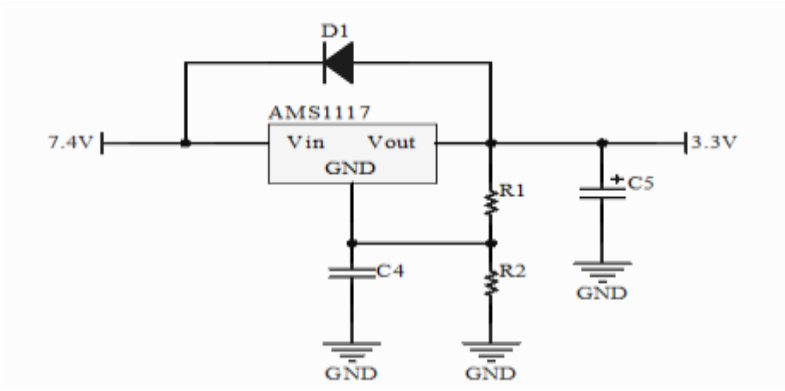

Fig.4 AMS1117 voltage regulator circuit

2.6 Software Design of Apparatus

The main program of the wearable intermediate frequency therapy apparatus is shown Figure 5.

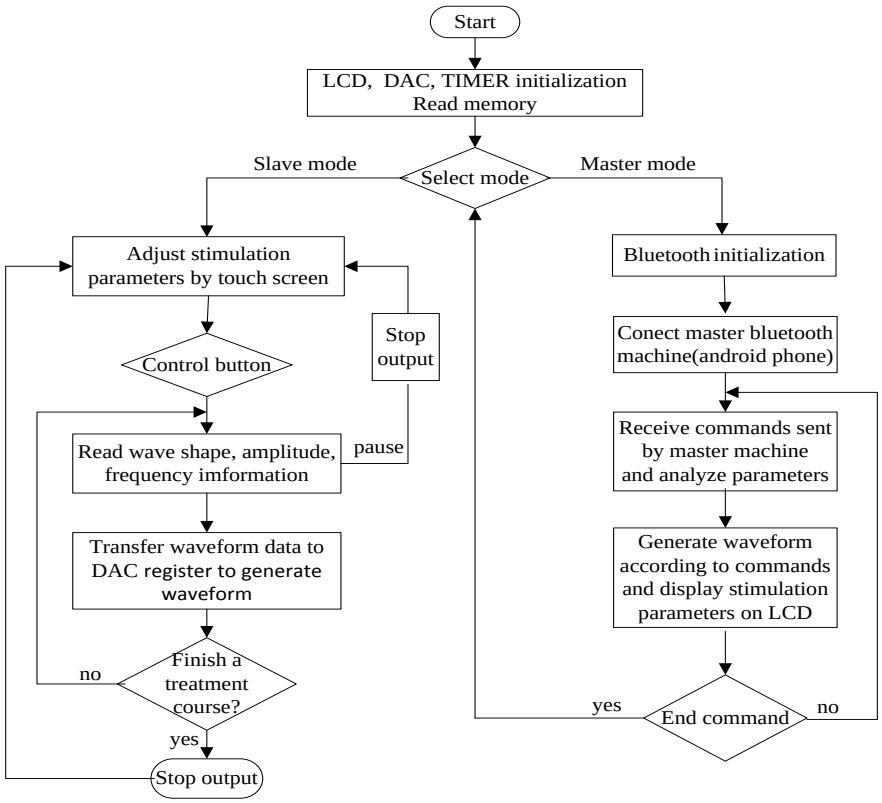

Fig.5 Flow chart of apparatus main program

III. EXPERIMENTAL RESULT

In this paper, the technic indexs of the waveform generator are that the output voltage peak-to-peak value is 0-99V, the modulation frequency ranges from 1Hz to 150Hz, the intermediate carrier frequency ranges from 1kHz to 5kHz and it can generate base waveforms, including pulse trapezoidal wave, pulse triangular wave, pulse triangular wave and pulse sinusoidal wave. We use oscilloscope to measure the output therapy waveform and the result is shown in Figure 6. We can see the medium frequency current is modulated by low frequency current. After experiment, the waveform generator achieves the technic indexs. When DAC channel output voltage is 0V, the waveform generator output voltage is 0V. When DAC channel output voltage is 2.1V, which is less than the supply voltage of master chip, 3.3V, the waveform generator output voltage is 99V and the maximum current is 26mA.

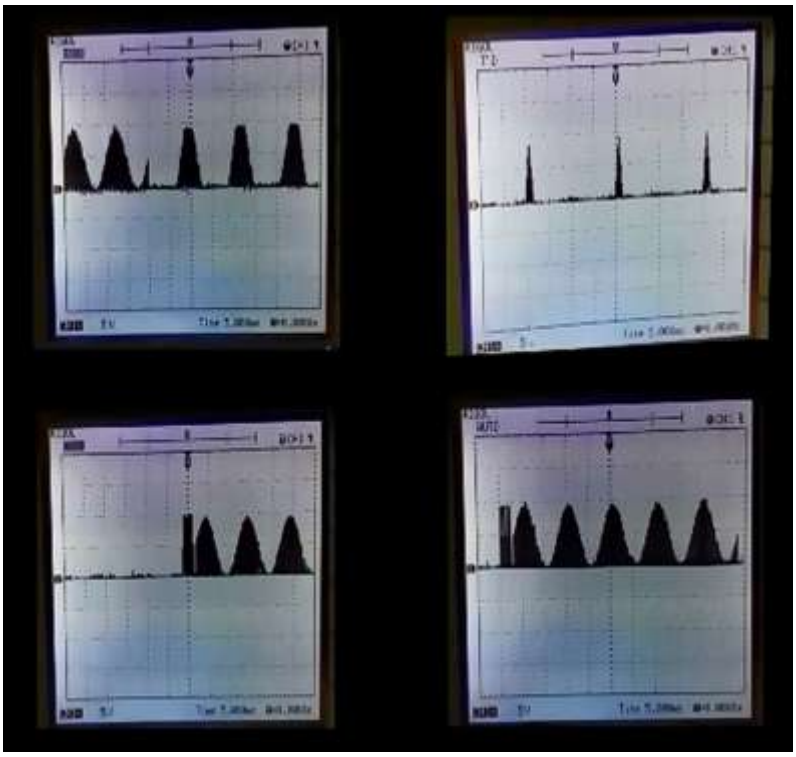

Fig.6 The measured waveform

The intermediate frequency therapy apparatus using the waveform generator is shown in Figure 7. The apparatus size is 10cm*7cm*4.8cm, which is reduction in volume compared with the existing devices can be worn on the arm or stomach. The wearable intermediate frequency therapy apparatus uses rechargeable lithium battery for power supply and its actual endurance can reach 24h.

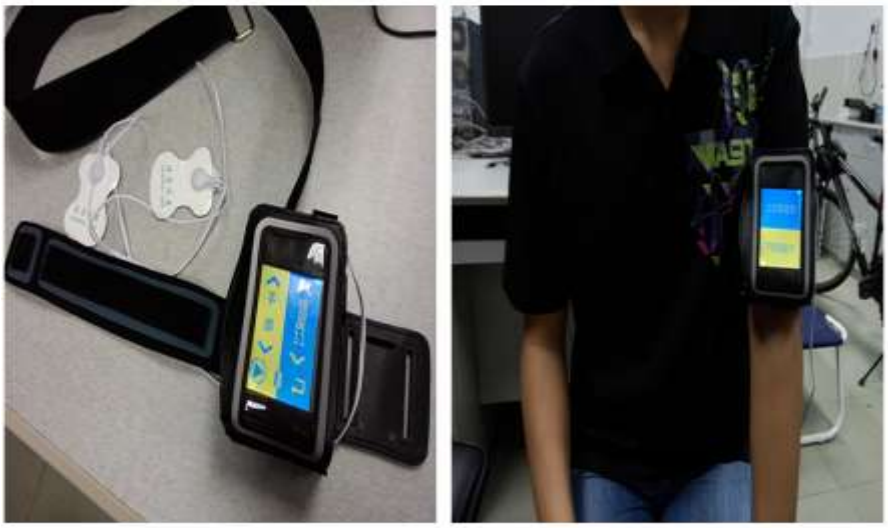

Fig.7 Wearable intermediate frequency therapy apparatus

IV. SUMMARY

This paper designed a waveform generator for the wearable intermediate frequency therapy apparatus. The waveform generator had advantageous of low power, wearable and safe isolation with the frequency and amplitude adjustable controlled by software, which can output waveform of any combination of a certain frequency and provide a good hardware platform to the treatment of waveform study.

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