

EXPERIMENTAL INVESTIGATION OF A CURRENT GENERATOR FOR BIOIMPEDANCE-PLETHYSMOGRAPHY

Bistra Draganova Nenova, Ivo Tsvetanov Iliev

Technical University – Sofia, e-mail: izi@tu-sofia.bg

There is proved necessity of pulse wave detection by electronic means in an emergency when promptness and reliability are of great importance. Taking into account the specific requirements resulting from such application, experimental investigation of a current generator for bioimpedance-plethysmography is carried out. The preferred current injector circuit includes a bridge with driven switches as an interface to the patient. The proposed output excitation signal has form of shortened symmetrical bipolar square wave. A bioimpedance measuring system is realized in which the generator is under microprocessor control. This solution enables flexible output signal tuning with easily variable frequency and duty cycle. Experimental investigations are conducted to determine the optimum to the purpose interrelation between current injector output characteristics, power supply and electrode spacing.

Keywords: bioimpedance, plethysmography, pulse wave detection

INTRODUCTION

Recent studies on the ability of health professionals to check the carotid pulse have reported this diagnostic tool to be highly unreliable and time-consuming [1], [3]. Even with prolonged palpation significant errors in recognition of pulselessness of the carotid artery occur [2]. European Resuscitation Council Basic Life Support Group recommended in 1998 that the carotid pulse check be "de-emphasized" and that the expression "look for signs of a circulation" should be used instead [3]. In an emergency, pulse wave detection by electronic means proves to be of crucial importance to the fast and correct patient status establishment.

The bioimpedance method for blood circulation monitoring, involving applying a periodic excitation signal to the bio-object and sensing the corresponding reaction, has been an object of intensive research during the last years. The applicability of bioimpedance-plethysmography to vascular pulsations sensing in case of an accident brings forward some relevant requirements. It would be advantageous to have a non-invasive, simple, convenient, reliable and low-power real-time design while bioimpedance measurement accuracy itself is not essential.

Existing bioimpedance apparatuses using sine wave excitation signal injection to the patient are distinguished for their precise results [4], [5]. Unfortunately, this is achieved at the expense of complicated and energy consuming electronic circuitry [6]. Square wave current excitation signals, which are also preferred in implantable devices, appear to be most suitable to emergency application. The increased bioimpedance measurement errors due to the higher harmonics content of pulse

waveforms are still quite tolerable for blood flow detection purposes. Moreover, application of switching mode circuits allows the most desirable design compactness and low power consumption [6].

Using of a large number of distantly spaced electrodes is often reported to provide better measurement accuracy at higher amplitude of the sensed signal [7]. This is inadmissible in case of an accident when simple manipulation of easily accessible locations is needed.

OBJECTS

We have for an object to suggest and investigate the performance of a current generator circuit applicable to bioimpedance-plethysmography in an emergency. Using bipolar square waveform of the injected current and closely spaced electrodes we aim to obtain stable and reliable blood circulation signals. Experimental investigations must be conducted to determine the optimum to the purpose interrelation between current injector output characteristics, power consumption and electrode spacing. An appropriate solution of a complete bioimpedance measuring system is needed to allow pulse wave detection at variable parameters of the current generator output unit (frequency, duty cycle, power supply).

THE CURRENT GENERATOR UNIT

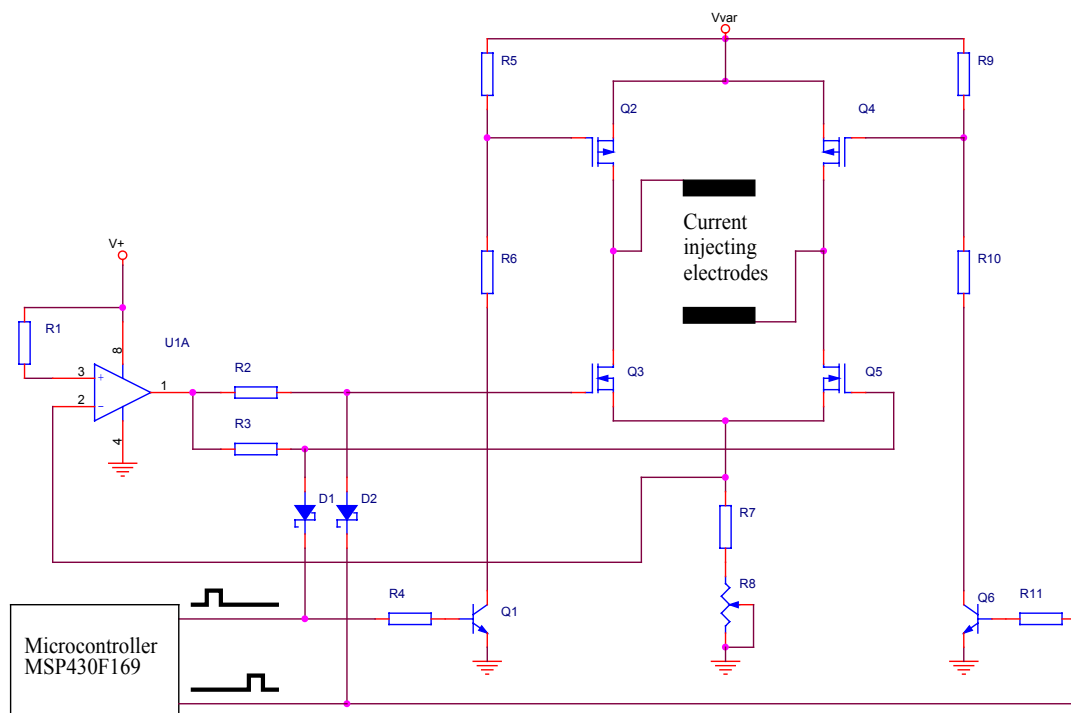


Fig.1 Current generator module circuit diagram

Fig.1 shows the proposed current generator module circuit diagram. The stable current through the patient is set by op-amp U1, resistor R7 and trimming potentiometer R8 which provides current amplitude adjustment. The interface to the injecting electrodes is accomplished by means of switches forming a MOSFET H-

bridge. Proper driving of these switches provides bipolar square pulses to the patient. This is despite the fact that the output circuit operates from a single (unipolar) supply, V_{var} . To produce a single rectangular pulse at the output one half of the H-bridge must be switched on for a time while the other half is switched off. For example, when there is a logic "1" at the base of transistor Q1 and a corresponding logic "0" is applied to the base of transistor Q6: diode D1 is with reverse bias, diode D2 conducts, transistors Q1 and Q6 are switched on and off respectively. Thus the forming one half of the bridge MOSFETs Q3 and Q4 are turned off and the current flows through the other half of the bridge: Q2-patient-Q5-(R7+R8). The current direction through the patient may be reversed by an exchange of the voltage levels at the bases of Q1 and Q6, which will switch over the H-bridge. The appropriate waveforms of the driving signals are also illustrated in Fig.1.

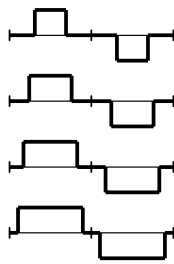


Fig.2 Shortened symmetrical bipolar square waves of the current generator output

In the presented circuit solution the current generator output stage is microprocessor driven. This enables extremely flexible variation of output signal characteristics in response to control signals from the microcontroller. Since the generator is intended for application in portable devices, the low-power high-performance microcontroller MSP430F169 is chosen which would allow the total power consumption to be reduced.

The particular output signal waveforms preferred for the purposes of the present investigation are shown in Fig.2. The current injector produces shortened symmetrical bipolar square waves with easily variable frequency (up to a few hundred kilohertz) and duty cycle (up to 100%).

THE EXPERIMENTAL EMBODIMENT

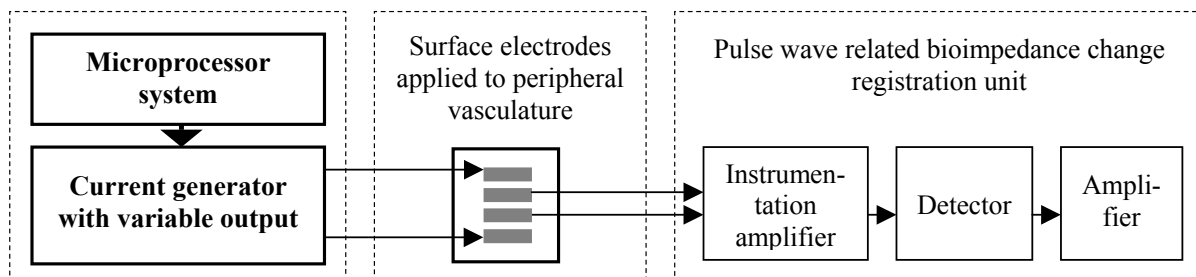


Fig.3 Bioimpedance measuring system devised for the purposes of the present investigation

The functional diagram of the implemented experimental embodiment is illustrated in Fig.3. Essentially, it represents the bioimpedance measuring system devised for the purposes of the present investigation. Surface electrodes applied to peripheral vasculature form the interconnection to the patient. The measurement method involves providing of a periodic current excitation signal to the body part via

a pair of current injecting electrodes. The flowing through the body electrical current develops a potential corresponding to the pulsatile impedance variation of the tissues in accordance with the blood circulation. A second electrode pair, positioned between the first electrodes, senses the pulse wave related voltage changes.

The bioimpedance measuring system includes the proposed microprocessor controlled current generator with variable output. The microprocessor system drives the generator's output stage under program control. This solution enables flexible tuning of the injected shortened symmetrical bipolar square waves.

The corresponding reaction of the body segment to the mentioned excitation signal is sensed via the voltage electrodes and processed by the pulse wave related bioimpedance change registration unit. The sensed voltage is first applied to the input of an instrumentation amplifier. An amplitude detector follows that rectifies the modulated signal. After removing the DC component from the signal, an amplification of the resulting pulse wave takes place. The output signal thus obtained, which is indicative of the bioimpedance being measured and hence of the blood flow in the body segment, is visualized by an oscilloscope.

EXPERIMENTAL INVESTIGATIONS AND RESULTS

The tests are carried out with the electrode array placed longitudinally along the forearm (between the palm-side of the wrist and the elbow). The electrodes are closely spaced.

- Bioimpedance plethysmograms are examined at different parameters of the input signal with the power supply of the current generator output stage V_{var} (Fig.1) varying from 5 to 12 volts. The minimum value of V_{var} that allows obtaining of stable pulse waves during the measurements is determined to be about 6 volts. The estimation of this value is needed to lower the overall power consumption in the end application.

- Experimental investigation of the current generator is carried out to assess its performance at different frequencies of the shortened symmetrical bipolar square waves being injected (Fig.2). The implemented microprocessor program control provides easy frequency adjustment in the range between 1kHz to about 300kHz. The optimum to the set purposes working frequency proves to be about 50kHz. Around this value the blood circulation signal is highly stable and reliable. Both significant increasing and significant decreasing of the frequency results in degraded quality and/or instability of the registered waveform.

- Experimental investigation of the current generator is carried out to estimate the effect of the duty cycle of the shortened bipolar square wave excitation signal upon the blood flow signal. Four different duty cycles are tested for every of the examined frequencies in the range from 10kHz to 120kHz: 33%, 50%, 66% and 80% (Fig.2). Only for the approximating to 100kHz frequencies, an increased duty cycle leads to better signal quality. For the considered optimum frequency range around 50kHz no performance difference is observed between the waveforms with the four different duty cycles. Since current flows through the patient only during the duty

cycle of the applied pulses, the least duty cycle of 33% proves to be the optimum for the set purposes (the upper waveform in Fig.2). The decreased duty cycle would allow reducing the overall power consumption in the end application.

CONCLUSIONS

1. A current generator for bioimpedance-plethysmography and in particular for pulse wave detection in an emergency is proposed.

2. A complete bioimpedance measuring system is realized to allow experimental investigation of the generator's performance.

3. Experimental investigation of the proposed generator is carried out to assess its applicability to the intended purpose. Important parameters are determined using closely spaced electrodes: power supply of the output stage, optimum working frequency and duty cycle of the injected signal.

3. On the basis of the experimental investigation may be concluded that the proposed current generator is applicable to blood circulation detection in an emergency. The proposed solution allows stable and reliable signal to be obtained at closely spaced electrodes and reduced power consumption.

Acknowledgment: This work has been supported by the TU-Sofia Research Fund, Grant 545HH-3/2005.

REFERENCES

- [1] Ochoa FJ., Ramalle-Gomara E., Carpintero JM., Garcia A., Saralegui I., Competence of health professionals to check the carotid pulse, *Resuscitation*, 1998 Jun, 37:3 173-5
- [2] Eberle B., Dick WF., Schneider T., Wisser G., Doetsch S., Tzanova I., Checking the carotid pulse: diagnostic accuracy of first responders in patients with and without a pulse. *Resuscitation*, 1996, 33:107–16
- [3] Anthony J. Handley, Koenraad G. Monsieurs, Leo L. Bossaert, European Resuscitation Council Guidelines 2000 for Adult Basic Life Support, *Resuscitation* 48 (2001) 199–205
- [4] Petrova G., PhD Thesis: Methods and electronic devices for impedance-cardiography, Technical University-Sofia, 2000
- [5] Hatib F., PhD Thesis: Methods and electronic devices for bioelectroimpedance measurements, Centre of Biomedical Engineering, BAS, 1998
- [6] Min M., Kink A., Land R., Parve T. Patent number WO2004052198 Method and device for measurement of electrical bioimpedance, 2004
- [7] Schookin S., Zubenko V., Beliaev K., Morozov A., Yong W., Patent number US6161038 Non-invasive monitoring of hemodynamic parameters using impedance cardiography, 2000