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OPTICAL RECEIVING AND TRANSMITTING DEVICES FOR CONTROLLING BLOOD FLOW DURING HEMODIALYSIS[12]

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Abstract: *The aim of the present study is to present a prototype of an electronic system for recording blood loss by optical method, in the rupture of fibers on a dialyzed filter during manipulation. The presented photointeractor registers the presence of a volume of 0.1% erythrocytes, and the signaling time does not exceed 2s. The light indication and the audible alarm warn of detection and continue the loss of blood, including a "Bluetooth" module, notifying medical staff to a central prescription and a mobile phone. Integrated monitoring system in a hemodialysis machine, improving the current medical approach by implementing appropriate actions to prevent risks to the lives of patients during therapy.*

Keywords: *hemodialysis; electronic system; optical; blood flow; control.*

INTRODUCTION

Chronic kidney disease is a global public health problem with adverse consequences of renal failure and premature death. It affects 10% of the world's population, and 250,000 new patients are diagnosed each year. More than 10% of Europeans suffer from chronic kidney disease. It is no coincidence that one of the sittings of the European Parliament addressed the problem of kidney disease, such as the silent epidemic of Europe, because these diseases are asymptomatic. It is important to draw the public's attention, to increase its health culture and to focus on the problems of kidney disease.

In Bulgaria, 12.8% of the population or every eighth person (about 700,000 - 750,000 people) suffers from kidney disease. Nearly 90% of those affected have kidney failure, with the percentage of women affected being around 12.9–13.8% and that of men at 17.1%. Over 3,800 of the patients are on hemodialysis. 84 specialized centers have been established for them in the country.

The electronic system for monitoring the level and loss of blood ensures the safety of the patient during hemodialysis treatment. It is considered the most important procedure that should never be compromised. An integrated monitoring system in the hemodialysis machine can improve the current medical approach by appropriate actions to prevent risks to patients' lives during therapy (Kimata et al., 2013).

The aim of the present study is to present a prototype of an electronic system for monitoring and recording blood loss by optical method, in case of rupture of the fibers of the dialysis filter during the performed manipulation.

MATERIALS AND METHODS

Blood transports oxygen from the lungs to the various tissue cells of the human body. Hemoglobin (Hb) is the oxygen-binding protein contained in red blood cells (erythrocytes). In a healthy human the

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arterial hemoglobin is nearly saturated with oxygen (100% HbO2, 0%Hb) (Ho-Chiao Chuang et al., 2015).

A. Requirements for blood flow monitoring and block structure synthesis systems

The blood flow detector is an essential part of the electronic blood flow control system, which protects patients from blood loss during four hours of hemodialysis. The specific requirements and justifications for the implementation of the electronic system are expressed in the following (Daugirdas, Blake and Ing, n.d., Yedke and Joshi, 2018).

- To monitor and detect erythrocytes in the dialysis solution after passing through the dialyzer, distinguishing with great accuracy appeared air bubbles;
- Send a warning signal to a medical computer or mobile device, including an audible alarm;
- To work stably and with high sensitivity, registering the presence of a very low concentration of blood cells 0.1% in a relatively large amount of spent solution;
- To provide the possibility for calibration and service.

In order to reduce the error caused by ambient light, it is necessary to ensure good isolation of the optical device (Stegmayr, Forsberg, Jonsson and Stegmayr, 2007).

Dyshemoglobins with different absorption spectra shown in Fig. 1, but also motion artifacts, and various physiological and pathological conditions can cause problems with optical measurements. When a hemoglobin molecule lost the capacity of reversibly binding oxygen under physiological conditions, either permanently or temporarily, it is denoted as a dyshemoglobin. The two most common variants of dyshemoglobin are carboxyhemoglobin (COHb) and methemoglobin (MetHb) (Misra, 2005).

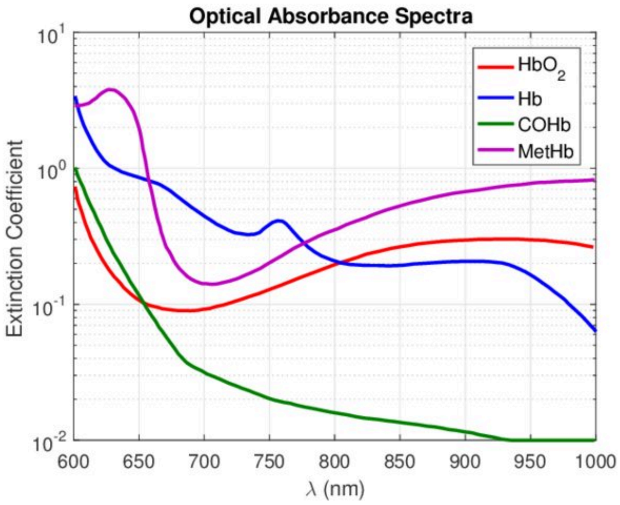

Fig. 1. Optical absorbance spectra of oxyhemoglobin (HbO2), reduced hemoglobin (Hb), carboxyhemoglobin (COHb) and methemoglobin (MetHb)(Van Gastel, Stuijk and De Haan, 2017)

The molecular excitation coefficient is a characteristic of the ability of hemoglobin forms to absorb the light wave passing through it, based on the Bouguet-Lambert law (1)

$$I = I_o \ell^{-\beta X} \qquad (1)$$

where: I, Io are the energy intensities, respectively before and after the passage of the wave through the test substance; X is the depth of the earring.

$$E = \lg\left(\frac{I_o}{I}\right) \qquad (1)$$

where: E is the extinction of light in the given sample.

Because substances absorb selectively, the absorption coefficient and extinction depend on the wavelength of light (Nissenson and Fine, 2009).

Different types of hemoglobin are defined by the presence of oxygen molecules in the blood. The most common forms are De-oxy (Hb) hemoglobin and Oxy (O_2Hb). Both forms occur in the spent dialysis solution and differ in blood color, dark and light red, respectively. Identical absorption (extinction) of the light wave with a length of 820 nm is observed, which can be seen in the graph of Fig. 1. When selecting a transmitter / receiver pair in the blood flow detector, it is mandatory to observe the condition that the peak radiation is a wavelength of 820nm and 940nm.

The block diagram of the blood flow detector is shown in fig. 2. The erythrocyte threshold level monitor controls the output of a signal when registering blood cells above 0.1%. Hypersensitivity is also a side effect of a dialysis procedure.

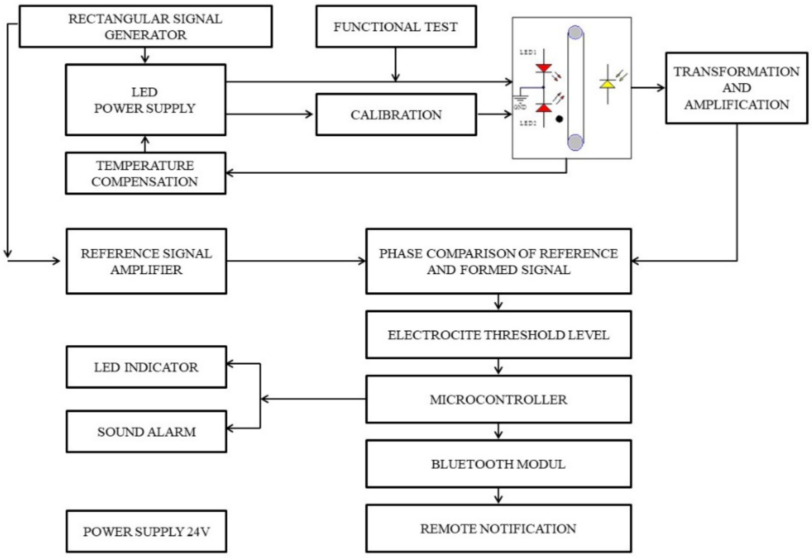

Fig. 2. Block diagram of a blood flow detector

The microcontroller controls the visual and audible warning signal, as well as the peripherals. The Bluetooth module transmits signals to the central reception or via a mobile phone to a doctor in a timely manner. The LED indicator reflects registered blood cells during the current work near the patient.

The designed blood flow detector is a prototype and can be integrated into hemodialysis equipment. If single erythrocytes are registered, the output analog signal from the threshold level block is very short. When blood is read in a volume of more than 0.1%, this signal is fed to the ADC input of the microcontroller, and the LED indicator and the audible alarm are turned on. A warning signal via "Bluetooth" is also sent to the central reception as well as to the mobile phones of medical staff.

DEVICES FOR CONTROLLING BLOOD FLOW DURING HEMODIALYSIS

A. A. Block emitter to the electronic system for blood flow control during hemodialysis

The SMT820 / 940-C LED emitter was selected, consisting of two diodes in one housing, emitting a light wave in the infrared spectrum with a centered peak of 820 nm and 940 nm. The emitter has two colors with a common cathode, with a temperature range from -20˚C to + 80˚C, high productivity, possibility for pulse control of the power supply, production of "Marubeni America Corporation".

The peak emission of the emitted wave of D1 has a wavelength $\lambda = 820nm$, intensity $Ie = 2900mW / sr$ at $IF = 0.5A$, $tp = 150\mu s$, $VF = 3.6V$. The peak emission of the emitted wave of D2 has a wavelength $\lambda = 940nm$, intensity $Ie = 2900mW / sr$ at $IF = 0.5A$, $tp = 150\mu s \div$, $VF = 3.3V$.

The photodiode SFH 213 BPN manufactured by OSRAM Opto Semiconductors was chosen as the receiver of the emitted wave, taking into account its sensitivity.

The schematic diagram of the transmitter is shown in fig. 3 and consists of a rectangular pulse generator, LED power supply, calibration unit, functional test and temperature compensation. The rectangular pulse generator generates periodic signals with an amplitude of 10V and a frequency of 700Hz. The time diagram of the operation of the LED source of electromagnetic waves is presented in fig. 4.

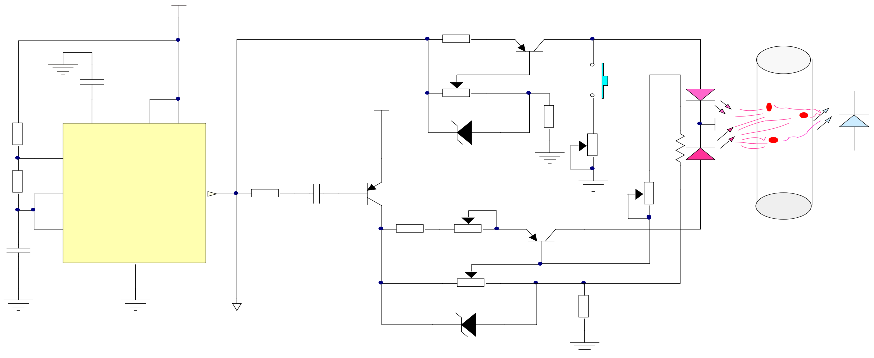

Fig. 3. Block of the emitter for control of the blood path during hemodialysis

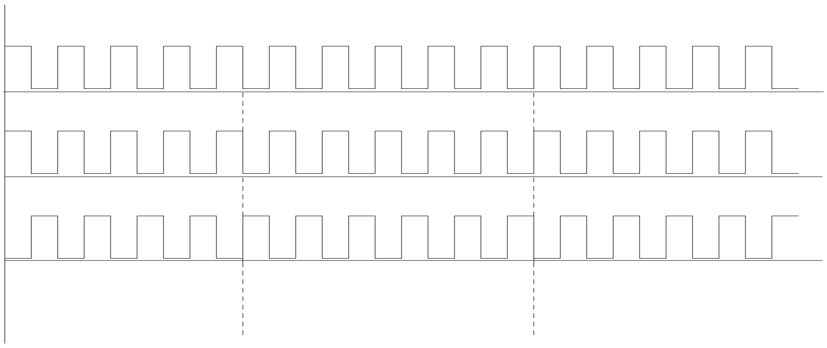

Fig. 4. Timing diagram of the operation of the LED source of electromagnetic waves U = f (t)

The generated pulses at the output (A) of the high level generator unlock the transistor Q2. A current flows through the resistor R4, the emitter-collector junction of Q2 and the LED, during which an electromagnetic (light) wave of length λ = 820 nm (B) is emitted. Resistor RA1 changes the voltage through the divider formed by R5 and RA1, which changes the collector current, and hence the current through the LED. The use of a variable resistor is required by the condition for the emission of a light wave from the two LEDs D1 and D2 with the same intensity with a value of Ie = 2900mW / sr. The zener diode of the DZ1 stabilizes the voltage applied to the base. This forms a constant current through the LED and a constant electromagnetic wave.

At a signal at the output of the generator with a low level of the half-cycle, the transistor Q2 is blocked. Unlock transistor Q1. A current is formed in the circuit +Vcc, the emitter-collector transition of Q1, R6, RA2, the emitter-collector transition of Q3 and LED D2, which emits an electromagnetic wave (C). The variable resistor RA3 and the zener diode DZ2 perform the function of balancing the light fluxes from D1 and D2.

The variable resistor RA2 is used for calibration related to the formation of light radiation with a wavelength λ = 940nm. The LEDs housed in one housing are two connected to each other by a common cathode. They emit waves of different lengths, which defines different stresses in the right direction. For λ = 820nm is VF = 3.6V, and for λ = 940nm is VF = 3.3V. Precise voltage regulation is extremely important due to the fact that waves with λ = 820nm register blood cells, and λ = 940 nm air bubbles, which in turn absorb less light radiation than blood cells.

The temperature stabilization unit is realized with NTC-10K-3950 thermistor with negative temperature coefficient, attached to the LED housing. The series-connected variable resistor RA5 achieves voltage linearization in the set range of (25 ÷ 50) (C temperature change of resistance. The value of the resistance of RA5 Rt25º = 10kΩ. As the temperature of the LED increases, the resistance Rt50º = 3.57kΩ increases the voltage drop URA5, whereby the base current of the transistor Q3 decreases, respectively the collector current decreases, ie. stabilizes the current through the LED.

The functional test unit is made of SW-F and resistor RA4. The switch has a NO contact, which when closed mixes the collector circuit of the transistor Q2, through the variable resistor RA4 and reduces the current through the LED to 60mA. The resulting electromagnetic wave simulates radiation after absorption by registered blood cells from the photodiode. The photocurrent in radiation without absorption is Ip = 0.135µA and decreases to Ip = 0.90µA after resorption of the luminous flux by erythrocytes.

B. Receiver block for conversion, amplification and phase comparison of the optical signal

The schematic diagram of the receiver is shown in fig. 5 and includes - an optical to electrical signal converter, an alternating signal amplifier, a reference signal amplifier, a phase matching step and a blood cell threshold level unit. Accordingly, FIG. 6 expresses the principle of work in time diagrams in the absence of blood cells, in their registration and the presence of air bubbles. Receiving the optical signal from the photodiode generates a variable signal that controls the transistor Q4. When selecting it, the photocurrent Ip = (90 ÷ 135) (A is taken into account.

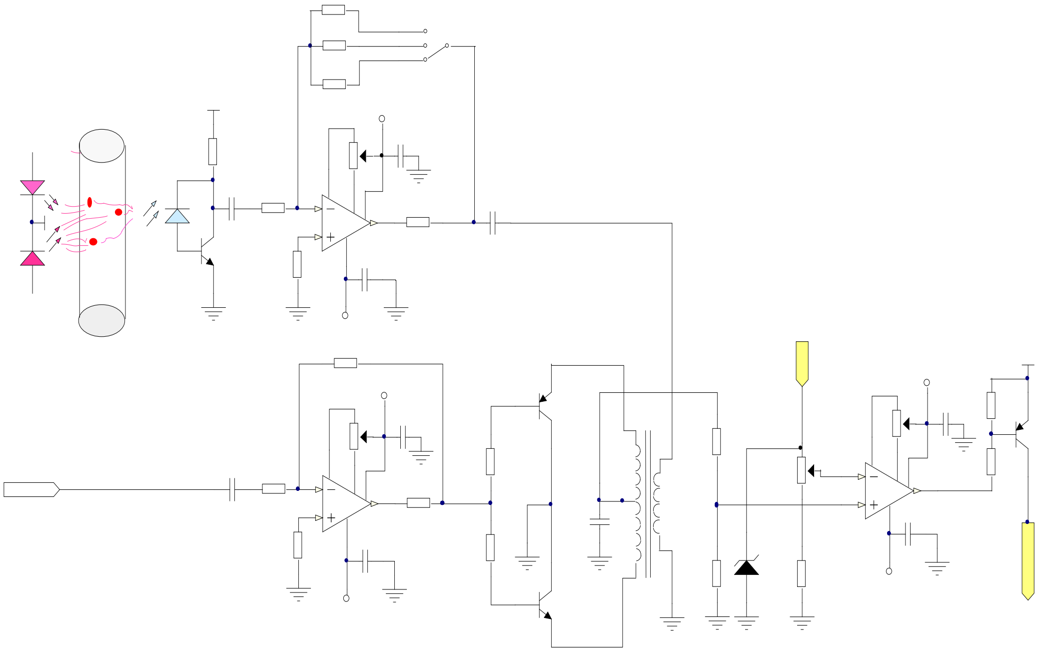

Fig. 5. Block for conversion, amplification and phase comparison

The output signal from the transistor Q4, (FD) is fed to an AC amplifier made by the operational amplifier. The output of the amplifier (E) is connected to a pulse transformer LL-1573 manufactured by "LUNDAHL Transformers". Its secondary winding has two symmetrical coils. The transformation ratio is 1: 1: 1. The static resistance of each of the windings is 50Ω. Frequency band at RL = 50Ω e 10Hz ÷ 200kHz.

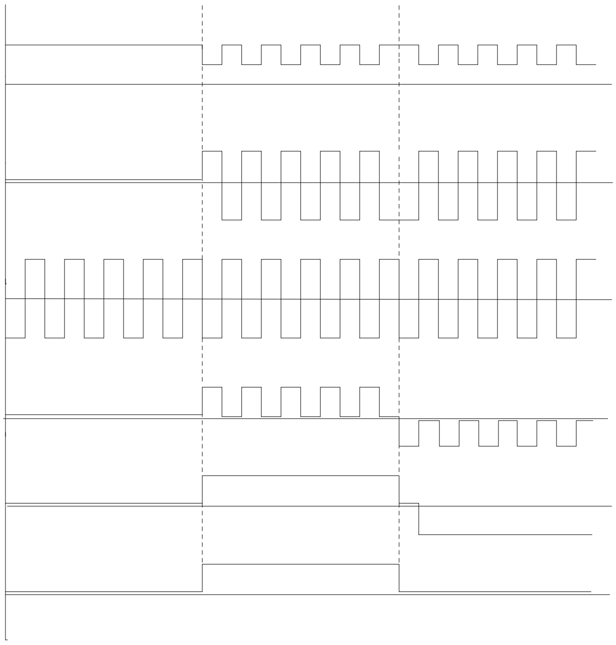

Fig. 6. Time diagram of the system operation U = f (t)

The reference signal amplifier (F) controls the transistors in the phase matching unit composed of the pulse transformer LL-1573 and the transistors Q5 and Q6 in key mode controlled by the pulses of the amplified reference signal. The registration of blood cells forms at the output of IC2 pulses oriented negatively due to the high degree of absorption of radiation by D1. On the other hand, D2 forms positively oriented pulses, out of phase 180º in the registration of air bubbles due to the very small degree of absorption of light waves. Depending on the shape of the pulses (E), the primary winding of T1 and the sequential switching of the transistors from the reference signal (F) to the midpoint of the secondary winding of T1, a signal (G) is formed determining the presence of blood cells in the dialysis solution. Capacitor C12 is used to smooth the output signal (H).

The unit for determining 0.1% blood cell content was realized by the comparator performed by IC4. The output signal from the phase comparison step (H), fig. 6, is fed to the non-inverting input of an operational amplifier. A reference voltage is applied to the inverting input, which defines the absence of blood cells fig.6 {(J) - I}. A signal is formed at the output of the comparator when, the value of the input voltage is less than the resistive fig.6 {(J) - II}.

The determination of the reference voltage is performed with very high accuracy, using calibration standards (pure filtrate and 0.1% erythrocytes) and the calibration procedure is repeated many times.

CONCLUSION

The presented photointerapter registers the presence of a volume of 0.1% erythrocytes, and the signaling time does not exceed 2s. A light indication and an audible alarm warn of the occurrence and continuation of blood loss by the patient undergoing hemodialysis treatment.

The included "Bluetooth" module notifies the medical staff to the central reception and on a mobile phone.

The integrated monitoring system in the hemodialysis machine improves the current medical approach by implementing appropriate actions to prevent risks to the lives of patients during therapy.

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