Sensitive and Accurate Measurement Environment for Continuous Biomedical Monitoring using Microelectrodes

L. Majer, V. Stopjaková, E. Vavrinský

Department of Microelectronics, Slovak University of Technology
Ilkovičova 3, SK-812 19 Bratislava, Slovakia
E-mail: libor.majer@stuba.sk

Abstract. *This paper presents a new non-invasive biomedical monitoring of selected psychosomatic processes. The proposed method measures human skin conductivity using the interdigitated array (IDA) microelectrodes, which allow continual monitoring and analysis of complicated physiological, pathophysiological, and therapeutic processes. The main goal is monitoring of psycho-galvanic reflex of the human skin that might be very useful for stress identification in medical and psychological experiments. An integrated monitoring system, applicable also in portable measurement environment, was designed and developed. Comparison to a standard bridge-based measurement system was done in terms of accuracy, sensitivity and other main features. The measurement method itself as well as results achieved are discussed.*

Keywords: non-invasive biomedical monitoring, skin conductivity measurement, interdigitated array (IDA) microelectrodes, psycho-galvanic reflex

1. Introduction

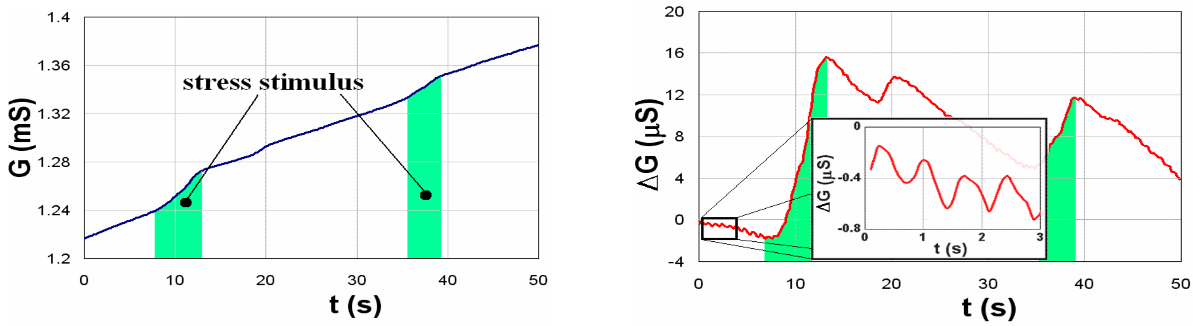
Even though measurements of the electrical conductivity, resistance or impedance of skin surface have a long history, the way how physiological changes in a human tissue are reflected in electrical impedance parameters has not been very clear [1]. The simple psycho-galvanometer was one of the earliest tools of psychological research [2]. The psycho-galvanic reflex (PGR) is the main detection parameter of stress, excitement stimuli or a shock, and it is characterised with immediate change of the skin conductivity [3]. Although, technical realization of these measurements is very simple, in practice, there is a problem with reproducibility and comparison. First, it was assumed that increase of skin conductivity during a stress stimulus is only caused by skin perspiration. Later, a very important factor of the potential barrier near the stratum lucidum layer, which thickness changes due to the nervous system, was discovered and proven [4].

In this paper, a new method of biomedical monitoring of psycho-physiological processes, based on skin conductivity measurement using a dedicated integrated monitoring system with the interdigitated array (IDA) microelectrodes, is presented. The proposed approach offers continuous monitoring and analysis of human skin electrophysiological parameters in a completely safe and non-invasive manner. The principle of PGR-based physiological monitoring is described in [5].

2. Preliminary work

A thin film IDA microelectrodes system of different sizes and topologies was designed, developed and realized. Then, experimental measurements of the electrodermal response upon selected stress stimuli were performed using the developed microelectrode array. The planar microelectrode system was applied on forefinger of the non-dominant hand. During conductivity measurements a drift of the signal is occurred due to skin polarization effects –

electrodermal phenomena (EDF) (Fig. 1a). To minimize this effect, the measured skin conductivity is corrected using an exponential function $G(t) = A + B(1\text{-}e^{-t/C})$, where G is skin conductivity, t is time and A, B, C are constants (Fig. 1b) [5]. It is also useful to depict ΔG (relative change of current ΔI at a constant supply voltage U and frequency f). This experiment brought one very important finding: there is another parameter besides the electrodermal response that might be sensed - the hearth pulses, as shown in a zoom-in window of Fig. 1b.



a) b)

Fig. 1. Typical time responses of EDR: a) uncorrected, b) further processed signal

In many experiments carried out, the influence of different factors such as microelectrodes dimensions, input signal amplitude and frequency values, skin hydration (sweating), and the microelectrode placement on the measured signal have been investigated. The achieved results show that although the absolute values of conductivity might differ upon different conditions, the conductance time responses are very similar. Optimal input signal amplitude from 1.5 V to 3 V has been selected. The signal frequency is not so critical, however, an optimal value in order of ones kHz has been proved. A proper IDA microelectrode dimension is: 200μm/200μm (finger/gap ratio) (Fig. 2 on the right).

Moreover, a comparison of the developed microelectrodes approach to the commercial laboratory-like measurement system, based also on galvanic skin response but using macroelectrodes, was carried out. Standard psycho-tests performed by experts show that the measured responses taken from both systems are similar and the microelectrode signals are much more stable with a shorter response time [5].

3. The proposed integrated monitoring system

The complex measurement environment for continuous and non-invasive monitoring of the skin impedance has been developed. Several methods applicable to continuous measurement of human skin impedance were analyzed first. At last, the auto balancing bridge method was chosen because of a few reasons (high accuracy, short time, high repeating rate of measurements, frequency and amplitude signal definition, possibility to measure both real and imaginary impedance components, controllability by a microprocessor, digital processing, etc.). The proposed measurement system (Fig 2.) consists of the IDA microsensor described above, integrated circuit AD5933, microprocessor ADuC832, and a personal computer.

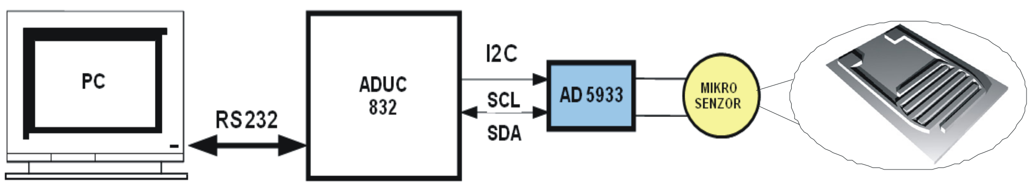
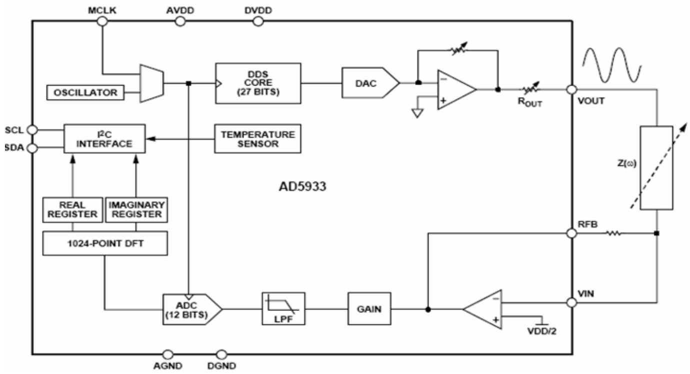


Fig. 2. Block diagram of the monitoring system using the planar IDA microelectrodes

The core of the proposed monitoring system is the integrated circuit AD5933 (Fig. 3) by Analog Devices [6] that provides measurement of human skin impedance sensed by the developed microsensor system. The measurement process is controlled by the microprocessor ADuC832 [7] via I2C interface. Using a serial interface RS232, the microprocessor then sends the measured data to a personal computer providing data storage. Additionally, the microcontroller also provides an initial configuration of the integrated circuit AD5933 that is needed at the measurement beginning. The configuration includes mainly setting of frequency and amplitude of the input signal used for measurement of unknown impedance. The microprocessor also controls time slots during which the measurements are performed. After the measurement in the respective time slot is done, the microprocessor reads and sends the data from AD5933 circuit to a PC, where the data are stored and further processed.



Impedance Range	100 Ω ÷ 10 MΩ
Output Frequency Range	1k Hz ÷ 100 kHz
Internal Oscillator Frequency	16,777 MHz
Power Requirements	2,7 V ÷ 5,5 V
Total System Accuracy	0,5 %
Temperature range	-40 °C ÷ 125 °C

Fig. 3. Integrated circuit AD5933 and its main properties

The AD5933 circuit is composed of the following parts: an input signal generator, a 12-bit A/D converter, a DFT (Discrete Fourier Transform) circuit, a thermal sensor, and I2C interface. The generator provides a sine wave input signal of certain frequency and amplitude at the output VOUT. Unknown impedance is connected between VOUT and VIN terminals. Thus, the magnitude and phase of the current flowing through a load depend on its impedance. This current is then transformed to voltage that is converted into a digital signal by the D/A converter. Finally, the DFT circuit provides discrete Fourier transform of the converted signal. As a result, values of real and imaginary parts of a loaded admittance are measured. Photograph of the PCB of the monitoring system is shown in Figure 4.

4. Graphical User Interface

A graphical user interface (GUI) in C++ under Windows XP platform has been developed in order to provide necessary calibration of the measurement as well as storage, displaying, and postprocessing of the measured data (real and imaginary components of the impedance, and phase of the measured impedance). The developed software allows an easy and user-friendly control of the measurement process and data displaying and storage. From the measured data, absolute values of impedance and admittance as well as its phase are computed and all these parameters can be displayed in several graphical and numeric modes. The main GUI panel is shown in Fig. 5. It is sectioned to the main menu, graphical and numerical parts, and the operating part showing the currently measured data. The easy measurement control is provided only by three buttons (start, pause and stop). The computer port and measurement hardware setup are performed automatically to simplify the measurement process for a user. Besides the measurement control, setup, and calibration, the developed software enables saving of all the measured data, which can be saved to a table format, e.g. MS Excel, for further post-processing, analysis or evaluation.

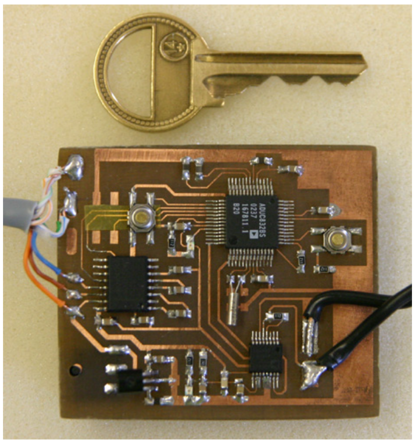


Fig. 4. PCB of the monitoring system

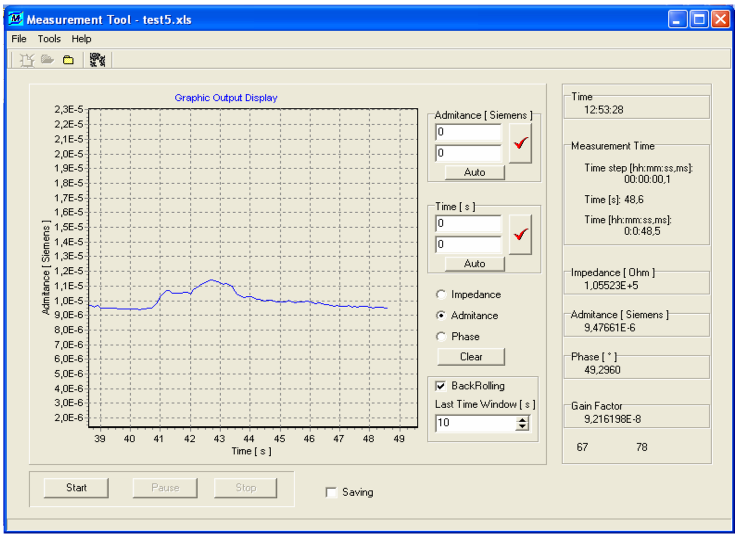
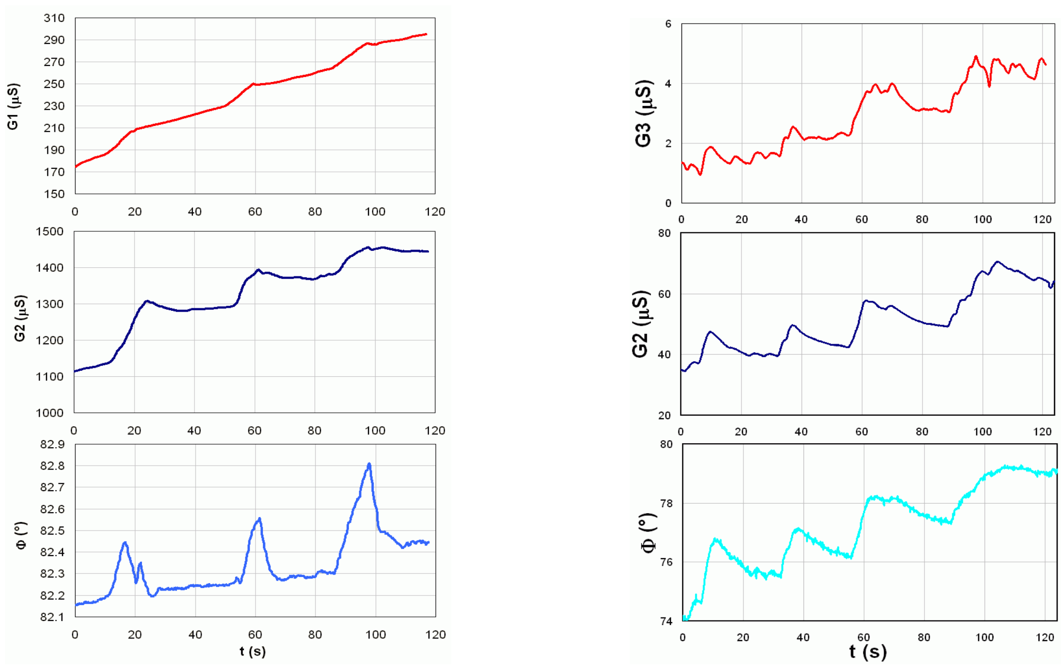


Fig. 5. The GUI main panel

5. Achieved results

Finally, experimental measurements and the achieved data evaluation have been carried out. Comparison of the results obtained by a standard laboratory bridge instrument (*G1*– admittance) to the data measured by the developed monitoring system (*G2* and *Φ* – admittance amplitude and phase, respectively) is shown in Fig. 5a. This experiment shows the developed monitoring system is more sensitive to stress stimuli. Moreover, the phase of skin impedance may offer more sensitive monitoring of psychogalvanic response since it reflects admittance changes significantly (high peaks in the lowest waveform).



a) b)

Fig. 5. Comparison of the achieved results

As the last experiment (Fig. 5b), our microelectrode approach was compared to a classical macroelectrodes GSR method [8]. The waveforms are as follows: G3 – skin admittance obtained by macroelectrodes, *G2* and *Φ* – admittance and phase measured by the microelectrode approach). Certainly, for each method the input signal parameters were set in a proper way. In both cases, the physiological response has been evoked by the same stress stimuli. The standard psychotests performed have showed that the response signals obtained from both GSR methods match and the microelectrode signals are more stable and accurate.

6. Future work

Since the developed measurement equipment offers new opportunities for non-invasive continuous portable biomedical monitoring, next work will include mainly design and development of a portable version of the system using RF wireless data transfer, followed by integration of the whole monitoring system into a single chip.

7. Conclusions

The integrated measurement system applicable in a portable measurement environment for the reliable and precise stress detection by the psychoglavanic reflex monitoring has been developed. The system is based on an auto balancing bridge measurement method offering digital processing and displaying of the measured data in the developed software operating under Windows XP platform. The experimental results show that the microelectrodes are able to sense the electrodermal response in a very precise and fast way. Interesting outcome has been observed – the psychogalvanic reflex might be much more accurately sensed by the skin admittance phase since this parameter reflects the human skin conductivity changes significantly. The achieved accuracy, voltage and frequency ranges are suitable not only from human biomedical monitoring point of view but also from the measurement system integration and miniaturization requirements.

Acknowledgements

The presented work has been supported by the Ministry of Education of the Slovak Republic under project No. VTP1013/2003.

References

[1] Olmar S.: Bioelectrochemistry and Bioenergetics 45. 2, 1998, pp. 157-160.

[2] Wakelam K.: Biofeedback and the Human Energy Field, 2000, pp. 7-9 (3).

[3] http://www.qubitsystems.com/electro.html/ - Qubit systems – Human electrophysiology.

[4] Weis, M., Danilla, T., Matay, L., Hrkút, P., Kákoš, J.: Noninvasive Biomedical Sensors on the Biology - Interface of Human Skin. Proceedings of the 7th International IMECO TC-13 Conference on Measurement in Clinical Medicine: Model Based Biomeasurement, Stará Lesná, 1995, pp. 89-91.

[5] Vavrinsky E., Tvarozek V., Marman P., Weis M.: Monitoring of psychophysiological processes by skin conductivity measurements using microelectrode arrays. European Medical and Biological Engineering Conference, Prague, Czech Republic, 2005.

[6] http://www.analog.com/ – AD5933 Datasheet.

[7] http://www.analog.com/ – ADuC832 Datasheet.

[8] http://www.trans4mind.com/psychotechnics/gsr.html/ - Shepherd P.: The Galvanic Skin Response Meter.