Available online at www.sciencedirect.com
SciVerse ScienceDirect
Procedia Chemistry 6 (2012) 203 – 210
Procedia Chemistry

2nd International Conference on Bio-Sensing Technology

Design of non-invasive setup for car driver biomonitoring

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Abstract

The design of the car driver monitoring system is presented with a novel IDAT microsensor applied. We have developed new thin film multipurpose microsensors (IDAT) consisting of an impedance sensor based on the interdigital array of microelectrodes which is integrated together with temperature resistive sensor on single chip. The developed microsensor allows monitoring of psychogalvanic reflex, heart pulse and skin temperature using depth impedance analysis of different skin layers by choosing the appropriate size of microelectrodes.

Keywords: Microsensor; biomonitoring; integrated array of microelectrodes; car driver monitoring; electrode/skin interface;

1. Introduction

The need for miniaturization of biomedical sensors has pushed the importance of microsystem technology and their application in medical devices, particularly microelectronics and micromachining. However the successful development of high integrated and miniaturized electronic instrumentation and sensors still needs to overcome large dimensions of mezo-micro-nano structures. Thin films serve as both: the source of new compound materials (particularly in optoelectronics) as well as well-defined and reproducible micro-/nano- interfaces between sensing, recognition and bio-chemical-physical-electrical transductions of signals in sensors.

We are interested in biomonitoring of human cognitive processes and psychophysiological conditions of car drivers in order to enhance road safety. Safety in traffic depends on a number of factors. One

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doi:10.1016/j.proche.2012.10.147

decisive aspect is how to keep fit the driver. Actually, an often used method is the evaluation of abnormal car driver actions (sudden changes of direction with no direction indicators or hard cornering). Main disadvantage of such a system is that they offer no prediction. More effective are systems with considered prediction, which offer enough reaction time before undesirable situations, and so they can minimize human error factors and improve road-traffic safety [1]. There are studies [2] about smart steering wheel which constantly checks the driver's vital signs such as heart rate, skin conductance and oxygen saturation in the blood. The vision is to detect the moment, when the driver is no longer well and consequently to initiate appropriate means of protection. Another team is developing a car seat that monitors the driver's heart activity [3]. The car seat uses electrocardiograph technology to track the electrical impulses and spot irregularities such as signs of heart attack or some other cardiovascular problem. The heart monitor car seat will also detect symptoms of other conditions, such as high blood pressure or electrolyte imbalances.

Our design of non-invasive setup for car drive biomonitoring is combination from various mentioned systems and is capable to sense psycho-galvanic reflex (PGR) – skin conductivity changes, heart rate + ECG, body temperature and respiration frequency. To improve the reliability of our measurements, these parameters are monitored by duplicate methods by local microsystems technologies and additional macro sensors. Microelectrodes offers higher signal stability with shorter response times, which can save live, contrariwise macroelectrodes offers more stabile contact to skin. Suitable system must be therefore built with combined macro/micro sensors. We implemented our system to the virtual reality driving simulator.

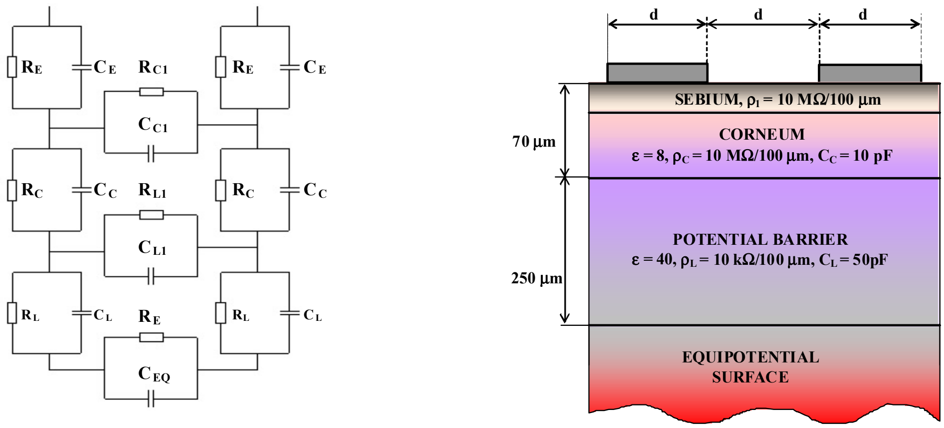
2. Theoretical background and simulations

2.1. Psychogalvanic reflex - Theory of skin conductivity changes

Psychical stress is a very troublesome and undesired factor, dramatically affecting the central neural system, and it might invoke significant psychical as well as health problems and inconveniences [4]. In general, it has been observed that PGR represents psycho-physiological activation, starting from the lowest amplitude in sleep up to the top amplitude under a strong activation. The amplitude fluctuation depends on the level of psychological activation, where the skin conductivity represents volume of sympathetic activity. First, it was assumed that increase in the skin conductivity during a stress stimulus is only caused by the skin perspiration. Later, an important factor of potential barrier existence near the stratum lucidum layer was discovered, analyzed and proven. Its thickness changes due to the nervous system activity. The greatest degree of conductivity variations occurs in the skin of palms and bottom parts of fingers [5-6].

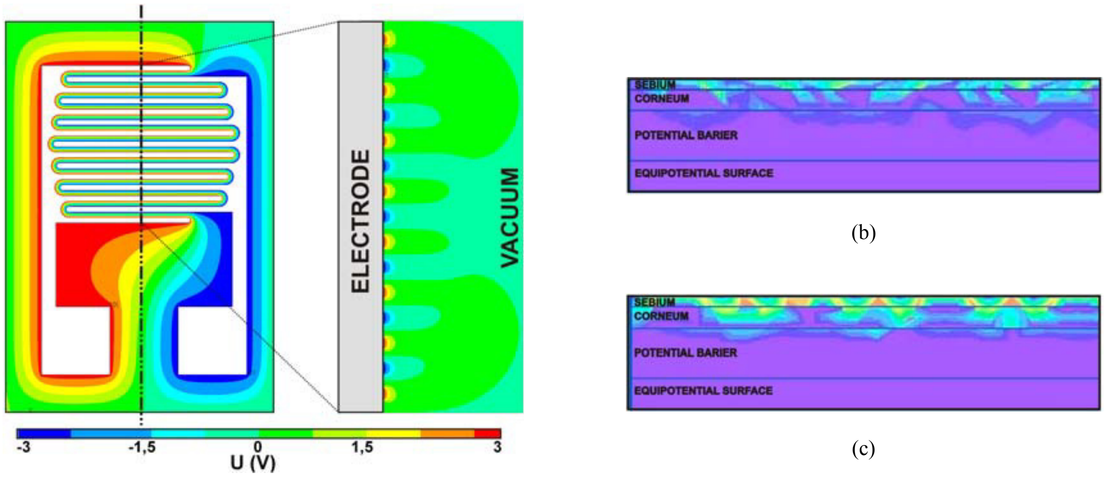
2.2. Microsensor/human skin interface

From electrical model of IDA (interdigital array) microelectrode/skin interface (Fig. 1) and simulations (Fig. 2) the important outcome has arisen. The electric field distribution and depth of penetration into the outer skin layers depend mainly on the configuration and size of an electrode system. This knowledge provides the possibility to examine different (separate) layers of epidermis by electrical impedance method. In short we can say that „electric field penetration depth" into human body is relative close to "distance between the coplanar electrodes". It is perfectly valid for symmetric configuration, where the distance between electrodes is equal to electrodes width. The results of analytical analysis also showed that in case of non-symmetric electrodes the electric field is more enclosed in the outer layers of the skin laminar structures. This system consists of the periodical electrode structure with different sizes (one electrode width is different to opposite electrode width). In a non-symmetric structure, the density of the electric field intensity lines along the planar structures of the skin is 30 % higher in outer layers [7].



(a) (b)

Fig. 1. Model of human skin: (a) reciprocal electrical model, (b) skin structure physical parameters and typical dimensions.



(a) (b) (c)

Fig. 2. IDA microsensor/human skin interface simulations (electric field distribution):
(a) ANSYS simulation – Symmetric IDA microelectrode;
QuickField simulation of microelectrode connected to skin:
(b) Asymmetric IDA microelectrode configuration;
(c) Symmetric IDA microelectrode configuration.

If different electrodes are applied on human skin, various space distribution of electrical field into the skin occurs.

In case of using macroelectrodes, while the distance between the coupled electrodes is greater than the thickness of electric active layers of skin h (stratum corneum - the outermost layer of the skin with potential barrier) $d >> h$, the vector intensity lines of the electric field are enclosed perpendicularly to the skin surface across the planar skin structures through dermis at high conductance (Fig. 3 a, b).

If microelectrode pairs are utilized, when the distance between the electrodes is less than thickness of electric active layers of skin: $d < h > s$ (s – thickness of stratum corneum), the lines of electric field are enclosed in parallel direction relative to laminar skin structures of epidermis (of lower conductance) in stratum corneum. From inner layers of skin, the electric field intensity lines are embossed to the surface (to the area with a lower conductivity) by the influence of the potential barrier which is generated by electrical double-layer around stratum lucidum (Fig.3c). Dynamic electrical properties of potential barrier reflect the fact that it is responsible for trans-epidermal transports – substance exchange, water transport and thermo regulation (Fig. 3c). Under a stress stimulus the potential barrier narrows down and the electric field can reach inner layers of human skin with higher conductivity, and therefore, the total conductivity increases (Fig. 3d). Such configuration is therefore ideal for the analysis of electrophysiological processes in human skin under stress [6]. Therefore in our designed sensor system we used IDA microelectrodes with utilized 200 µm / 200 µm (finger/gap) dimensions.

In case of too small or asymmetric microelectrode shapes the vector intensity lines of the electric field are enclosed in top layers of stratum corneum and the flow of electric lines is independent on thickness of potential barrier (Fig. 3e, f). Such electrodes are more suitable for surface analysis in field of cosmetics.

Utilized microelectrodes can also monitor heart rate (Fig. 4), which has been also experimentally verified. This is due to variation of blood pressure in veins, which shifts high conductivity skin layers, closer to surface – in the sensitive part of human body, and the absolute value of conductivity is changing.

Therefore, the utilized microsensor allows continual monitoring and analysis of complex physiological, pathophysiological, and therapeutic processes.

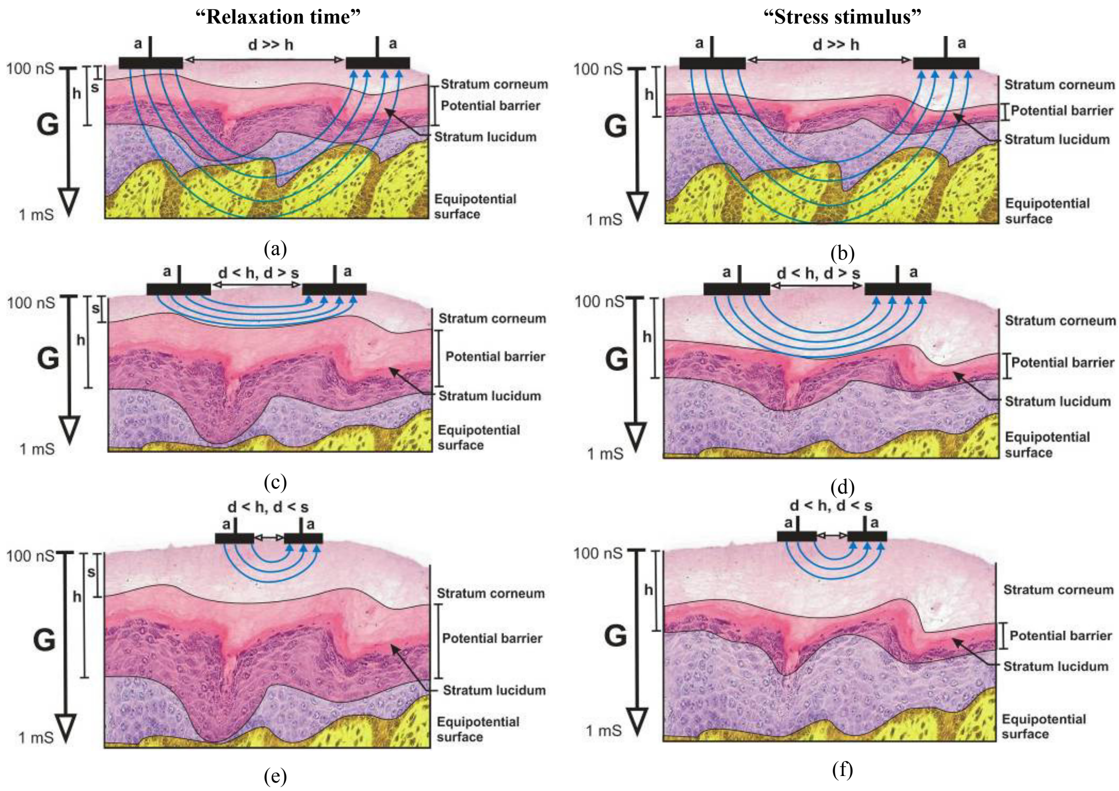


Fig. 3. The dominant vector intensity lines of the electric field inside of human skin by using:
- macroelectrodes: (a) in relaxation, (b) under stress stimulus;
- microelectrodes: (c) in relaxation, (d) under stress stimulus;
- "too small" microelectrodes: (e) in relaxation, (f) under stress stimulus.

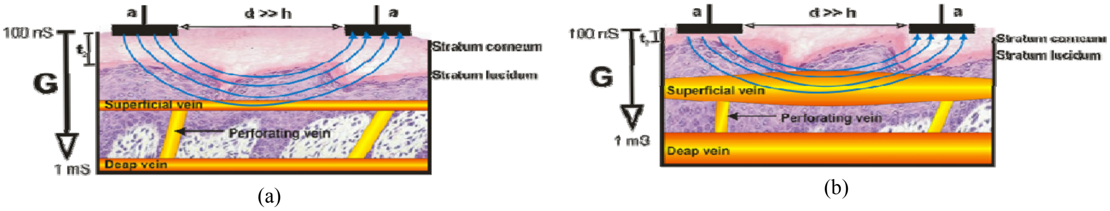


Fig. 4. Principle of heart rate analysis: (a) diastolic phase, (b) systolic phase.

3. Sensor system design

The proposed and designed car driver monitoring system, illustrated in Fig. 5, consists of:

- two local IDAT microsensors on a steering wheel for monitoring of psychogalvanic reflex (PGR), skin temperature and heart pulse;
- two conventional PGR and 2 ECG macroelectrodes (for monitoring of conductance and ECG between left and right hand);
- one smart pressure sensor, placed in the driver seat for heart pulse and respiration frequency monitoring [8]. It can be partially used for the driver weight determination.

The design of measurement unit is based on the modular programmable automation controller CompactRIO (NI 9014) with implemented measuring software. We used this configuration of measuring cards: NI 9263 (4-Channel, 100 kS/s, 16-bit, ±10 V, Analog Output Module), NI 9219 (24-bit, 100S/s, Ch-Ch Isolated Universal Analog Input Module), NI 9203 (8-Ch ±20 mA, 200 kS/s, 16-Bit Analog Current Input Module), NI 9234 (4-Channel, ±5 V, 51.2 kS/s per Channel, 24-Bit IEPE) [9].

Fig. 5. Sensor system design.

3.1. IDAT microelectrodes

Recently, new thin film microsensors (IDAT), depicted in Fig. 6a, have been developed, with an interdigital array (IDA) of microelectrodes is integrated together with temperature resistive (meander) sensor (T) on a single chip. The developed microsensor allows measurement of PGR and partially heart pulse by IDA structure and body temperature by T resistive meander, locally in one spot. The microelectrodes were fabricated in standard thin film technology: Pt (Au) films (150 nm in thickness) underlaid by Ti film (50 nm) were deposited by „rf sputtering" on Al_2O_3 substrates, and microelectrodes were lithographically patterned by lift-off technique. The total size of the microelectrode chip is 10 x 13 mm. IDA structure was made in symmetric configuration: 200 µm / 200 µm (finger/gap) dimensions. Pt thin film is used to minimize the polarization effect. The IDAT microelectrodes were placed up on steering wheel and connected to NI 9219 card (Sample frequency: 100 Hz).

The typical PGR output signal is shown in Fig. 6b. The heart rate can be easily DSP. On Fig. 6c is shown measured calibration function of temperature resistive (meander) sensor.

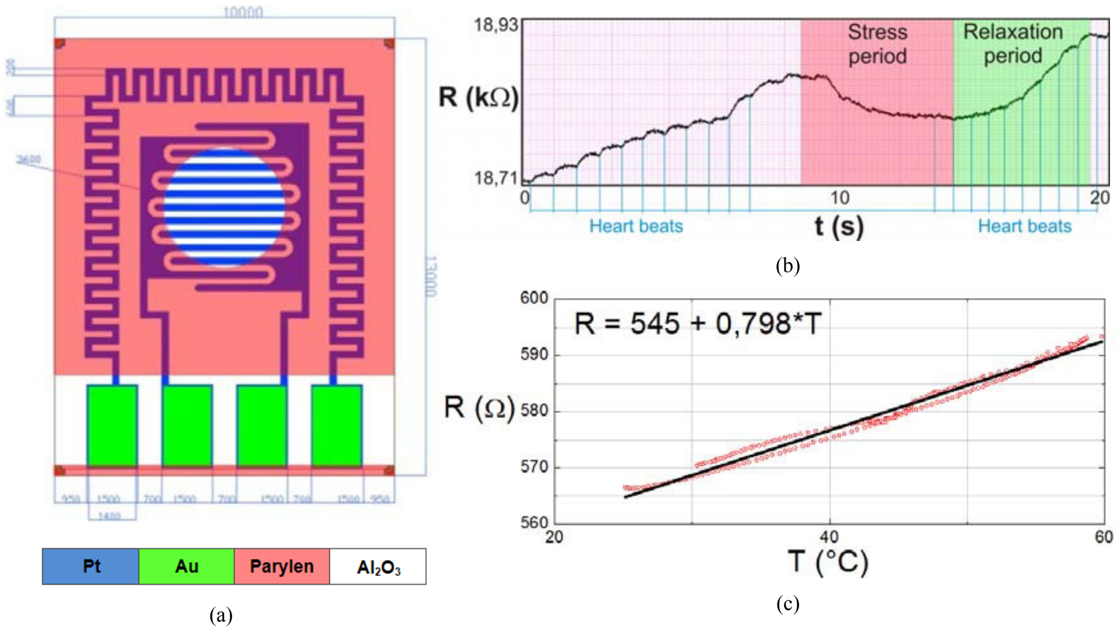


Fig. 6. IDAT microelectrode: (a) Design; (b) Psychogalvanic reflex (skin conductivity) and heart pulse (BPM) measured by IDAT microelectrode placed on steering wheel; (c) Calibration curve of temperature resistive (meander) sensor.

3.2. ECG and PGR by macroelectrodes

For global monitoring of ECG and PGR in steering wheel we used aluminium macro electrodes:

- ECG electrodes were connected to NI 9234 (Sample frequency: 25,6 kHz (can be reduced to about 100 Hz)). The signal was DSP by IIR filters: Bandpass filter: (Cutoff frequencies: 1 – 130 Hz, Order: 10, Topology: Bessel) and Bandstop filter: (Cutoff frequencies: 48 - 52 Hz, Order: 10, Topology: Bessel).

- Conductivity (PGR) electrodes were serial connected to NI 9263 (±10 V Analog Output Module: V_{OUT} = 3V, f = 1 kHz) and NI 9203 (Analog Current Input Module, Sample frequency: 100 Hz)

Typical result for ECG monitoring is shown in Fig. 7. Standard psychotests showed that the response signals of IDAT microelectrodes and macroelectrodes were similar. IDAT microelectrodes signals were more stabile with shorter response time, but for better reliability in real praxis, we need to spread microsensors on several positions of steering wheel – to obtain more fixed contact. In today´s state of R&D is suitable to combine macro and micro-sensors. Macroelectrodes offer very fixed contact between human skin and electrodes and the total reliability is very good.

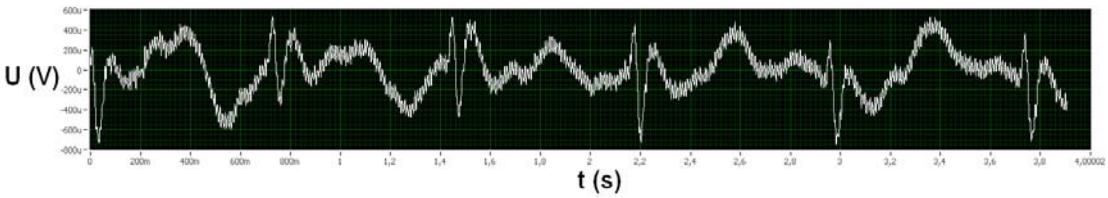


Fig. 7. ECG signal from a steering wheel.

3.3. Smart pressure sensor implemented in car seat

A biomonitoring seat sensor was developed. In this set-up, the smart pressure sensor Treston DMP 331 converts mechanical (pressure) force from air filled seat cushion (modified medical pressure cuff XXL) to the output current, measured via a serially connected National Instruments 9219 card (24-bit, 100 Hz sample frequency). As the power supply we used 12 DC battery to keep the automotive standards. Treston DMP 331 is a smart sensor with the following features [10]: hybrid integrated technology, pressure range 0 – 0,6 bar, output current 4 - 20 mA, input voltage 12 - 36 V.

Typical measured signal is shown in Fig. 8. With this sensor system we can monitor heart pulse and respiration frequency. Additionally, this system can be used also for measurement of a driver weight and later identification of person sitting at the steering wheel. We tested as well seat cushion with liquid, however there was no significant difference observed.

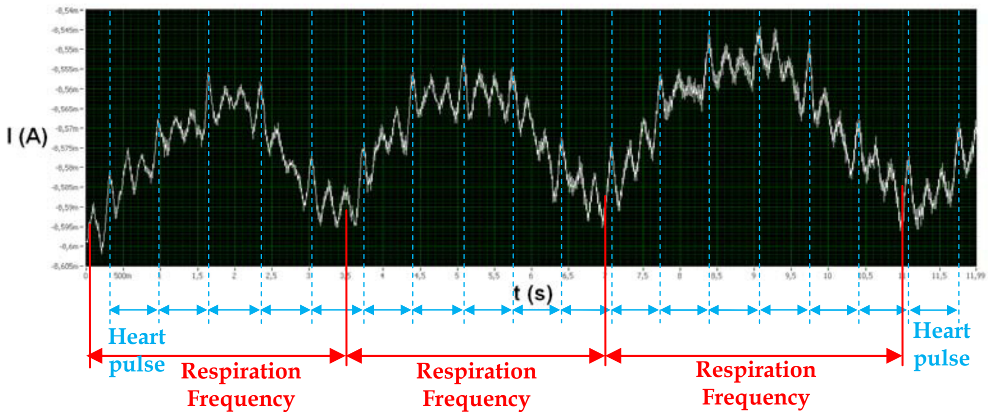


Fig . 8. Heart pulse and respiration frequency measured by the seat sensor.

4. Conclusion

The novel principle of described bio-sensing method is based on a special configuration (IDA) of the thin-film microelectrode system, which generates an electric field with intensity lines across (transversely to) planar structures of the skin. Simulations of electric field distribution in microelectrode/skin interface define dimensions of IDA microelectrodes (their width and gap between them) and determine the depth of electric field penetration into skin planar structures in the order of 10 - 200 micrometers.

Configured set-up offers continuous biomonitoring and analysis of different electrophysiological aspects of human physiology in a completely safe and non-invasive manner. This technique also has no undesired influence on natural physiological processes. Motivated by the promising results achieved so far, the research will go on by integration of the whole biomonitoring system into a real car conditions.

The system can be also enhanced with infrared camera for monitoring of face mimic representing different psychological emotions, which are visually recognized and diagnosed using software “eMotion”. Emotional reconnoiter of a car driver conditions is influenced by many cognitive processes, such as mind organization, vigilance, planning or fatigue. Nervous and angry people can be very dangerous for traffic road safety. One of the negative aspects of driving is also a lack of events on the road and instant driver’s drowsiness. To minimize this effect, a driver’s head, eye-lid and papilla movement sensing will be researched in next work.

At last, car driver monitoring system can by enhanced by electromyography EMG analyzer, Doppler sensors for respiration frequency and driver movement measurement, or online alcohol sensors etc will be examined in connection to this field.

Acknowledgements

This work has been done in Center of Excellence CENAMOST with support of Slovak Research and Development Agency Contracts No. VVCE-0049-07, project VEGA 1/0459/12, VEGA 1/1110/12, and ENIAC No. 120 228 (Project MAS - Nanoelectronics for Mobile Ambient Assisted Living).

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