Wireless Charger for Implantable Biotelemetry System

Yevhenii Antonenko
Department of physical and biomedical electronics and integrated information technology
V.N. Karazin Kharkiv National University
Kharkiv, Ukraine
antonenko@karazin.ua

Mychailo Buriak
Department of physical and biomedical electronics and integrated information technology
V.N. Karazin Kharkiv National University
Kharkiv, Ukraine
dailycarmichael@gmail.com

Oleksii Osypenko
Department of physical and biomedical electronics and integrated information technology
V.N. Karazin Kharkiv National University
Kharkiv, Ukraine
googlish97@gmail.com

Dmytro Shtoda
Department of physical and biomedical electronics and integrated information technology
V.N. Karazin Kharkiv National University
Kharkiv, Ukraine
dshtoda@ukr.net

Nikolay Chizh
Department of experimental cryomedicine
Institute for Problems of Cryobiology and Cryomedicine of the National Academy of Sciences
Kharkiv, Ukraine
n.chizh@ukr.net

***Abstract*—This paper presents a description of the wireless charger for biomedical telemetry system for experimental animals. General information on the advantages of using telemetry in longitudinal biomedical researches is presented. The areas of application of wireless telemetry systems and their advantages over wired analogues are argued. A reliable method of transferring energy from the charger to the sensor-implant is described.**

***Keywords*—wireless charger, telemetry system, implant, experimental animal**

I. Introduction

Nowadays, it is difficult to imagine the carrying out of biomedical researches to the development of diagnostic, therapeutic devices and systems, the implementation of modern surgical approaches and the assessment of the impact of new pharmacological medicines without randomized pre-clinical trials using experimental animals. Reliability of obtained data can be increased by using large statistical samples and long-time of an experiment, up to the life cycle of a biological object. Due to the high research requirements, the registration of indicators of various body functions in condition of physiological norms, experimental pathology and using of a therapeutic factor have primary role. Telemetry systems are a technical solution for collecting accurate physiological data with minimal errors. The technology is based on an implantable sensor that transmits information about the required measured parameters, such as blood pressure, temperature, heart rate and other biochemical parameters, via a wireless communication channel. Telemetry systems have many advantages. Telemetry allows to carry out researches with awake animals, excluding the impact of anesthesia, stress and restriction of free movement. It should be noted that the cost of researches can be significantly reduced. It became possible due to reducing the required number of animals, maintenance of protocols, reducing data processing time and significant reduction of operating costs. This method is more humane and meets all bioethics standards. In addition, the use of biometrics makes it possible to carry out multicenter studies, while laboratories can be located in different places, and researchers can receive real-time data, that will eliminate deliberate falsifications and random distortions of research results.

However, in order to be able to make measurements throughout the life of an experimental animal, it is necessary to maintain the operability of the implant and to monitor continuously the charge of the built-in low-capacity battery. The main feature of this technical problem is reliable transferring of energy to the distance up to 5 cm from the bottom of the cage for an animal and minimizing of heat dissipation on the elements of the implant due to induction heating. Usually, the transfer of energy is carried by capacitive [1-2] or induct ive coupling [3-6]. Also, there are systems of wireless energy transmission for powering biomedical implants [7-9]. Further, the technical solution for a wireless charger is considered. Taking into account the versatility of the method, the telemetric system in combination with a device for wireless power has a broad scope in biomedical researches: pharmacy (preclinical trials of medical drugs), cryomedicine (evaluation of local cryoablation and general hypothermia) and other biomedical researches.

II. General Principles

In general, the telemetry system of biomedical indicators is a hardware-software complex, which consists of an implant sensor, an interface device and a wireless charger (Fig. 1). The system is controlled by specialized high-level software. The body of the implant is made of bioinert material in the form of a capsule and it has the shape of a parallelepiped with dimensions of 46x15x8 mm. The implant has ability to record temperature or ECG depending on the requirements of research. The data transmission is carried out at a frequency of 433.92 MHz, which is the optimal solution from the point of view of the information transmission density and the attenuation of the electromagnetic wave in biological tissues of the experimental animal. A miniature ceramic antenna is used as an emitter of an electromagnetic wave. The main feature of the implant is not only the transfer of biomedical indicators, but also the transfer of information about the embedded battery state. The power transmission to the implant is carried out by electromagnetic method at a frequency of 79.6 kHz. The data about the charging current allows to optimize the charge process throw the selecting the minimum required power. The battery voltage data allows to stop the charge process in time. The charger is built into the bottom of the cage for the experimental animal. The bottom

978-1-5386-2467-8/18/$31.00 ©2018 IEEE

of cage is a planar matrix of coils manufactured by a PCB technology. The inductance of each coil is approximately 1 μH. The main element of the charger is a switching scheme which provides the serial connection the one of the 25 coils to the capacitor.

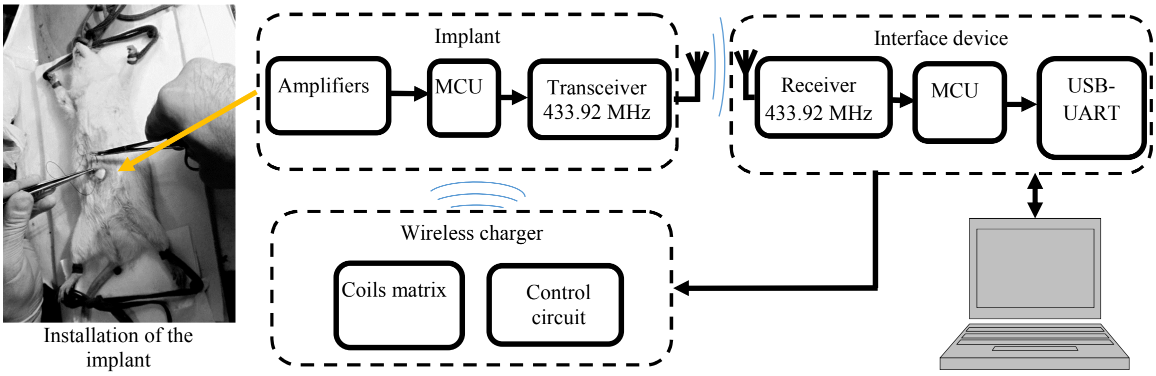

Fig. 1. Simplified block diagram of the telemetry system.

These two elements form oscillatory circuit tuned at the frequency of 79.6 kHz. The power to the oscillating circuit is fed from the full-bridge circuit, which is assembled of insulated-gate-transistors. The control of switching circuit is carried out via serial wire bus extending from the interface device. The main element of the interface device is a microcontroller performing the function of a command interpreter which is received from a computer. Telemetry data processing and wireless charger management are performed using the PC software. Data exchange between the telemetry system and the computer is via the USB interface.

The problem of electromagnetic compatibility of the entire system in a wide frequency band is of particular importance. The frequencies of various biological signals usually are in the range from 0.1 up to 1000 Hz (depending on the species). In our case, the frequency of communication channel is 433.92 MHz. Thus, the charger should not affect the operation of biosignal amplifiers and the communication channel.

III. Technical Implementation

The construction of wireless charger consists of two printed circuit boards: a matrix of coils and a control board. The matrix of coils has a size of 20x30 cm, the size of the active area is 20x20 cm. The area of the active zone is filled with flat coils to form a matrix of 5x5 elements. Coils are connected to switching circuit, as shown in Fig.2. The capacitor *C1* switches to one of the coils *L1-L25* and forms a series resonant circuit. The use of a sequential oscillatory circuit as an energy transmitter is caused by at least three reasons. The first reason is to ensure the safety of the power keys of the bridge circuit. In case of a parallel circuit when the operating is on a non-resonant frequency, the impedance of the resonant circuit tends to zero. It will lead to break down of the switching transistors. The second reason is that in case of current resonance, the resistance of the circuit tends to zero, and almost all energy is transmitted as electromagnetic waves. The third reason is a simpler technical implementation of the switching circuit. Fig.2 shows only the general commutation scheme, the generator with a full-bridge converter is designated as *G*. The switching device consists of a pulse generator based on the PWM controller SG3525 and the coils control circuit (Fig. 3).

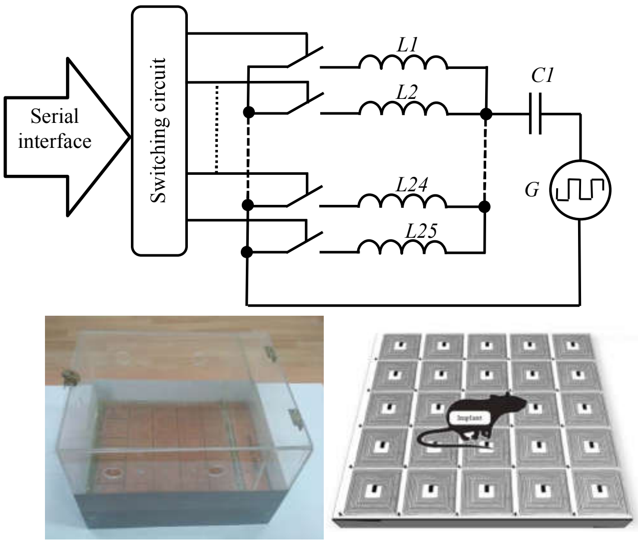

Fig. 2. Block diagram and general appearance of the wireless charger.

The control scheme is based on the following principle. The control signal over the serial bus is fed to the circuit of the four shift registers SN74HC594, the outputs of which are connected to the MC14504 logic level inverters (in this case, a conversion from 3.3V to 12V is required).

The need for logical levels matching is due to the fact that the management of the scheme is carried out by microcontroller with the logic level at 3.3V, the same power supply is required the shift registers, but the switching transistors must be fed from a source of at least 10V. From the logical level converter, the signal arrives at the analog-digital switch based on the HCF4350 chip, the outputs of which are connected to drivers based on complementary transistors IRF7343 series. Schottky diodes in the gate circuit of the switching transistors accelerate discharge of the gate after the transistor is turned off. Such measures allow to prevent the occurrence of the shoot-through current. The outputs of the drivers are connected to the matrix of coils. The element of the coil switching scheme described above is shown in Fig.3. Due to the cumbersome electrical circuit, the Fig. 3 shows full scheme of commutation only for the first three channels (coils *L1-L3*).

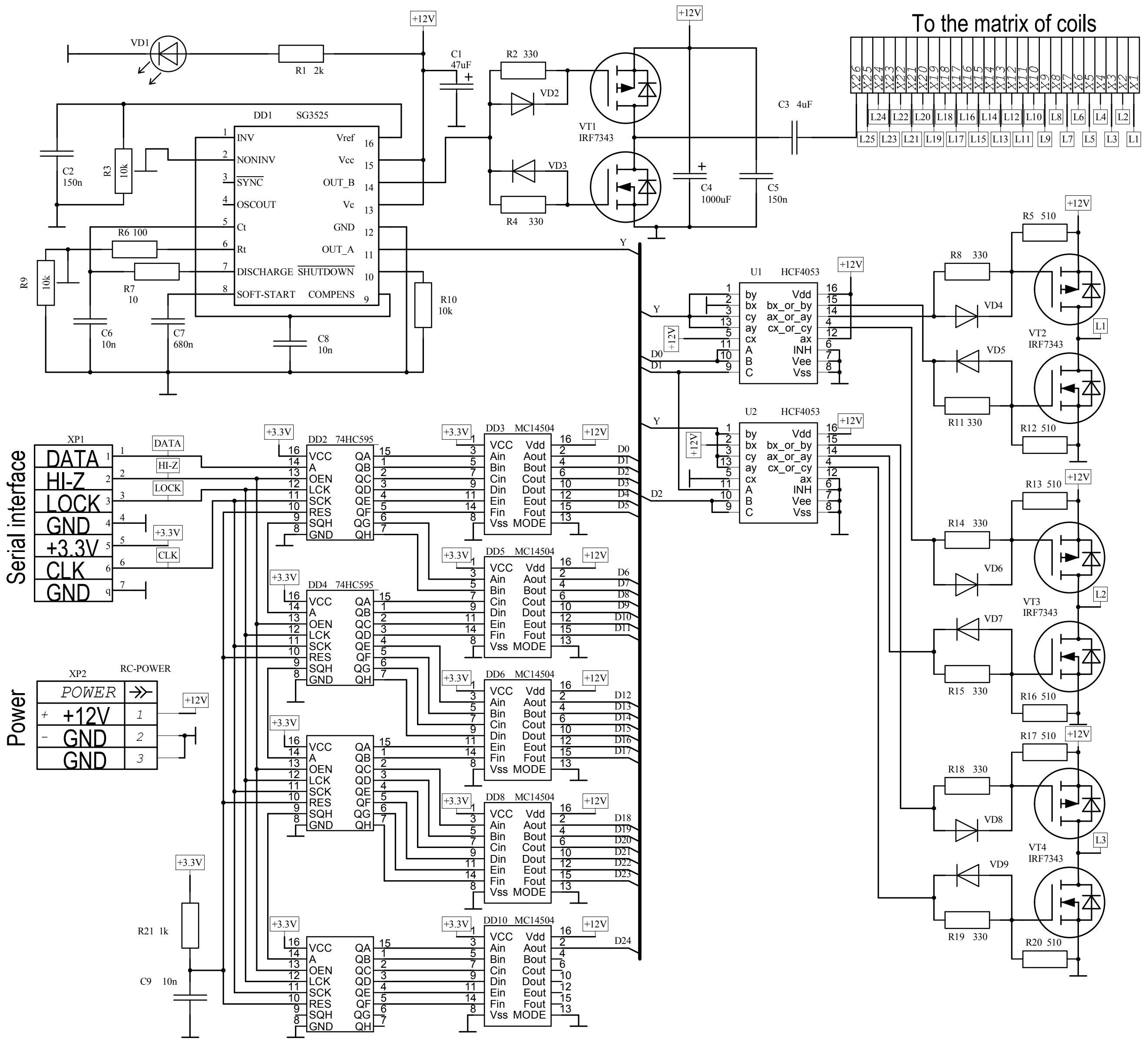

Fig. 3. Electrical circuit of coil switching for the first three channels.

The software control of the charger is important. It is possible to optimize the charging process, as the voltage and the charge current values of the battery are included in the transmitted data. To reduce power consumption and to maintain the battery in a charged state, an algorithm for searching an object (experimental animal) over a coil matrix is implemented. In this case, the energy will be supplied only to the coil over which the object is located. The control algorithm of the charger is simple and consists of two parts: a primary object search and object tracking. Primary search is happening either when you first switch on, or when the object is lost and is carried out by the direct enumeration of the elements of the matrix. In this case, the energy is alternately feed on each coil. In the process of switching coils, the charge current of the battery of the implant is registered. After finding the element that provides the maximum charge current, it is assigned the status of the main and tracking of the object begins. The object tracking is provided by the periodic (1 time in 2 seconds) power supply to the elements contiguous with the main one. The interrogation time of adjacent matrix elements does not exceed 100 ms and depends on the current location of the animal being studied. The number of adjacent elements can be 8, 5 or 3. This approach improves the efficiency of the charging process, reduces the level of electromagnetic radiation of the charger and ensures the continuous monitoring of physiological parameters of experimental animal.

A parallel resonant circuit loaded by a voltage multiplier is used as a receiving device. The usage of a parallel oscillating circuit (voltage resonance) is due to the need of having the output of the receiver voltage about of 5 V, which is supplied to the charge controller of the lithium-ion battery. A similar principle is described in [10], but in addition to the transfer of energy for device powering, the data transmission is also carried out.

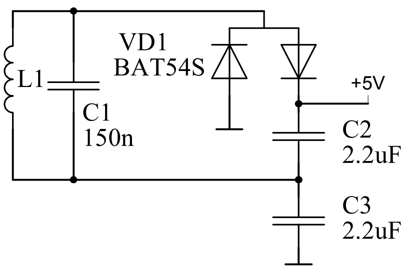

Fig. 4. The circuit of the electromagnetic energy receiver.

The interaction of the transmitter and receiver of electromagnetic energy is well described by the coupled circuits theory [11, 6]. It should be borne in mind that the quality factor of the receiving circuit depends on the load resistance, which is variable. When battery is deeply discharged, the efficiency of energy transfer will be lower. Thus, it is advisable to keep the battery in a charged state, that happens in practice. Special attention requires to be paid to electromagnetic compatibility. So, to prevent the influence of electromagnetic radiation of the charger to the measuring circuit of the implant, filter with a cutoff frequency of 1 kHz is used. The influence of the charger on high-frequency communication channel was not found experimentally.

This wireless charger has been tested as a part of a hardware-software complex of the ECG telemetry system for rats. In carrying out of experimental researches on laboratory rats, the following advantages of the manufactured telemetry system were established.

a) Using the telemetry setup allows experimenters to obtain reliable results the electrophysiological parameters of animals in natural conditions without stress or anesthesia, that is very important in the heart rate variability analysis.

b) The mobility of experimental researches. The system allows to register physiological parameters at a distance of 20 m from the test object.

c) Bioethical aspects of research. The system makes it possible to minimize a number of animal contacts with the experimenter, that brings the animal closer to its natural habitat. Despite the need for an implantation operation, the restoration and adaptation take place in a relatively short period of time. Using wireless charging has minimal impact on the animal's body.

IV. Conclusion

Designed wireless charger extends the application of telemetry systems for experimental animals. The use of telemetric systems for preclinical testing of drugs and other therapies is a promising direction for the development of research and diagnostic systems at the present stage of development of biomedical technologies.

The optimal schematic solution for wireless chargers is based on the use of the matrix of emitters of electromagnetic energy instead of a single coil. This approach shown the effectivity in longitudinal studies of heart rate variability in rats. Previous experience with using one coil was leading to significant induction heating of the elements of the implant when the animal is located in the center of the coil and to the absence of charge in case of moving the animal from the center of coil. Thus, this charger solves the technical problem of the uninterrupted power supply of the implant. Also, the possibility of keeping to bioethical principles in experimental animal studies is realized.

References

[1] J J. Dai and D.C. Ludois, "Single active switch power electronics for kilowatt scale capacitive power transfer," IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 3, pp. 315-323, March 2015.

[2] M. Kline, I. Izyumin, B. Boser, and S. Sanders, "Capacitive power transfer for contactless charging," In Applied Power Electronics Conference and Exposition (APEC), Twenty-Sixth Annual IEEE, pp. 1398-1404, March 2011.

[3] F. Musavi, W. Fariborz, and E. Wilson, "Overview of wireless power transfer technologies for electric vehicle battery charging," IET Power Electronics, vol. 7, pp. 60-66, 2014.

[4] S. L. Ho, J. Wang, W. N. Fu, and M. Sun "A comparative study between novel witricity and traditional inductive magnetic coupling in wireless charging," IEEE Transactions on Magnetics, vol. 47, pp. 1522-1525, 2011.

[5] J. M. Miller, O. C. Onar, C. White, S. Campbell, C. Coomer, L. Seiber, and A. Steyerl, "Demonstrating dynamic wireless charging of an electric vehicle: The benefit of electrochemical capacitor smoothing," IEEE Power Electronics Magazine, vol. 1, 2014, pp. 12-24.

[6] W. Zhang, S. C. Wong, K. T. Chi, and Q. Chen, "Design for efficiency optimization and voltage controllability of series–series compensated inductive power transfer systems," IEEE Transactions on Power Electronics, vol. 29, pp. 191-200, 2014.

[7] P. Li and B. Rizwan, "A wireless power interface for rechargeable battery operated medical implants," IEEE Transactions on Circuits and Systems II: Express Briefs, vol. 54, pp. 912-916, 2007.

[8] S. Y. R. Hui, W. Zhong, and C. K. Lee, "A critical review of recent progress in mid-range wireless power transfer," IEEE Transactions on Power Electronics, vol. 29, pp. 4500-4511, 2014.

[9] P. Si, A. P. Hu, S. Malpas, and D. Budgett, "A frequency control method for regulating wireless power to implantable devices," IEEE transactions on biomedical circuits and systems, vol. 2, pp. 22-29, 2008.

[10] M. Ghovanloo and K. Najafi, "A wideband frequency-shift keying wireless link for inductively powered biomedical implants," IEEE Transactions on Circuits and Systems, vol. 51, pp. 2374-2383.

[11] X. Lu, P. Wang, D. Niyato, D. I. Kim, and Z. Han, "Wireless charging technologies: Fundamentals, standards, and network applications," IEEE Communications Surveys & Tutorials, vol. 18, pp. 1413-1452, 2016.