Test methods for integrated experimental prototypes of wireless charging of implants’ power supply sources and implantable biotelemetric system

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Abstract. This article discusses the well-known inductive wireless power transfer for implantable devices. These devices are intended for use in the area of medicine, pharmacology and human physiology. Implantable small-sized devices are introduced into the body surgically and autonomously monitor and control the functional state of individual organs and systems. However, the currently existing implantable devices must be periodically removed from the body of the object of observation to replace the source of energy, and then reinstall into the body. Developed by the authors wireless charger for transcutaneous energy supply of implantable modules automatically adjusts the power of the electromagnetic field. It gives the possibility to use either non-rechargeable power sources or batteries charged via wireless power transmission. The integration scheme of experimental prototypes of wireless charging device and implantable biotelemetric system is considered. The methodology of three consistent tests of integrated charging device and implantable biotelemetric system is discussed. The tests’ results verified the compliance of the specified parameters with the requirements of the technical specification.

1. Introduction

Nowadays, the research community is interested in the development and use of biotelemetric systems for remote health monitoring. It leads to their miniaturization while expanding the functional and high-quality practical medicine with a receipt of new technologies. However, biotelemetric systems need to be surgically removed from biological objects from time to time to replace the source of energy supply, and then reinstall them into the body. These surgeries can adversely affect the health of a biological object. This paper describes the testing of the developed experimental prototypes of wireless charging of implants’ power supply sources and implantable biotelemetric system (BTS).

The developed experimental prototype of the charging device [1] consists of the transmitting and receiving modules (figure 1). Developed charging device modules should be used in conjunction with the implantable biotelemetric system. The transmitting module sets the operating frequency and provides a change in the power of the force field to correct the output power level of the receiving module.
In addition to this, the experimental prototype of BTS was developed [2], also consisting of transmitting and receiving modules (figure 2). The BTS is intended for testing in biological objects and should transmit ECG, EMG, temperature, accelerometry signals, as well as parameters received from the receiving module of the charging device: housing temperatures and the receiving module, the voltage on the battery during charging, charging current.

The receiving module of the charging device through the board-to-board connector is connected to the transmitting module of the biotelemetric system, which, when encapsulated, can be placed inside a biological object. Charging device’s transmitting module is placed on the body of a biological object opposite the charging device’s receiving module and generates an electromagnetic field, the energy of which is converted at the last to charge a rechargeable power source (battery, supercapacitor) of the biotelemetry transmitting module.

Receiving module of charging device and transmitting module of BTS have a shape with rounded corners, consistent with each other and allowing them to work together. Due to the board-to-board connector, the receiving module of the charging device is located in the immediate vicinity of the printed circuit board of the transmitting module of BTS, through which it is connected to the battery or to an array of capacitors. Hermetically encapsulated products can then be implanted into a biological object at a depth that meets the stated technical specifications. Thus, in the process of modules integration, the complete modules are connected to each other into a single functional unit – an integrated charging device and BTS (figure 3).
Figure 3. Integrated charging device and BTS.

For the implementation of the energy transfer the transmitting module antenna of the charging device should be placed outside the biological object on the same axis with the receiving module antenna of charging device. When power is connected to the transmitting module of the charging device, it begins to generate an alternating electromagnetic field, which allows to obtain at the output of the charging devices’ receiving module sufficient power to charge the battery of the BTS’ transmitting module. The BTS receives and displays information on a PC for its further monitoring and analysis. Conceptual model is shown on the figure 4.

Figure 4. Conceptual model of integration of wireless charging device and BTS.

2. Preparation for integrated charging device and implantable biotelemetric system testing
Two main approaches to solve the problem of implantable biotelemetric systems’ power supply are considered in [1, 3, 4]. These are the usage of either non-rechargeable power sources or batteries charged via wireless power transmission. Non-rechargeable power supplies are effective in the case of low power consumption along with the ability to ensure an adequate lifetime of the implantable system (pacemakers, subcutaneous cardiac monitors for short-term use). In the case of more resource-intensive multichannel stimulation tasks, telemetric collection of a set of parameters to achieve a sufficient period of operation, it is advisable to use a wireless power transmission.
Successful joint operation of the developed by the authors experimental prototypes of the wireless charging device of the implant batteries (wireless power supply of non-accumulator implants) and the BTS is confirmed by receiving a signal from the accelerometer sensor of the transmitting part of the biotelemetric system while testing, as well as the voltage and charge current of the battery on the device’s receiving module are displayed on the screen of the personal computer monitor.

Physiological saline solution is currently regarded as one of the most common simulators of the internal environment of a biological object [5] in the laboratory testing. Physiological saline is understood to be aqueous solutions of salts in such a concentration that the osmotic pressure of the solution to be equal to the intracellular osmotic pressure of the body. Thus, the balance of osmotic pressure between the solution and body tissues is maintained [6]. Physiological solution is also called isotonic. In an isotonic solution, water molecules are excreted and absorbed by the cell in equal measure, which provides its normal functioning.

Most frequently used is a solution of sodium chloride in a concentration of 0.9%. This solution contains nothing but salt (sodium chloride) and water. This salt concentration is considered optimal to maintain the solution isotonic properties. It is a colorless transparent liquid slightly salty in taste.

Thus, the saline solution in the laboratory is prepared on the basis of sodium chloride. To prepare one liter of saline solution it is required 9 grams of salt and a liter of distilled water. Salt dissolves in water quickly enough. The resulting saline solution is suitable only for testing the technical characteristics of implantable devices. For the intravenous injections the implementation of such solution is absolutely inappropriate.

3. Testing of joint functioning of the integrated charging device and implantable biotelemetric system

The determined parameters of the tests of the joint functioning of the integrated charging device and BTS are presented in table 1.

| Tests’ number | Type of tests (verification) | Units of measure | Nominal value | Maximum deviation |
|---------------|------------------------------|-----------------|---------------|------------------|
| 1             | Testing of joint functioning of the integrated charging device and BTS. Registered parameters: | mA | at least 40 | ±5% |
|               | − Charge current on the receiving module of the charging device | | | |
|               | − Voltage on the receiving module of the charging device | V | 4.1-4.2 | ±5% |
|               | − Accelerometer signal | presents | | |

The testing 1 sequence is shown in figure 5.

Continue with items 5 and 6 of the test program, fixing the values of the indicators, until the voltage on the battery is 4.1-4.2 V.

Test objects are considered to have passed the test, if the values of the recorded indicators do not exceed the values given in table 1.
1. Place the integrated charging device and BTS in a cuvet with saline solution

2. Install the transmitting circuit of the integrated charging device and BTS at a distance of 20 mm from the antenna of the receiving module charging device

3. Install the BTS’s receiving module with the antenna at the distance of 0.5 m from the integrated charging device and BTS

4. Activate the BTS’s transmitting module using the transmitting module of the charging device

5. Control the functioning of the integrated charging device and BTS

6. Control the temperature of the receiving antenna of the charging device using a multi-channel temperature meter to prevent overheating of the surrounding tissues of the biological object

Figure 5. Test programs “Testing of joint functioning of integrated device and BTS”.

4. Testing of operability of the implantable biotelemetric system at integration with the charging device

The aim of testing is to verify the operability of BTS when integrating with charging device in the simulation environment of biological object [7]. When activating transmitting module of BTS placed in the simulation environment, on the computer screen, which is connected to the BTS’ receiving module, signals are being visualized (battery voltage, accelerometry signal), indicating the overall correct functioning of the BTS in the simulation environment.

Table 2. The determined parameters and accuracy of their measurements (Testing 2).

| Test’s number | Type of test (verification) | Units of measure | Nominal value | Maximum deviation |
|---------------|-----------------------------|------------------|---------------|-------------------|
| 2             | Testing operability of integrated charging device and BTS in biological object simulated environment | Battery voltage | V | +5% |
|               | Registered parameters:      | Common-mode rejection presents | 4.1-4.2 |
|               | amplifiers’ bandwidth       | presents          |               |

The testing 2 sequence is shown in figure 6.
Continue testing, fixing the values of indicators every 10 minutes, to confirm the stability of the work.

1. Place integrated charging device and BTS, protected by moisture-proof closure, in a cuvet with saline solution.

2. Put the receiving module of BTS at the distance of 0.5 m from the integrated charging device and BTS.

3. Connect the receiving module of BTS via USB port to the computer.

4. Install the MatLab program on the PC, which performs visualization, registration, archiving of information entering the computer through the receiving module.

5. Activate BTS’s transmitting module elements using transmitting contour of the charging device.

6. Monitor the integrated charging device and BTS operating status. BTS working capacity is confirmed by visualization of signals on the monitor screen received from the BTS’s transmitting part (battery voltage, accelerometer signal).

7. Verification of biopotential BPS amplifiers for bandwidth and common-mode rejection.
   - Connect the generator in series to the terminals of the amplifiers of the biopotential block of the implantable BTS.
   - The value of the test signal is 1 mV.
   - Set the frequency of the test signal from the generator - 1 kHz;
   - Check the signal’s passing through the ECG channel amplifier;
   - Set the frequency of the test signal from the generator - 30 Hz;
   - Check the signal’s passing through the amplifier EMG channels
   - Set the frequency of the test signal from the generator - 100 Hz;
   - Check the signal’s passing through the ECG channel amplifier;
   - Set the frequency of the test signal from the generator - 100 Hz;
   - Verify the signal’s passing through the amplifier EMG channels
   - Close the information inputs of the bio-potential amplifiers among themselves and transmit them a signal from a 50 Hz generator with an amplitude of 1 mV;
   - Check common mode rejection by observing the absence of a 50 Hz signal at the outputs of bio-potential amplifiers on the monitor screen

**Figure 6.** Test program “Testing the efficiency of integrated charging device and BTS in the simulation environment of a biological object”.

During the first testing insufficient common-mode rejection was noted, which caused further resistors correction.

The test object is considered to have passed the test if the signals given in figure 2 are received.

5. Testing of operability of charging device at the integration

Test number 3 is to verify the performance of the charging device when aggregating.
Table 3. The determined parameters and accuracy of their measurements (Testing 3).

| Test’s number | Type of test (verification)                                                                 | Units of measure | Nominal value | Maximum deviation |
|---------------|-------------------------------------------------------------------------------------------|------------------|---------------|-------------------|
| 3             | Testing of operability of the charging device at integration                              |                  |               |                   |
| 3.1           | Testing the direction and speed of data transfer between the transmitting and receiving modules of the developed charging device | Baud            | at least 1200 | ± 0.5%            |
| 3.2           | Testing the power transmitted from the transmitting module to the receiving one           | Watt            | at least 0.2  | ± 5%              |
| 3.3           | Testing the battery charge current and power supply of non-accumulator implants           | mA              | at least 40   | ± 5%              |
| 3.4           | Testing the characteristics of the charging device                                       |                  |               |                   |
| 3.4.1         | Testing the implant battery charge at a depth of at least 20 mm                           | mA              | 40            | ±5%               |
| 3.4.2         | Testing the operation of the non-accumulator implant after turning off the force-field generator | C               | 10            | 0.5               |
| 3.4.3         | Testing the possibility of changing the frequency and power of the force field           | kHz             | 880           | –                 |

6. Testing the possibility of modifying the frequency and power of the force field

The frequency can be modified by replacing the clock frequency division factor of the microcontroller, but its final result should be equal to 880 kHz.

The power of the force field is altered by changing the fill factor of the pulse signal supplied by the microcontroller to the input of the D class amplifier, from the output of which the signal is transmitted to the contour of the transmitting antenna of the charging device’s transmitting module. This coefficient has a value from 0 to 100%, i.e. the power can vary from 0 to the maximum value, which is determined by the action of information coming from the receiving module of the charging device at a speed of at least 1200 baud. Power should be sufficient to provide a charging current of at least 40 mA at a voltage of at least 4.1 V.

7. Conclusion

Performing this research, technical tests of integrated charging device and implantable biotelemetric system were carried out, which verified the compliance of the specified parameters with the requirements of the technical specification.

At the beginning of work on the transmitting and receiving modules of the wireless power transmission device, it was necessary to study inductors of various forms [4]: cylindrical, toroidal, spiral, since the shape of the inductors influenced, in particular, on the distribution form of the electromagnetic field strength, as well as on the form of the distribution of the coupling coefficient (or mutual inductance) of the coils at their different mutual arrangement.

In the course of full-scale tests of the device’s modules, the impact of the load matching of the amplifier of the transmitting module on obtaining the maximum output current at different mutual arrangement of the transmitting and receiving inductors was also studied, which made it possible to optimize the parameters of the key components of the circuit during their development. At the same
time, the topology of specific elements was taken into account, which allowed minimization modules’
dimensions, especially the receiving module of charging device.

The experimental prototypes of the implantable biotelemetric system were tested to assess the
performance of the device in biological objects (in the simulation environment of a biological object),
which established the compliance of the test object with technical requirements. As a result of the tests,
it was recommended to select the nominal values of the resistors to improve the reduction of the common
mode interference.

The development of technical testing procedure of the integrated charging device and biotelemetric
system allowed to check the joint operation of the modules of the charging device and the biotelemetric
system and proved their normal functioning when working together.

The results of the tests confirmed the normal functioning of the integrated charging device and
biotelemetric system.

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