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Semi-passive powered biotelemetry for small animals

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ABSTRACT

Mice and rats make up 95% of all animals used in medical research and drug discovery and development. Monitoring of physiological functions such as ECG, blood pressure, and body temperature over the entire period of an experiment is often required. Restraining of the animals in order to obtain this data can cause great inconvenience. The use of telemetric systems solves this problem and provides more reliable results. However, these devices are mostly equipped with batteries, which limit the time of operation or they use passive power supplies, which affects the operating range. The semi-passive telemetric implant being presented is based on RFID technology and overcomes these obstacles. The device is inductively powered using the magnetic field of a common RFID reader device underneath the cage, but is also able to operate for several hours autonomously. Being independent from the battery capacity, it is possible to use the implant over a long period of time or to re-use the device several times in different animals, thus avoiding the disadvantages of existing systems and reducing the costs of purchase and refurbishment.

1. Introduction

Animal testing is part of fundamental research and essential in drug licensing processes and safety assessments. In Germany, scientists use around 500,000 rats each year [1]. In the case of continuous monitoring of physiological signals, manual measurements are still quite common. This means, the animal has to be taken from its usual environment and has to be restrained by hand or by using special restrainers throughout the measurement. The procedure consequently has a huge impact on heart rate as well as blood pressure and the results cannot be compared with normal behaviour [2]. Biotelemetric systems, which are used as an alternative, measure physiological functions and transfer the resulting data wirelessly [3]. Animals equipped with such implants can be kept in their normal environment whilst specific physiological functions are tracked 24/7 without disturbing the animals.

However, a major disadvantage of today's biotelemetry systems is their power supply concept. They often rely on batteries, which limit the operational time [4]. Normally, an experiment ends when the battery runs out of power. Consequently, a new device must be used or the old one must be extracted to exchange the batteries. In most cases, this also involves the use of a new animal. To achieve longer operation time bigger batteries need to be used, which increase the size and the weight of the implants and make them unsuitable for small rodents. Passive telemetric devices without batteries work with strong magnetic fields to transfer energy to power them, but today's systems do not use the same field for energy transfer and communication [5,6]. Therefore, a doubled amount of antennas is necessary to handle data transfer and to power the devices.

Another already existing wireless communication technology, radio-frequency-identification (RFID), uses only one single antenna for communication and powering the device. RFID is designed especially for passive operations and, as the name implies, used for wireless identification. The technology is commonly used and well accepted in veterinary medicine, animal-farming and

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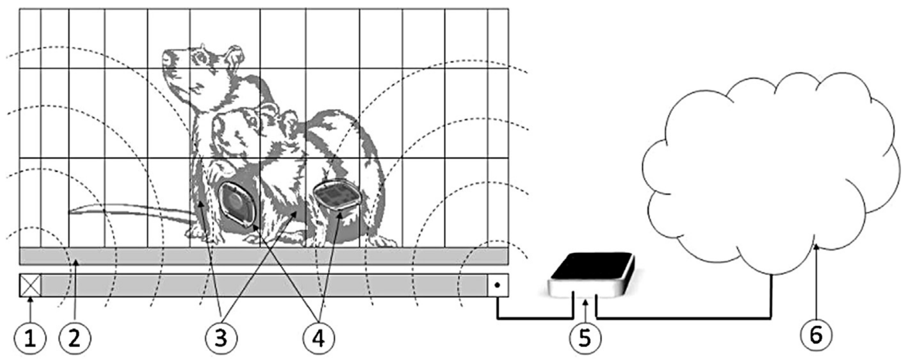

Fig. 1. Concept sketch of a configuration to power and to communicate with RFID based implants. (1) Antenna; (2) cage; (3) animals; (4) implants; (5) RFID reader device; (6) IT cloud.

animal-tracking [7–9]. Several applications exist which extend the so-called tags with sensor abilities. RFID is used as a temperature logger [10] or in animals to monitor ECG [11] or intra-ocular pressure [12].

However, passive transponders are not able to operate outside the field or in unfavourable positions. The field always has to be sufficient, even in the case of special operations where power consumption increases temporarily or in the case of animal movement. As a consequence, strong fields and complex antenna geometries are required.

The aim of our investigations is to present an alternative to conventional passive or active power supply concepts. The hereby-presented power supply is immune to temporary field interruptions and spikes of power consumption. Therefore, the power source does not determine the size or the lifetime of the implant. Thus, it is possible to build a small enough device, which is able to monitor ECG, arterial blood pressure, and body temperature for several months in small animals.

2. Concept and overview

The presented system is mainly focused on monitoring the physiological signals of rats. The subjects are individually housed in Eurostandard Type III cages, with a floor area slightly larger than an A4 page and a height of around 24 cm. Alternatively, groups of up to four animals are held in double-sized Type IV cages. Each animal is equipped with one RFID compatible implant.

As depicted in Fig. 1, each cage in the presented concept is equipped with one antenna below the cage to provide a passive power supply. One Watt of power for the small cage or two Watts for the bigger cage is sufficient to generate an adequate magnetic field inside the cage. Therefore, commercial RFID reader devices, e.g., ID ISC.MR101 or ID ISC.LR2500 (Feig Electronic GmbH, Germany) are used.

However, due to animal activity and necessary procedures such as cage cleaning or examinations, a passive power supply is unreliable for continuous recording. Sometimes, the animals stay in an unfavourable position for hours, making it impossible to transfer energy. The hereby-presented power concept bridges over any interruptions to the power supply by using electricity storage devices such as double layer capacitors or secondary batteries, which are charged during favourable conditions. In contrast to common RFID systems, which are classified into active and passive [13] with and without battery, as well as semi-active, where active transponders operate passively inside the field to spare battery lifetime [14], the hereby-presented power supply concept is called semi-passive.

The following chapters introduce and describe the technologies developed and used to build a semi-passive telemetric device able to measure physiological functions in vivo with several weeks of operation. The presented biotelemetry system uses the ISO standard 15693 [15] for digital data transfer. Consequently, the implant is powered by magnetic near field with a carrier frequency of 13.56 MHz. The field inside the type III cage and electrical interaction between reader and implant are discussed in chapter 3, "Power supply". In chapter 4, "Implant" and chapter 5, "System" we show an implementation of the concept, which is finally tested as part of an in vivo study, described in chapter 6.

3. Power supply

The power transfer between reader and implant takes the idea from the well-known wireless charging of batteries, used, e.g., for electric toothbrushes or portable game consoles. The reader antenna represents the primary winding of a loosely coupled transformer whereas the implant antenna corresponds to the secondary winding. In the case of the presented semi-passive power supply, no permanent power transfer is required. It is possible to use a one-dimensional loop antenna, which is part of the circuit board. Therefore, conductor tracks are arranged at the edge of the board, which enclose an area of 29×21.5 mm.

Fluctuations of the harvested power as well as the load are compensated for by the energy storage device. The implant is able to operate outside a proper magnetic field for several hours. Consumption peaks, which happen for example during write access to the used EEPROM, are buffered. Only the mean power must be taken into account. In the case of harvested power, the mean power is related to the spatial arrangement of implant and reader antenna, which depends on the animal's behaviour, because a freely moving animal changes position and orientation of the implant antenna constantly.

Therefore, the following chapter shows orientation and strength of the magnetic field inside the type III cage. The results of the analysis are used to model the electrical interactions between reader and implant as well as the effect of antenna matching. Finally, a power circuit based on the used antenna matching is suggested.

3.1. Analysis of the magnetic field

Shape and orientation of the magnetic field depends on the antenna geometry, for which mostly no closed analytical solution exists [16]. As a consequence, numerical methods are needed to calculate the H-field inside the cage and to determine the necessary parameters for an electrical equivalent circuit, which model the interactions between implant and reader. For this purpose, a specially developed numerical analysis is used [17], which is optimized to the parameters of the equivalent circuit. The method is implemented in Mathcad [18]. The basic idea is to approximate a given random geometry of two antennas [Fig. 2] by a number of line