ACSP · Analog Circuits And Signal Processing

Enver Gurhan Kilinc
Catherine Dehollain
Franco Maloberti

Remote Powering and Data Communication for Implanted Biomedical Systems

Springer

Analog Circuits and Signal Processing

Series Editors

Mohammed Ismail, Dublin, USA
Mohamad Sawan, Montreal, Canada

More information about this series at http://www.springer.com/series/7381

Enver Gurhan Kilinc • Catherine Dehollain
Franco Maloberti

Remote Powering and Data Communication for Implanted Biomedical Systems

Springer

Enver Gurhan Kilinc
RF-IC Group
École Polytechnique
Fédérale de Lausanne
Lausanne, Switzerland

Catherine Dehollain
RF-IC Group
École Polytechnique
Fédérale de Lausanne
Lausanne, Switzerland

Franco Maloberti
Integrated Microsystem Laboratory
Universita degli Studi di Pavia
Pavia, Italy

ISSN 1872-082X ISSN 2197-1854 (electronic)
Analog Circuits and Signal Processing
ISBN 978-3-319-21178-7 ISBN 978-3-319-21179-4 (eBook)
DOI 10.1007/978-3-319-21179-4

Library of Congress Control Number: 2015947503

Springer Cham Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media (www.springer.com)

To my family. . .
Also, to my love Berra. . .

Preface

With recent developments in electronics and progress on micro/nano/biotechnologies, implantable biosystems have become more common. These systems help to improve the quality of health care. The measurement results can be obtained more precisely from the tissue thanks to the biosensors placed inside the body. Moreover, the patient can be monitored continuously for a long-term duration. All these benefits of the implantable systems help to diagnose the patient accurately, follow the progression of the treatment, or develop new therapy strategies for the patient.

The laboratory animals, especially rodents, are commonly used in many medical research projects due to their small size and reconfigurable DNA sequence. These animals are also essential in developing new drugs and medications. The drugs create side effects and toxic effects in the body. Therefore, the drugs should be tested on small animals before using them on humans. In this scope, an implantable biosensor system is necessary to monitor the vital signals of the animal continuously for a long-term duration. In addition, the animal should be in a stressless and natural environment to obtain reliable measurement results from the animal. Accordingly, the animal should be in a conventional living space and move freely to reduce stress.

This study proposes a batteryless remote-powered implantable microsystem for the freely moving small animal. Firstly, many different studies of the implantable systems for small animals have been investigated, and the current problems are pointed out. Accordingly, the objectives of this study have been defined. A prototype of an implantable system is realized, and the performances of the system are verified. The size and weight of the system should be minimized as much as possible for the comfort of the small animal. The volume and weight of the proposed microsystem are $12 \times 12 \times 2.3\,\text{mm}^3$ and 1.05 g, respectively. The overall implantable system is capable of remote powering and data communication. The power is transferred wirelessly by an optimized remote-powering link with more than 21 % of power transfer efficiency over a 30 mm distance. The link is driven by an efficient class E power amplifier at 13.56 MHz.

The implantable remote-powering electronics consist of AC-to-DC conversion & supply voltage generation and power management blocks. The induced AC voltage is converted to a DC voltage by a passive full-wave rectifier. The rectifier performs with 80 % of power efficiency for a 2 mW load condition. A high-speed voltage regulator follows the rectifier to generate clean and stable 1.8 V supply voltage. The voltage regulator has more than 60 dB of power supply rejection ratio at DC and in the frequency band of interest. The power management unit enables or disables the biosensors and communication blocks according to the available power level of the implantable system. The received power by the implantable system changes according to the movements of the animal. Moreover, the load of the rectifier also changes by the number of active biosensors and communication blocks. The power at the implantable system may not be sufficient to perform the functions; hence, the transferred power level should adapt to the demand of the implantable system. Therefore, the power feedback loop helps to keep the power level of the implantable system at a certain level by adapting the transferred power dynamically.

Data communication is another important challenge to overcome. There are different scenarios for uplink and downlink communication. One solution is to transmit the data by using the same channel with remote powering. However, a free moving animal in the living space can easily change the amplitude of the remote-powering signal. Accordingly, a suitable modulation method should be chosen to distinguish between data transmission and animal movement. Moreover, data communication using the remote-powering channel reduces the performance of the remote powering. In order to solve this issue, a low-power transmitter is implemented to operate over another channel at 869 MHz. The received signal is measured as −61 dBm at 40 cm away from the transmitter. In addition, a custom-designed receiver is realized with −85 dBm input sensitivity. The data rate of uplink communication can increase up to 1.5 Mb/s. For downlink communication, a PPM demodulator is designed to receive the commands at 13.56 MHz which are sent by using a remote-powering link. Therefore, the data rate is chosen as 5 kb/s to make sure the remote-powering performance is not degraded.

Finally, the power needs to be delivered to the implantable system in the whole living space. Therefore, the wireless power transfer should cover the whole bottom of the living space. An intelligent remote-powering (IRPower) system is proposed to track the animal in the living space and deliver the power to the implantable system efficiently. In addition, the IRPower system allows the continuous monitoring and the animal movement recording.

Lausanne, Switzerland Enver Gurhan Kilinc
Catherine Dehollain
Pavia, Italy Franco Maloberti
2015

Contents

Chapter 1
Introduction

The advances in micro, nano and bio-technology help to create multidisciplinary medical systems by combining several fields in a single unit. These medical systems improve the healthcare quality which promotes the comfort of the human at low cost. Especially, miniaturization of the systems allows to implant the devices in the body. The implanted devices need to be replaced at the end of their lifetime. Therefore, the low-power electronic is required to increase the life span of the implanted devices and reduces the number of the invasive surgeries. In addition, the transcutaneous cables which energize the devices are replaced by the wireless power transfer methods for the mobility and health of the patients.

1.1 Implanted Bio-devices

The implanted bio-devices play a significant role in the human life. The artificial organs and prostheses are produced to take place of malfunctioned organs; the smart monitoring systems are designed for detection and also treatment of the diseases, and also the actuators are developed to activate and treat the organs. The recent studies also show that there are many remotely or self powered implantable systems targeting different parts of the body and applications. We recall here some examples of state-of-the-art implementations: pacemakers [1, 2], cochlear implants [3], neural prostheses [4, 5], retinal prosthesis [6, 7], vestibular prosthesis [8], knee prosthesis [9], brain-machine interface [10], monitoring and actuation systems [11–18].

The animals are crucial to bring out innovations in the medical technology. Firstly, the implantable medical systems need to pass the safety, biocompatibility, reliability, etc. tests to obtain the medical system clearance. In addition, the systems

E.G. Kilinc et al., *Remote Powering and Data Communication for Implanted Biomedical Systems*, Analog Circuits and Signal Processing 131,
DOI 10.1007/978-3-319-21179-4_1

have to be approved by the health and human authorities before they come into the market. Therefore, as an intermediate step, the animals are used to satisfy many approvals and clearances tests [19–21].

On the other hand, the animals, especially rodents, are used in many research projects to develop new treatment (systems, drugs, etc.) or detect and monitor the illness [22–26]. This research work presents a remotely-powered implantable biosensor system for freely moving animal for continuous long-term monitoring.

1.2 Present and Future

The research activity in medicine and biology extensively uses experiments because biological systems are extremely complicated; having reliable and accurate models is very difficult. Likely, in the future many biological mechanisms will be analyzed using computer simulations based on relevant physical and biological inputs. Having good models and powerful computers will minimize invasive testing and the use of animal for experiments, giving a proper answer to pressing demands. The road to this solution is long and will require massive, sophisticated and accurate data acquisition systems. The use of animals and invasive or non-invasive in-vivo experiments is the unavoidable road to bring out this kind of innovations in the medical technology. As additional benefit of research the safety, biocompatibility, reliability associated to the use of implantable medical systems will significantly improve and will conform severe regulations required to obtain the medical systems clearance. In addition, it will be possible to fasten the introduction into the market of advanced systems verified and approved by the health and human authorities.

An alternative to in-vivo experiments we have in-vitro solutions. They have advantages and disadvantages. Advantages are that the experiment environment is free from contamination, in-vitro avoids the need for laboratory personnel experienced in animal handling and simplify the overall experimental setup. However, for a percentage of researches the used culture is not suitable for growing antibodies or hybridomas (Fig. 1.1). Therefore, animals, especially rodents, must be used in a number of research projects to develop new treatment (systems, drugs, etc.) or to study and monitor illness. The availability of miniaturized physical, chemical and biological sensors enable the use of implanted micro-systems capable to collect relevant information and to transmit data to an external unit. This, in addition to analyze specific problems, provides directions for model developments. However, the miniaturization of systems, the increased complexity of the data acquisition, the processing and the data transmission poses serious challenges to the designer, especially for powering. This, as illustrated in previous examples where powering can be by battery on board, by an implanted rechargeable battery or by a remotely-powered solution.

Figure 1.2 shows the evolution of in-vivo experiments. In the past we had bulky systems partially implanted with wire connection between them, now the system is implanted with remote powering sensors and data transmission, in the future the

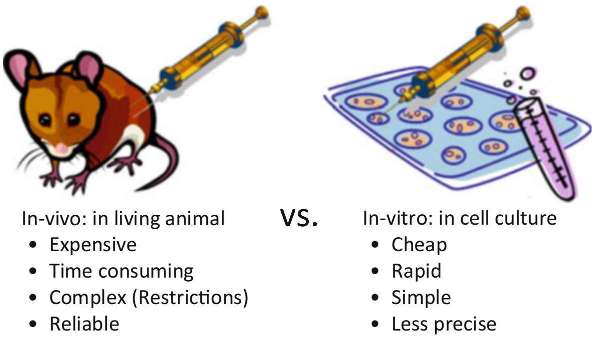

Fig. 1.1 Comparison of in-vivo and in-vitro experiments

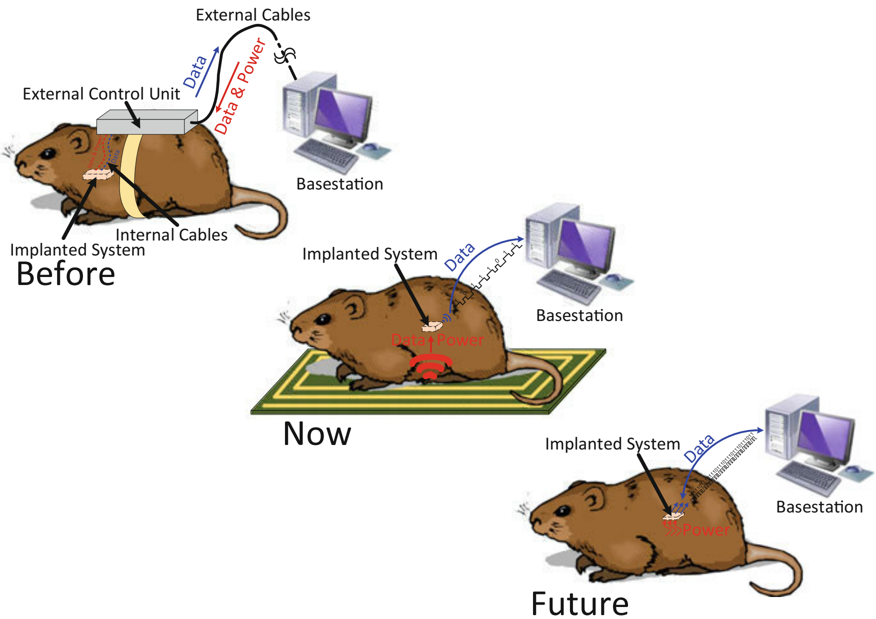

Fig. 1.2 Evolution of implanted systems for in-vivo experiments

implanted system will have harvested powering and internal consumption capable to include actuators for delivering drugs and interacting in feedback with a biological model that will learn from the measured data.

Miniaturization of devices for diagnostic and therapy, low power consumption, sensors and electronic integration, augmenting the devices intelligence have been the initial goals of applications for almost all branches of medicine. Now, research efforts in biomedical engineering have more general objectives: enhancing the quality of life and extending the life itself. In the next few decades, research will favor devices for restoring the functions of tissue, will produce more sophisticated implantable electronic devices, will allow autonomous operation. Patients with have multiple implanted electronic systems that will communicate one each other to adjust their operation at optimum. Next will have functional tissues grown from biological material directly in the body placed into the right position so that tissues will be restored and repaired.

Certainly, a lot of knowledge is needed for producing the above mentioned results, like having biological materials with properties similar to human living tissue or artificial biological structures. Also, lot of knowledge is necessary for understanding mechanism of illness for beating them. Research with implanted bio-systems will open the way to the require deep comprehension of mechanisms. However, power harvesting and power management, will become more and more demanding because the use of multiple sensors for measuring and monitoring at the same time physiological and bio-mechanical quantities inside of the body, data transfer and signal processing will be possible only if the required power is made available.

1.2.1 Rodents in Research

We have seen that for many situations it is necessary to do experiments with implanted devices using small animals. The key requests of an implanted system are the size, the autonomy and the data communication capability. The volume is an issue but system in the order of 1 cm^3 is normally acceptable [27, 28]. Autonomy is important if it is desired to have the operation for months or years. Often, the use of batteries is not a viable solution because of weight, size and life time issues. Therefore, power harvesting or remote powering solutions are necessary. Harvesting the power inside a living body is insufficient to power multi-sensor systems with short range two-way communication. Remote powering provides a reliable solution to monitor the animal continuously.

The small laboratory animals are commonly used animals for developing new treatments and research applications [29–36]. The small animals, especially rodents, are preferred in research activities due to their DNA sequence which is close to human, small size, reproducibility. The most essential feature of these animals is suitable for modification on their DNA sequence which permits to create DNA sequence similar to human genome [37]. In addition, the life span of the rodents is shorter hence they become adult quickly [38, 39]. The short life cycle helps to obtain quick response to the examinations.

On the other hand, the size of these animals allow to store larger number of animals in a certain space compared to other animals. However, the small size brings out difficult challenges for designing of implantable device. The implantable device must be small and light-weight to be placed in a small animal. Consequently, the implantable device should be batteryless and remotely powered to reduce the overall size and weight.

Generally, the animals are anesthetized during the monitoring and measurement phase. However, the measurement results are affected due to consciousness level