Analog Circuits and Signal Processing

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Gürkan Yılmaz · Catherine Dehollain

Wireless Power Transfer and Data Communication for Neural Implants

Case Study: Epilepsy Monitoring

Springer

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To my family
Kiraz, Hilmi and Serkan

and

To my love Eva-Liisa

—Gürkan Yılmaz

Preface

Recording neural activities plays an important role in numerous applications ranging from brain mapping to implementation of brain–machine interfaces (BMIs) to recover lost functions or to understand the mechanisms behind the neurological disorders such as essential tremor, Parkinson's disease, and epilepsy. It also constitutes the first step of a closed-loop therapy system which employs a stimulator and a decision mechanism additionally. Such systems are envisaged to record neural anomalies and then stimulate corresponding tissues to cease such activities.

Methods for recording the neural signals have evolved to its current state since decades, and the evolution still goes on. This book focuses on how to eliminate all the wired connections for new-generation neural recording systems: implantable wireless neural recording systems with a case study on in vivo epilepsy monitoring. The scope of this book can be defined as wireless power transfer, wireless data communication, biocompatible packaging, and compulsory experiments on the way to human trials.

First of all, wireless power transmission is realized using 4-coil resonant inductive link topology which exploits the magnetic coupling phenomena. In addition to the power transfer, a reliable DC power supply is generated in the implant by means of a half-wave active rectifier and a low drop-out voltage regulator. The operation frequency, 8.5 MHz, has been optimized by taking tissue absorption and bandwidth limitations for data communication into account.

Secondly, wireless data communication solutions have been investigated, and two different solutions have been implemented for different application scenarios: First solution is to use load modulation scheme, which actually relies on varying the load according to the incoming neural data. However, there is a trade-off between data rate and power transfer efficiency for this solution, which in return leads us to implement the second solution, dedicated transmitter at a higher frequency. Consequently, a transmitter which can work at MICS (402–205 MHz), ISM (433 MHz), and several MedRadio bands has been implemented to transmit neural data to an external base station which includes a discrete receiver.

Following the integration of all electronic circuits which have been fabricated using UMC 180-nm MM/RF technology, the implant has been packaged using biocompatible polymers (PDMS, medical grade epoxy, and Parylene-C). Packaging provides the bidirectional diffusion barrier feature which enables in vitro and in vivo experiments to be conducted.

Finally, three levels of experimentation have been conducted to validate the operation of the system: in air for electrical characterization, in a tissue-mimicking solution for in vitro characterization, and in a mouse brain for in vivo characterization.

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September 2016

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Contents

Acronyms

AC	Alternating current
ADC	Analog-to-digital converter
ASK	Amplitude-shift keying
BER	Bit error rate
BW	Bandwidth
CMOS	Complementary metal–oxide–semiconductor
DAC	Digital-to-analog converter
DC	Direct current
DR	Data rate
E	Electrical field strength
EA	Error amplifier
ECG	Electrocardiography
ECoG	Electrocorticography
EEG	Electroencephalography
EIRP	Effective isotropic radiated power
ESA	Electrically small antenna
FDA	Food and Drug Administration
FoM	Figure of merit
FPGA	Field-programmable gate array
FSK	Frequency-shift keying
H	Magnetic field strength
IC	Integrated circuit
iEEG	Intracranial electroencephalography
ISM	Industrial, Scientific and Medical
kbps	Kilobit per second
LDO	Low drop-out
LSK	Load-shift keying
Mbps	Megabit per second
MEA	Microelectrode array
MI	Modulation index

MIM	Metal–insulator–metal
MOSFET	Metal–oxide–semiconductor field-effect transistor
MUA	Multi-unit activity
OOK	On–off keying
OPAMP	Operational amplifier
OTA	Operational transconductance amplifier
PA	Power amplifier
PCB	Printed circuit board
PSR	Power supply rejection
PSRR	Power supply rejection ratio
PTE	Power transfer efficiency
PZT	Lead zirconate titanate (piezoelectric ceramic material)
RF	Radio frequency
RFID	Radio frequency identification
RMS	Root mean square
RX	Receiver
SAR	Specific absorption rate
SNR	Signal-to-noise ratio
SoC	System on chip
SRF	Self-resonant frequency
TX	Transmitter
VCO	Voltage-controlled oscillator
WHO	World Health Organization
WPT	Wireless power transfer