ULTRAsponder

In vivo Ultrasonic Transponder System for Biomedical Applications

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1 R = Report, P = Prototype, D = Demonstrator, O = Other

2 PU = Public, PP = Restricted to other programme participants (including the Commission Services, RE = Restricted to a group specified by the consortium (including the Commission Services), CO = Confidential, only for the members of the consortium (including the Commission Services)

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1 Executive summary

The first ULTRAsponder Workshop has been organized as satellite event of the 2010 ESSDERC / ESSCIRC conference which was held in Sevilla, Spain, from September 13th to 17th 2010.

In this deliverable the workshop programme and abstracts are collected and presented. All talks given during the workshop are publicly available on the publication section of the ULTRAsponder website at the following address:

http://www.ultrasponder.org/project/dissemination/publications/publications.html .

2 Workshop programme

Title of the workshop linked to the ESSCIRC 2010 conference (www.esscirc2010.org): Low power electronics for medical applications in the frame of the FP7 ICT European project ULTRAsponder

Date: Friday 17th September 2010, from 9:00 AM to 4:45 PM, Sevilla, Spain.

Organiser

Dr. Catherine Dehollain: coordinator of ULTRAsponder. Web page: www.ultrasponder.org
Ecole Polytechnique Fédérale de Lausanne (EPFL), GR-SCI-STI, Station 11, CH-1015 Lausanne, Switzerland
E-mail: catherine.dehollain@epfl.ch, direct phone: 0041 (0) 21 693 69 71

Summary of the workshop

The two sessions in the morning are devoted to the ULTRAsponder project thanks to six presentations. They are focused on **remote powering and communications through ultrasound**, and on **low power data acquisition and low power digital processing**. The session in the afternoon is dedicated to four presentations in the domain of **low power electronics for medical applications** performed by worldwide recognized scientists.

The FP7 ICT European Project **ULTRAsponder** aims at developing a new system with a high degree of **reliability and accuracy of the clinical data**, while providing the patients with high level of safety and user friendliness. Though the project intends to propose a general solution to several possible pathologies, such as acute diabetes, epilepsy and other debilitating neurological disorders, it focuses its efforts on one **demonstrator devoted to chronic cardiac diseases**. For this specific application, **continuous monitoring** is particularly important to follow the day and night heart activity, thus allowing to understand **how the heart reacts** to different kinds of **stresses**, to different kinds of **activities** and to different sorts of **medications**. A continuous monitoring of a patient can also give the physicians the possibility to make a **direct comparison** of the actual patient condition with a past condition (one day, one week or one month earlier). Therefore continuous monitoring is a major leap forward in the diagnosis and the treatment of **cardiac congestive heart failure** (CHF).

ULTRAsponder aims at developing an innovative technology based on **ultrasonic telemetry techniques**, for communication between one sensor deeply implanted in the human body (**the transponder**) and a **control unit** which is used for both **wirelessly recharging** the implanted device and **transmitting the received information** to the external world. Web address: http://www.ultrasponder.org

Registration

The registration is mandatory by using the web page of the ESSCIRC-ESSDERC 2010 conference

Fees: This workshop is free of charge

Program of the workshop: see next page

Program of the workshop

8:45: Opening of the desk at the entrance of the room

SESSION 1: Remote powering and communications through ultrasound
9:00: Opening of the workshop, Catherine Dehollain, EPFL, RF IC group, Lausanne, Switzerland

9:10: FP7 ICT European ULTRAsponder project: In Vivo Ultrasonic Transponder System for Biomedical applications
Speaker: Catherine Dehollain, EPFL, RF IC group, Lausanne, Switzerland

9:30: Ultrasound for wireless energy transfer and communication for implanted medical devices
Speakers: Catherine Dehollain and Francesco Mazzilli, EPFL, RF IC group, Switzerland

From 10:00 to 10.30: Coffee break

10:30: Possible acoustic paths for communication and energy transfer with deeply implanted sensors using ultrasound
Speaker: Benjamin Cotte, INSERM, Unit U556, Lyon, France

SESSION 2: Low power data acquisition and low power digital processing
11:00: Data compression in medical implants
Speaker: Pal Anders Floor, Oslo University Hospital, Interventional Center, Oslo, Norway

11:30: Low-power data acquisition system for very small signals with 12-Bit-SAR-ADC
Speaker: Christof Dohmen, IMST GmbH, Kamp-Lintfort, Germany

From 12:00 to 13.30: Lunch

13:30: Low power digital processing
Speaker: Marc Morgan, CSEM, Neuchatel, Switzerland

SESSION 3: Low power electronics for medical applications
14:00: Electro magnetical fields and implanted medical devices: MRI compatibility
Speaker: Volkert Zeijlemaker, Medtronic, Bakken Research Center, Maastricht, Netherlands

14:30: Low power analog electronics for portable and autonomous applications
Speaker: Franco Maloberti, University of Pavia, Integrated Microsystem Laboratory, Italy

15:00: RF CMOS sensors for contactless health monitoring
Speaker: Domenico Zito, University College Cork and Tyndall National Institute, Cork, Ireland

From 15:30 to 16.00: Coffee break

16:00 Battery-less wireless sensors based on low power UHF RFID tags
Speaker: Ivan Rebollo, Farsens S.L., San Sebastian, Spain

16:30: Closing of the workshop: Catherine Dehollain, EPFL, RF IC group, Lausanne, Switzerland

3 Workshop abstracts

ultrasponder

In Vivo Ultrasonic Transponder System for Biomedical Applications
Catherine Dehollain (EPFL, Switzerland)

Healthcare methodologies are constantly evolving due to the research and technology advancements made in the field of sensing and monitoring, promoting the use of wearable wireless devices for clinical applications. This opens the way to promising possibilities in terms of **prevention** and **treatment** of **patients requiring continuous surveillance or therapeutics**.

The EC FP7 Project ULTRAsponder consists of a group of scientists, engineers and medical doctors and aims at developing a new system with a very high degree of **reliability and accuracy of the clinical data**, while providing the patients with **high level of safety and user friendliness**. Though the project intends to propose a general solution to several possible pathologies, such as acute diabetes, epilepsy and other debilitating neurological disorders, it focuses its efforts on one **demonstrator devoted to chronic cardiac diseases, and in particular Cardiac congestive Heart Failure (CHF).**

For this specific application, **continuous monitoring** is particularly important to follow the day and night heart activity, thus allowing to understand **how the heart reacts** to different kinds of **stresses**, to different kinds of **activities** and to different sorts of **medications**. A continuous monitoring of a patient can also give the physicians the possibility to make a **direct comparison** of the actual patient condition with a past condition (one day, one week or one month earlier). Therefore continuous monitoring is a major leap forward in the diagnosis and the treatment of CHF.

ULTRAsponder aims at developing exclusive and unprecedented technologies based on **ultrasonic telemetry techniques**, for communication between one or several sensors or stimulators deeply implanted in the human body (**the transponders**) and an external **control unit** which is used for both **wirelessly recharging** the implanted devices and **transmitting the received information** to the external world. The **key objectives** are the following:

- To develop innovative wireless data and energy transmission techniques for ultra low power sensor/actuator nodes immersed in aqueous media,
- To achieve small footprint, high flexibility, modularity and generality, which can easily be adaptable to any implantable microsystem,
- To perform bidirectional acoustic wireless data transmission,
- To enable local low massive signal processing capabilities to reduce transmission time and data load,
- To develop ultrasonic transponders actuating and either intermittently or continuously monitoring parameters for biological applications, where considerations are given to miniaturization, power consumption, functionality, production and cost aspects,
- To prove the concept by developing a new technology for a network of ultra-low power transponders deeply implanted inside the body for long term periods,
- To assess the overall system in a real environment for a particular application aimed at measuring physiological parameters and correlating them (data fusion) to perform advanced diagnostics.

Coordinator: Dr. Catherine Dehollain
EPFL, Faculty STI, RFIC Group, Station 11, Building ELB, CH-1015 Lausanne, Switzerland.
E-mail: catherine.dehollain@epfl.ch Phone: +41 (0) 21 693 69 71 Web: http://www.ultrasponder.org/

Ultrasound for Wireless Energy Transfer and Communication for Implanted Medical Devices

Francesco Mazzilli and Catherine Dehollain
EPFL, Faculty STI, RFIC Group, Station 11, Building ELB, CH-1015 Lausanne, Switzerland
E-mails: francesco.mazzilli@epfl.ch, catherine.dehollain@epfl.ch

By exploiting the capability of acoustic waves to penetrate deeper in the body tissue without being significantly attenuated, new implanted medical devices (IMDs) are appearing among health monitoring applications. The system requirements for IMDs are longevity that is determined by the energy storage element, and by the modulator power consumption within the transponder. Therefore, a load modulation technique (backscattering modulation), largely exploited in radio frequency identification (RFID), may be the best candidate for medical devices due to its low power consumption. However, IMDs should be tested in-vitro for primary analysis of side effects so that this new technology can be accepted for clinical use.

This talk discusses the possibility of using acoustic waves to charge a lithium battery and to allow wireless communication in IMD applications. First, the motivation of the work is presented focusing on medical applications. Secondly, an in-vitro platform to characterize ultrasound is described and the construction of the platform is presented. Thirdly, experimental results of the use of ultrasound as source for wireless energy transfer and communication are shown.

Possible acoustic paths for communication and energy transfer with deeply implanted sensors using ultrasound

Benjamin Cotté, Cyril Lafon and Jean-Yves Chapelon

Inserm, U556, Lyon, F-69003, France ; Université de Lyon, Lyon, F-69003, France

In the context of the ULTRAsponder project, ultrasound is used to communicate between one or several sensors implanted in the human body (transponders) and an external system (control unit), and also to transfer energy to the sensors in order to recharge their battery. To optimize the performance of the system during the communication and energy harvesting phases, an adequate acoustic path must be found between the control unit and the transponder. The goal is to ensure minimum signal attenuation along the acoustic path, and to limit possible side-effects, that are mainly temperature increase in the tissues and cavitation. In this study, different positions of the transponder and control unit are tested. Using the inner organs segmented data of the Visible Human Male, the tissue layers around each position can be identified and visualized. For each combination of transponder and control unit positions, a computational grid can be generated that takes into account the geometry and the attenuation of the tissue layers along the acoustic path. The acoustic pressure field is then calculated using a model based on the Rayleigh-Sommerfeld diffraction integral. The model is first validated by comparison with *in-vitro* experiments. Then, model results are presented for realistic configurations in the context of the ULTRAsponder project. These results enable us to give estimates of the maximum signal amplitude that can be sent by the control unit and to determine what are the most suitable positions of the transponder and control unit.

Data compression in medical implants

Pal Anders Floor, Oslo University Hospital, Interventional Center, Oslo, Norway

Wireless transmission of data from devices placed within the human body has several challenging technical problems, most of which are confined to the physical size and onboard computational resources in terms of power and processing capabilities.

A potential candidate for reducing power consumption at the transmitter side (transponder) is compression. The compression scheme should be deployed in such a manner that it reduces the rate of the signal significantly on one hand and on the other hand that it does not consume huge computational resources quantified in terms of power consumption.

Signals resulting from the measurement of most physical phenomena and processes will be correlated in time. Correlation is redundant and can therefore be removed from relevant signals at the transmitter and added at the receiver without any loss of information. In applications where power is a scarce resource it is important to remove as much redundancy as possible prior to transmission with the lowest possible computational resources so that the waste of power is kept at an absolute minimum.

A potential scheme for the removal of temporal correlation is *differential pulse code modulation* (DPCM). For a broad range of correlated signals, DPCM is known to provide significant compression at low complexity.

Exploiting correlation between different measuring devices placed within the body might be another possibility for lowering signal rates and power consumption per sensor. For implants a distributed scheme will be necessary since making sensors placed within the body cooperate is very difficult, if at all possible. Another advantage in using a distributed scheme is that no receivers will be necessary in the sensors. *Distributed quantization* (DQ) is a potential scheme that should be investigated. In DQ quantizers for several sensors are co-optimized taking inter-sensor correlation into account. Through joint decoding at the receiver, compression gains can be achieved through reducing the overall transmission power or signal rates if the correlation is high. DQ can potentially be used in conjunction with DPCM to exploit both temporal and inter-sensor correlation.

In this talk DPCM compression and DQ is discussed for a simple sensor network consisting of at most two sensors and one joint receiver (CU).

Low-Power Data Acquisition System for very small signals at low frequencies with 12-Bit-SAR-ADC

Christof Dohmen, Jörn Driesen, Daniel Peitscher, Frank Henkel
IMST GmbH, Carl-Friedrich-Gauß-Str. 2, 47475 Kamp-Lintfort, Germany,
www.imst.com

The described data acquisition system is intended for use in a bio-medical implant of the Ultrasponder-project for in-vivo measurements. An acoustic ultrasound connection to the ex-vivo control unit provides power to the implant and serves as a bidirectional communication path. Thus low power consumption at a reasonable conversion speed were main goals in the design.
The biomedical signals of interest have rather low voltage levels at very low frequencies. Therefore, a chopping technique is applied to overcome the 1/f noise limitations in the analog front-end. Precautions are made to preserve the living tissue from undesired DC currents.
The chopped biomedical input signal is amplified by low-power stages prior to demodulation to the original frequency spectrum of nearly 0 Hz to 50 Hz. A fully differential anti-aliasing filter of 4th order cancels out the remaining disturbances of the high frequency chopping pulses. The subsequent 12-bit SAR-type ADC converts the signal and is operating with a sample rate up to 50 kS/s at a rail-to-rail input voltage range. The data is transmitted to an external controller via a FIFO-buffered SPI communication interface.

ESSCIRC 2010 Workshop - Low power electronics for medical applications in the frame of the FP7 ICT European project ULTRAsponder

Low power digital processing

By Marc MORGAN, CSEM – Swiss Center for Electronics and Microtechnology

Contact: marc.morgan@csem.ch

This presentation describes the ULTRAsponder core System-on-Chip and the low power features which were designed into the SoC. This circuit was designed in the early stages of the ULTRAsponder project in order to have prototypes available to develop the software and an in-vivo demonstrator before the end of the project. This SoC contains:

1) an ultra-low power processor designed for DSP and control type processing. The CSEM's icyflex1 processor with its dual MAC architecture was used. The presentation goes into some detail concerning the architecture and the low power features in the icyflex1 processor.

2) the standard peripherals for a microcontroller (Timers, Watchdog, I2C, SPI, UART, GPIO, IRQ controller), a DMA controller to optimize power consumption during slow communication phases, a JTAG tap to support on-chip debug and an ultra-low power 32-kiHz RTC.

3) a wide range of power management features to support power supplies from 1.0 V to 3.6 V and to power external devices.

4) support for 3 power modes (normal, sleep, hibernation) which allow the SoC to power down to 1 µW. Combined with a very low duty cycle, the ultra low power SoC offers maximum flexibility as far as autonomy and processing power is concerned.

Electro Magnetic Fields and Implanted Medical Devices: MRI compatibility

Volkert Zeijlemaker Medtronic Bakken Research Center Maastricht, The Netherlands

Future Implanted medical devices need to be compatible with Magnetic Resonance Imaging. [MRI] Techniques that are using non electromagnetic communication ULTRAsponder have an advantage. The implantable electronic circuitry may nevertheless be susceptible for interference from MRI due to the circuitry design and the sensors.

To understand the “adverse effects” MRI physics is briefly explained. The three physical quantities used by MRI: static magnetic field, electromagnetic field and magnetic gradient fields, impose different challenges for the implanted medical device during MRI. Force and torque on the ferromagnetic parts of the device. Radio frequency electromagnetic fields transmit power resulting in voltages on elongated structures. Temporary magnetic gradients may induce currents in conductive materials.

The clinical need for MRI requires MRI compatibility for implants. There is no alternative for a number of imaging modalities on function of organs or for the imaging of soft tissues. Further medical personal should avoid the ionizing radiation from X rays, MR is the alternative.

Briefly some design limitations are described. If the restrictions are early known and implemented in the project, significant improvements could be obtained. In-vitro testing and modelling are important tools to guide the design and ultimately prove the concept so that the device becomes useful for medical application.

The awareness from the regulatory bodies to ask for MRI compatibility is increasing. In medical emergencies physicians often has to use MR for patients with implants to be able to save the life of a patient.

Low power analog electronics for portable and autonomous applications

Franco Maloberti
University of Pavia
Integrated Microsystems Laboratory

Portable and nomadic systems require developing power effective and power aware design methodologies for either analog or digital circuits. For data converters, low power and optimal resolution implies a favorable allocation of the noise budget. The noise comes from different sources: quantization, sampling, clock jitter, spur interference and board interference. The distribution of the available noise power, that becomes lower and lower as the supply diminishes, depends on the specification of the system and it may require one or more extra-bits in the data converter.

The growing relevance of power efficiency is demonstrated by the great attention on the figure of merit (FoM) of data converters that, in the past few years, has been reduced by almost two orders of magnitudes. The presentation shows that obtaining power effectiveness is a matter of trade-offs between architecture, design methodologies, and implementation of circuits.

Advancements in technology challenge analog low power design. In addition to a reduced supply voltage, the worsening of transconductance and output resistance degrades the intrinsic gain and makes it difficult to design high gain op-amps. Noise, both thermal and 1/f, also increases. Moreover, accuracy and linearity of passive and active components is problematic at minimum features. All those limits must be understood and accounted for to ensure effective analog circuits design. After discussing the above general issues this presentation describes the design of significant achievements and illustrate their experimental verifications. The given examples pertain a very low power data converter and a low power high-gain low offset amplifier for sensor interfaces applications.

The technology scaling is not just problematic for the analog limits but also offer new opportunities for ensuring optimal performances at the lowest possible power. Nanometer technologies make it available digital transistors at a virtual zero cost either accounting for the silicon area and the consumed power. The feature favor the so called digital assisted analog techniques that compensate for various limits with calibration and, more in general, the control of the static and dynamic operational point of analog circuits. The issue is discussed at the general level for giving the flavor of challenges and opportunities.

RF CMOS sensors for contactless health monitoring

Domenico Zito

University College Cork and Tyndall National Institute

Abstract – In the framework of ongoing technology trends, even well-known systems, traditionally implemented by using hybrid technologies (bulky and expensive), may provide us new interesting opportunities. In fact, due to several challenges in the modern society, innovative miniaturized sensors are expected at the crossroads between information communication technology and the life and geo-sciences. The today microelectronic systems in standard silicon technologies, especially CMOS, are capable of integrating very complex functionalities and operating with radio-frequency (RF) signals up to a few hundred GHz. In addition to traditional wireless data communication (e.g. mobile phones, wireless local area networks, etc), RF signals could be exploited also for contactless sensing of important information, including the vital signs of human beings. Despite the differences among the possible applications, they can all be grouped under the same discipline named "*advanced radio-frequency engineering"*.

This lecture reports the work performed by the research group based at the University College Cork and Tyndall National Institute, in Ireland, toward the realization of innovative contactless sensors to be mostly used in the medical field for health monitoring.

In particular, the lecture reports two innovative contributions derived by combining the System-on-Chip (SoC) approach in nano-scale CMOS technology with the life and geo-sciences. The former regards a SoC Ultra-Wide_Band (UWB) radar sensor for contactless cardiopulmonary monitoring. The latter focuses on a SoC radiometer for temperature remote sensing. For both sensors we report the framework and motivations, basic theoretical concepts, current results, and the future directions of ongoing research.

Domenico Zito, MIEEE Solid-State Circuits Society (S'00–M'04) and Communication Society (M'08), received the M.Sc. degree in electronic engineering and Ph.D. degree in information engineering from University of Pisa, Italy, in 2000 and 2004, respectively. In March 2009, he joined University College Cork and Tyndall National Institute as a "Stokes" Lecturer in Microelectronic Engineering (analogue and mixed-signals). Prior to joining UCC/Tyndall, he worked with the RF Advanced Design Center of the University of Catania (Italy) within STMicroelectronics in Spring 2001, and the RFIC design team within the Drive Unit of Austriamicrosystems, Graz (Austria) in 2002. In 2005, he became an Assistant Professor of Electronics at University of Pisa (Italy). He is co-author/author of more than seventy papers in peer-reviewed international journals and conference proceedings (six invited papers), one chapter of book, one book edited and two patents. His primary interests relate the design of radio-frequency, microwave and millimetre-wave front-ends on standard CMOS and Bi-CMOS technologies. He had the responsibility of about ten EU and National projects, 36 test-chip designs (96% passed at 1st foundry-run). He is the National Coordinator for Ireland of the EU COST Action IC803 on Emerging Wireless Applications. He is leading a EU cluster on innovative systems for biomedical applications.

Dr. Zito is in the Reviewers' Board of several peer-reviewed international journals (JSSC, T-MTT, MWCL, TCAS-I, TCAS-II, Int. Journal of Circuit Theory and Applications, Analog Integrated Circuits Design and Signal Processing, etc) and is serving as a member and Chair of the Technical Program Committee and special sessions organizer in IEEE international conferences.

Domenico Zito received three research awards at IEEE conferences in 2005, 2007 and 2009, two best paper award nominations (IEEE EuMIC 2006 and IEEE BCTM 2006), and the "First Price" (10KE) at European Wireless Business Idea "Mario Boella" Competition in December 2005.

Title of the workshop linked to the ESSCIRC 2010 conference (www.esscirc2010.org):

Low power electronics for medical applications in the frame of the FP7 ICT European project ULTRAsponder

Date: Friday 17th September 2010, from 9:00 AM to 4:45 PM, Sevilla, Spain.

16:00 Battery-less wireless sensors based on low power UHF RFID tags

Speaker: Ivan Rebollo, FARSENS S.L., San Sebastian, Spain

Summary:

A long range UHF RFID tag suitable for battery-less wireless sensors is implemented. The main theoretical limitations involving maximum communication distance between the tag and the reader are discussed obtaining useful system design guidelines. Using these guidelines an analog front-end is designed in a low cost 0.35µm CMOS process. The proposed analog front-end together with the EPC C1G2 compatible digital core allow the implementation of power management techniques, that together with the power optimized blocks such as voltage limiter, band-gap, regulators, clock generator and ASK demodulator provide a long reading range. The implemented voltage multiplier uses Schottky diodes to provide efficiencies higher than 35%. The measured UHF RFID analog front-end current consumption is 7.4µA. A complete wireless sensory system is implemented assembling the analog front-end chip to a matched dipole antenna, to an ultra-low power commercial sensor and to a module based digital core (field-programmable gate array - FPGA - and digital core replica power consumption module). Measured results show a successful wireless communication up to 2.4m from a 2W EIRP output power reader to a digital module plus low power sensor (temperature, pressure, humidity, etc.) with average power consumption lower than 37.5µW. Temperature and acceleration prototypes have been built showing communication ranges of 2m and 1m respectively using a commercial reader. These characteristics allow the use of the proposed sensory system in a battery-less wireless sensor network.