Ultra-Low-Power Embedded Wireless Systems for RF Medical Telemetry and Telehealth

Ultra Låg-Effekt Inbyggda Trådlösa System för Medicinsk Telemetri och Televård

Project duration: 2008-2010
Grant: 6M SEK

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Project members

- Atila Alvandpour (PI), professor, division head
- Jerzy Dabrowski, associate professor
- Behzad Mesgarzadeh, assistant professor
- Christer Svensson, professor emeritus
- Arta Alvandpour, research engineer
- PhD students:
  
  Timmy Sundström (PhD in 2011), Jonas Fritzin (PhD in 2011)
  Dai Zhang (Lic. in 2012), Ameya Bhide, Ali Fazli, Fahad Qazi, Amin Ojani, Daniel Svärd.
Advanced medical implant devices for improved patient care and reduced healthcare costs

Examples:

Cardiac rhythm management devices e.g. pacemakers and implantable defibrillators

Neurostimulators

Deep brain stimulation for treatment of Parkinson’s disease other neurologic and psychiatric disorders

Spinal cord stimulation for reducing chronic pain of arms, legs, etc.

Wireless implant telemetry for remote monitoring of patients at home.

Source: St. Jude Medical Inc.
Power (battery lifetime) is the major challenge for implant devices

- Large demand for increasingly advanced sensor interface, data acquisition, data conversions, signal processing and wireless communication.
- Require extremely low power consumption to operate up to 10 years or longer with a small non-rechargeable battery!
Objectives

Develop innovative system-on-chip solutions for:

- Energy-efficient radio transceiver frontends
- Ultra-low-power data converters
- And other related challenging building blocks for medical implant devices

Other applications

The project and results support a wide range of other applications requiring low power operation, such as body network area, sensor networks, wireless sensors, mobile phones, small radio base-stations, and much more!
Summary of results during 2008-2010

Developed several innovative solutions for energy efficient radio transmitters, radio receiver frontends, and ultra-low-power ADCs

- Demonstrated by more than 8 IC prototype chips, designed and fabricated in CMOS technologies.
- Benchmarked against state-of-the-art previous work, and published in top international journals (5) and conferences (6) in the field.

A few highlights:

- **A Class-D outphasing radio Power Amplifier (PA) in 90nm CMOS**, with 34 dB and 4 dB suppression of 3rd and 5th harmonics, relaxing the filter requirements.
- **First reported Class-D outphasing CMOS PA with 32dBm peak power**, fulfilling WCDMA, EDGE, and LTE standards without pre-distortion.
- **A 53-nW 9.12-ENOB 1-kS/s SAR ADC in 0.13-µm CMOS** (lowest reported power for such ADCs).
- **A DLL-based on-chip clock multiplier with lowest reported power**.
Progress after 2010

- Continue the work on ultra-low-power ADCs, low-power radio transmitters and radio wake-up receivers, resulting so far in 3 new journal papers and 4 conference papers.
- Two PhD degrees form the project in early 2011.
- Project highlights:
  - A 3-nW 9.1-ENOB SAR ADC at 0.7 V and 1 kS/s in 65nm CMOS. *Currently lowest reported power, about 90% lower than the state-of-the-art (which is the previous 53nW ADC from this project)*.
  - An OTA-less 2nd order sigma-delta modulator ADC with best reported energy-efficiency (FOM) of 0.29 pJ/step.
  - First reported Class-D outphasing CMOS PA with 1.6Hz bandwidth, supporting WCDMA, EDGE, and LTE.
  - Novel phase pre-distortion (linearization) technique, improving the linearity of the Class-D outphasing for radio base-station applications.
  - A wake-up radio receiver for ultra-low-power sensors and RFID cards, with 8μA I_{DC}, f_c=2.54 GHz.
### Example of results and fabricated chips

**A 53-nW 9.12-ENOB 1-kS/s SAR ADC for Medical Implant Devices**

*IEEE Journal of Solid-State Circuits, July 2012*

**A Class-D outphasing RF amplifier with harmonic suppression in 90nm CMOS**

*IEEE Transaction on Circuits and systems, 2012*

**A +32dBm 1.85GHz Class-D Outphasing RF PA in 130nm CMOS for WCDMA/LTE**

*IEEE European Solid-State Circuits Conf., Sep. 2011*

**A Low-Power Digital DLL-Based Clock Generator in Open-Loop Mode**

*IEEE Journal of Solid-State Circuits, July 2009*
Example of results and fabricated chips (Cont.)

A 3-nW 9.1-ENOB SAR ADC at 0.7 V and 1 kS/s in 65nm CMOS for Medical Implant Devices


Wake up radio, 18µA $I_{DC}, f_c=2.54$ GHz, $f_{bb}=100$KHz

To be submitted for publication

Modeling and Digital Predistortion of Class-D Outphasing RF Power Amplifiers

IEEE Transactions on Microwave Theory and Techniques, 2012

Three ultra-low-power sigma-delta ADC solutions in one chip for pacemakers. With active, mixed, and passive loop filters, achieve 76 dB, 70 dB and 67 dB peak SNDR, while consuming 2.1 µW, 1.27 µW, and 0.92 µW

To be submitted for publication
Technology readiness level

The project has created and offers a highly specialized know-how for design of ultra-low-power system-on-chip RF, analog and mixed analog-digital integrated circuits. Particularly, we now offer innovative solutions for:

- Energy-efficient Radio transmitter front-ends, including DACs, RF modulators and CMOS Class-D out-phasing radio power amplifiers.
- Low-power, low-cost radio with wakeup radio and wireless sensors
- Low-frequency ADCs with resolutions of 10-14 bits and with state-of-the-art low power consumption in nano-Watt range
Other grants and supports

• **Zarlink Semiconductor**, 25K USD/year (2008-2011) and a researcher/co-supervisor from the Zarlink located at the group in LiU during 2008-2011.

• **ERICSSON**, 500K SEK for radio power amplifiers in 2010.

• **Kapsch TrafficCom**, more than 500K SEK for industrial implementation of the low-power wireless receiver.

• **Intel, USA**, 50K USD in 2010 and 50K USD in 2012 for wideband PA, and on-chip low-power clocking respectively.

• Partial support from a **SSF** project on flexible radio frontends and ADCs (expires in 2013).

• About 500 K SEK from **ELLITT** (excellence center at Linköping –Lund in Information Technology) on wideband digital transmitters.
Industry contacts, industry partners, and employments

- **Industry contacts and partners, the project has shared knowledge and results with:**
  - St. Jude Medical (Stockholm), Zarlink (Stockholm), ERICSSON, Intel-USA, Kapsch TrafficCom (Stockholm), SP-Devices (Linköping), Anacatum (Linköping).

- **Industry employments from this project:**
  - The project has so far produced two PhD degrees in 2011, both are employed by the industry partners.
    - Dr. Jonas Fritzin (PhD research on RF PA) employed by ERICSSON (Stockholm) as expert RF circuit designer.
    - Dr. Timmy Sundström (PhD research on the ADC) employed by SP-devices (Linköping).
Forecast

Contributions to future products of the industry partners:

- The knowledge and the innovative circuit technologies from this project have been already shared with industry partners such as Zarlink and ERICSSON, supporting the companies in development of their future products.
- Kapsch TrafficCom is currently implementing the knowledge and solutions from this project to their future wireless car toll collection products.

Future commercialization possibilities:

- Ongoing discussions for commercialization (in form of IPs) with two other companies, showing strong interest in the ultra-low-power ADCs as well as other solutions from this project.
- Ongoing analysis and investigation for establishment of a spin-off company.
Conclusions

‘Banbrytande IKT 2007’ was an excellent initiative

- Taking away the requirement for financial support from industry allowed the companies in Sweden to ‘comfortably’ participate in long-term cutting-edge research collaboration with academia.

- Created a highly specialized Swedish competence in ultra-low-power IC design, supporting future medical implant devices, wireless communications, and many other applications.

- Produced experts for Swedish industry

- Created opportunities for future commercialization and new companies.
Thank you
and
Thank you VINNOVA

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