# Analog VLSI and Biological Systems

**RLE Group**
Analog VLSI and Biological Systems Group

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## Introduction

The group's research focuses on bioelectronics. We work on bio-inspired electronics, which takes inspiration from neurobiology to architect novel and efficient electronics, and on electronics for biomedical applications. Our research is interdisciplinary and lies at the interface between neurobiology and circuits. Theoretical models of neurobiological systems and experimental implementations of circuits with real-world impact are both very important to our research.

Neurobiology provides several examples of extremely power-efficient design. Power-efficient operation is very important for biomedical applications that need to run on a small implanted battery for several years. In both bio-inspired and biomedical electronics, analog computation is important for efficiency.

We concentrate on applying low power analog microelectronics to the design of bionic systems, mixed-signal computing systems and sensory systems. Traditionally, analog designers have relied on technology improvements or on a bag of circuit tricks to reduce power. Our emphasis is on achieving low power through fundamentally new architectures and topologies that are inspired by neurobiology, through feedback techniques that encode knowledge of the error or knowledge of the world into the structure of the circuit, through low-noise techniques that achieve precision without wasting power, through mixed-signal techniques, and by exploiting the power-efficient subthreshold region of MOS transistor operation.

## 1. Bionic Ear

**Sponsors**
David and Lucille Packard Foundation Fellowship, under contract number 2001-19533

**Project Staff**
Michael Baker, Timothy Lu, Christopher Salthouse, Ji-Jon Sit, Lorenzo Turicchia, Serhii Zhak,Professor Sarpeshkar

This project focuses on the design of ultra-low-power analog cochlear-implant processors, and on processors that take inspiration from the human ear to perform better in noisy environments. A recent success resulted in an analog bionic ear processor that cut power consumption by more than an order of magnitude over the best digital solutions. The power consumption of this

processor is so low that it will enable 30 year operation on a 100mAh rechargeable battery. This project also explores the use of an analog silicon cochlea, which maps the biophysics of the inner ear to a chip, as the basis for a cochlear-implant processor. The silicon cochlea has the potential to revolutionize speech recognition and patient performance in the presence of background noise -- a critical limiting factor today – while doing hundreds of mega floating point operations per second on a modest mW of power. A novel ear-inspired companding algorithm that has shown excellent promise for improving recognition in noise is being mapped onto ultra-low-power electronic chips. These chips will be used in portable speech-recognition and cochlear-implant systems. Work on the silicon cochlea has shed insight into how the biological cochlea ingeniously converts a filtering problem that scales quadratically into an easier problem that scales linearly. A new project in the lab is researching how to build an "RF cochlea", an ultra-wide-band spectrum analyzer that mimics the traveling-wave architecture of the cochlea, but at RF frequencies.

## 2. Time-Based Hybrid Computing

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**Project Staff**
Micah O'Halloran, Heemin Yang, Professor Sarpeshkar

This project attempts to combine the best of analog and digital computation to perform computations more efficiently than either individual paradigm can accomplish alone. The goal is to combine the analog advantages of low power and good technology exploitation with the digital advantages of divide-and-conquer processing, signal restoration, and programmability. This work is based on the dual nature of signal representation of the brain's neurons, which appear to have features of both analog pulse-time and digital pulse-count signal processing. Some fruits of this research include an ultra-low-power time-based analog-to-digital converter that improves the conversion efficiency of conventional time-based techniques from exponential to linear and a record-setting analog memory element. Hybrid State Machines built with this approach are being explored for designing novel control architectures, for ultra-low-power speech and sequence recognition, and for designing programmable vision chips.

## 3. Analog VLSI Vision Systems

**Sponsor**
Catalyst Foundation Fellowship

**Project Staff**
Maziar Tavakoli-Dastjerdi, Micah O'Halloran, Professor Sarpeshkar

This project uses low-power bio-inspired photoreceptors as front ends for analog VLSI motion sensors and in pulse oximetry for vital-sign monitoring of medical patients. Analog motion sensors are inspired by correlation circuits in houseflies and are important in robotic, security camera, and web-camera applications.

## Publications

### Journal Articles, Published

M. O'Halloran and R. Sarpeshkar, "A 10nW 12-bit Accurate Analog Storage Cell with 10aA Leakage," *IEEE Journal of Solid-State Circuits* 39(11): 1985-1996 (2004).

M. Tavakoli and R. Sarpeshkar, "A sinh resistor circuit and its application to tanh linearization," *IEEE Journal of Solid State Circuits* 40(2): 536-543 (2005).

L. Turicchia and R. Sarpeshkar, "A Bio-Inspired Companding Strategy for Spectral Enhancement," *IEEE Transactions on Speech and Audio Processing* 13(2): 243-253 (2005).

R. Sarpeshkar, C. Salthouse, J.J. Sit, M. Baker, S. Zhak, T. Lu, L. Turicchia, and S. Balster, "An Ultra-Low-Power Programmable Analog Bionic Ear Processor,*" IEEE Transactions on Biomedical Engineering* 52 (4): 711-727 (2005).

### Journal Articles, Accepted for Publication

H. Yang and R. Sarpeshkar, "A Time-Based Energy-Efficient Analog-to-Digital Converter," *IEEE Journal of Solid-State Circuits*, forthcoming.

### Meeting Papers, Published

M. Baker, T. Lu,  and R. Sarpeshkar, "A low power AGC with Level Independent Phase Margin," *Proceedings of the IEEE 2004 American Control Conference*, Boston, MA , June 30-July 2, 2004.

S. Zhak, S. Mandal, and R. Sarpeshkar, "A proposal for an RF Cochlea," *Proceedings of the Asia Pacific Microwave Conference*, New Delhi, India, December 15-18, 2004.

R. Sarpeshkar, M. Baker, C. Salthouse, J.J. Sit, L. Turicchia, and S. Zhak, "An Analog Bionic Ear Processor with Zero-Crossing Detection," *Proceedings of the IEEE International Solid State Circuits Conference (ISSCC)*, San Francisco, CA, February 6-10, 2005.

J. Guiness, B. Raj, B. Nielsen, L. Turicchia, and R. Sarpeshkar, "A Companding Front End for Noise-Robust Automatic Speech Recognition," *Proceedings of the IEEE International Conference on Acoustics, Speech, and Signal Processing*, Philadelphia, PA, March 18-23, 2005.

K. H. Wee, J. J. Sit, and R. Sarpeshkar, "Biasing Techniques for Subthreshold Translinear Resistive Grids," *Proceedings of the IEEE Symposium on Circuits and Systems*, Kobe, Japan, May 23-26, 2005.