

## **Analog VLSI and Biological Systems Group**

### **Academic and Research Staff**

Professor Rahul Sarpeshkar

### **Graduate Students**

Heemin Yang, Michael Baker, Micah O'Halloran, Ji-Jon Sit, Christopher Salthouse, Serhii Zhak, Maziar Tavakoli-Dastjerdi, Soumyajit Mandal, Kenghoong Wee, Tim Lu, Andrew Selbst (MEng expected June 2005)

### **Post-Doctoral Associate**

Lorenzo Turicchia

### **Support Staff**

Rosemarie Englund

### **Introduction**

The aim of biologically inspired electronics is to emulate biology in building ultra low power, real time, compact systems from an analog circuit engineer's or physicist's point of view. Such systems are useful as smart sensors. They are also useful in biomedical applications where the low power and biomimetic capabilities are particularly advantageous. Biologically inspired systems yield insights into how biology works via engineering synthesis that would be very hard to attain via scientific analysis. Work in the group focuses on three projects, the low-power bionic ear project, the time-based hybrid computing project, and the analog VLSI vision systems project.

### **Low-Power 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 improvements in digital technology one to two decades in the future will still consume more power. 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 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 for use in portable speech recognition systems 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.

## **Time-Based Hybrid Computing**

### **Sponsors**

Office of Naval Research, under contract number N00014-00-1-0244; David and Lucille Packard Foundation Fellowship, under contract number 2001-19533; Office of Naval Research, under contract number N00014-02-1-0434

### **Project Staff**

Micah O'Halloran, Alex MeVay, Heemin Yang, Professor Sarpeshkar

This project attempts to combine the best of analog and digital computation to perform computations more efficiently than either individual system 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. We are applying the hybrid analog/digital approach to create ultra-low-power time-based analog-to-digital converters, analog memories, novel control architectures and programmable sensory data processors.

## **Analog VLSI Vision Systems**

### **Sponsor**

Catalyst Foundation Fellowship

### **Project Staff**

Maziar Tavakoli-Dastjerdi, Micah O'Halloran, Professor Sarpeshkar

This project maps the distributed-feedback loops of biological photoreceptors to create low-power high-performance electronic photoreceptors. These photoreceptors are used in analog visual motion sensors that contain VLSI (very large-scale integration) chips. Such motion sensors are inspired by correlation circuits in houseflies and are important in robotic, security camera and tracking applications.

## **Publications**

### **Journal Articles Published:**

MeVay, A., and R. Sarpeshkar, "Predictive Comparators with Adaptive Control", in press, IEEE Transactions on Circuits and Systems II: Analog and Digital Signal Processing, Vol. 50, No. 10 pp. 579-588, 2003.

Baker, M., and R. Sarpeshkar, "A Low-Power High-PSRR Current Mode Microphone Preamplifier", IEEE Journal of Solid State Circuits, Vol. 38, No. 10 pp. 1671-1678, 2003.

Zhak, S., M. Baker, and R. Sarpeshkar, "A Low Power Wide Dynamic Range Envelope Detector", IEEE Journal of Solid State Circuits, vol. 38 (10), 2003.

Sit, J.J., and R. Sarpeshkar, "A micropower logarithmic A/D with offset and temperature compensation", IEEE Journal of Solid State Circuits, Vol. 39, No. 2 pp. 308-319, 2004.

Turicchia, L., and R. Sarpeshkar, "A Bio-Inspired Companding Strategy for Spectral Enhancement", IEEE Transactions on Speech and Audio Processing, in press, scheduled for publication in early 2004.

O'Halloran M, and R. Sarpeshkar, "A 10nW 12-bit Accurate Analog Storage Cell with 10aA Leakage," accepted for publication, IEEE Journal of Solid-State Circuits, expected publication date Nov. 01 2004

Tavakoli, M., and R. Sarpeshkar, "A sinh resistor circuit and its application to tanh linearization", accepted for publication, IEEE Journal of Solid State Circuits, expected publication late 2004.

**Submitted for Publication:**

Sarpeshkar R, C. Salthouse, J.J. Sit, M. Baker, S. Zhak, T. Lu, T. Turicchia, and S. Balster, "An Ultra-Low-Power Programmable Analog Bionic Ear Processor", submitted to IEEE Transactions on Biomedical Engineering

**Accepted Conference Papers**

Baker, M., Lu, T., Salthouse, C., Sit, J.-J., Zhak, S., Sarpeshkar, R., "A 16-channel Analog VLSI Processor for Bionic Ears and Speech Recognition Front Ends" IEEE Custom Integrated Circuits Conference, San Jose, CA, September 2003

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

**Theses**

Lu, Tim, *A Feedback Analysis of Outer Hair Cell Dynamics*, Master of Engineering thesis, Department of Electrical Engineering and Computer Science, MIT, 2003.

Mandal, Soumyajit, *RF Power Extraction Circuits*, Master of Science thesis, Department of Electrical Engineering and Computer Science, MIT, 2004.