Challenges for Low-Power Bio-Medical RFIC
Sayfe Kiaei
Professor
Arizona State University
NSF Connection One Center
sayfe@asu.edu

ECTC 2011
Science & Technology Convergence

Biology and Medicine

Nanotechnology

Electronics

Neurobiology
Chem, Phys, Geo, Space

ECTC 2011
Bio-Telemetry

- Wireless Telemetry
- Diabetes
- Blood Pressure
- Cholesterol
- DNA Meter

- Location + Position + Orientation
Intelligent Wireless Systems

Internet Access

Computer & Entertainment Systems

Home Control Systems

Home Security

Wireless Telemetry

ECTC 2011
Typical Wireless Body Area Network
System Requirements

- Adaptive
- Low-Power / Self Powered
- Reconfigurable
- Miniature
- Harsh Environment
Challenges in:

* Medical Implanted Communication System (MICS)
* Implanted Sensor
* Adaptive SNR Digital Hearing Aid System
Implantable RF Transceiver

Applications:
- Treating Heart conditions (regulating heart rates via pacing and/or defibrillation)
- Time Release Pain Control
- Internal Imaging
- Time Release Location Aware Drug Delivery

System Constraints:
- Power, Size, Complexity
- System, Architecture
- RF Circuit: Sensitivity, Selectivity, Linearity, Power
- Packaging, Harsh Environment

ECTC 2011
MICS Specifications [1]

- 402-405 MHz operating band
- 10 channels, 300 KHz each
- -16 dBm (25µW) maximum Tx Antenna power
- Data-rate, modulation schemes, and BER not specified
- Wakeup Rx: 98%, Rx (1%), Tx (1%)

Transceiver Architecture

ECTC 2011
The inventor of FM radio, Edwin Armstrong, invented and patented the regenerative circuit while he was a junior in college, in 1914. He patented the super-regenerative circuit in 1922, and the superheterodyne receiver in 1918.

Reconfigurable Front-End

I. SRO (Wake-Up & Injection Locked PA)

II. LNA (RX Mode)

III. PA (TX Mode)
All Digital PLL

Non-coherent FSK
Shorter Lock time

All Digital Implementation
DDS (Direct Digital Synthesis)
Frequency discriminator
Frequency-to-voltage
Frequency-to-digital

ECTC 2011
IC Floor Plan
0.18 micron CMOS

ECTC 2011
Wireless Capsule

Typical Capsule with Imaging Capability*

* Low-Power Ultrawideband Wireless Telemetry Transceiver for Medical Sensor Applications
Yuan Gao*, Member, IEEE, Yuanjin Zheng, Member, IEEE, Shengxi Diao, Wei-Da Toh, Chyuen-Wei Ang, Minkyu Je, Member, IEEE, and Chun-Huat Heng, Member, IEEE
Implantable Wireless Neural-Sensor and Control

SKIN
VDD
GND
DC Power
Regulation
External Unit
LOW NOISE
PRE-AMPLIFIERS & FILTERS
ADC
A1
AN-1
AN
~ ... &
Communication
Control
5
Uplink
Data &
Control
Passive
Uplink Modulator
Uplink Data & Control
Serializer, Digital Modulator, Synchronization & Communication Control
8bits N*10KSp s
8b
5
80Hz 4kHz f
~ 40dB passband gain

Implantable Wireless Neural-Sensor and Control

External Unit
SKIN
Power-On Reset
DC Power Regulation
Undervoltage Detection
Implant

CONTROL

ECTC 2011
Cochlear Implant Used as Sensor
Integrated Hearing Aid

- MicroPhone Array
- MEMS Based
- Adaptive CT ΣΔ Modulator
Adaptive-Microphone Array DHA

ECTC 2011
Matched MEMS Microphones for Ultra-small Hearing Aids

A fabricated capacitive microphone covered by Ge-Se solid electrolyte on suspended parylene membrane. (a) Top view, (b) Ag nano-dendrite from Ni tip, (c) backside view of the microphone
Comparative Performance with Significant Reduced Power Consumption → Prolong Battery Life of Hearing Aids (The most demanded feature)
A graph showing the relationship between voice level (dB SPL) and frequency (Hz) under different environmental conditions.

- **Noisy Environment**: 55 dB minimum DR required.
- **Quite Environment**: 65-85 dB minimum DR required.
- **23 dB SPL Maximum Input Referred Noise Required**.

The graph includes red lines indicating the noise levels and frequency ranges for each environment.
## Power Scaling

<table>
<thead>
<tr>
<th>Power (uW)</th>
<th>SNR (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>106</td>
<td>87</td>
</tr>
<tr>
<td>72</td>
<td>85</td>
</tr>
<tr>
<td>55</td>
<td>82</td>
</tr>
<tr>
<td>47</td>
<td>75</td>
</tr>
</tbody>
</table>

ECTC 2011
All Flexible Microfluidics

- Existing medical implants are structurally rigid
- Damage surrounding tissues or muscles

- All flexible micro-fluidics for implantable modules
- Reservoirs, Channels, Valves, Pumps in a flexible enclosure
- Low-power osmotic pumps
Fabricated Proto-type Separation

Two chambers with 5-20µm bead

Customized housing

Commercially available SEC Column (~ 1 ft)

Microfabricated SEC Column (~ 5mm)

A factor of ~ 20,000 size reduction

ECTC 2011
Thank You