Microelectronics Interfacing Neural Devices (MIND)

Dr. Albert Swiston
MIT Lincoln Laboratory
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Motivation
State of the Art

Current *in vivo* electrical neurophysiology understanding is based on grossly invasive, bulky, necessarily cannulated technology platforms.

Surgical installation
- Internalization and deactivation

Glial scarring and chronic inflammation
- Poor device performance

All of these technologies are subject to a strong observer effect:
- Observation affects the system!

Higher spatio-temporal resolution than ever before, with fewer biological issues

The Vision

- Power/Comms Chip
- Sensor Chip
- Energy Harvester and Comms Element(s)
- Dangling Electrodes
How It Works

Peripheral Nervous System
Sensor Interface ASIC Tapeout

- Neural sensor custom ASIC: low-noise neural amplifier, 10-bit ADC, digital spike detector
- Size: 330 μm × 270 μm
- Average power consumption <4 μW*

<table>
<thead>
<tr>
<th></th>
<th>Single Channel Size (μm)</th>
<th>Power (μW)</th>
<th>Analog Front-End</th>
<th>ADC (ENOB)</th>
<th>Spike Detector</th>
<th>Amp Noise (μVrms) (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIT LL MIND</td>
<td>330 × 270</td>
<td>~4*</td>
<td>Y</td>
<td>9.4 *</td>
<td>Y</td>
<td>4.25 (1–10e3)*</td>
</tr>
<tr>
<td>Seo 2016</td>
<td>750 × 750</td>
<td>N/A</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>180</td>
</tr>
<tr>
<td>Shulyzki 2015</td>
<td>200 × 200</td>
<td>12.9</td>
<td>Y</td>
<td>5</td>
<td>N</td>
<td>7.99 (10–5e3)</td>
</tr>
<tr>
<td>Biederman 2015</td>
<td>160 × 160</td>
<td>3.02</td>
<td>Y</td>
<td>8.2</td>
<td>N</td>
<td>7.5 (100–10e3)</td>
</tr>
</tbody>
</table>

* Simulated results

- Total system power requirement <10 μW
  - Based on published values of ultrasound power harvesting for given volume
- Combines small size, mixed-signal (analog + digital), ultralow-power, low-noise sensor into one ASIC chip
- Further size and power reduction planned

First MIND Chip Received December 2016
Action Potentials in Heart Cells

Use easily cultured heart cells for first experiments

MIT LL MIND
Average Spike per Epoch (110 spikes)

COTS Measurement
Average Spike per Epoch (153 spikes)

Morphologically similar waveforms, easily detect firing
Biological Activity: Effect of Norepinephrine

Neurotransmitter/drug used to raise heart rate

Norepinephrine added

Stable sensor able to detect biological events

5 s window mean/stdev
Biological Activity: DHA (Fish Oil)

Drug used to lower heart rate

DHA added

5 s window mean/stdev

Stable sensor able to detect biological events
Summary

• MIND is trying to revolutionize how we observe the nervous system
• Wireless, tiny, trivially introduced into body
• MIND chips are able to observe cell behavior *in vitro*

• Next Steps
  – Leverage advances in metamaterials of optical comms
  – *In vivo* testing in rodents