Wireless Interface for Implantable Electronics

Rizwan Bashirullah
Presentation Overview

- State of the art implant electronics
- Power and data coupling mechanisms
- BMI wireless electronics
- Summary
State of the Art Implant Electronics

- Michigan - Neural Recording Micro-system
- MIT - Bionic Ear
- NCSU - Retinal Implants
MICHIGAN Neural Recoding Microsystem

- Multiplexed Active probes
- 64 sites / 8 channels
- Spike Detection ASIC with compression
- Clock frequency 2.5MHz
- 4 modules (256 sites/ 32 channels)
Michigan Neural Recoding Micro-system

<table>
<thead>
<tr>
<th>Active probes specifications</th>
<th>64 sites / 8 channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-chip probe selection</td>
<td>60dB</td>
</tr>
<tr>
<td>On-probe gain</td>
<td></td>
</tr>
<tr>
<td>Time division multiplexing</td>
<td>8:1 @ 20kHz per channel</td>
</tr>
<tr>
<td>Power consumption</td>
<td>756uW</td>
</tr>
<tr>
<td>Area</td>
<td>5mm²</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spike Detection ASIC Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADC Resolution</td>
</tr>
<tr>
<td>Sampling frequency</td>
</tr>
<tr>
<td>Neural data rate</td>
</tr>
<tr>
<td>Average compression</td>
</tr>
<tr>
<td>Average output data rate</td>
</tr>
<tr>
<td># channels w/o compression</td>
</tr>
<tr>
<td># channels w compression</td>
</tr>
<tr>
<td>Clock frequency</td>
</tr>
<tr>
<td>Power</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Micro-system Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td># of sites</td>
</tr>
<tr>
<td># of channels</td>
</tr>
<tr>
<td>Per channel data rate w/o compression</td>
</tr>
<tr>
<td>Per channel data rate w compression</td>
</tr>
<tr>
<td>Power</td>
</tr>
<tr>
<td>Power consumption per channel</td>
</tr>
</tbody>
</table>
Ultra low power bionic ear processor

- Deaf patients (70-80dB loss)
- 8-20 electrodes
- Secondary battery (2.8V/100mAh)
- 1000 wireless recharges
- 30 year lifetime
- 750uWatts for stimulation

<table>
<thead>
<tr>
<th>Portion of System</th>
<th>Power Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microphone Front End Circuit and Microphone Bias</td>
<td>106.4μW</td>
</tr>
<tr>
<td>Automatic Gain Control Circuit</td>
<td>28μW</td>
</tr>
<tr>
<td>Bandpass Filters</td>
<td>37.8μW</td>
</tr>
<tr>
<td>Envelope Detectors</td>
<td>18.2μW</td>
</tr>
<tr>
<td>Logarithmic A/D and Digital CIS Output</td>
<td>56μW</td>
</tr>
<tr>
<td>Bias Circuits</td>
<td>4.2μW</td>
</tr>
<tr>
<td>Entire Chip Processor</td>
<td>251μW</td>
</tr>
</tbody>
</table>
Retinal Prosthesis

- Retina-3.55 chip
  - 60 drivers pixel stimulators and each is with a dedicated driver.
  - Each driver is designed to deliver current up to 600μA to a load of 10kohm.
  - 4 bit resolution.
  - Comprehensive digital design with data error detection using CRC and checksum.
  - Clock and data recovery circuits
  - Internal Reference Generators
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Physical Power Coupling Methods

- Capacitive Coupling
  - Very close range only
- Antenna based methods
  - Poor object penetration
- Inductive coupling
  - Good range and simplicity
Optimal Coil Diameter

- The interrogator zone
  - The read range of the reader roughly corresponds with the radius of the transmitter antenna.
  - Optimal antenna radius $R$ for a given range $X_{\text{max}}$ is: $R \sim X_{\text{max}}$

Field Strength $H$ at a distance of $x=20\text{mm}$, where the coil radius $R = 5 - 55\text{mm}$
Inductive link and power regulation
Back-telemetry Operation

- Noise due secondary current variation
- Power Carrier
- Change in $Z_r$ due to Load Modulation
- Inductive Link
- $V_{dropout} +14 \text{ V}$
- Load Modulation
- Secondary Current Variation

- Data In
- Data Out
- Load Modulation
- $I_{load}$
- $Z_r$
- Change in $Z_r$ due to Load Modulation
- Inductive Link
- $V_{dropout}$
Power Link

- Design Considerations
  - Bio-safety standard (H_{limit} < 16.3A/m @ 1MHz)
  - Power density < 10mW/cm²)
- Efficiency
  - Minimize loss on implanted unit (avoid temp. increase)
  - 70-80% rectifier efficiency (high-voltage/low current desirable)
- Component integration
  - Increase frequency
  - Decrease delivered power (ultra-low power circuits)
- Back-telemetry
  - Load-shift keying (simple implementation)
  - Low data-rates (5-10kb/s @ 1MHz)
  - High-Q/Low bandwidth tradeoff

~5kb/s back-telemetry data
Smart power delivery

- Temperature increase pattern induced by the implanted microchip due to heat dissipation
- Smart Power Transfer Objectives
  - Minimize heat dissipation by detecting induced voltage
  - Use back-telemetry to control external power transfer level
  - Establish Optimum Power Transfer despite coil misalignments

Maximum temperature increase in the eye model as a function of the power dissipated.
Power and data interference

- Decouple power and data carriers
  - Optimize power for high-Q (low loss, narrow bandwidth)
  - Optimize data link for maximum data rates (higher operating frequencies)
- Strong power carrier interference present at all times
  - Place data coil orthogonal to power coils
  - Additional filtering is required

![Diagram showing reduced power interference coupling with external and implanted power coils, data loop antenna, and chip boundary.]
H-field Limitations and Induced power

- $H_{\text{LIMIT}}$ is 16.3A/m @1MHz
- Optimal inductor value to minimize power loss yields $L_2=80\mu$H
- Regulation/Rectification Efficiency = 30%
- Maximum delivered load power at 7mm is 1.8mW

![Diagram](image)
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Brain Machine Interface (BMI)

**GOAL:** Allow subjects to interact seamlessly with a variety of actuators and sensory devices through the expression of their voluntary brain activity.

- **Wireless Transmitter**
- **Bio-amplifiers**
- **Spike detection**
- **Low-power Signal processor**
- **Robotic Actuators**
- **Power and bi-directional data transmission**
Electrical specifications wish list

- Long operation life
- Biocompatible
- Miniature in size (few millimeters at most)
- 10-16 bits of resolution at 25kHz!
- High-data rates (>2Mb/s)
- Large number of recording/stimulating channels
- Low operating frequency
- FCC and power density specifications
- Large operating range
What does small mean?

- Implies integration …and new challenges
- Typical external components
  - Coil, RF antenna
  - resonant cap, decoupling cap
  - rectifier diode
  - telemetry switch (high-voltage)
  - battery
- Issues
  - Higher operating frequencies
  - Parasitic loss (i.e. diode, capacitors)
  - Breakdown voltages
  - Parasitic diodes
Inductively Coupled RFID at 13.56Mhz

- **Systems using a short or planar coil**
  - Good range and simplicity
  - Good object penetration
  - Moderate FCC restrictions
  - Inexpensive to mass produce

- **Antenna**
  - the size of a credit card
  - High Q (low loss)

![Diagram of Tag with components: Chip, Coil, Conductive Epoxy, Epoxy/Sealant]
Small Antenna

\[ P_{RAD} = I^2 R_{RAD} \]

Radiated power is small
Depends on Peak current

<table>
<thead>
<tr>
<th>Frequency</th>
<th>100MHz</th>
<th>300MHz</th>
<th>400MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation Resistance (Ohms)</td>
<td>25 ( \mu \Omega )</td>
<td>2 m( \Omega )</td>
<td>6.4 m( \Omega )</td>
</tr>
<tr>
<td>Loss Resistance (Ohms)</td>
<td>0.707</td>
<td>2.12</td>
<td>2.825</td>
</tr>
<tr>
<td>Resonant Capacitor (pF)</td>
<td>14pF</td>
<td>1.6pF</td>
<td>0.94pF</td>
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<tr>
<td>Radiated Power (I=5mA)</td>
<td>-62dBm</td>
<td>-43dBm</td>
<td>-38dBm</td>
</tr>
</tbody>
</table>
Tissue Attenuation

Factors determining signal attenuation

- Frequency
- Conductivity
- Permittivity
- Permeability

\[ \alpha = \omega \sqrt[2]{\frac{\mu \varepsilon}{2}} \left[ \sqrt{1 + \left( \frac{\sigma}{\omega \varepsilon} \right)^2} - 1 \right] \]

<table>
<thead>
<tr>
<th>Tissue Name</th>
<th>Frequency (MHz)</th>
<th>Conductivity (S/m)</th>
<th>Relative permittivity</th>
<th>Loss tangent</th>
<th>Wavelength (m)</th>
<th>Penetration Depth (m)</th>
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</thead>
<tbody>
<tr>
<td>Dry Skin</td>
<td>1</td>
<td>0.01324</td>
<td>990.8</td>
<td>0.2402</td>
<td>9.457</td>
<td>12.71</td>
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<tr>
<td></td>
<td>10</td>
<td>0.1973</td>
<td>361.7</td>
<td>0.9807</td>
<td>1.439</td>
<td>0.5606</td>
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<tr>
<td></td>
<td>100</td>
<td>0.4912</td>
<td>72.93</td>
<td>1.211</td>
<td>0.3097</td>
<td>0.1046</td>
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<tr>
<td>Wet Skin</td>
<td>1</td>
<td>0.2214</td>
<td>1833</td>
<td>2.171</td>
<td>5.378</td>
<td>1.337</td>
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<tr>
<td></td>
<td>10</td>
<td>0.366</td>
<td>221.8</td>
<td>2.966</td>
<td>1.401</td>
<td>0.3104</td>
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<tr>
<td></td>
<td>100</td>
<td>0.5232</td>
<td>65.97</td>
<td>1.426</td>
<td>0.3153</td>
<td>0.09649</td>
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<tr>
<td>Body Fluid</td>
<td>1</td>
<td>1.501</td>
<td>84</td>
<td>321.1</td>
<td>2.577</td>
<td>0.4115</td>
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<tr>
<td></td>
<td>10</td>
<td>1.502</td>
<td>70.01</td>
<td>38.56</td>
<td>0.8054</td>
<td>0.1316</td>
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<tr>
<td></td>
<td>100</td>
<td>1.504</td>
<td>69.08</td>
<td>3.914</td>
<td>0.2272</td>
<td>0.04656</td>
</tr>
</tbody>
</table>
Ground Reference

- Ground is where you grow potatoes!
- Need to characterize impedance of ground connection
  - Ground in Retinal Systems
  - Ground in BMI systems
- Ground stability
  - Amplifier performance when ground impedance is high
  - Frequency dependence
Summary

- Key goals for wireless implantable electronics
  - Low power, miniaturization, high data rates, long operation lifetime
- Miniaturization implies
  - High operating frequencies
  - Increased losses (careful design)