Miniature Implantable Medical Devices

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Miniature Implantable Medical Devices

1. Miniature Implantable Medical Devices
2. Enabling Technologies
3. Design Opportunities
4. Custom IC Design Techniques
5. MIMD Case Study
6. Conclusions
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Miniature Implantable Medical Devices

**IMDs**
Pacemakers/Defibrillators
Spinal Cord Stimulators
Drug Infusion Pumps
Chest/Abdomen
Long Leads
Invasive Surgery
\~ 15 to 50 cc

**MIMDs**
Cardiac Monitors
Peripheral Nerve Stimulators
Micro Infusion Pumps
Head/Neck/Limbs
Small Leads
Minimally Invasive
< 5 cc
Miniature Implantable Medical Devices

• **MIMD Examples**
  - Insertable Cardiac Monitor
    ![Reveal LINQ](https://www.medtronic.com/)
  - Leadless Pacemaker
    ![Abbott](https://www.cardiovascular.abbott/)
  - Peripheral Nerve Stimulator
    ![Nalu](https://nalumed.com/)
  - Vagus Nerve Stimulator
    ![Setpoint Medical](https://setpointmedical.com/)
Miniature Implantable Medical Devices

• Vagus Nerve Stimulator

- Device volume $\ll 5$cc

Small enough to implant at point of therapy

- Electrodes attached to nerve

- Leads routed to neck

- IMD implanted in chest
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Enabling Technologies

• **Micro-Electro-Mechanical Systems (MEMS)**
  • Microscopic sensors, actuators & machines
  • Fabricated on silicon wafers
  • Semiconductor processes & equipment

**Medical Examples**

Pressure Sensors – Blood Pressure
Accelerometers – Position, Activity
Chemical Sensors – Glucose
Fluid Pumps – Drug Delivery
**Enabling Technologies**

- **Solid State Batteries (SSB)**
  - Functions like standard rechargeable Li-Ion battery
  - Fabricated on silicon wafers
  - Semiconductor processes & equipment
Enabling Technologies

- Integrated Passive Devices (IPD)
  - Resistors, capacitors, inductors
  - Fabricated on silicon wafers
  - Semiconductor processes & equipment

**Device Types**
- High Density Capacitors
- High Q Inductors
- Polysilicon Resistors
- Metal Interconnects
Enabling Technologies

- Chip-Scale Packaging (CSP)

28-pin CSP: 250x smaller than DIP
Enabling Technologies

- **Stacked Chip-Scale Packaging (SCSP)**
  - Multiple chips in one package
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Design Opportunities

- Low/Small Temperature Range

- Military: (-55 to +125)
- Industrial: (-40 to +85)
- Commercial: (0 to +70)
- IMD: (+10 to +50)
- Post-Implant: (+35 to +40)
Design Opportunities

- **Low Frequency Requirements**
  - EEG/ECG bandwidth ~ 200Hz
  - Blood pressure bandwidth < 100Hz
  - Accelerometer bandwidth < 1KHz
  - Stimulation therapy < 10KHz
  - [5G Wireless > 50GHz]
Design Opportunities

- **Moderate Precision Requirements**
  - Stimulator DAC amplitude ~ 8-bits
  - ECG/EEG ADC resolution ~ 12-16 bits
  - Pressure sensor ADC resolution ~ 10-bits
  - Accelerometer ADC resolution ~ 10-bits
  - [Audio DAC ~ 24-32 bits]

  **8-bits = 256 steps**

  **32-bits > 4 billion steps**
Design Opportunities

- **Non-Volatile Memory (NVM)**
  - Included in most MCUs – or OTP in ASIC
  - Holds memory when power is removed
  - MCU/RAM can be disabled – most of the time
  - Calibration for analog circuits
    - Reduces analog performance requirements
Design Opportunities

- **Battery Recharge**
  - Required for most MIMDs
  - Recharge session used for communication
  - Communication used to calibrate circuits
    - Reduces absolute accuracy requirements
    - Reduces accumulation of timing errors
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Custom IC Design Techniques

- **Application-Specific ICs (ASICs)**
  - Eliminate unnecessary features & functions
  - Optimize performance for single application
  - Optimize size & power for MEMS interfaces
  - Optimize interconnect for SCSP
  - Optimize overall integration
  - Optimize total power consumption
    - Enables battery size reduction

*Customize design to minimize size & power*
Custom IC Design Techniques

- Complex Power Management
  - Multiple supply domains
  - Switched-mode power supplies
  - Detailed enable/disable control
  - Digital clock gating
  - Energy harvesting

Example MIMD
4V Battery
10V Wireless antenna
Inductive buck for battery charging
Capacitive buck for 1.8V analog/digital
Linear regulator for 0.9V timekeeping
Inductive boost for 18V Stimulation

Effective power management minimizes power consumption
Custom IC Design Techniques

- Ultra-Low Power Circuit Design
  - Example: Ultra low power voltage reference

- Switched-Cap Architecture
- nA Supply Current
- Sample/Hold Output

Sub-Vt Bias

Switched-Cap Architecture
Custom IC Design Techniques

- **Smart Integration**
  - Assess all available components
  - Consider size, power, cost, schedule, risk
  - Partition design: only customize as needed
  - [Not maximum integration]
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MIMD Case Study

- Vagus Nerve Stimulator
  - Programmable stimulation current
  - Wireless communication & recharge
  - Integrated power management & timekeeping
MIMD Case Study

- Vagus Nerve Stimulator

Volume < 1cc
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Conclusions

• MIMDs are achievable by capitalizing on Enabling Technologies and exploiting Design Opportunities

• Custom IC Design using unique Design Techniques allows us to optimize the solution

• Smart Integration approach helps to reduce time, cost, & risk
Learn More

• **IEEE – Engineering in Medicine and Biology Society**
  • EMBS is the world’s largest international society of biomedical engineers.
  • Join the Phoenix chapter - [https://www.embs.org/membership/](https://www.embs.org/membership/)

• **International Microelectronics and Packaging Society**
  • IMAPS is the largest society dedicated to the advancement and growth of microelectronics and electronics packaging.
  • Attend the Medical Electronics Workshop - [https://imaps.org/page/medical](https://imaps.org/page/medical)

• **The Center for Neurotechnology**
  • CNT is an Engineering Research Center funded by the National Science Foundation to create devices to restore the body's capabilities for sensation and movement.
  • Learn about the latest research - [https://centerforneurotech.uw.edu/](https://centerforneurotech.uw.edu/)

• **Cirtec Medical**
  • Cirtec Medical’s Semiconductor group is a full-service provider of low-power mixed-signal ASICs specializing in miniaturized portable and implantable medical devices.
  • Join our team - [https://cirtecmed.com/careers/](https://cirtecmed.com/careers/)
Thank You!

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