Custom IC Design for Implantable Medical Device Miniaturization

Andrew Kelly
Cactus Semiconductor Inc.
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Custom IC Design for Implantable Medical Device Miniaturization

- Miniature Implantable Medical Devices
- Enabling Technologies
- Design Opportunities
- Circuit Design Techniques
- MIMD Example
Miniature Implantable Medical Devices

- Sizes
- Applications
- Features
Miniature Implantable Medical Devices

**IMDs**
- ~15 to 50cc
- Pacemakers/Defibrillators
- Spinal Cord Stimulators
- Drug Infusion Pumps

**MIMDs**
- < 4cc
- ECG/EEG Monitors
- Peripheral Nerve Stimulators
- Micro Infusion Pumps

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Miniature Implantable Medical Devices

**IMDs**
- Chest/Abdomen
- Long Leads/Catheters
- Invasive Surgery

**MIMDs**
- Point of Therapy
- Head/Neck/Limbs
- Small Leads/Catheters
- Minimally Invasive
Miniature Implantable Medical Devices

Vagus Nerve Stimulator

- IMD Implanted in Chest
- Leads Routed to Neck
- Electrodes Attached to Nerve
Miniature Implantable Medical Devices

Vagus Nerve Stimulator

- MIMD
  - Small Enough to Implant at Point of Therapy?
- Electrodes Attached to Nerve
- Leads Routed to Neck
- IMD Implanted in Chest

Vagus Nerve Stimulation

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Enabling Technologies

- Micro-Electro-Mechanical Systems
- Chip-Scale Packaging
- Stacked Chip Scale Packaging
- Solid-State Batteries
- Custom IC Design
Enabling Technologies

Micro-Electro-Mechanical Systems (MEMS)

- Microscopic Sensors, Actuators & Machines
- Manufactured with Integrated Circuit Processes
  - Pressure Sensors – Blood Pressure, Respiration
  - Accelerometers – Position, Activity
  - Chemical Sensors – Glucose
  - Fluid Pumps – Drug Delivery
Enabling Technologies

Chip-Scale Packaging (CSP)

- Package Size ~ IC Size
Enabling Technologies

Stacked Chip Scale Packaging (SCSP)

- Multiple Chips in One Package
Enabling Technologies

Solid-State Batteries

- Chip-Scale Dimensions
- 10x Smaller than Typical IMD Batteries
Enabling Technologies

- Battery Capacity vs Volume

Typical IMDs

Extremely Low Capacity

Extremely Low Volume

MIMDs

Volume (cc)
Enabling Technologies

Custom IC Design

- Typically required for MIMD Miniaturization
  - Optimize Size/Power for MEMS Interfaces
  - Optimize Inter-Connect for SCSP
  - Maximize Integration
  - Minimize Total Power Consumption
Design Opportunities

- Temperature Range
- Frequency
- Precision
- Memory
- Recharge
Design Opportunities

Small Temperature Range

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

Low Frequency Operation

- EEG/ECG Bandwidth ~ 200Hz
- Stimulation Therapy < 200Hz
Design Opportunities

Low Precision Requirements

- Stimulator DAC Amplitude ~ 8-bits
- ECG/EEG ADC Resolution ~ 12-bits
- Pressure Sensor ADC Resolution ~ 10-bits
- Accelerometer ADC Resolution ~ 8-bits
Design Opportunities

Non Volatile Memory (NVM)

- Included in Most MCUs
- Holds Memory When Power is Removed
- MCU Can Be Disabled – Most of the Time
- Calibration for Analog Circuits
  - Reduces Analog Performance Requirements
Design Opportunities

Periodic Re-Charge

- Typically Once per Day
- Use Re-Charge Session for Communication
- Use Communication to Re-Calibrate Circuits
  - Less Accumulation of Timing Errors
  - Reduces Timing Performance Requirements
Circuit Design Techniques

- Stimulator Output Driver
- Oscillator
- Wireless Communications
- Power Management
Circuit Design Techniques

Stimulator Output Driver

2 Boost Converters

11V Max

Boost Converters

Current Mirrors

Timing Control

5.5V - VSTIM to VREF

5.5V - VREF to GND

VREF = Case

5.5V - VREF to GND

11V Max

3mA

1.5K
Circuit Design Techniques

Stimulator Output Driver – H-Bridge

One Boost Converter

Alternate Source/Sink

6.5V Max

6.5V - VSTIM to GND
Circuit Design Techniques

Crystal Oscillator

~ 1uW

VBAT

Amp

XIN

Crystal

XOUT

2 ASIC Pins

Large Crystal

> 3mm x 1.5mm
Circuit Design Techniques

Ultra Low Power (ULP) Oscillator

~ 200nW
80% Reduction

No Crystal

1 ASIC Pin

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Circuit Design Techniques

Wireless Communication

**MedRadio**
- 2-Way Communication
- Radio Frequency
  - 401 to 457MHz
  - ~ 500Kbps
  - ~ 2m
- Additional RFIC
- High Frequency Crystal
- RF Antenna
- 40mW from Battery
- Traditional Battery

**NFMI**
- 2-Way Communication
- Magnetic Induction
  - < 1MHz
  - < 10Kbps
  - < 10cm
- Integrated in ASIC
- No Crystal
- Shares Charging Antenna
- No Battery Power
- Solid State Batteries?

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Circuit Design Techniques
Wireless Communication

MedRadio

- 3.2cc
- RFIC
- Crystal Antenna
- BATTERY 20mm x 10mm x 5mm

NFMI

- 1.8cc
- Solid-State Batteries
- BATTERY 9mm x 9mm x 1mm

Low Profile

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Circuit Design Techniques
Power Management

- Customize to System’s Unique Requirements
- Sub-Circuit Supplies Don’t Match Battery
- Boosts & Bucks & Linear Voltage Regulators
- Mixed Solution Accounting for:
  - Battery Voltage, Capacity, Impedance
  - Average, Peak Current Loads
  - Sensor, Actuator Supply Requirements
  - MCU, Memory Supply Requirements
- Power Sequencing ➔ Circuits Enabled Only As Needed
MIMD Example

Neuro-Stimulator

- Features
- Block Diagram
- Device Dimensions
MIMD Example

Neuro-Stimulator

- 8-bit Programmable Current
- Up to 3mA at 6.5V
- For Typical Therapy:
  - 1mA Output
  - 1% Pulse Duty Cycle
  - 100% Therapy Duty Cycle
  - ~ 3 Days Between Recharges
- Volume < 1cc
- Implant at Point of Therapy
MIMD Example

Neuro-Stimulator
MIMD Example

Neuro-Stimulator Device

ASIC in MLF

< 1cc

MCU in WLCSP

Solid-State Battery Stacks

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Conclusions

- MIMD Miniaturization is Achievable
  - Each System is Unique → No Single Best Solution
  - Exploit New Technologies
  - Capitalize on Opportunities
  - Customization is Typically Required
Cactus Semiconductor Inc. is a fabless semiconductor company. We offer full turn-key product design and production as well as integrated circuit design services. Our expertise in power management and analog circuits find value in products targeted toward medical and portable applications.

Cactus Semiconductor Inc.
60 N. McClintock Drive, Suite #1, Chandler, AZ 85226
www.cactussemiconductor.com

Scott Montgomery: Sales
scott.montgomery@cactussemi.com
214-213-7396