Custom IC Design for Implantable Medical Device Miniaturization

Andrew Kelly
James McDonald
Cactus Semiconductor Inc.
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

**MIMIDs**

< 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

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

Vagus Nerve Stimulator

IMD
- Electrodes Attached to Nerve
- Leads Routed to Neck
- IMD Implanted in Chest

Vagus Nerve Stimulation

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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
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

[Diagram showing layers: Protective Film, Lithium Electrolyte (-), Solid-State Electrolyte, Cathode (+), Cathode Electrode (+ Collector), Anode Electrode (- Collector), Substrate]
Enabling Technologies

- Battery Capacity vs Volume

![Graph showing battery capacity vs volume for IMDs and MIMDs. The graph indicates an extremely low capacity and volume for IMDs compared to MIMDs. The graph is color-coded to differentiate between IMDs and MIMDs, with a black line representing the trend for MIMDs and a red line for IMDs.](image)
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

Boost Converters

5.5V

11.0V

VREF

VSTIM

OUT

GND

Current Mirrors

Timing Control

VREF = Case

2 Boost Converters

11V Max

5.5V - VSTIM to VREF

3mA

1.5K

5.5V - VREF to GND

3mA

5.5V - VSTIM to VREF

3mA

5.5V - VREF to GND

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Circuit Design Techniques

Stimulator Output Driver – H-Bridge

One Boost Converter

Alternate Source/Sink

6.5V Max

6.5V - VSTIM to GND

6.5V Max
Circuit Design Techniques

Crystal Oscillator

~ 1uW

1. Amp
2. Crystal
3. 2 ASIC Pins
4. Large Crystal > 3mm x 1.5mm

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Circuit Design Techniques

Ultra Low Power (ULP) Oscillator

~ 200nW
80% Reduction

1 ASIC Pin
No Crystal

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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

PCB

IDAC & Output Driver

TX/RX

AMUX

Timer

Oscillator

Registers

Power Management

SPI

MCU

ASIC

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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 \(\rightarrow\) No Single Best Solution
  - Exploit New Technologies
  - Capitalize on Opportunities
  - Customization is Typically Required
Contact Information

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

James McDonald: President
james.mcdonald@cactussemi.com
480-221-0987

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