Cactus Semiconductor

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Custom IC Design for Implantable Medical Device Miniaturization

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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

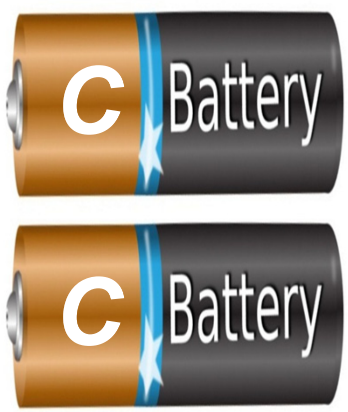
MIMDs

< 4cc

ECG/EEG Monitors

Peripheral Nerve Stimulators

Micro Infusion Pumps



54cc

16cc

< 4cc

Miniature Implantable Medical Devices

IMDs

Chest/Abdomen

Long Leads/Catheters

Invasive Surgery

MIMDs

Point of Therapy

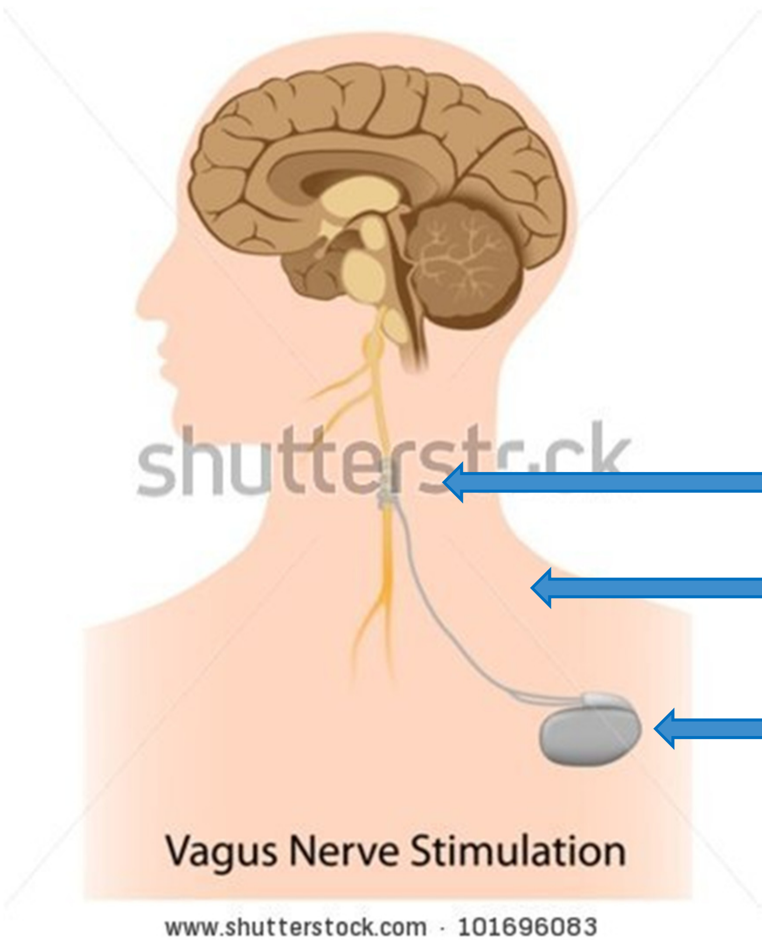
Head/Neck/Limbs

Small Leads/Catheters

Minimally Invasive

Miniature Implantable Medical Devices

Vagus Nerve Stimulator



IMD

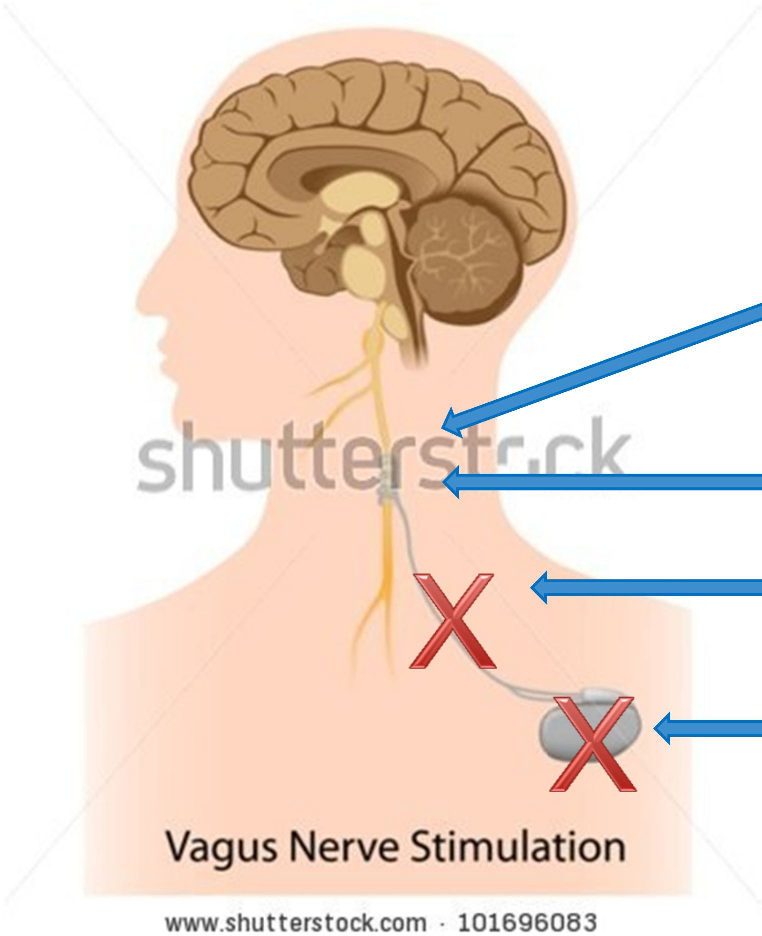
Electrodes Attached to Nerve

Leads Routed to Neck

IMD Implanted in Chest

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

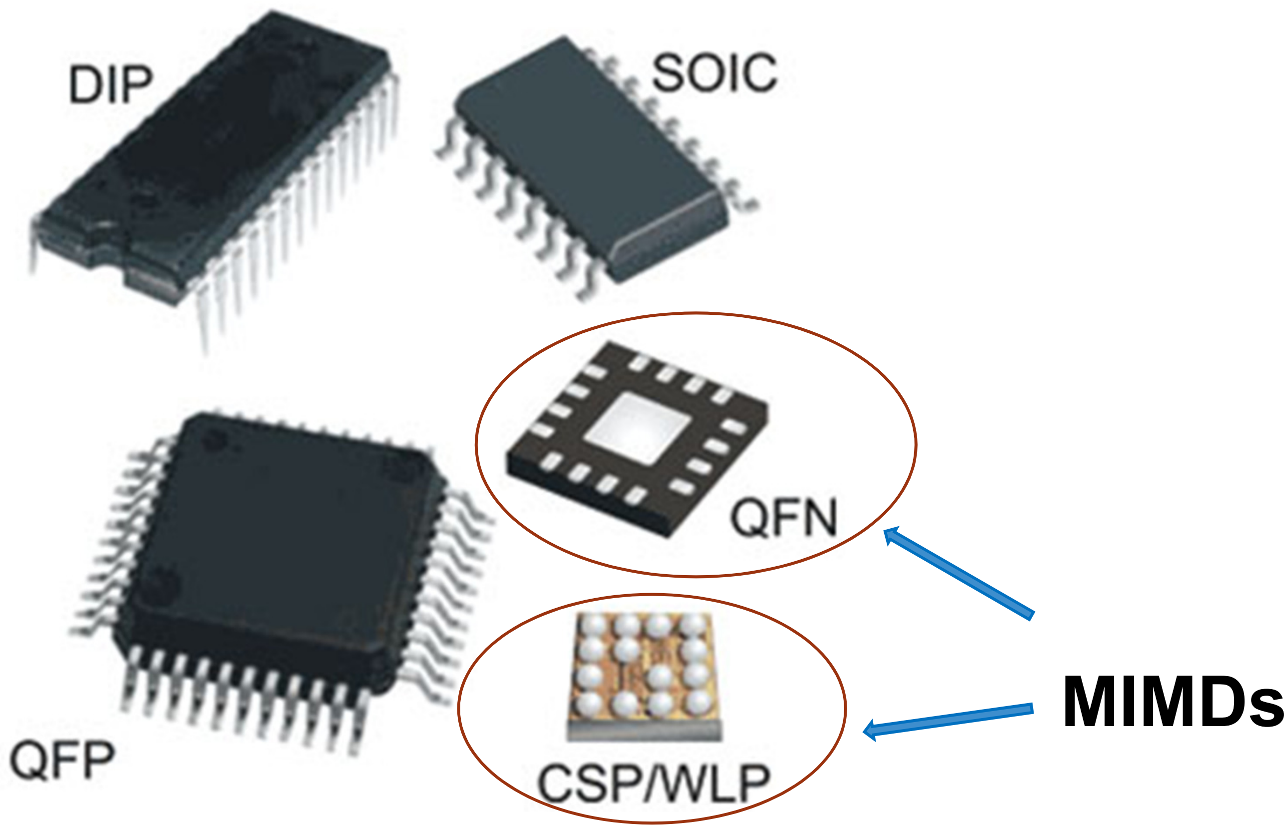
Micro-Electro-Mechanical Systems (MEMS)

- 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)

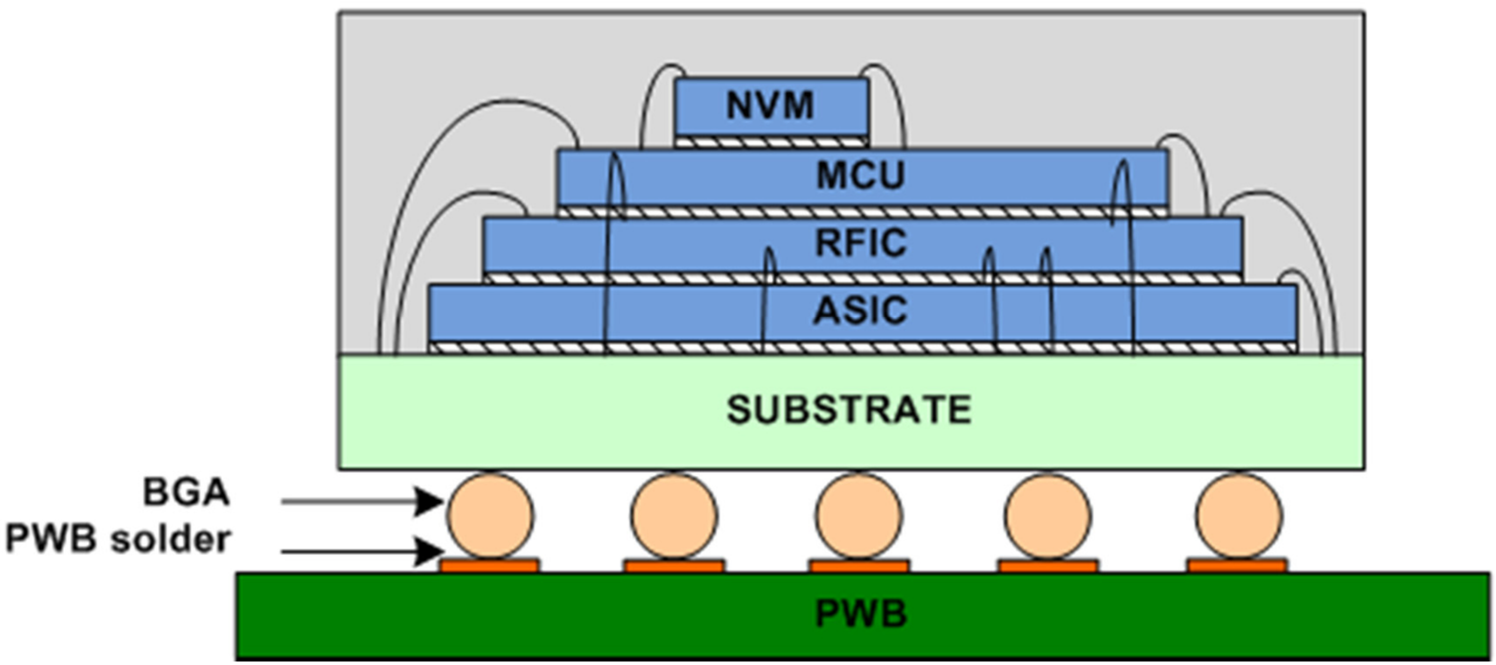
- Package Size ~ IC Size



Enabling Technologies

Stacked Chip Scale Packaging (SCSP)

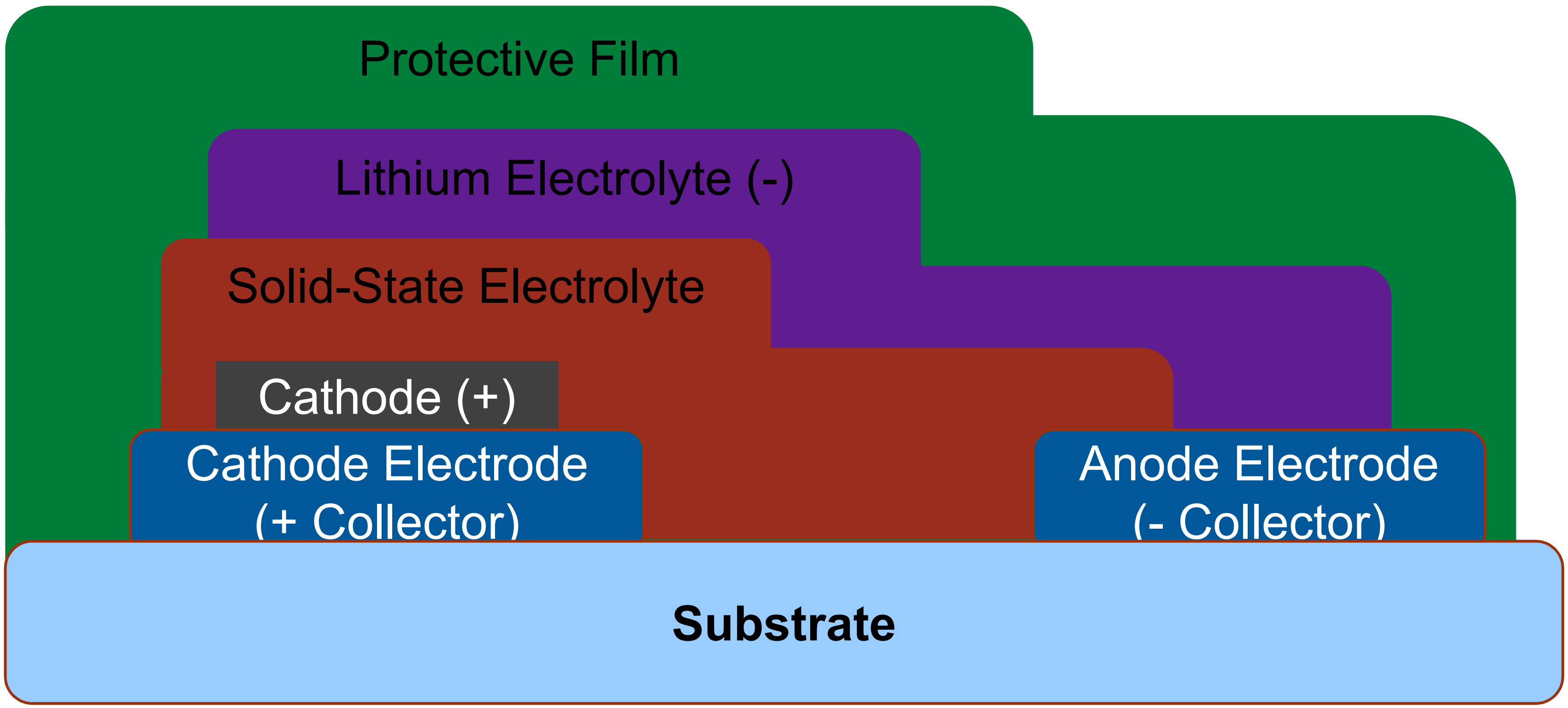
- Multiple Chips in One Package



Enabling Technologies

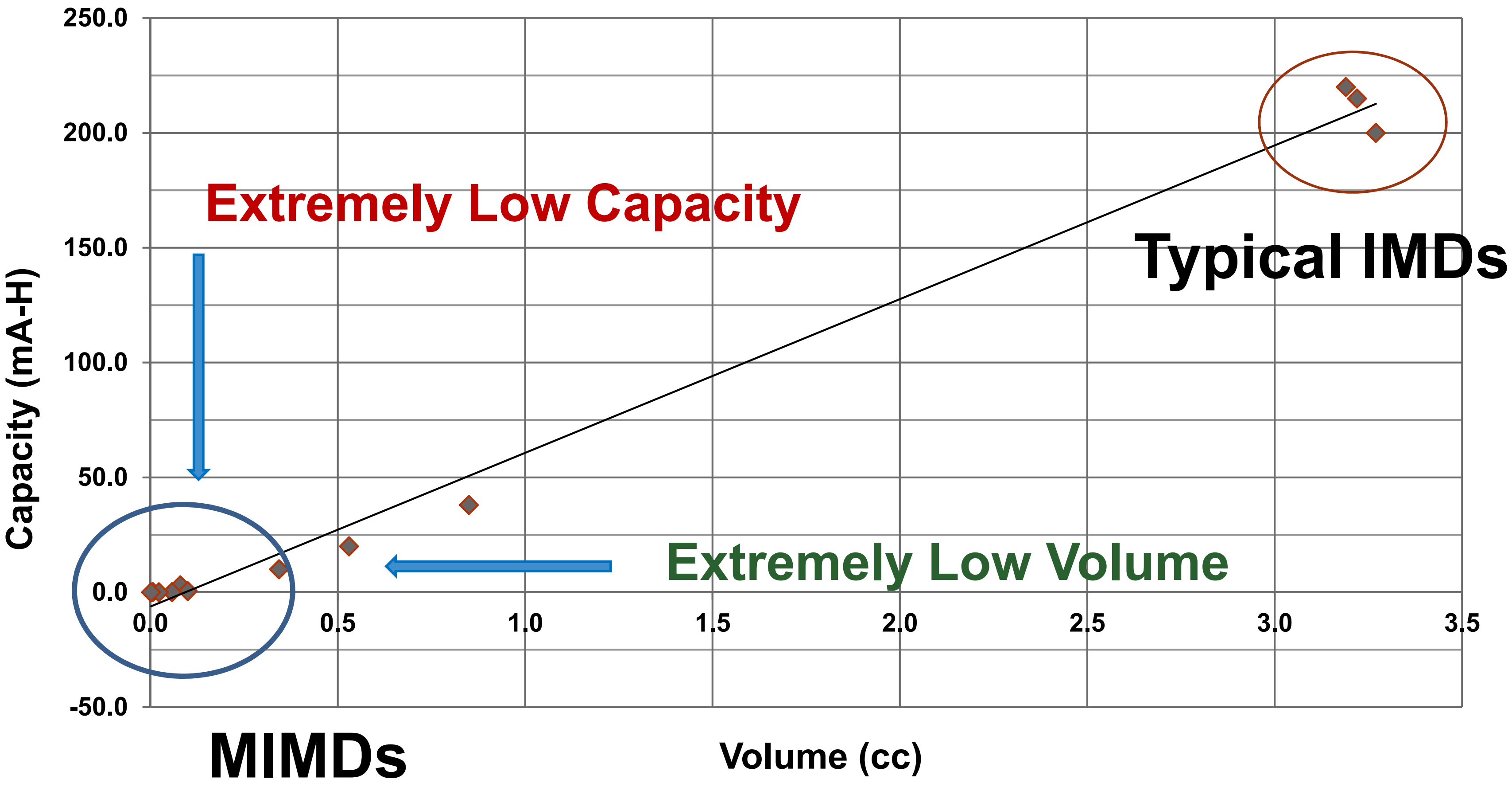
Solid-State Batteries

- Chip-Scale Dimensions
- **10x Smaller that Typical IMD Batteries**



Enabling Technologies

- Battery Capacity vs Volume



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

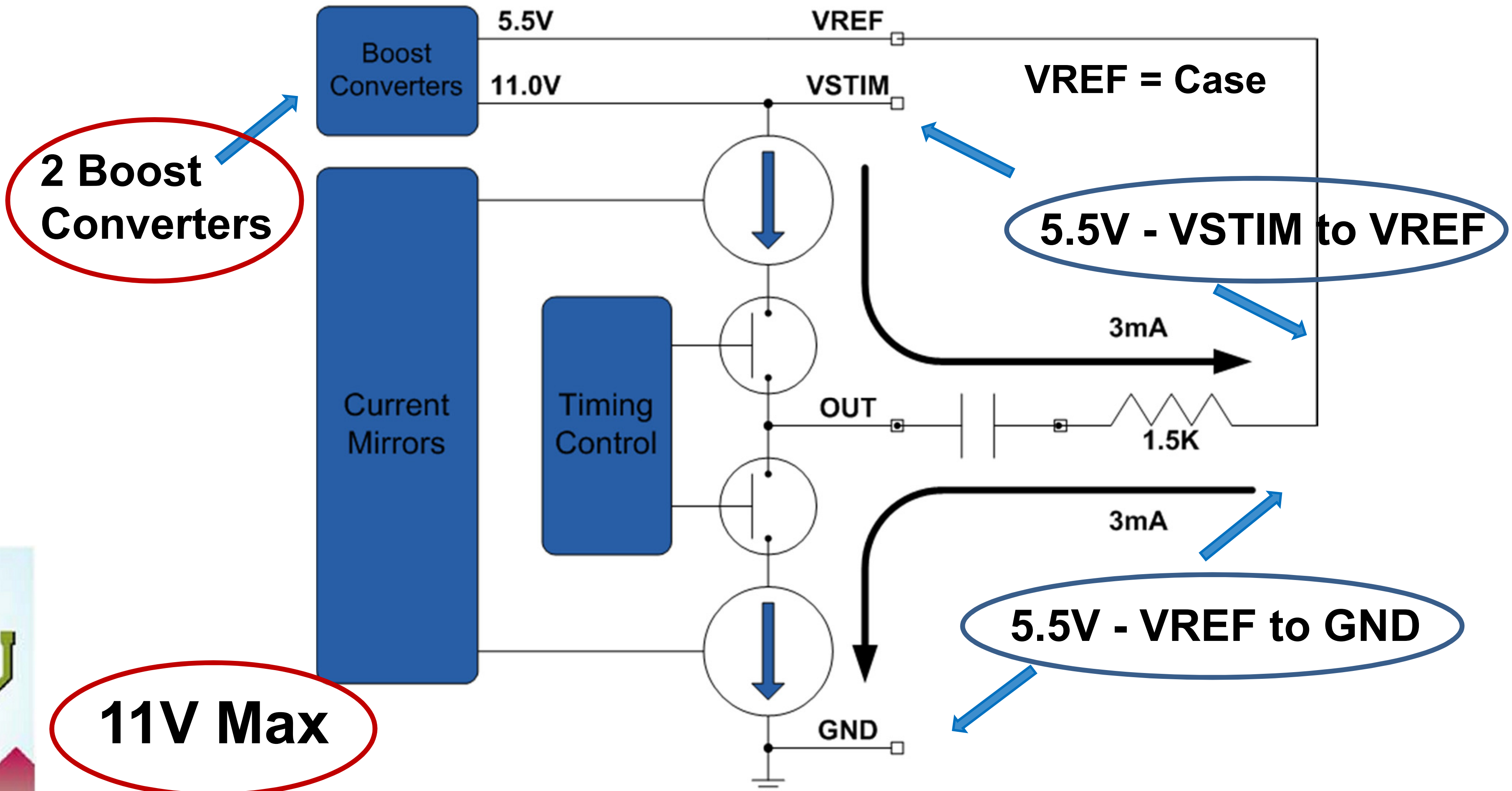
- Typically Once per Day
- Use Re-Charge Session for Communication
- Use Communication to Re-Calibrate Circuits
  - **Less Accumulation of Timing Errors**
  - **Reduces Timing Performance Requirements**

Circuit Design Techniques

- Stimulator Output Driver
- Oscillator
- Wireless Communications
- Power Management

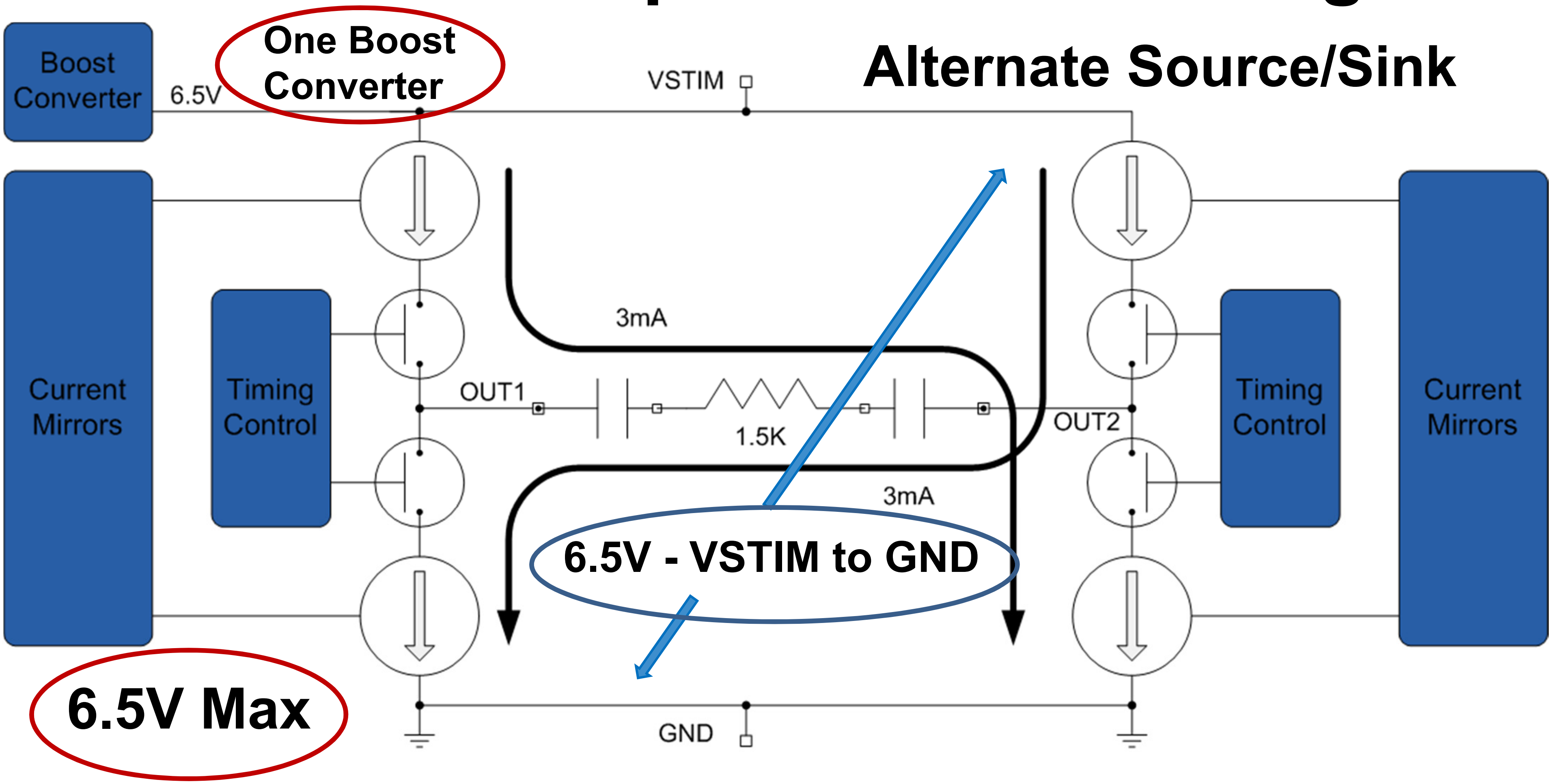
Circuit Design Techniques

Stimulator Output Driver



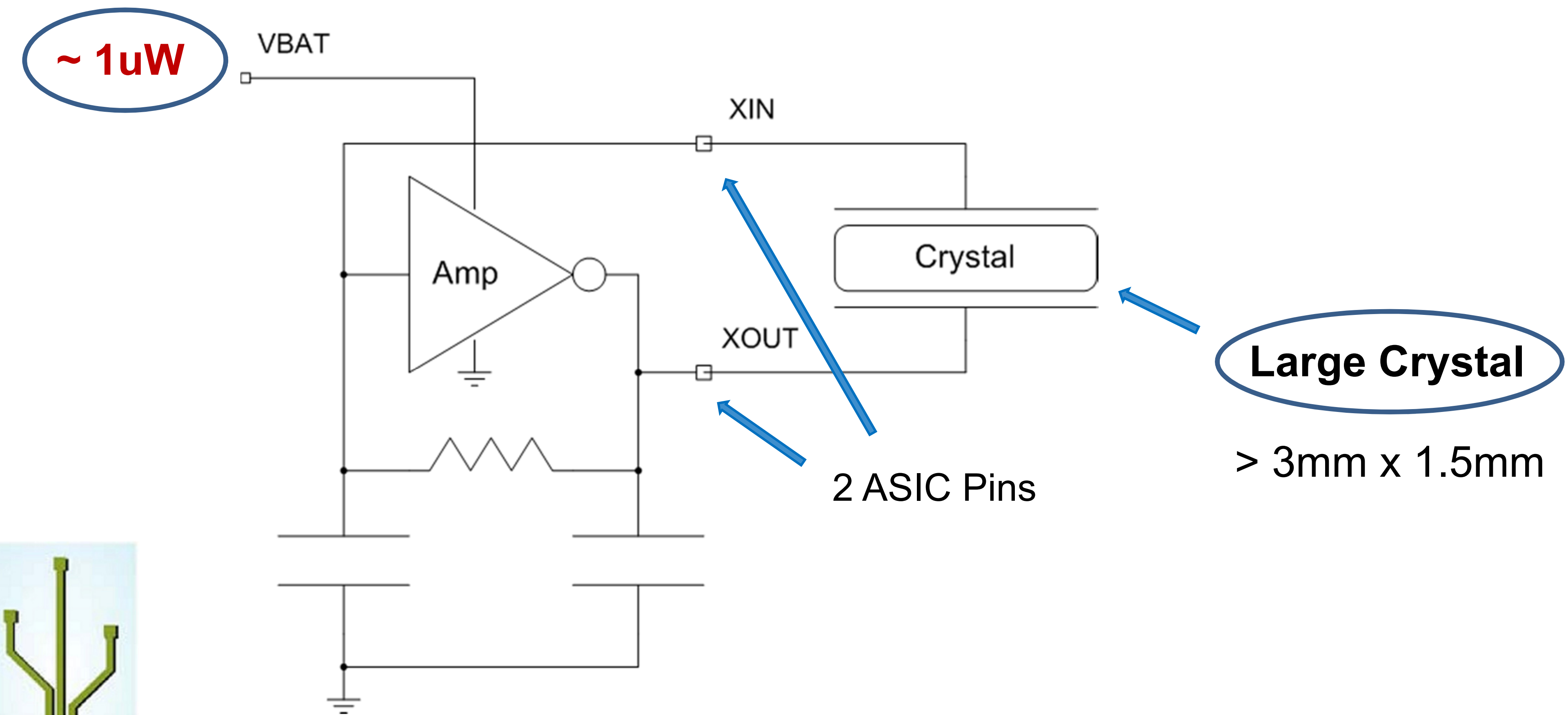
Circuit Design Techniques

Stimulator Output Driver – H-Bridge



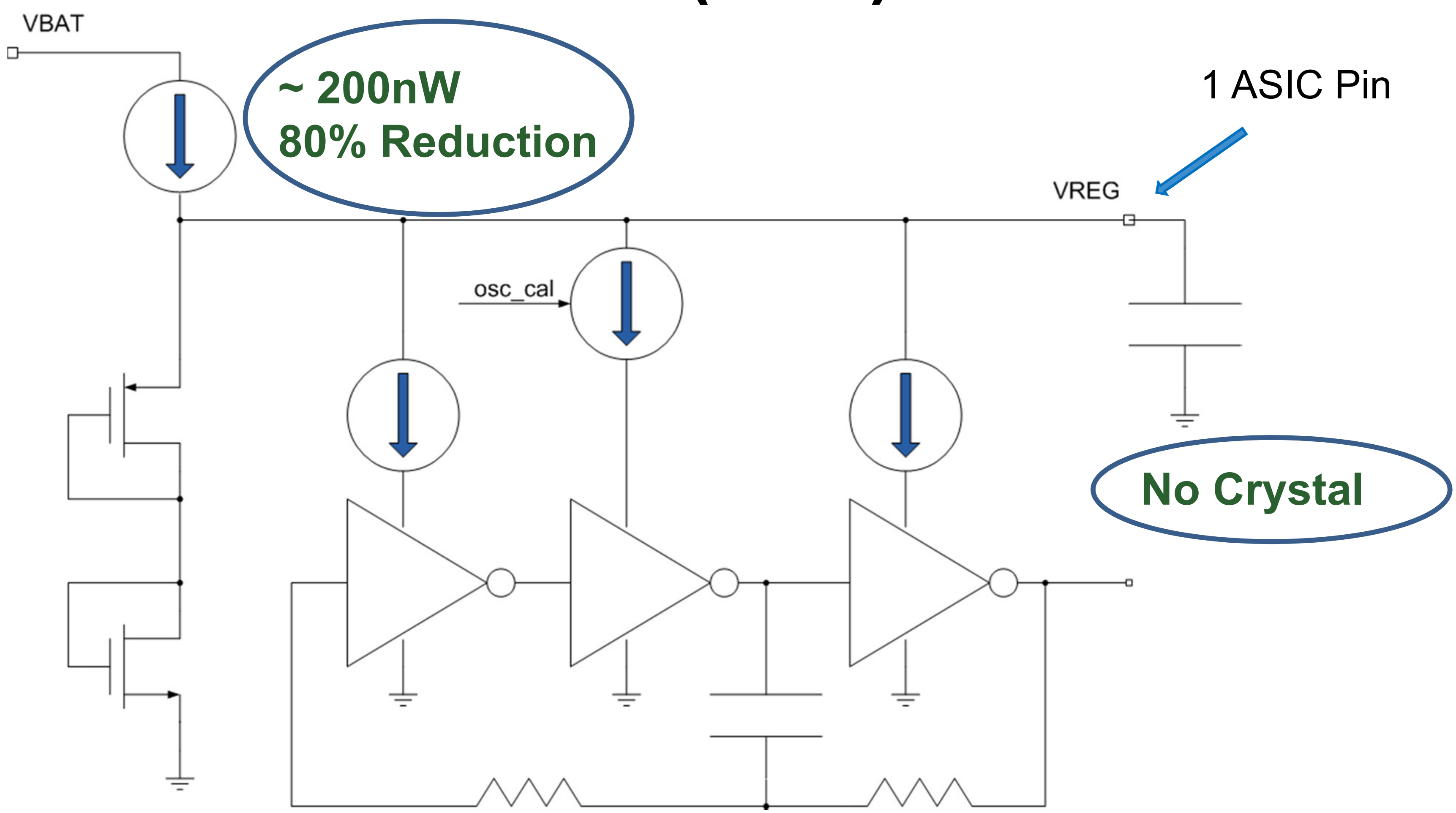
Circuit Design Techniques

Crystal Oscillator



Circuit Design Techniques

Ultra Low Power (ULP) Oscillator



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

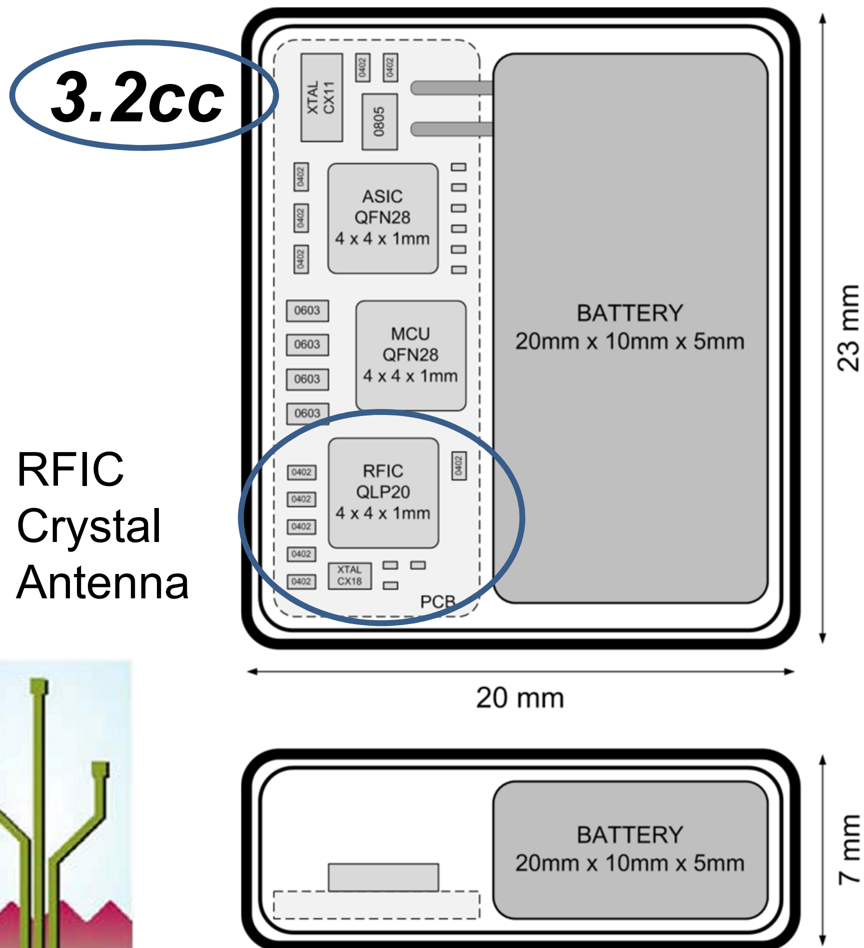
No Battery Power

Solid State Batteries?

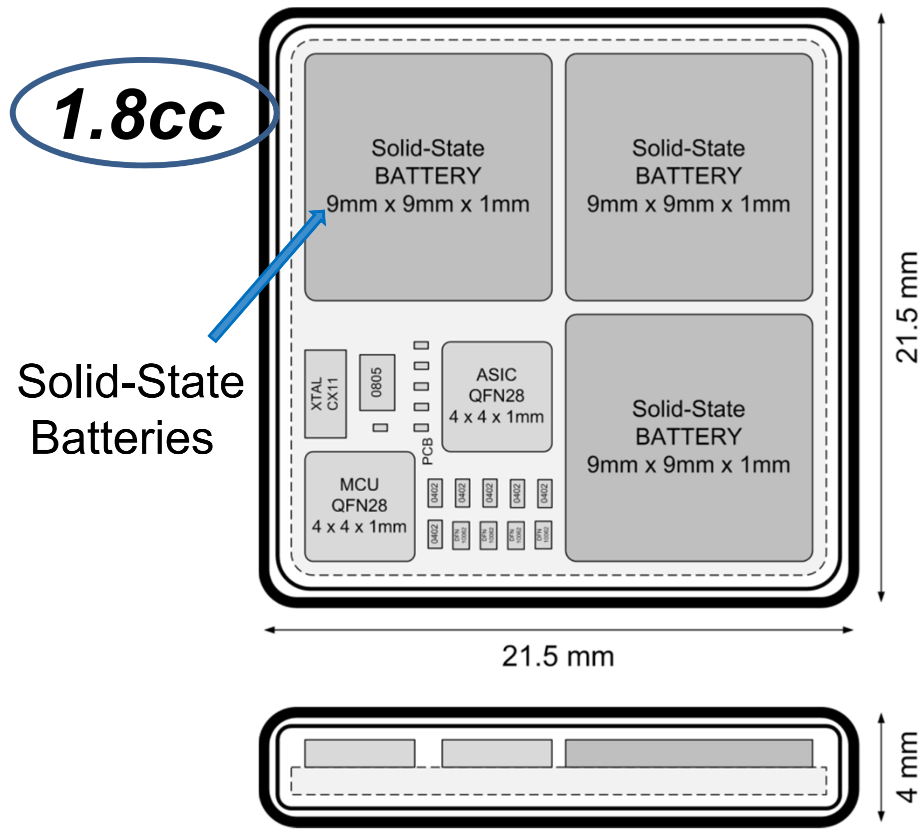
Circuit Design Techniques

Wireless Communication

MedRadio



NFMI



Low Profile

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

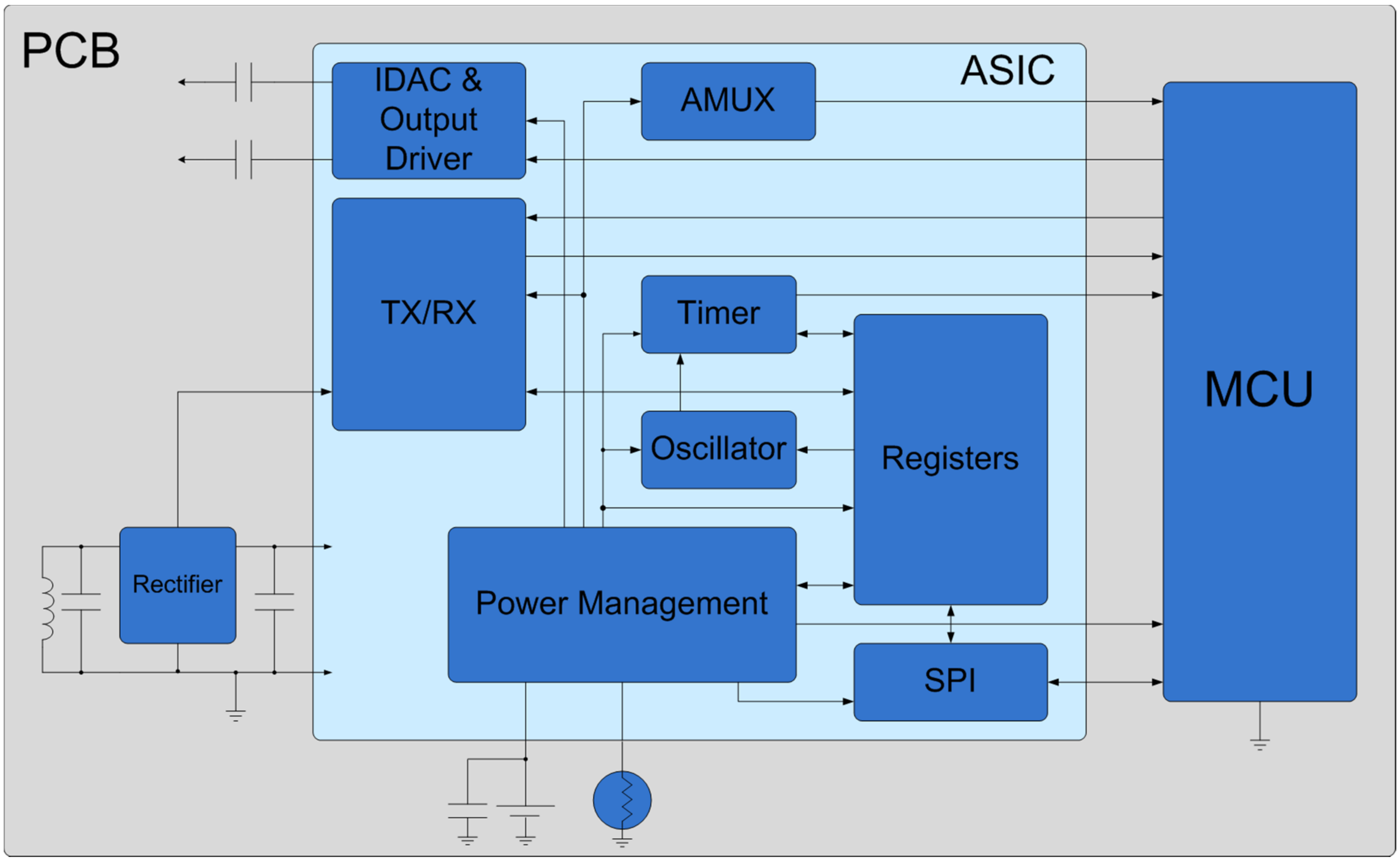
MIMD Example

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

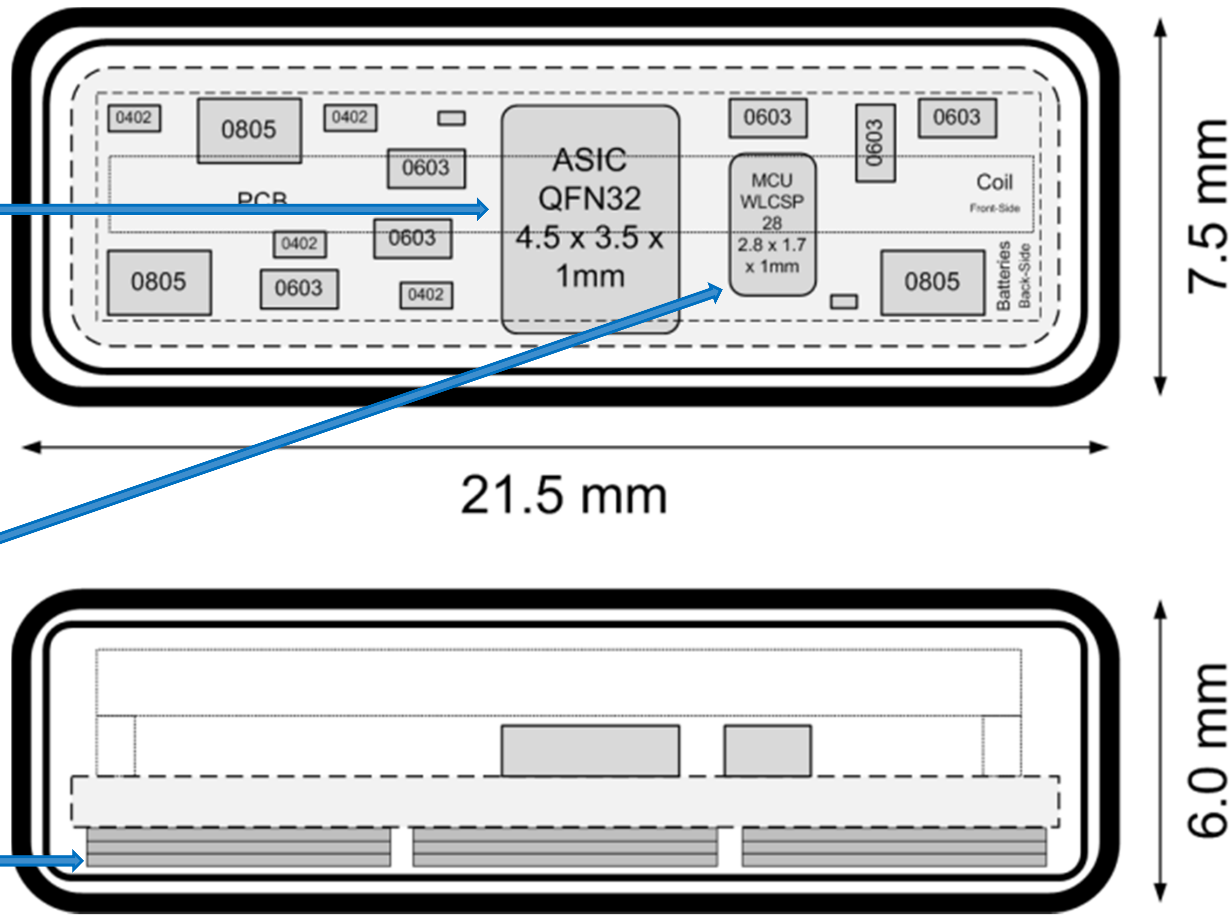
Neuro-Stimulator Device

ASIC in MLF

< 1cc

MCU in WLCSP

Solid-State Battery Stacks



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

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.

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