# MEMS Packaging for IoT Products

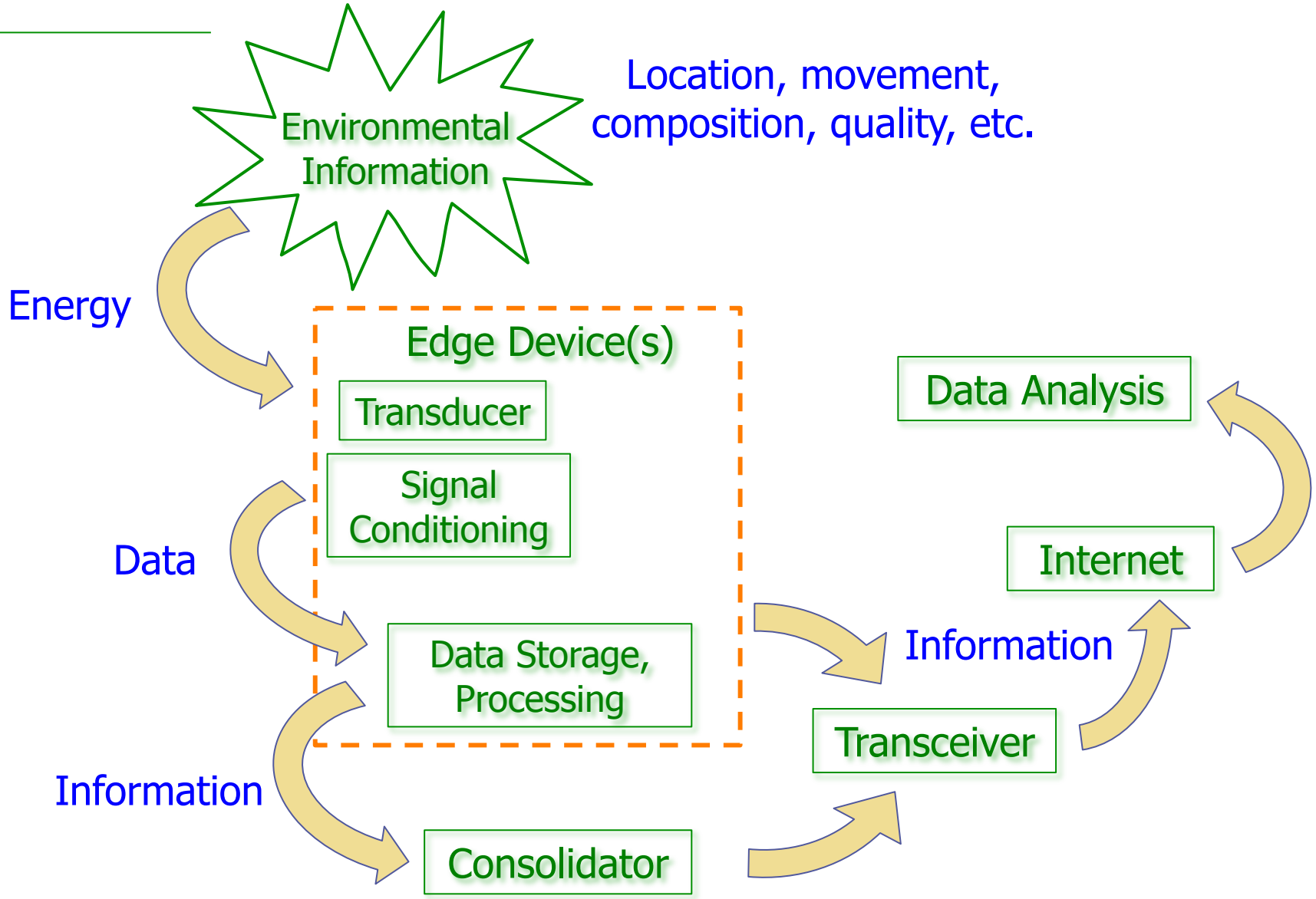
2015 MEPTEC Technology Symposium
Enabling the Internet of Things

Leland "Chip" Spangler, Ph.D.
Aspen Microsystems, LLC
719-440-5753

# Outline

- What is the IoT?
- System Partitioning and MEMS for IOT
- MEMS Packages for IoT Applications
- Custom MEMS Packages for IoT Applications
- Case Studies

# What is the Internet of Things

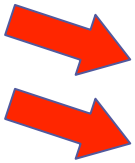


# IoT Application Examples

- Industrial
  - Process monitor
  - Inventory & asset monitor
- Consumer/Wearable
  - Health/activity monitoring
  - Entertainment
- Home/Business
  - Security/access control
  - Energy Optimization
- Medical
  - Implantables
  - Remote diagnostics
  - Inventory & patient tracking
- Automotive
  - Infotainment
  - Navigation
  - Telemetry (C2C and C2I)
- Environment
  - Water quality
  - Atmosphere
  - Agricultural monitoring
- Infrastructure
  - Structural health
  - Pipeline monitoring
  - Traffic control
  - Surveillance

# Sensors and MEMS for IoT Edge Devices

- Sensors convert environmental information to an electrical signal
- Some sensors are MEMS based
  - MEMS sensors are evolving at a rapid pace (size, function, cost)
- MEMS devices for IoT
  - Standard products/standard packages
  - Custom products in standard packages
  - Fully custom products/packages
- MEMS Packages for IoT
  - Cost, time to market challenges
  - Always desirable to use a standard product when possible
  - Custom MEMS product and package is a last resort



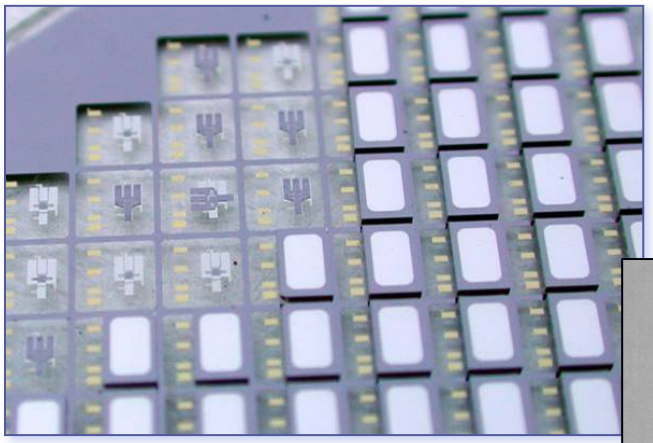
- What criteria determine if a custom package is needed?

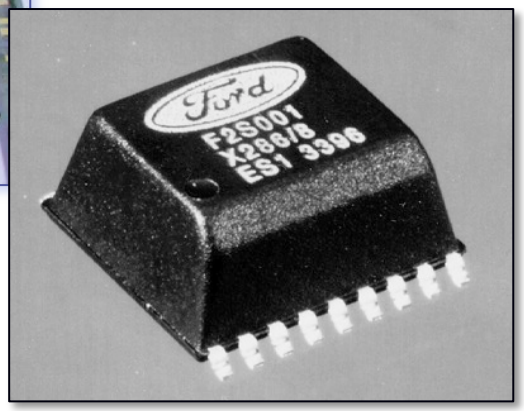
# System Partitioning and MEMS Packaging

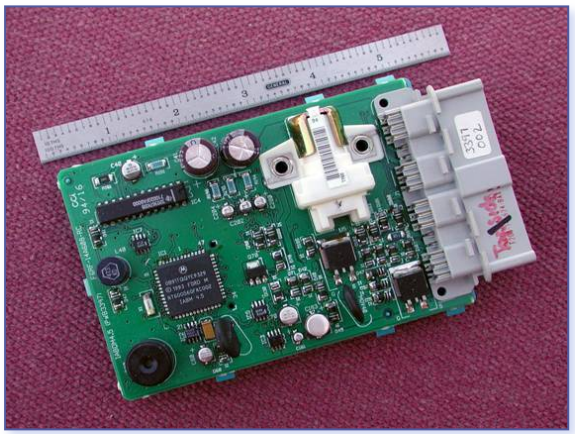
- What criteria can be examined to determine if a custom MEMS package is needed for an IoT application
  - Consider package hierarchy of electronic packaging
    - System->Module->Board->Component->Wafer
  - Consider the requirements for any electronic package
    - Signal transmission over various energy domains
    - Die protection
    - Power management
    - Usability
- Examining the following application requirements provides the answer.
  - Power budget
  - Form Factor
  - Sensing Interface

# Package Hierarchy in Electronics

- Level 4 – System level
- Level 3 – Box level
- Level 2 – Board level
- Level 1 – Component level
- Level 0 – Wafer-level

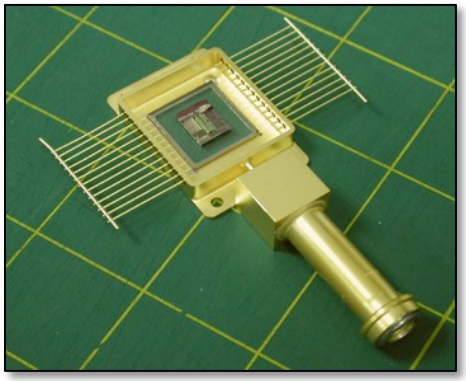


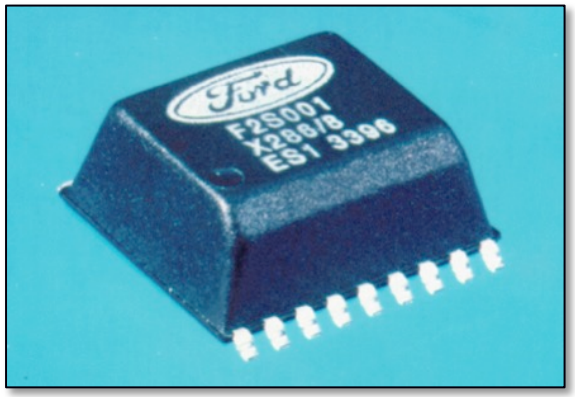


# Four Functions of a MEMS Package

1. Signal Transmission
   - Interface between the macro & micro worlds
   - Transmit desired signal energy into & out of the device
2. Die Protection
   - Environmental control
   - External forces
3. Power Management
   - Distribute power to components
   - Dissipate waste heat
4. Usability
   - Desired size & shape
   - Simplify socketing
   - Aesthetic appearance

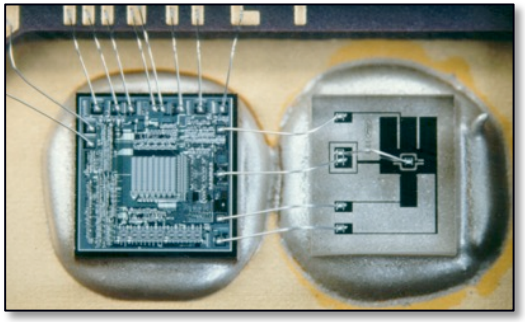


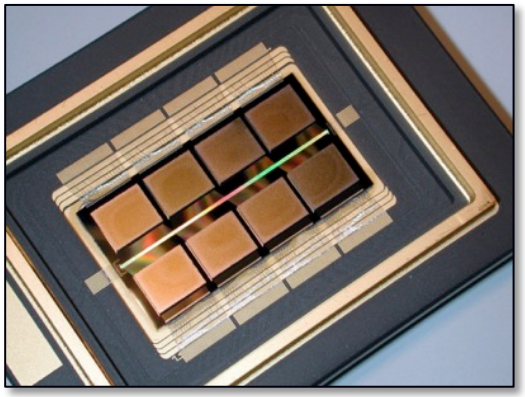



*Spangler & Kemp, Transducers 1995*

# Evolution of MEMS Devices

- Earliest MEMS Sensors-> Data oriented
  - Pressure sensors and accelerometers
  - Transducer chip and interface chip
- More complex MEMS -> Function driven
  - DNA Analysis
  - Gyroscopes
  - Ink Jets
  - Optical devices, Displays
- MEMS Evolution -> Information oriented
  - Inertial measurement systems
  - Sensor signals analyzed via an algorithm in a microprocessor
  - Package houses multiple die





*Winkler, et. al., 2006 Hilton Head*

*ST Microelectronics*

# Considerations for IoT MEMS Packaging

- System partitioning and IoT "Edge Devices"
  - Which functions should be combined with the sensor in the edge device?
    - Signal conditioning
    - Sensor algorithm
    - Energy harvesting
    - Data transmission
  - Which functions are incorporated into other parts of the system?
- Consider three factors in determining if a custom MEMS package is required
  - Power Budget
  - Form Factor
  - Sensing Interface

# Power Budget Considerations

< 1 microwatt — Power Budget — >1 Watt

- Very Low Power
  - Autonomous devices
  - Package should minimize interconnections loss
  - Potential for battery or solar cell integration into package
  - MEMS-based energy harvesting opportunities require custom packages
- Less restricted Power
  - Wireline connection mean power is less of an issue
  - Fewer partitioning constraints
  - Standard components should be suitable

# Form Factor Considerations

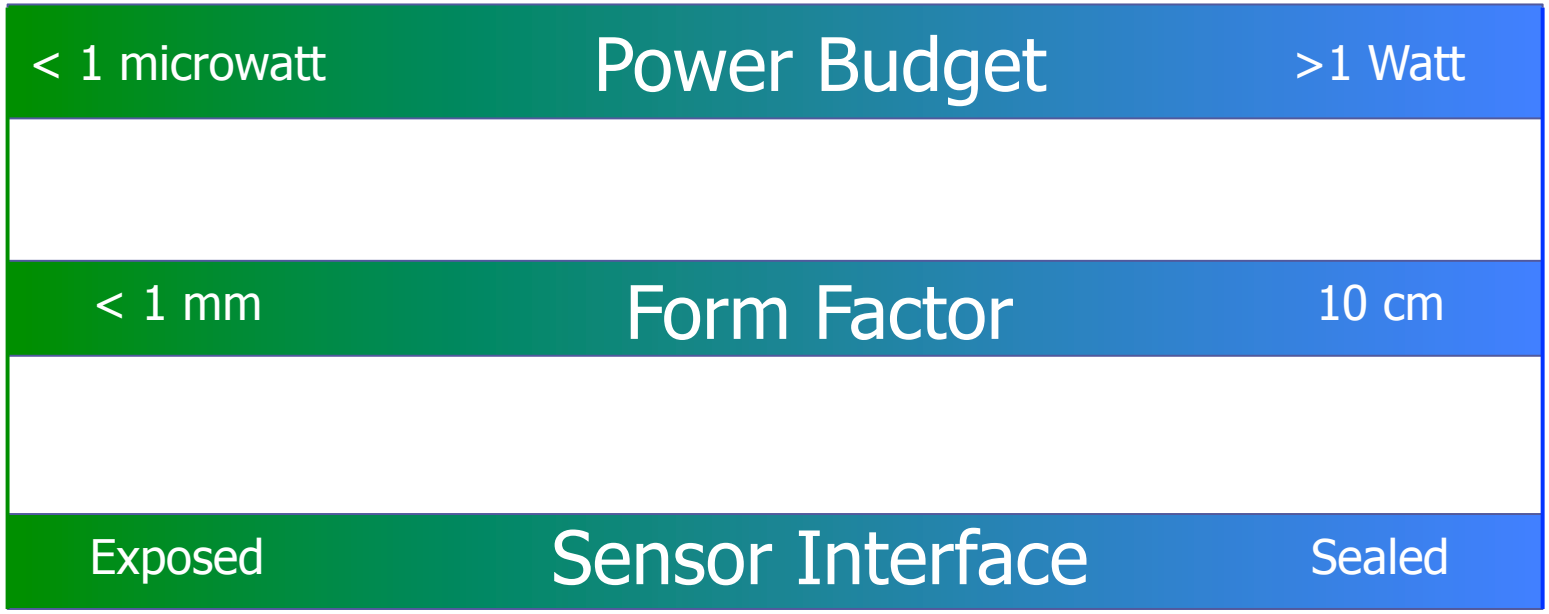

- Small and Constrained
  - Application has physical and/ or size constraints
  - Smart watch, implantable devices, etc.
  - New/unique applications often require package customization
- Large and unconstrained
  - Application is physically large allowing for flexible packaging
  - Automobile, factory floor, etc.
  - Rarely are custom packages required

# Sensor Interface Considerations


- Exposed
  - Package creates a port from environment to the sense element
  - Pressure sensor, water quality sensor, fingerprint sensor, etc.
  - Often requires customization at some level of package hierarchy
- Sealed
  - Energy transmission to transducer through the package body
  - Inertial sensors, magnetic sensors, etc.
  - Best to use a MEMS device in a standard package

# MEMS Package Considerations for IoT Applications

- By considering these three factors, one can determine if a custom MEMS package might be required.




Custom MEMS package might be required

Custom MEMS package probably not required

# IoT Applications

- Industrial
  - Process monitor
  - Inventory & asset monitor
- Consumer/Wearable
  - Health/activity monitoring
  - Entertainment
- Home/Business
  - Security/access control
  - Energy Optimization
- Medical
  - Implantables
  - Remote diagnostics
  - Inventory & patient tracking
- Automotive
  - Infotainment
  - Navigation
  - Telemetry (C2C and C2I)
- Environment
  - Water quality
  - Atmosphere
  - Agricultural monitoring
- Infrastructure
  - Structural health
  - Pipeline monitoring
  - Traffic control
  - Surveillance

| | | |
|---|---|---|
| < 1 microwatt | Power Budget | >1 Watt |
| < 1 mm | Form Factor | 10 cm |
| Exposed | Sensor Interface | Sealed |

# Case Studies to Illustrate …

- Consider the following applications:
  - Biometric Secure Card
  - Medical Diagnostics
  - Water Quality Sensor

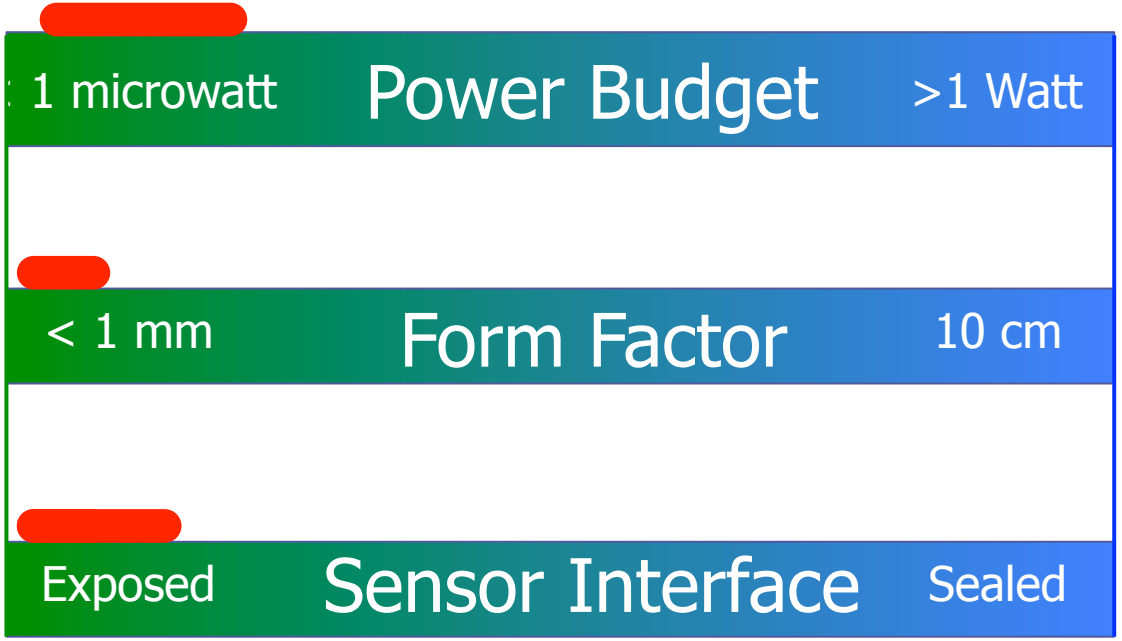
- Evaluate each application according to the three MEMS IoT package criteria
  - Power Budget
  - Form Factor
  - Sensor Interface

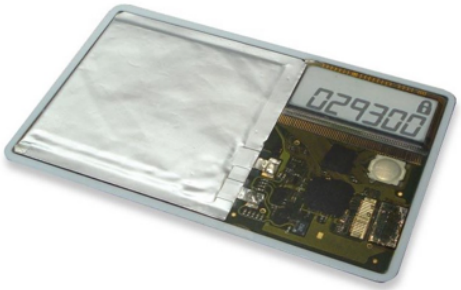
# Biometric Secure Cards

- An IoT device that verifies identity prior to use
- Applications:
  - OTP payments
  - Secure access
  - Location tracking
- Components
  - Secure microprocessor
  - Thin film battery and/or Solar cell,
  - Alpha-numeric display
- Credit card form factor
- IoT MEMS Device
  - Biometric sensor -> fingerprint sensor

# Finger Print Sensor Package for a Secure Card

- Biometric fingerprint sensor
  - Used in portable electronics since early 2000's
  - Early form factors allowed standard packaging
  - Integration of exposed sensor requires customization



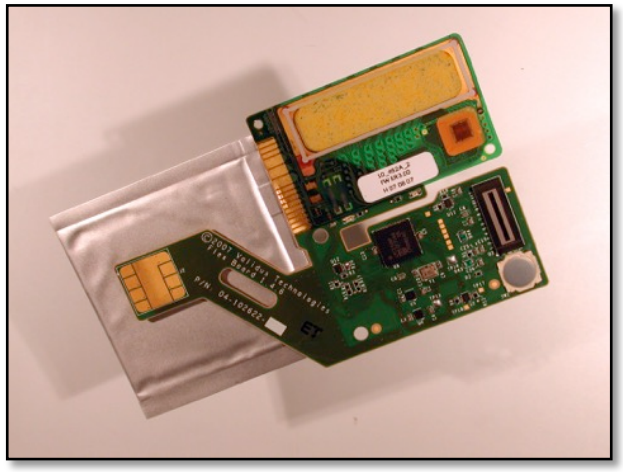



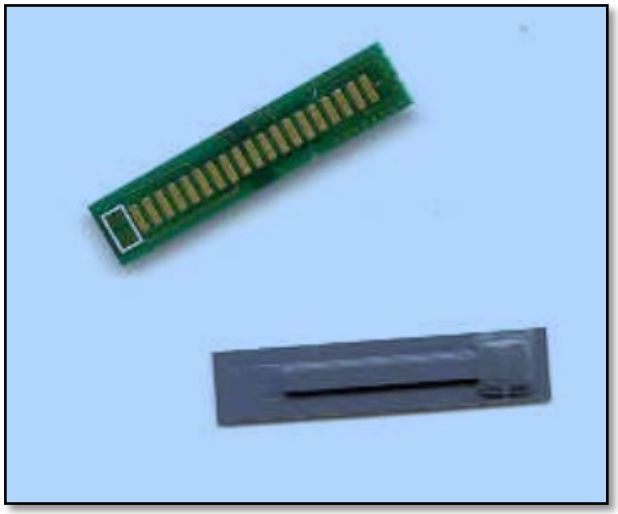
# Finger Print Sensor Evolution

- Conventional finger print sensors
  - First introduced in early 2000's
  - Form Factor: Too thick
  - Power budget: Could always be smaller
  - Sensor Interface: Exposed
- iPhone 5s fingerprint sensor w custom package


# Finger Print Sensor Package Customization

- Conventional finger print sensors
  - Form Factor: Too thick
  - Power budget: Could always be smaller
  - Sensor Interface: Exposed
- Custom MEMS package
  - Adapted backgrind process
  - Die stress compensation
  - Very thin substrate, low loop wirebonding
    Thin encapsulation

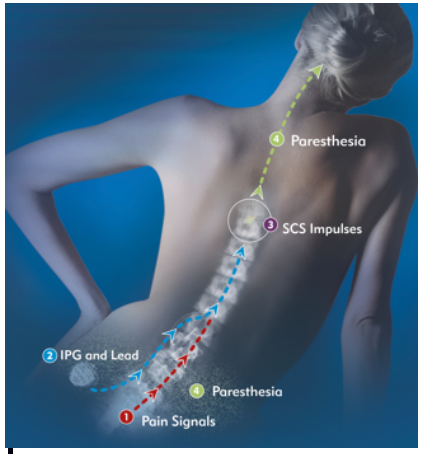


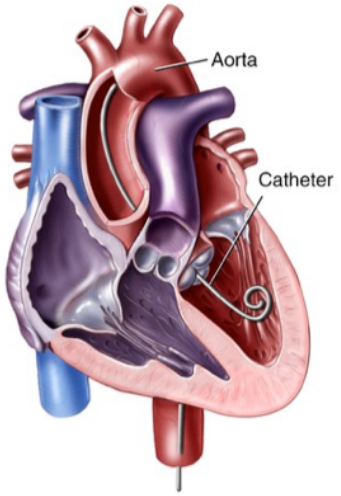
# Medical Diagnostics

- Real-time, continuous patient monitoring
  - Hemodynamics -> Heart attack
  - Neurostimulation -> Pain management
  - Thrombosis monitoring -> Blood thinners
- Two application spaces
  - Implantable monitor
    - Sensor & electrodes connected to a titanium box
    - Fully biocompatible
    - Size and power constraints
    - Wireless connection for power/data
  - Disposable cartridge
    - Analysis cartridge plugs into a hand held or desktop "reader"
    - Less challenging biocompatiblity requirements
    - Cost is a major factor
    - Form factor constraints

# Implantable Medical Diagnostics

- An IoT device that monitors/treats patient conditions
  - Hemodynamics
  - Neuromodulation
  - Diabetes, dry eye, thrombosis, etc.
- Chronic implant with companion unit
- Implant functions
  - Sensing -> pressure, chemistry, electrical potential
  - Stimulation -> electrical, drug delivery
  - Biocompatible packaging
  - Wireless power (RF, battery), Wireless data (RF)
- Companion unit
  - RF interface to implant
  - Data management via personal app and/or internet

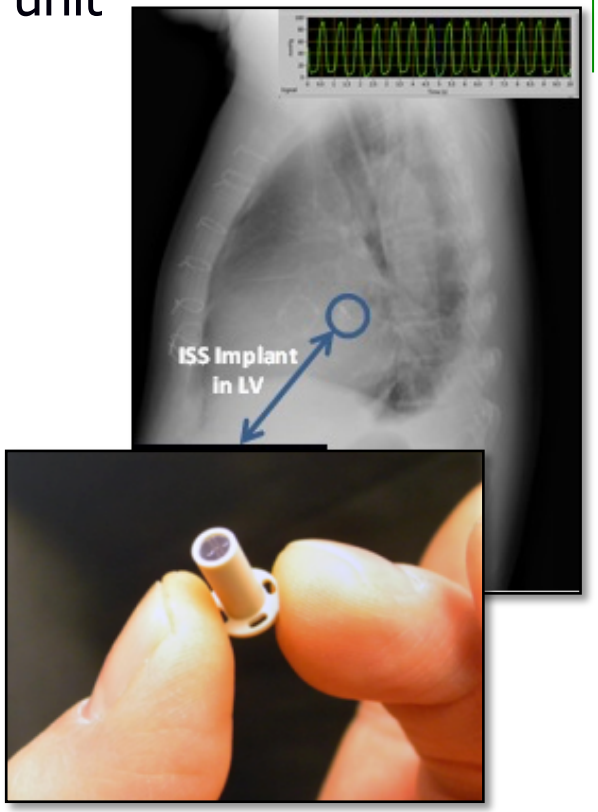


# Implantable Medical Devices

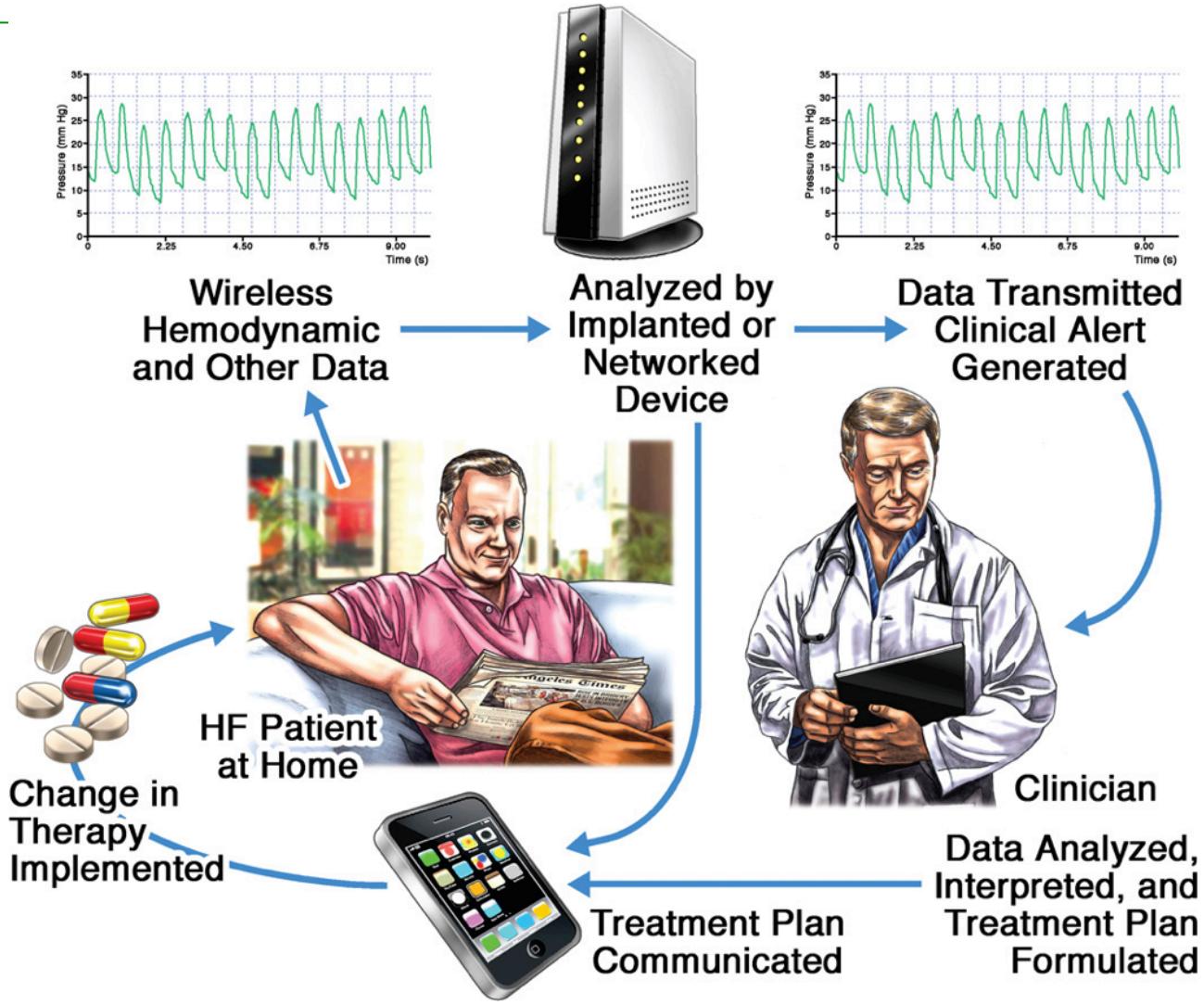
- Real-time hemodynamic monitoring
  - Monitor pressure directly in the left side of heart
  - Implant interfaces with companion readout unit
  - Readout unit facilitates internet connection

| | | |
|---|---|---|
| 1 microwatt | Power Budget | >1 Watt |
| < 1 mm | Form Factor | 10 cm |
| Exposed | Sensor Interface | Sealed |




Titan WIHM

# In-Home Hemodynamic Monitoring



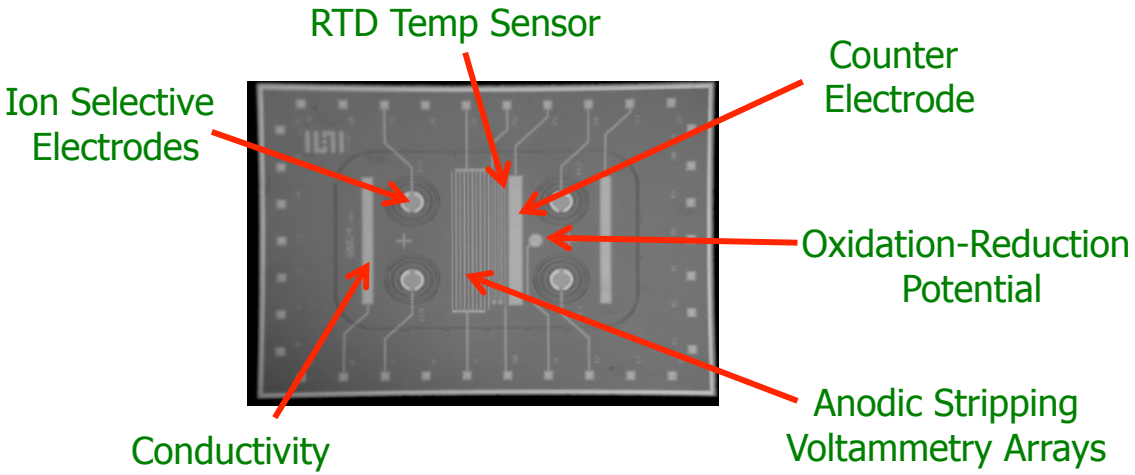

*A. Bui, G. Fonarow, "Home Monitoring for Heart Failure Management," J Am Coll Cardiol. 2012 Jan 10; 59(2)*

# Environmental Monitoring

- IoT devices that monitor the chemical makeup of the environment
  - Surface water, drinking water
  - Landfills, fracking sites
  - Air quality factory, motor vehicles
- Sampling systems have evolved
  - Grab or dip -> Lab analysis
  - Handheld devices -> On site analysis
  - Autonomous -> Continuous, remote analysis
- Application
  - Usually not form-factor constrained
  - Data collection from edge devices via a consolidator or polling (cellular access)

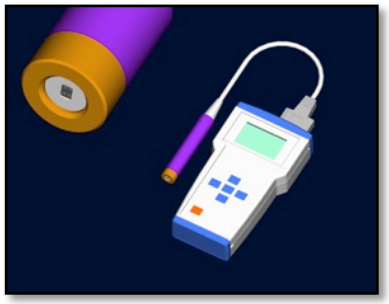
# Municipal Drinking Water Quality Monitor

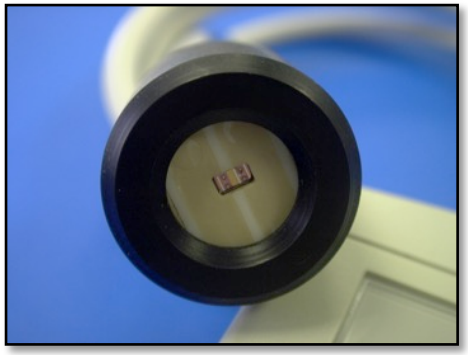
- Two types of municipal water distribution systems
  - Tree/branches -> Dead ends -> Stagnant water
  - Continuous loop -> No stagnant water
- Branched systems must have a monitor at ends of system
  - Many different chemical measurements must be taken
  - On-site analysis moving to continuous monitor (IoT edge device)
  - MEMS version will simplify installation, reduce cost

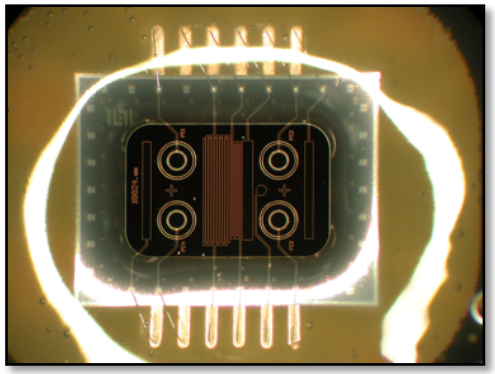



# Municipal Drinking Water Quality Monitor

- Continuous monitoring of water
  - Continuous immersion in water (long life required)
  - Implant interfaces with companion readout unit
  - Readout unit facilitates internet connection







| | | |
|---|---|---|
| 1 microwatt | Power Budget | >1 Watt |
| < 1 mm | Form Factor | 10 cm |
| Exposed | Sensor Interface | Sealed |

# Summary

- Most IoT applications don't require a custom MEMS package
- By considering three factors one can quickly determine if a custom MEMS device/package might be needed
  - Power budget
  - Form factor
  - Sensor interface
- IoT applications that might benefit from custom MEMS package include:
  - Medical diagnostics and monitoring
  - Portable electronics
  - Environmental sensors
  - Other small, low power, exposed sensor devices