Hybrid Fuel Cell / Lithium-Ion Powered, Power Conscious SiP ICs

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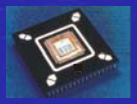
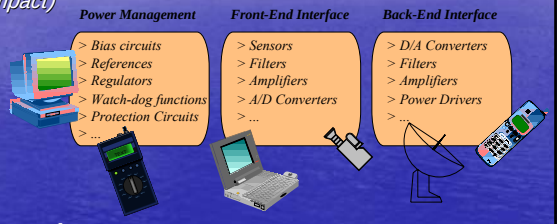
Outline

- Motivation
- SoC/SiP/SoP Solutions
- Electronic System
- Energy Sources/Storage
- Power Management
- The Future…



Motivation

- **Demand:** Military reconnaissance, remote space/field meters/monitors, implantable biomedical devices, and portable/mobile consumer electronics.
  - → *Portable (small and compact)*
  - → *Lightweight*
  - → *Long-Lasting (long life)*
  - → *Self-Powered*
  - → *Self-Sustaining*



Desirable Solution: ***Total Integration***

And for portability and low cost,

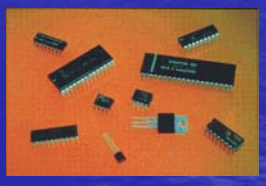
Total Chip Integration

- → *System-on-Chip (SoC) – integrate into silicon*
- → *System-in-Package (SiP) – integrate into the chip package*
- → *System-on-Package (SoP) – annex to the chip package*

3

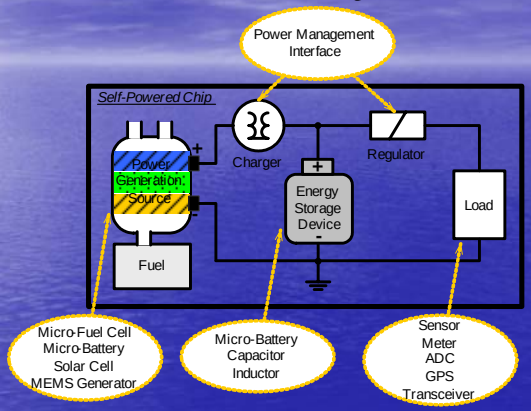
SoC/SiP/SoP Solutions

- **Integration of Chip-Compatible Components:**
  - → Energy Sources: Thermoelectric, RF-Derived, Solar, & Vibration-Based (electrostatic) Generators (MEMS)
  - → Energy Storage Devices: *(order: increasing energy)*
    - Inductors – MEMS, Planar Aluminum- and Copper-Based, & CMOS Active Multipliers
    - Capacitors – MEMS, CMOS Poly-Poly-Active, & CMOS Active Multipliers
    - Batteries – Thin-Film Lithium-Ion Technology
    - Micro-scale, Chip-Packaged Fuel Cells
  - → Application Circuits:
    - Transceivers, Monitors, Sensors, Converters, Controllers, Micro-Processors (CPUs), and so on.
  - → CMOS Power Management Circuits: *(interface)*
    - Mode managers, regulators, chargers, references, monitors, bias currents & voltages, etc.



4

Electronic System



- **Power Management Functions:**
  - ** Interface* ** Charge* ** Supply/Transfer* ** Load-Share*
  - ** Regulate* ** Power-Mode* ** Supervise* ** ...*

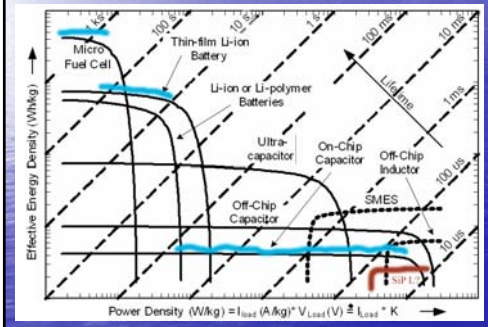
→ *Power Management Circuits = "**Brain**" and "Housekeeper"*

5

Energy Sources/Storage

- **Key** = *Maximize Operation Life (i.e., battery life or runtime)*

Ragone Plot



- * Fuel Cells: Slow, highest energy at light Loads
- * Li-Ion: Faster, highest energy during burst-peak loads
- * Capacitor: Fastest, highest energy during high peak transient (high di/dt) loads
- * Inductor: Cumbersome & slow but able to transfer energy in the form of current

→ ***Mode-hop*** *from device to device to operate @ maximum energy (stay on flat traces) & prolong operating life.*

6

Energy Sources/Storage - Fuel Cell

- Fuel Cell (FC): Electrochemical energy conversion device

  Fuel (e.g., hydrogen) + Oxidant (e.g., oxygen) → Water + Electricity (e.g., current)

- Categories:

  Alkaline FC (AFC)

  Molten Carbonate FC (MCFC)

  Proton-Exchange Membrane FC (PEMFC)

  Phosphoric Acid FC (PAFC)

  Solid-Oxide FC (SOFC)

  Direct Methanol FC (DMFC)…

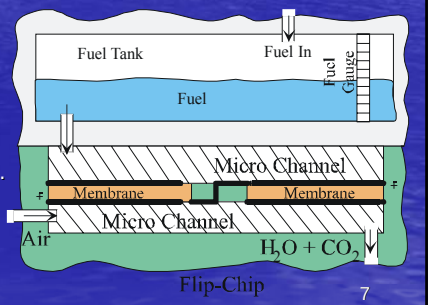
- DMFC is a variant of PEMFC:

  * Extracts ***hydrogen from*** liquid ***methanol*** directly, ***without*** the need of a ***bulky*** fuel ***reformer*** (necessary in other FC to transform hydrocarbon fuels into hydrogen).

  → Therefore,

  best suited for miniaturization

  (40% η at 50-130°C)



7

Energy Sources/Storage - Fuel Cell

- DMFC:

  * Issues:

    a. Methanol crossover: Fuel ***leakage***/loss across membrane

    * High temperature, diluted methanol, and exotic electrolytes help.

    b. Relatively low current ratings (i.e., ***low power***)

    * More concentrated methanol and ultra-capacitor technologies help

    c. High over-potentials: ***Slow*** electrolyte kinetics (slow response times - low BWs)

    * Active catalysts help

    * Constant fuel-flow control helps

8

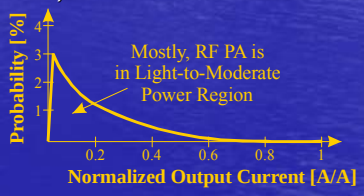
Energy Sources/Storage

- **Operation Life (i.e., battery life or runtime):**

Life [h] = Capacity [Ah] ÷ $I_{Load\_Weighted\_Total}$ [A] α 1 ÷ (I_{Load} · Probability_Density_Function)

→ For portable applications, ***PDF*** is ***highest*** at ***moderately light loads*** (e.g., idle 80% of the time)

→ ***Battery Life*** = function of highest I_{Load} · PDF ~ ***moderate light loads***



→ ***Fuel Cell*** has the ***most energy*** in this region

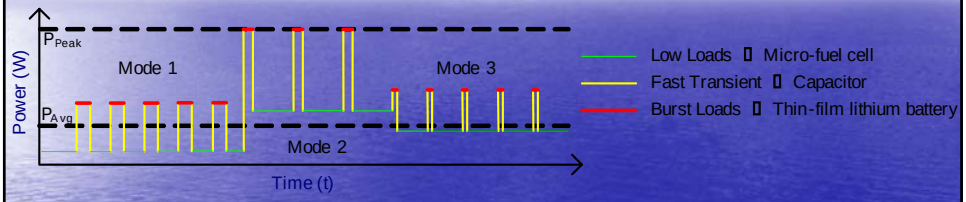
THUS, ***allocate volume & resources*** in chip accordingly

9

Power Management

- **Transferring Energy to the Load:**

Sample Load

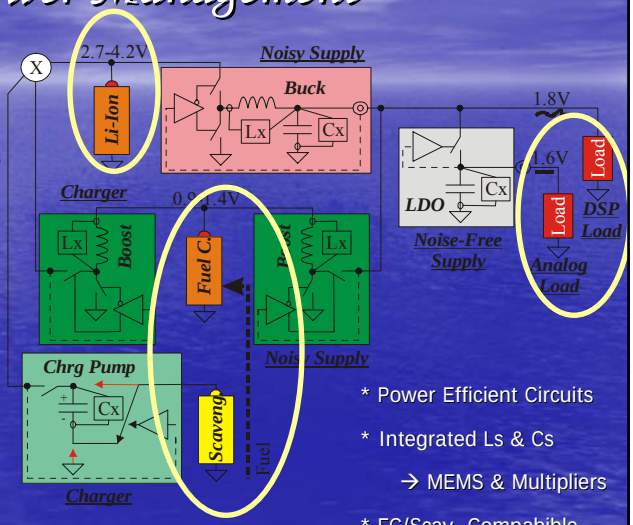


* Load mode hops – off, sleep, idle, receive, transmit, high performance, etc.
* FC supplies steady-state load - P_{avg} - (charges Li-Ion battery when $P_{Load} < P_{avg}$)
* Li-Ion supplies burst power (FC is slow)
* Capacitor supplies high di/dt loads (Li-Ion is not fast enough)
* Inductor help transfer FC/Li-Ion Energy to Capacitor

10

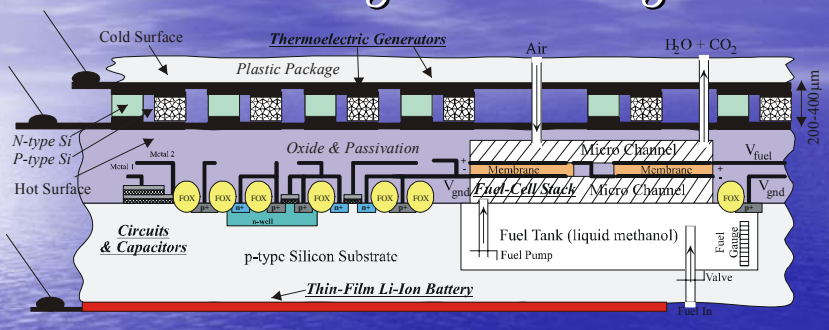
Power Management

- **Power System:**
  - * Analog = Noise Sensitive
    DSP ≠ Noise Sensitive
    → Dirty/Clean Supplies
  - * FC supplies DC &
    Li-Ion supplies Peak Bursts
  - * FC also charges Li-Ion
  - * Scavenger charges Li-Ion
  - * FC/Li-Ion charge Ls
  - * Ls supply power to load
    & charge Cs
  - * Cs supply transient loads



- * Power Efficient Circuits
- * Integrated Ls & Cs
  → MEMS & Multipliers
- * FC/Scav.-Compabible
  Circuits

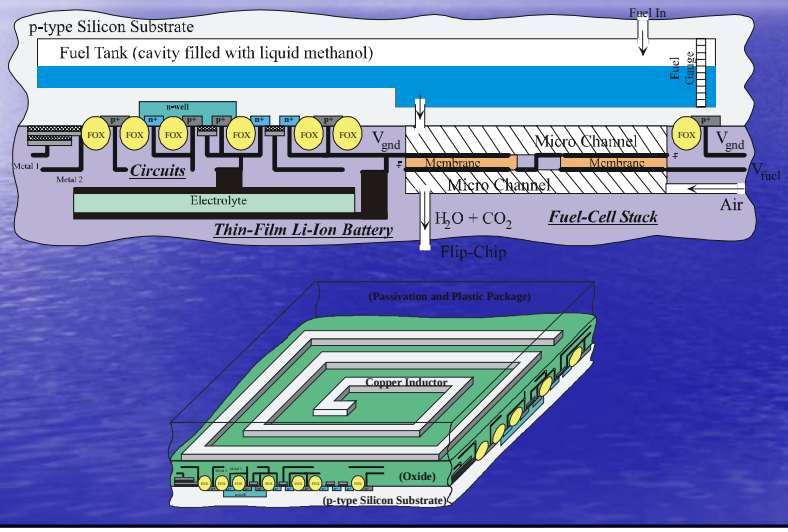
Power Management - Integration



- **Components:**
  - * MEMS Thermoelectric/Vibration Generators
  - * Planar Copper Inductors
  - * FC Stack
  - * Thin-Film Li-Ion Battery
  - * CMOS Inductor/Capacitor Multipliers
  - * CMOS Switching/Linear Regulators/References
  - * System Mode Manager

Power Management - Integration

Flip Chip Fuel Cell/Lithium Ion Hybrid



Power Management - Challenges

- **Package Integration:**
  - * Fuel Cells
  - * Energy Scavengers
  - * Planer Cu Inductors
  - * Thin-Film Li-Ion
  - * Power MEMS Inductors
  - * Bulk Capacitors
  - * Re-Fueling (unnecessary for disposable applications)
  - * Testability*
- **Power Management:**
  - * *Multiple-Charger-to-Single-Battery System*
  - * *Multiple-Source-to-Single-Output Supply*
  - * Accurate/Fast System Health Monitors
  - * Emergency Battery Handoff
- **CMOS/BiCMOS Supply Circuits:**
  - * *Fuel Cell Compatible Boost Regulator*
  - * *Fast Capacitor Multipliers*
  - * Efficient, Low-Voltage Power Switches
  - * *Efficient Inductor Multipliers*
  - * *Scavenger-Compatible Intermittent Trickle Boost Charger*
  - * *Fuel Cell Compatible Boost Charger*
  - * Safe Mode-Hop Manager and PM Brain
  - * ...

The Future…

- **The Road**: ***Design Bridges*** → ***SiP/SoP/SoC***
  Product/Market/Process/Device/Circuit/System/IC/Package/PCB/Application
- **The Means**: *Technology Leaps → Robust, Low V, Low I_{in}, High I_{out}, High Perf. Mixed-Signal ICs →* ***Integration*** *of Power Passives and* ***Alternate Energy Storage*** *and* ***Sourcing Devices*** *(Li-Ion Batteries, fuel cells, etc.)…*
- **The Goal**: *Portable,* ***Self-Powered, Self-Sustaining, SiP/SoC/SoP*** *Solutions*

- End -

15