TerraSwarm

MBus: Enabling the Next Generation of Sensors and Systems

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University of Michigan

Sponsored by the TerraSwarm Research Center, one of six centers administered by the STARnet phase of the Focus Center Research Program (FCRP) a Semiconductor Research Corporation program sponsored by MARCO and DARPA.

How do you build an embedded system?

Goal: Build a “Temperature Sensor”

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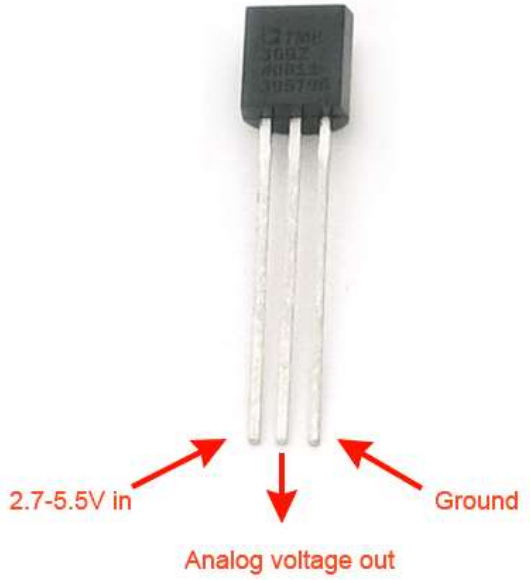
- Step 1:
  - Buy a temperature sensor



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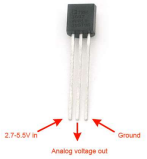

- Step 1: Buy a temperature sensors
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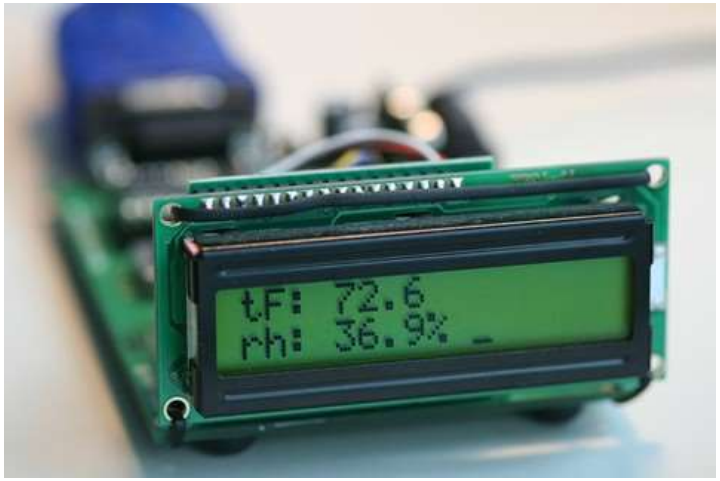

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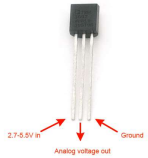

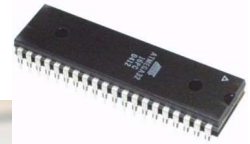

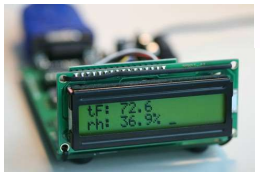

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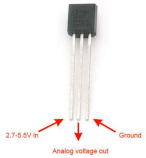

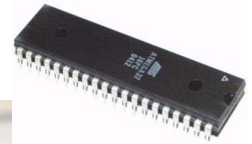

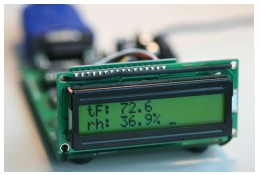

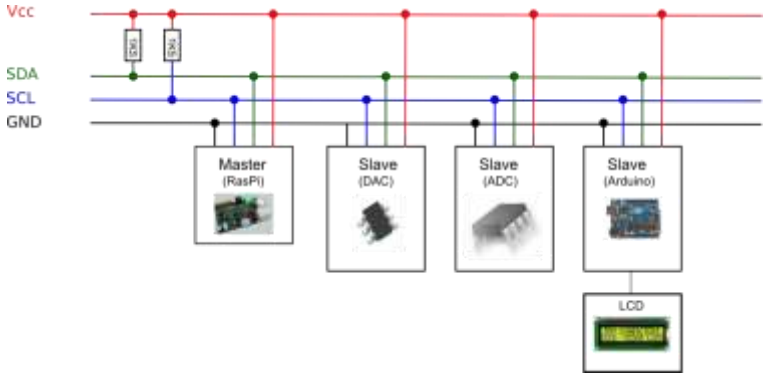

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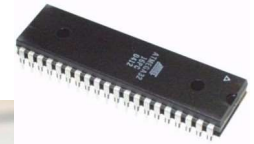

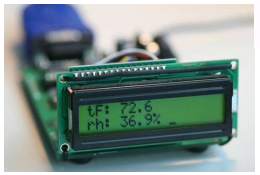

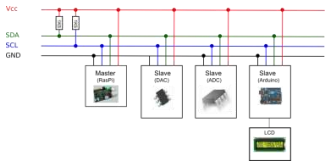

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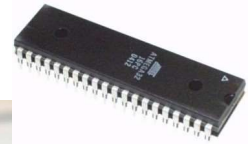

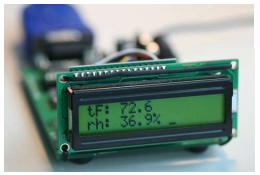

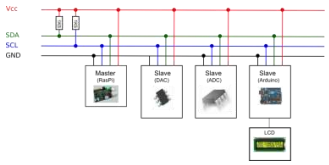

This is how you built an embedded system in 1980

Modern Technology “Cut the Cord”

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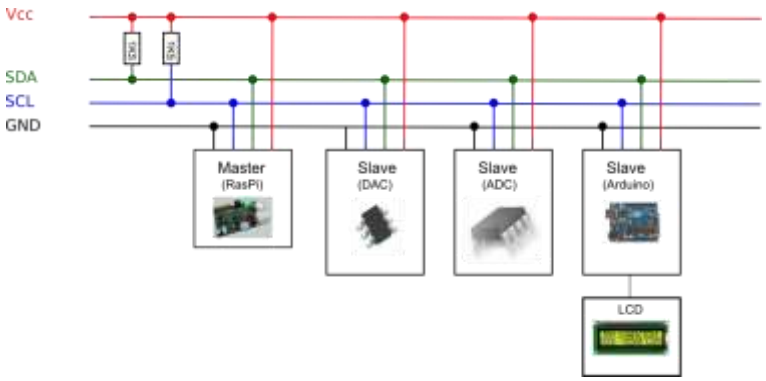

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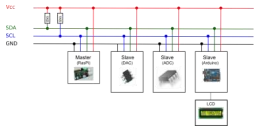

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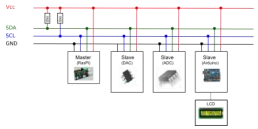
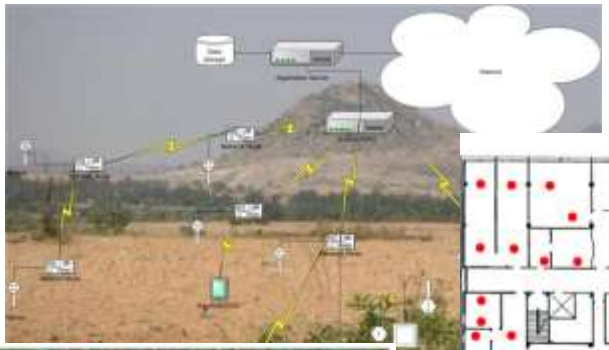


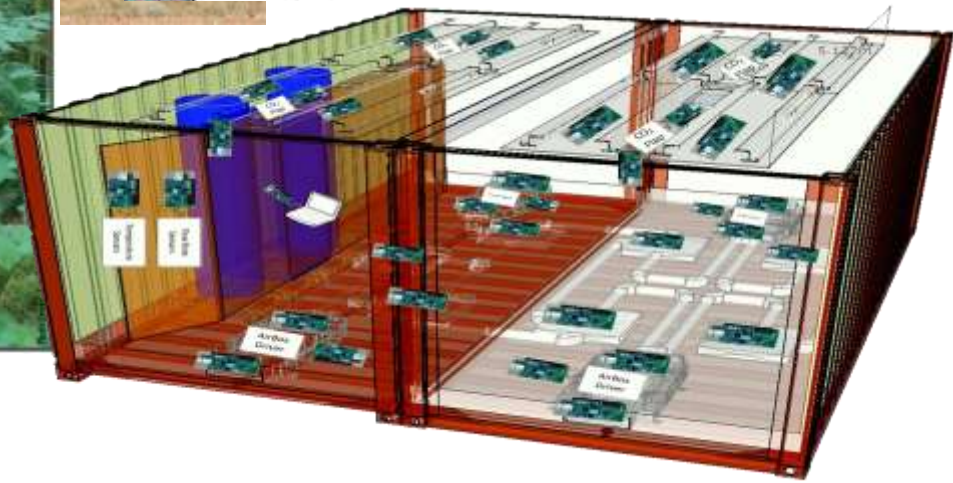
This is how you build an embedded system today

What does the next generation system look like?

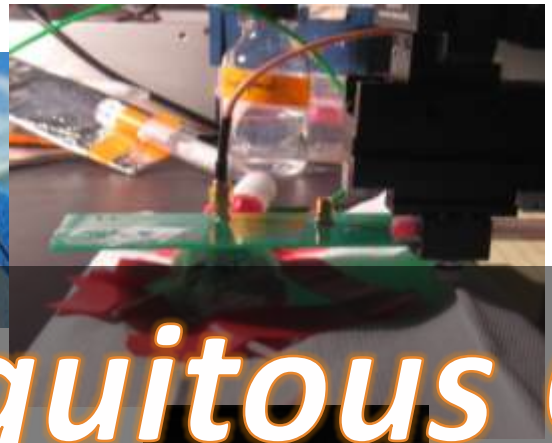
- To understand the future, look to the past

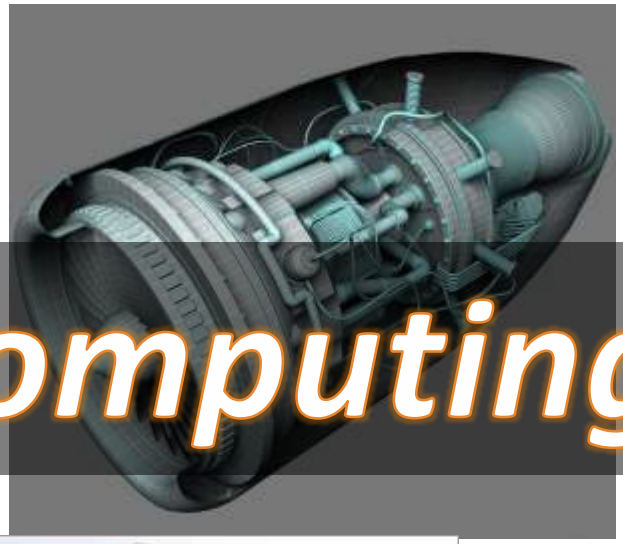
Cutting the cord let us put intelligence in more places



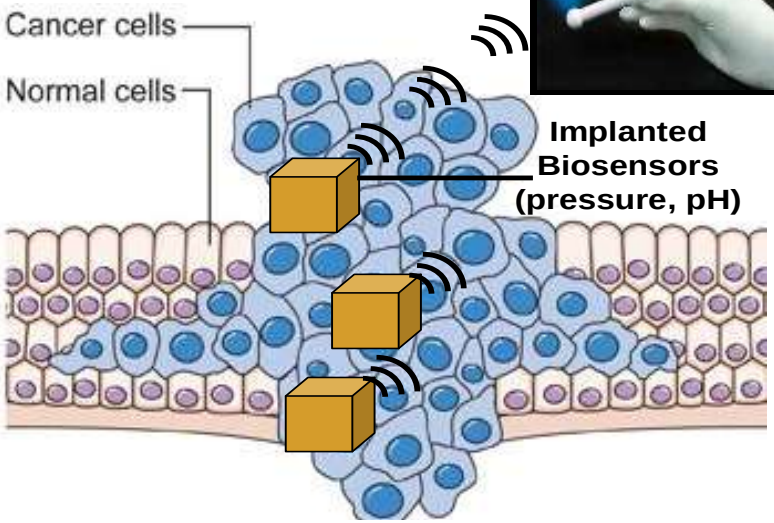


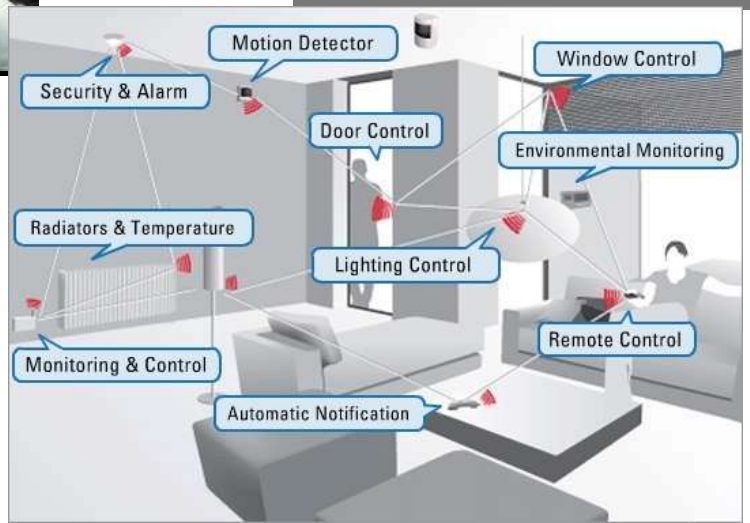
What niche does the next generation fill?





"Ubiquitous Computing"



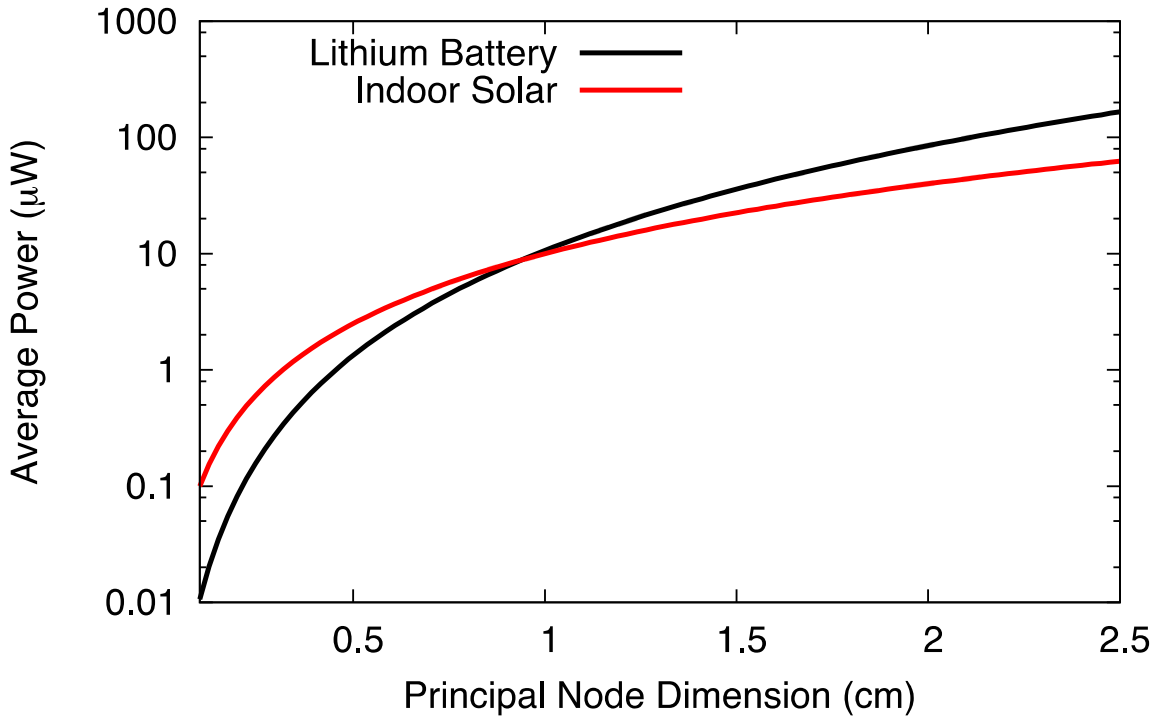


Why don’t we have ubiquitous computing already?

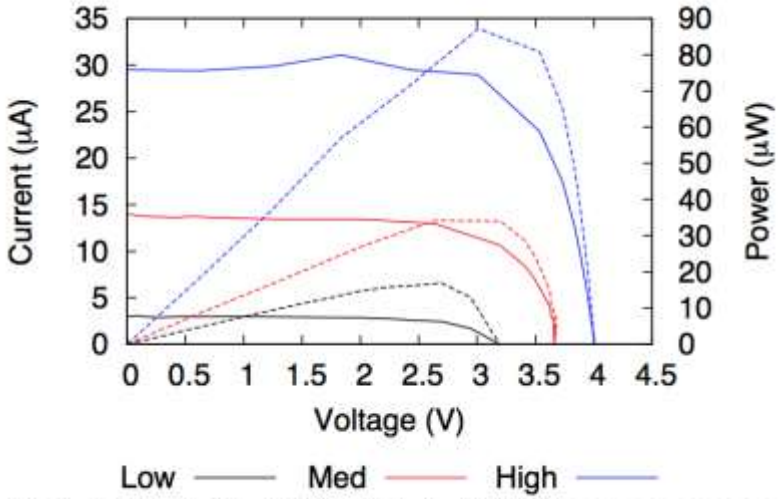
- Paid a heavy cost:
  - Batteries gave nodes a lifetime

=

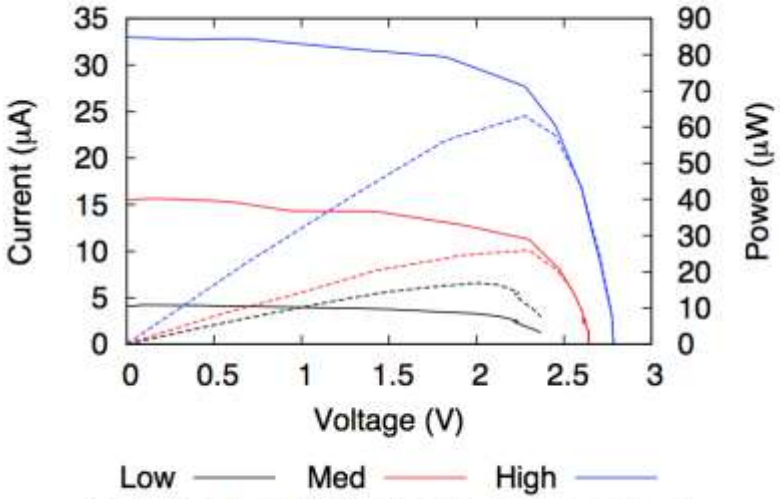
Batteries Dominate Node Volume



A new class of power emerges



(a) XOB17-4X3 IV (x3) Characteristics



(b) AM-1437 IV Characteristics

"Next Generation" nodes will have power budgets at or below 1 μW

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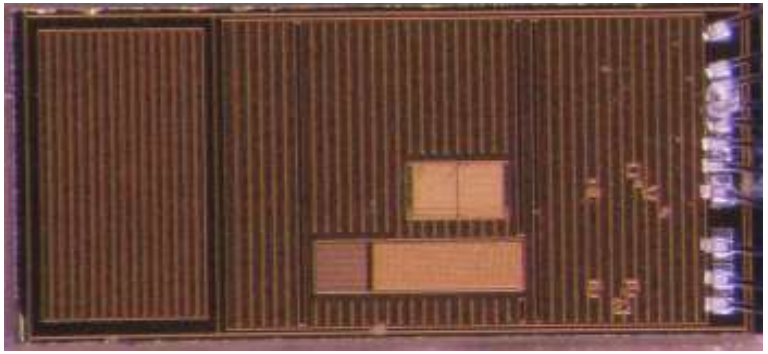

~10 pW standby, < 1 µW active

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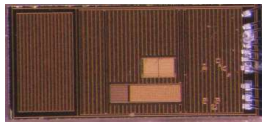
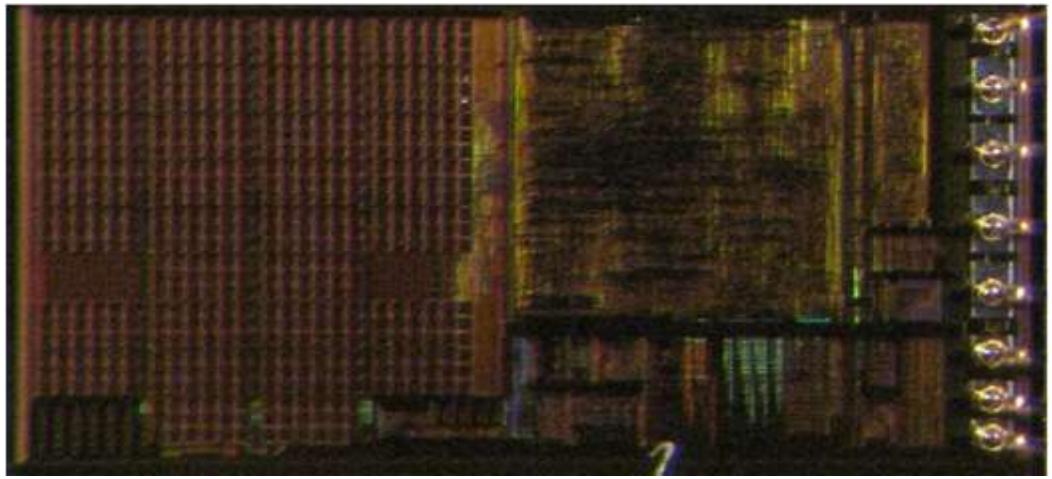


- Step 1: Build an ultra-low power temperature sensor
- Step 2: Build an ultra-low power microcontroller



~1 nW sleep, ~1 µW active

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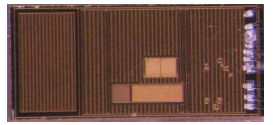
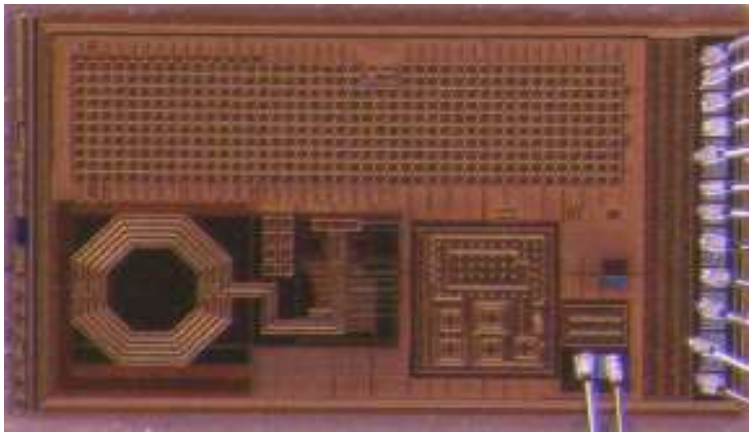
- Step 2: Build an ultra-low power microcontroller
- ~~Step 3: Outsource the display~~
- Step 4: Add ultra-low power communication





~10 pW standby, ~5 µW active

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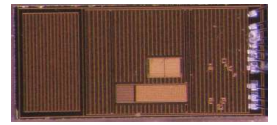
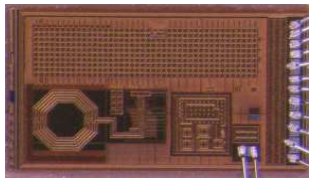
-
- Step 6: Add power





Energy Harvesting

Energy Storage

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- ***But How To Put It All together?***
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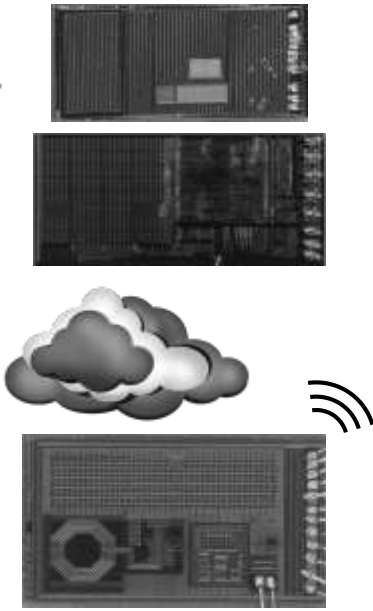

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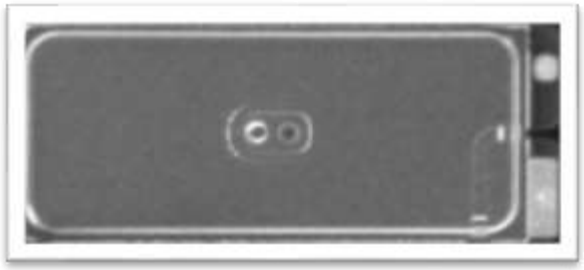
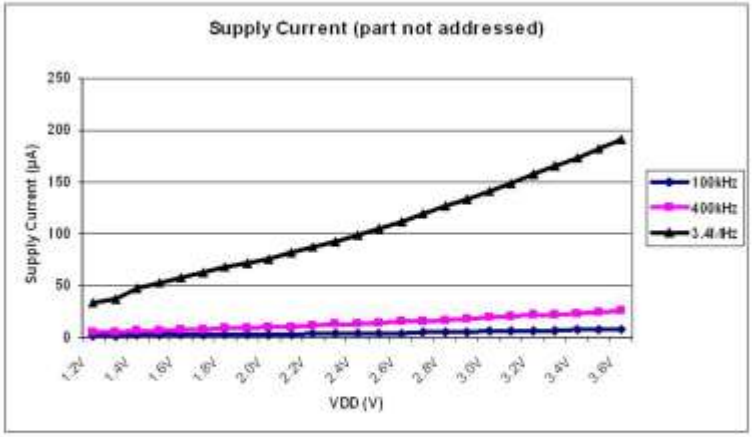


Energy Storage

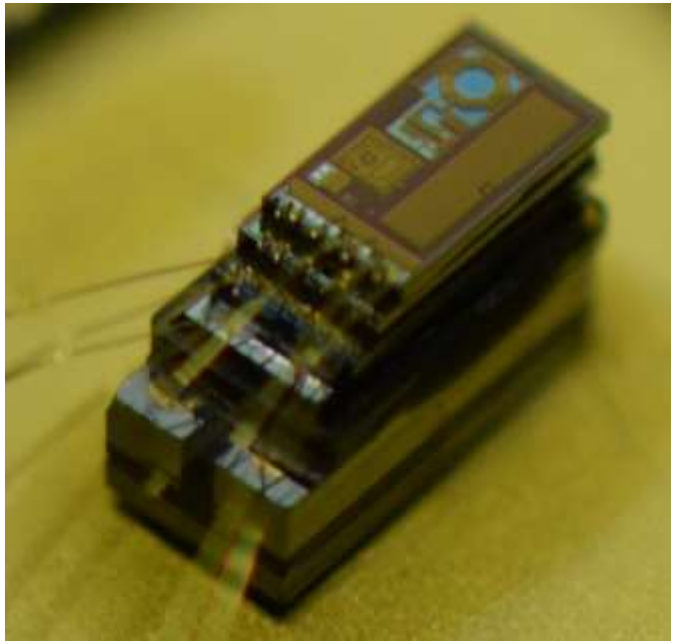
Composing ultra-low power systems: Why not open collectors?

- I2C, CAN, SMBus…
- Pros
  - Multi-master
  - Low wire count (~2)
- Cons
  - **Pull-up resistor burns power (order µW)**
  - Speed / power tradeoff



Composing ultra-low power systems: Why not “pure digital” buses?

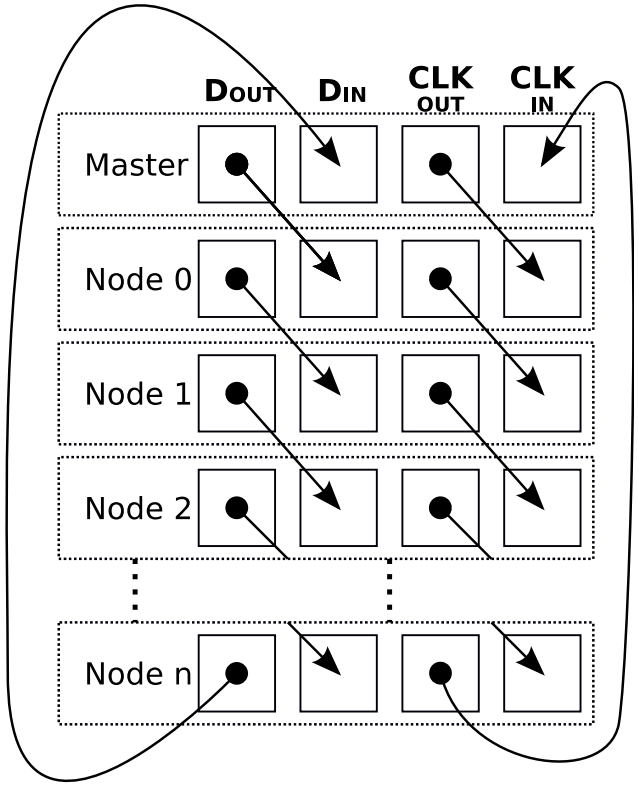
- SPI
- Pros:
  - Single-ended
  - Low (no) ACK overhead
- Cons:
  - Single master
  - 3 + N wires, N is chip count
    - **Wires can dominate size**
  - No ACK mechanism



We built a new bus (and we actually needed it)

MBus

- Pros:
  - Multi-master
  - Single-ended
  - Low wire count (4)
  - Reliable reset mechanism
  - Low ACK overhead
- Cons:
  - Topological Priority



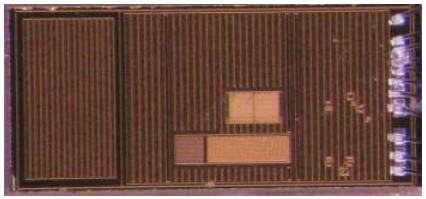
MBus System Topology

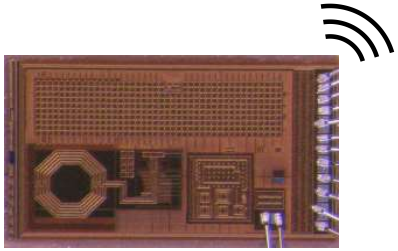
MBus Enables ultra-low power systems

- MBus is a *power-aware bus*
- So we can build *power-oblivious systems*

Ultra-low power computing turns things OFF

- How are ultra-low power chips ultra-low power?





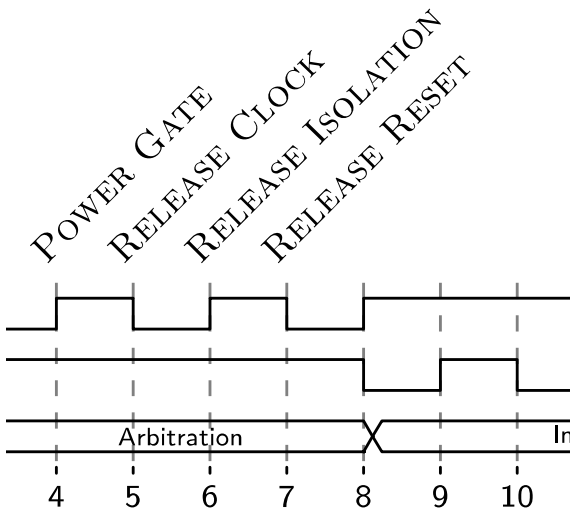
- *They turn OFF (power gating)*

Global State is Hard – So Don't Do It

- MBus guarantees message reception regardless of target chip power state
- *Power-aware bus*

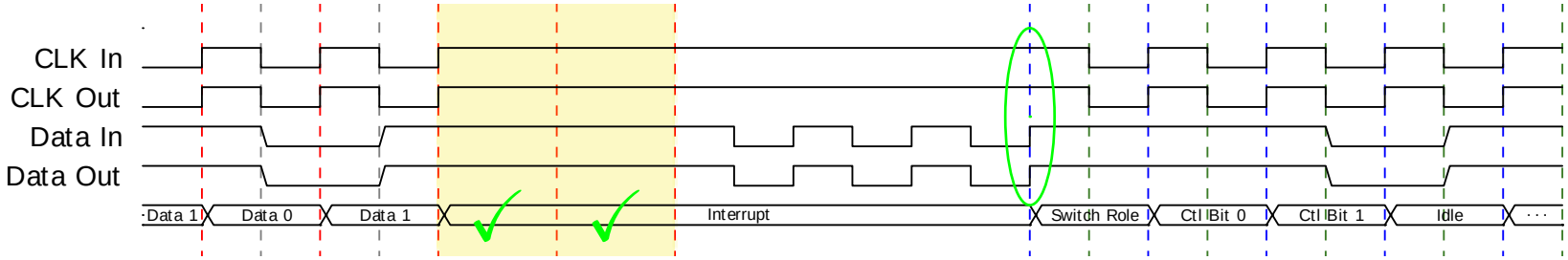
MBus Insight: Waking Nodes

- During arbitration, a node is either:
  - Awake or asleep
- Sleeping nodes will never arbitrate



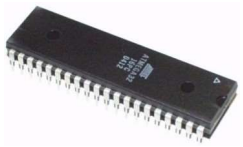
MBus Insight: Interrupt Procedure

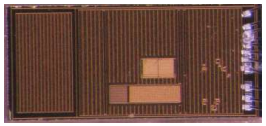
- In normal operation, DATA is always slower than CLOCK

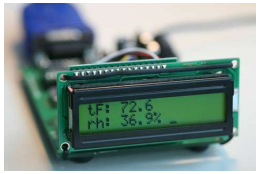


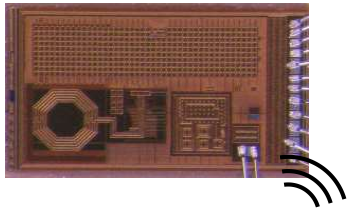
- Extremely reliable
  - “Independent” circuit

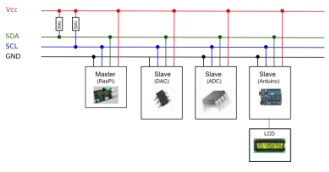
So how DO you build an embedded system?

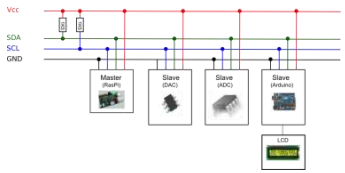






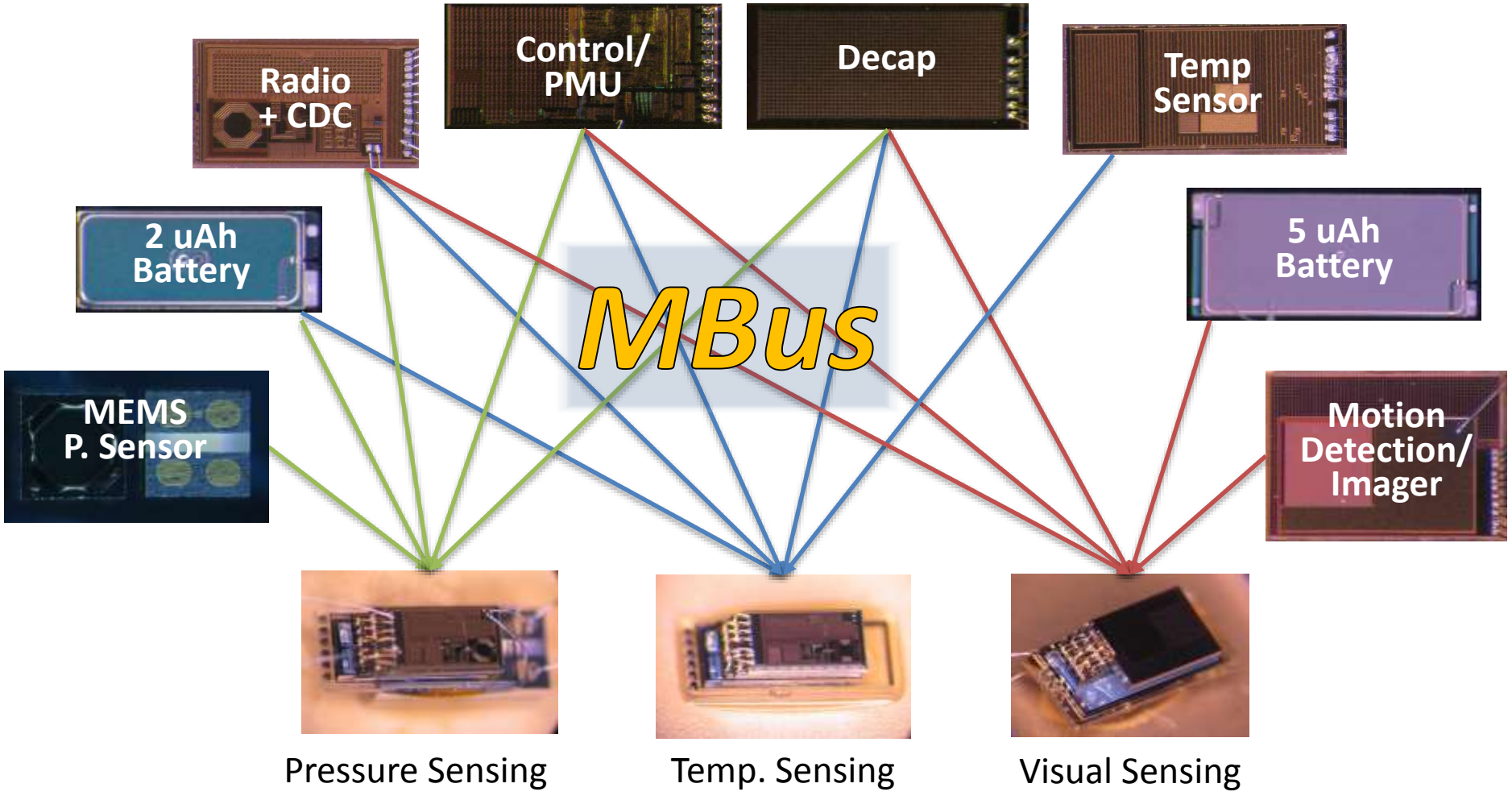






MBus

MBus enables modular construction of ultra-low power systems



The “modules” that made MBus possible

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