Ultra-Low Power Radios for Wireless Sensing

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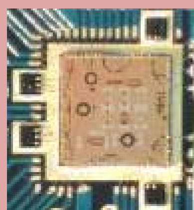
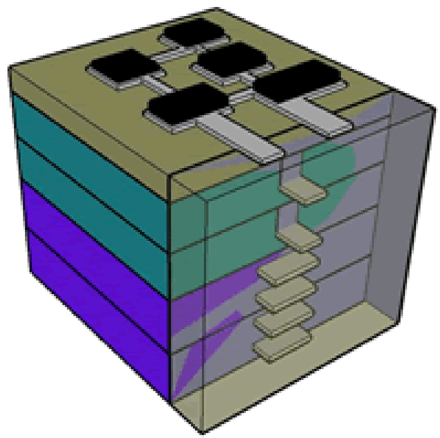
STATE OF CALIFORNIA ENERGY COMMISSION

Wireless Sensor Node

Low Power Radio

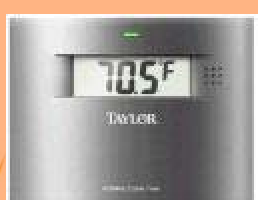


Power Storage



"Picocube"

Sensor



Renewable Power Supply

Low Power Radios

	Sentila moteiv	TI motes	Xbee reg.	Xbee pro.	Dust	UCB PicoCube	UCB WuRX
Supply Voltage [V]	3	3	3	3	3	1	0.5
RF Frequency [GHz]	2.4	2.4	2.4	2.4	2.4	1.9	1.9
max. datarate [kbps]	250	500	250	250	250	330	100
Typical range [m]	50	50	30	90	25	10	10
Power (RX) [mW]	65.4	56.4	165	181.5	18	NA	0.05
Power (TX) [mW]	58.5	63.6	148.5	709.5	21	3	NA
Power - down [uW]	15.3	2.1	3.3	3	3	6	NA
ADCs	12-bit 8 channel	10-bit 8 channel	10-bit 6 channels	10-bit 6 channel	NA	NA	NA

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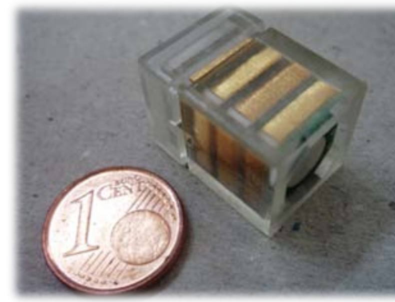
Innovations in ULP Radios

FBAR MEMS Resonator

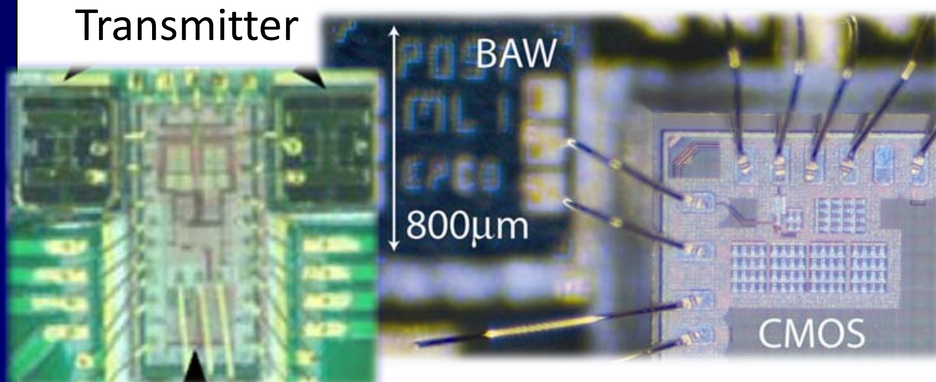
(Avago Technologies)

- MEMS-based ultra-low power receiver and highly efficient transmitter
- Low-voltage, low-power logic family
- Integrated, efficient energy conversion and innovative power management



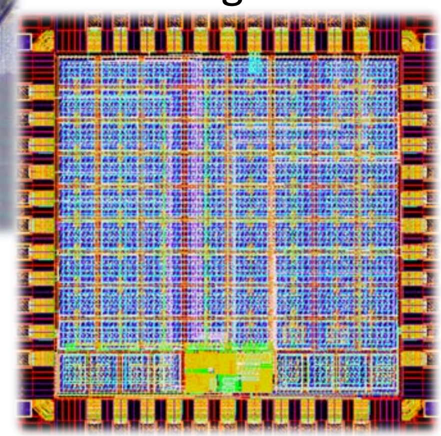
UCB PicoCube

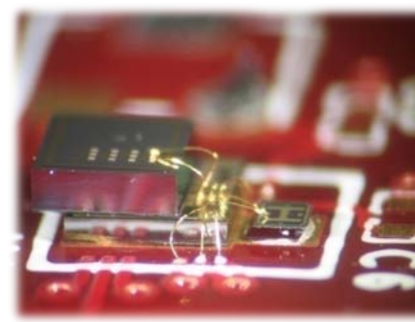
Transmitter



Receiver

Voltage converter and regulator





UCB mm^3 radio

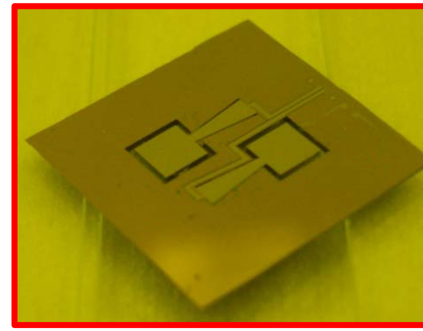
Past, Present and Future

- The radios we built …
  - … consume 1 to 2 orders of magnitude less power than commercial radios
  - …enable small wireless sensing nodes powered purely by energy scavenging
- In progress: Integration of radios with energy harvesting/storage and power conditioning
- Next step: Interfacing with sensors while improving performance and level of integration

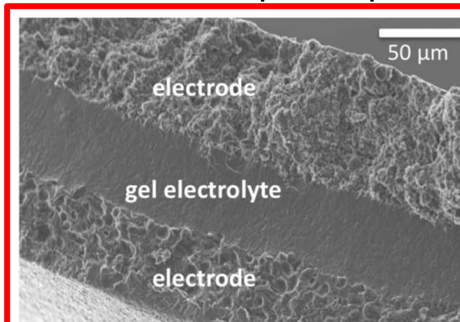
Integration: Active RFID

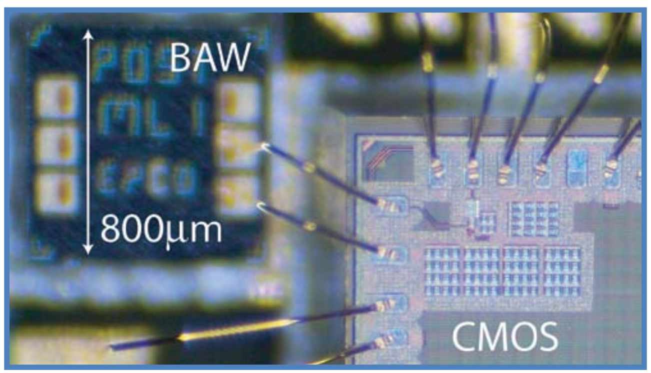
A fully integrated, self-powered active RFID tag based on our low power receivers and transmitters, low-voltage logic, innovative power management, efficient integrated energy harvesting and conversion, as well as thick-film printed energy storage technologies

Microfabricated energy harvester

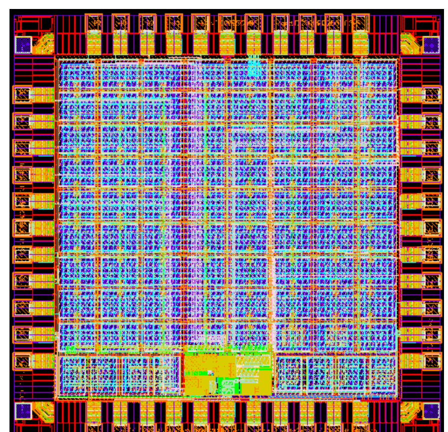


Printed super-cap



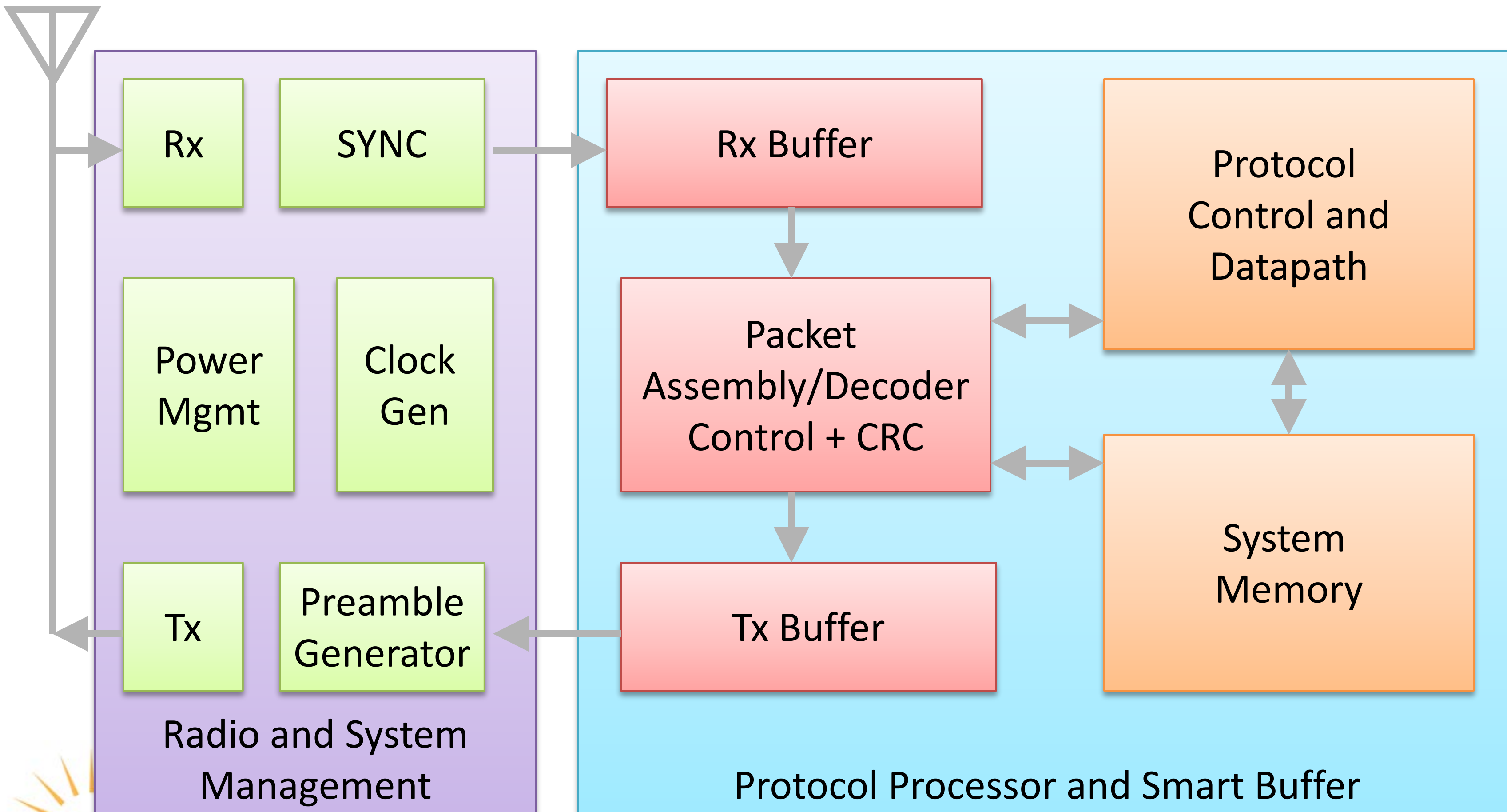


Low power radio



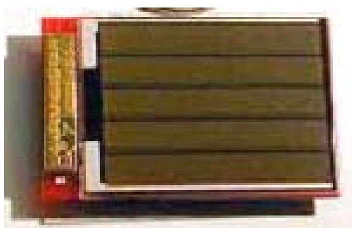
Voltage converter and regulator

Active RFID Tag Generation 1: Block Diagram



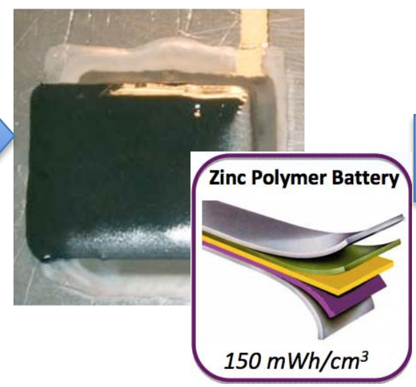
Powering the Active RFID

- Self-powered Active RFID Tag
  - **Self-contained** (postage stamp footprint but only mm's thick)
  - **Fully integrated** IC (single die)
  - **Small solar cell** harvests enough energy for 24 hour operation



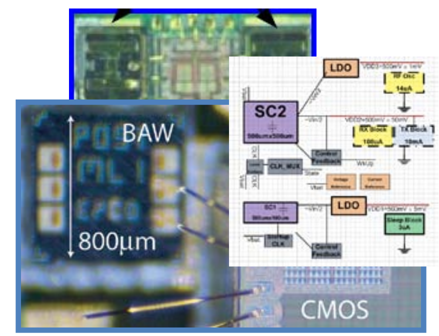
Solar Cell

- 2cmx1cm
- **10µW** avg (Indoor)
- V_{oc} = **2.4V**, I_{sc}=10uA



Printed Battery

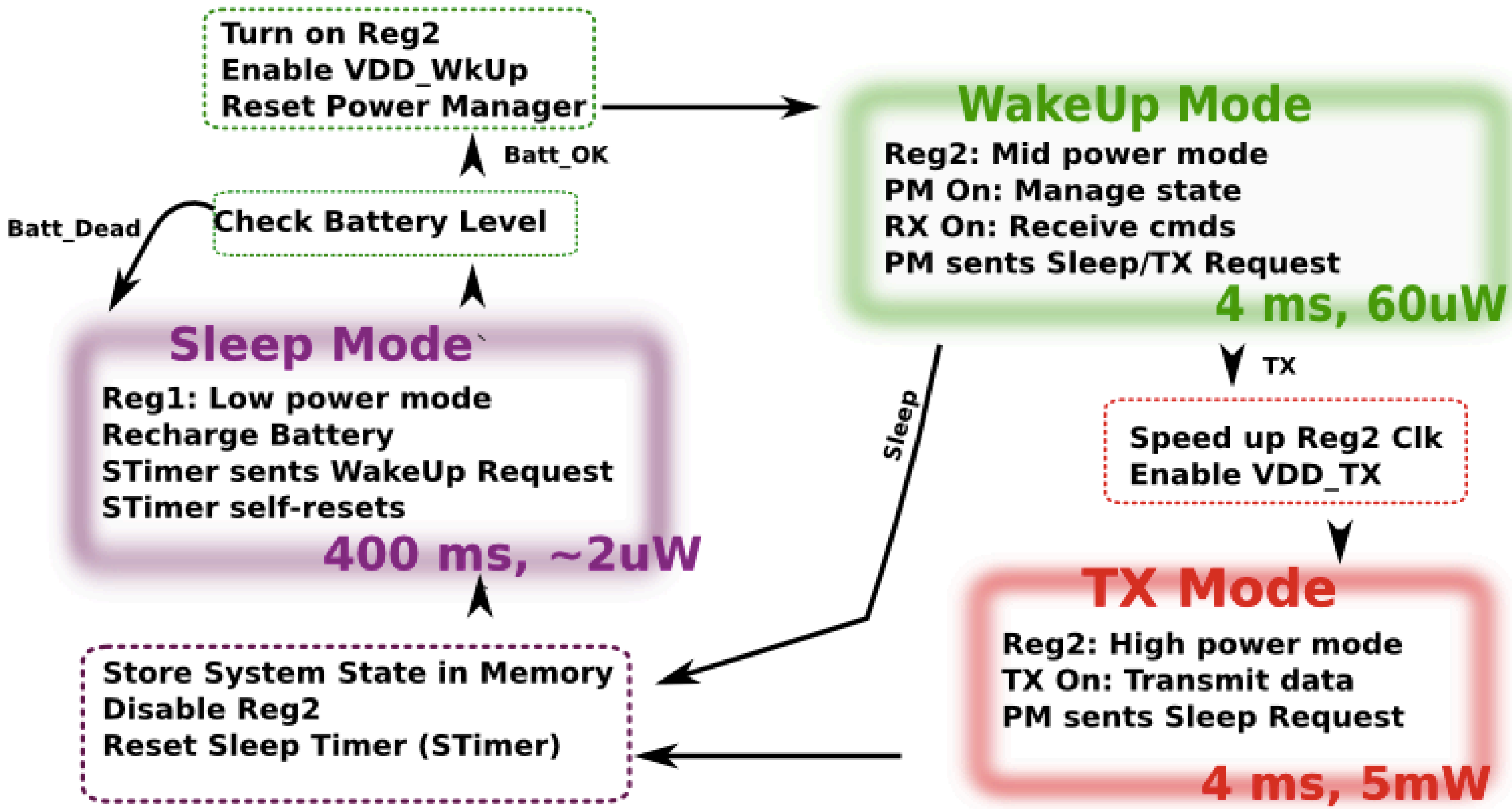
- 1cmx1cm
- V_{bat} ~ **1.1-1.8V**
- Integration w/ substrate



Loads (on Single Die)

- 50 µW RX
- 1mW TX
- **0.5V** Logic
- On-chip power management

Multi-Mode Duty-Cycled Operation



Rev 1: Bonded Chip Die Photo

Revision 1 Testing

- Bonding dies to printed circuit was difficult due to relatively tight pitch of bond pads-> complex system on a very small die (2mmx2mm)
- Issues related to serial peripheral interface (SPI) impaired ability to observe system signals

Revision 2

- Design was “respun” and sent back to foundry
- Revisions included increased bond pad pitch and simpler SPI
- Expected back: **Summer 2011**

Generation 1 - Summary

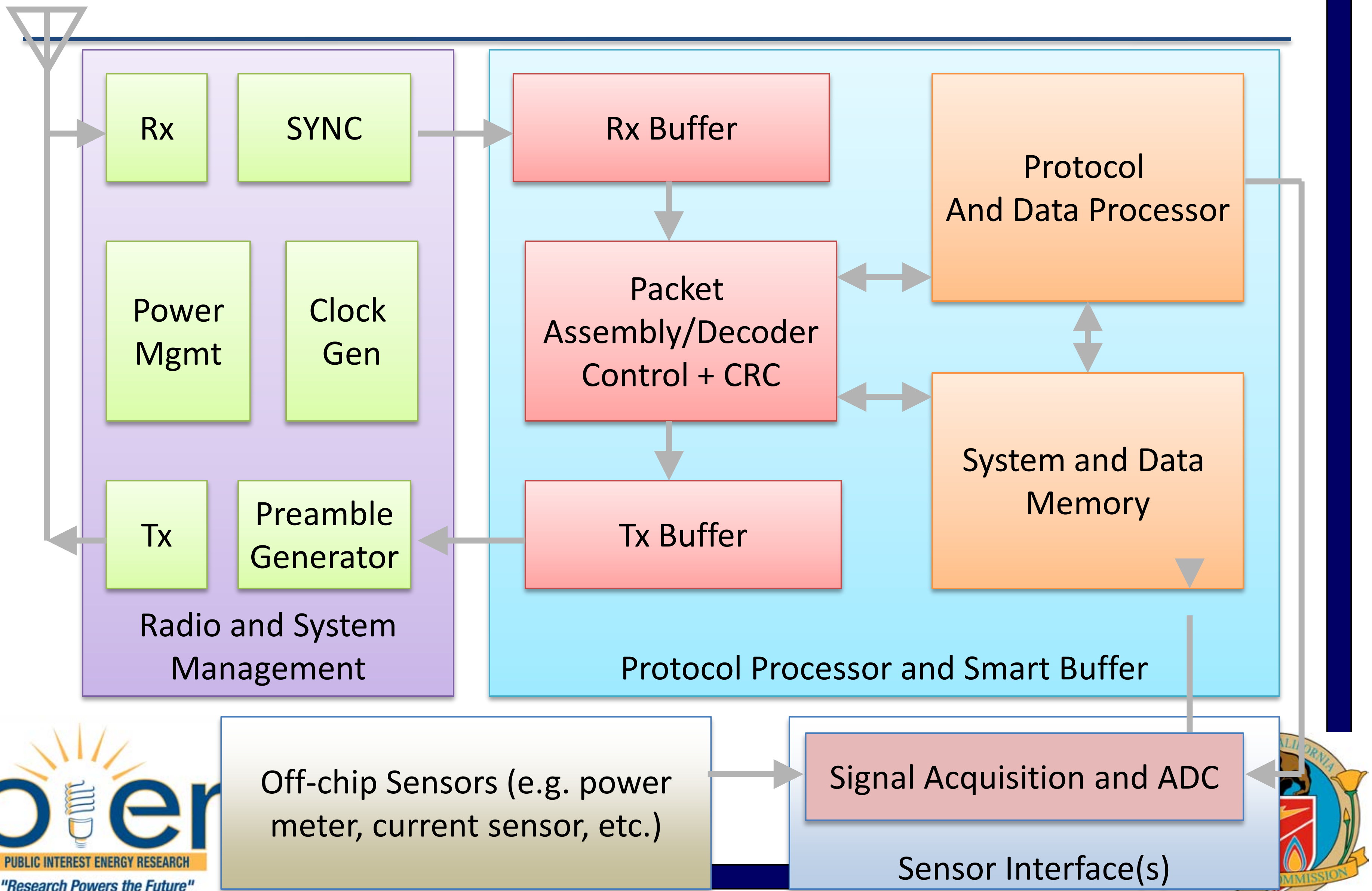
- Design contains all power management and communications circuits.
- Operates in the 2.4 GHz band providing 100kbps of data.
- System operates from an average of 10µW of power obtained by energy scavenging.

RFID Sensor Node: The 2nd Generation

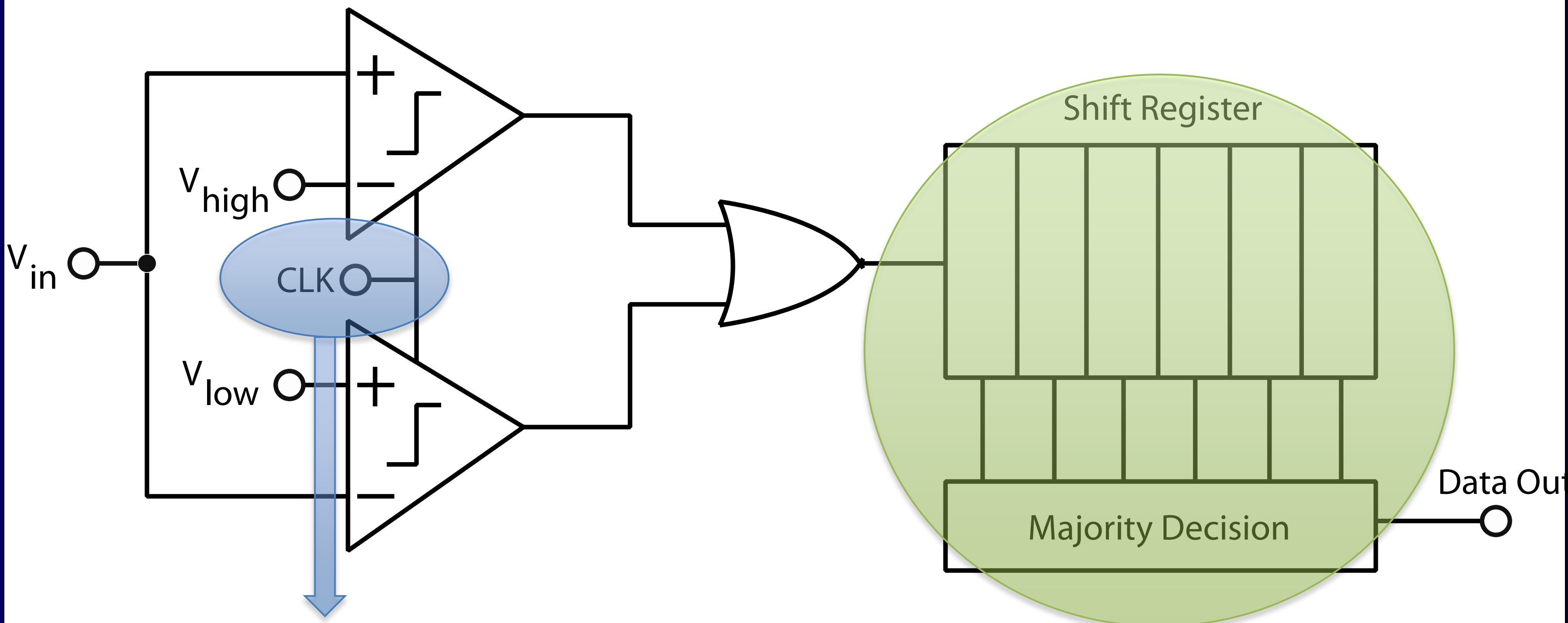
Goals: Build on first generation node to create integrated ActiveRFID Sensor node, supporting:

- Higher data rates (>1 Mbit/sec)
- Multi-channel approach offering more robustness
- One or more sensor interfaces
- On-chip data processing and data buffering
- Even further reductions in standby power (leakage control)
- **More advanced integration and co-design**
  - Integrated resonators (possibly supporting multi-channel)
  - Cost reduction through integrated passives
  - Antenna-transmitter co-design
  - Potentially closer integration with energy sources and battery

Expanded Active RFID Block Diagram



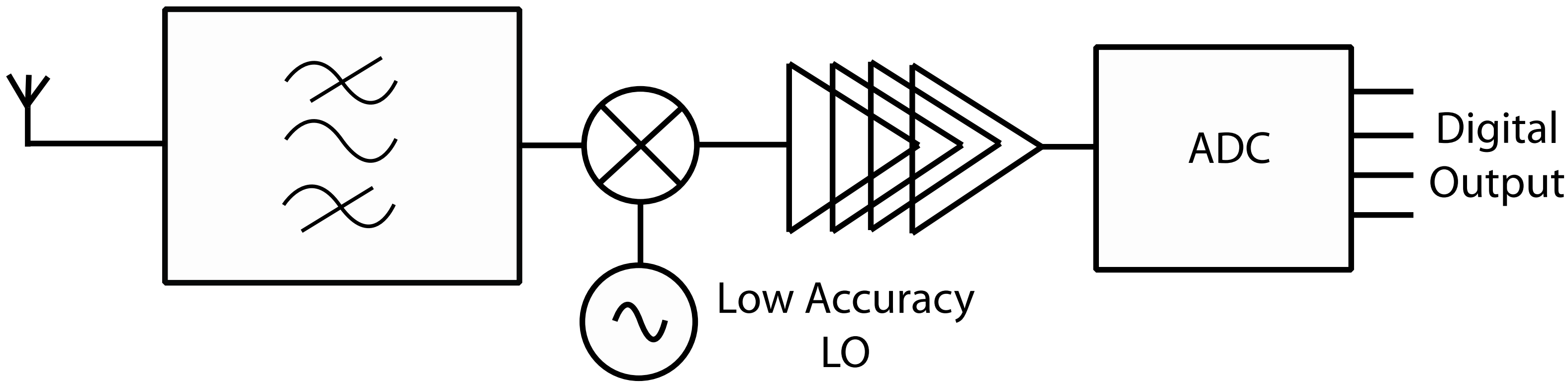
Speeding up the RX



The faster data rate will require clock rates to increase, which will burn more power in the sampling comparators.

In addition to the faster clock, more registers are needed for the majority vote. Trade-offs are being explored.

Power and Sensitivity Estimates



Block	Estimated Power
LO	15 µW
LNA	10 µW
IF Gain	10 µW
ADC / Digital	60 µW
Total:	95 µW

$$Sens. = 10 \cdot \log(kT) + 10 \cdot \log(BW_{IF}) + NF + SNR_{\min}$$

$$Sens. = -174\,dBm + 10 \cdot \log(30MHz)\,dB + 17\,dB - 1\,dB$$

$$Sens. \approx -83\,dBm$$

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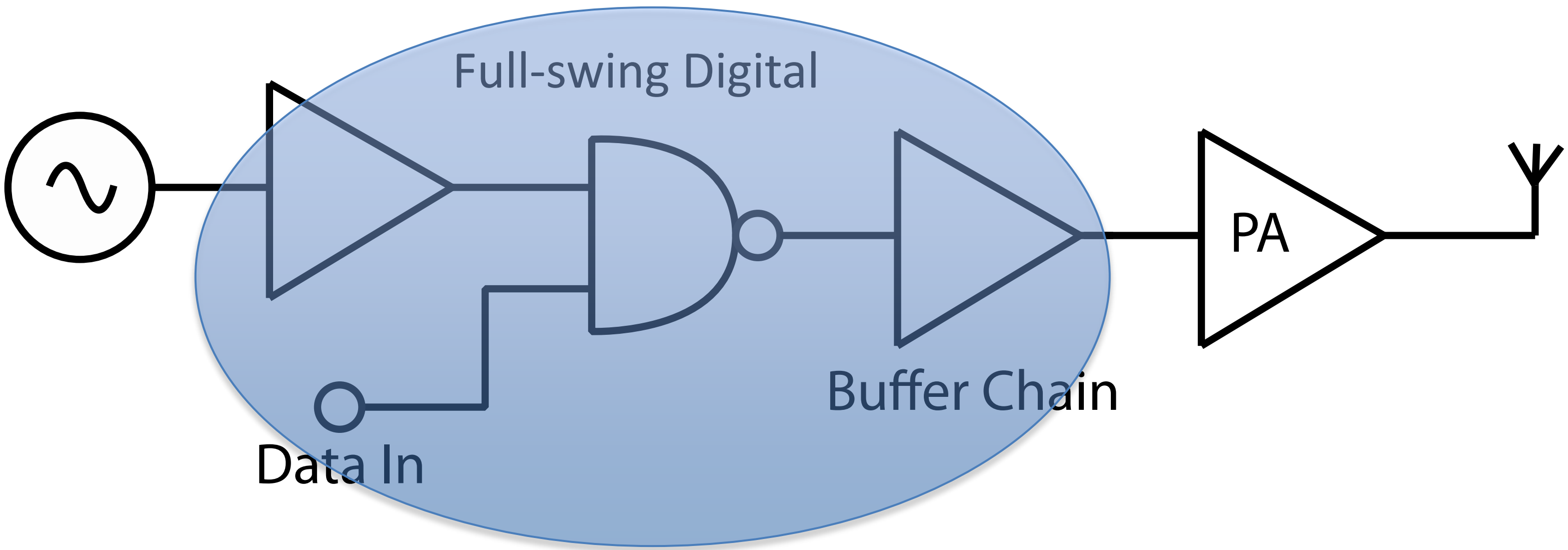
Proposed Switching PA



- Switching PAs offer higher theoretical efficiency
- Generally require more pre-PA power, but scaling has helped
- Since control is using fast digital circuits, data rate can increase

Sub-block	Power
Oscillator	50 μW
Digital & Buffer Chain	100 μW
PA Driver	900 μW

For 1 mW output power (estimated from simulation)

Towards Further Integration

- Resonators (BAW) on top of die
  - Enabling multi-band radios
- Reducing regulator area by 2.5D capacitance
  - In collaboration with industrial partners
- Alternative energy storage options
- Alternative scavenging approaches

A First Timeline

- End 2011:
  - Critical blocks designed
  - System design and architecture completed
- Tape-out targeted late spring 2012
- Complete prototype assembled by end 2012

Summary

- A first version of a fully integrated self-contained active RFID tag has been fabricated – testing is ongoing
- Fully functional first generation prototype expected by end of the year
- Conceptual work on the second generation incorporating a sensor interface, improving the radio and reducing the power consumption has started

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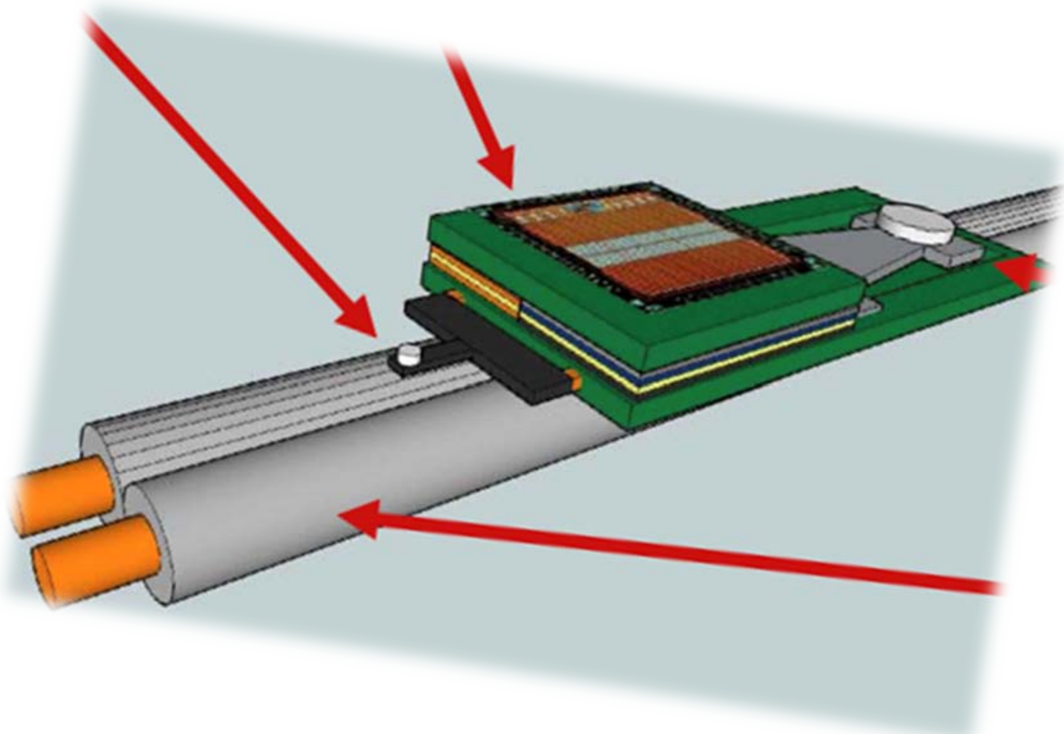

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Acknowledgements

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