Ultra-Low Power Radios for Sensing and Asset Management

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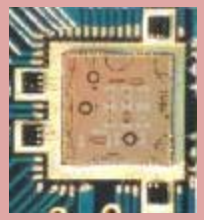
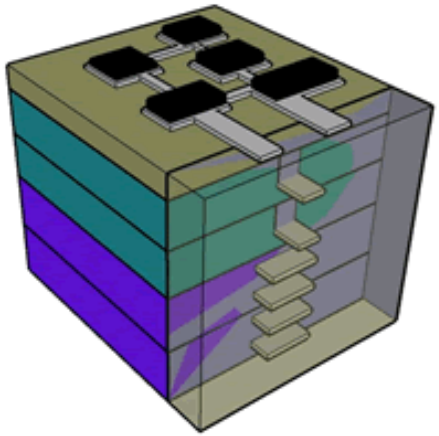
Tsung-Te Liu, Jesse Richmond, Wenting Zhou, Jan Rabaey

Wireless Sensor Node

Low Power Radio





"Picocube"

Power Storage

Sensor

Renewable Power

Supply

Our Radios

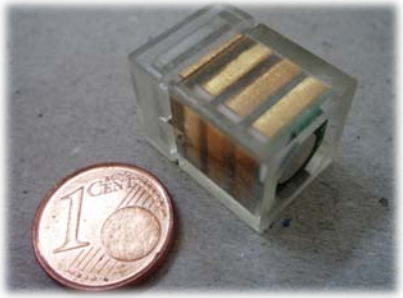
- Consume 2 orders of magnitude less power than commercial radios
- Enable small wireless sensing nodes powered purely by energy scavenging
- Can communicate over more than 10 m indoors at 100 kbps datarates
- Are a perfect match for Wireless Sensor Network (WSN) or active RFID applications

Innovations in ULP Radios

FBAR MEMS Resonator

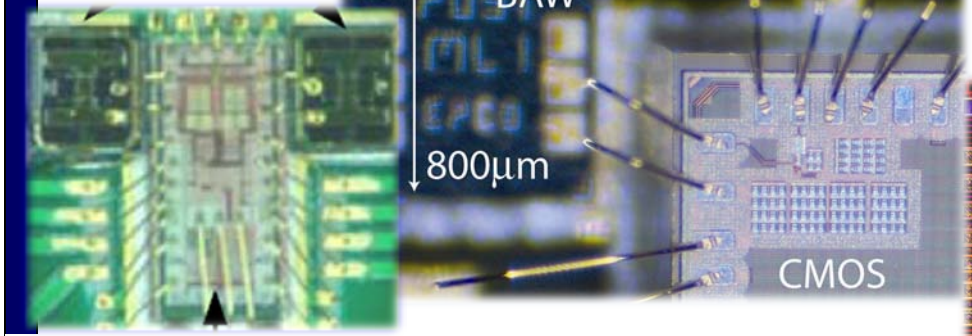
(Avago Technologies)

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



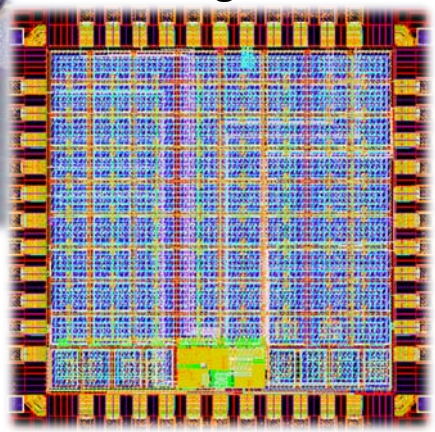
UCB PicoCube

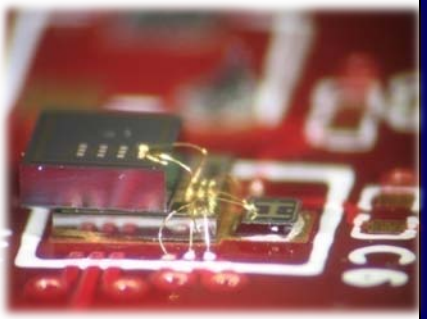
Transmitter



Receiver

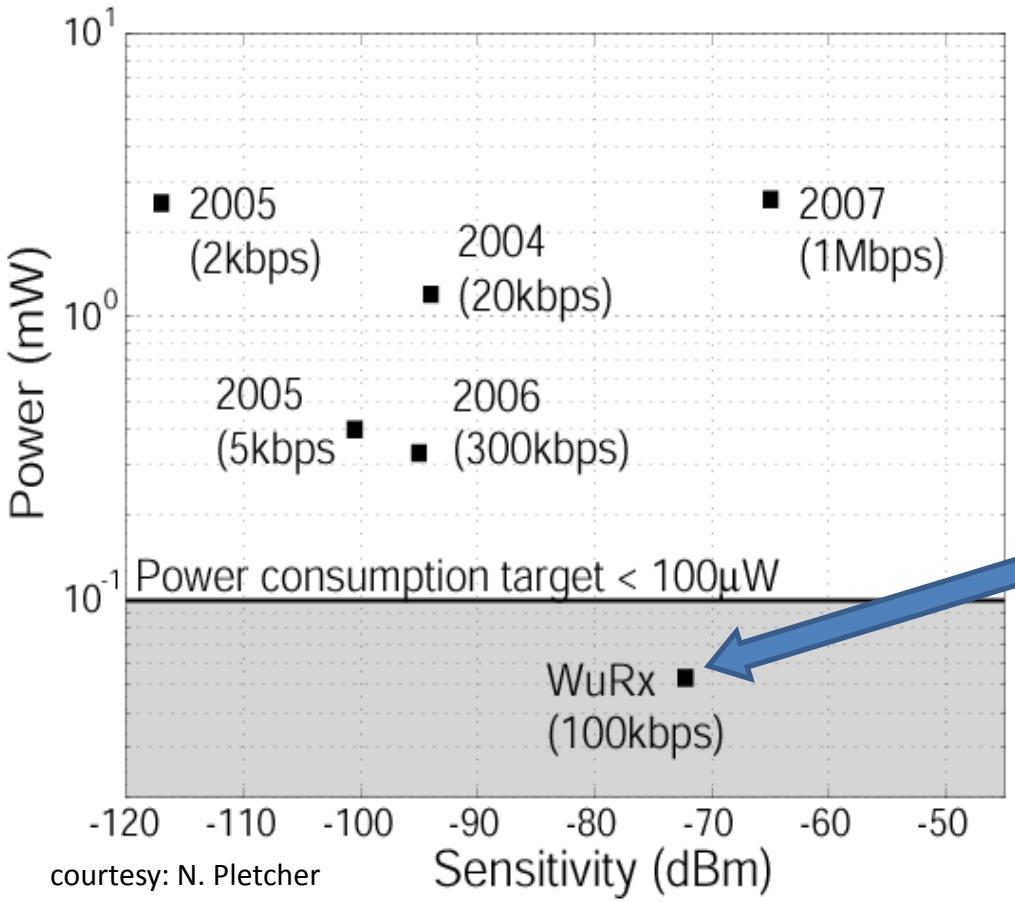
Voltage converter and regulator





UCB mm^3 radio

A 50 µW Receiver

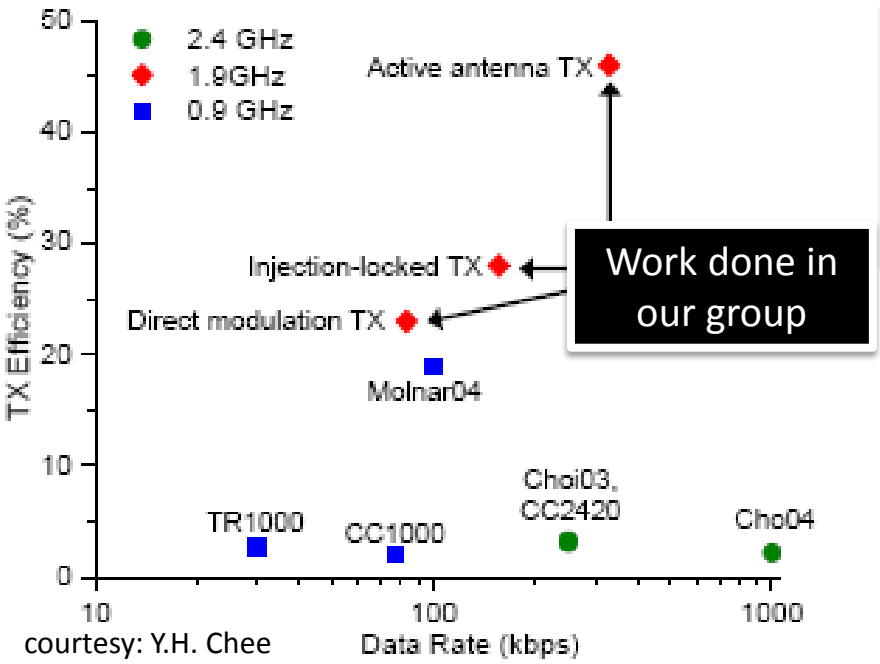


courtesy: N. Pletcher

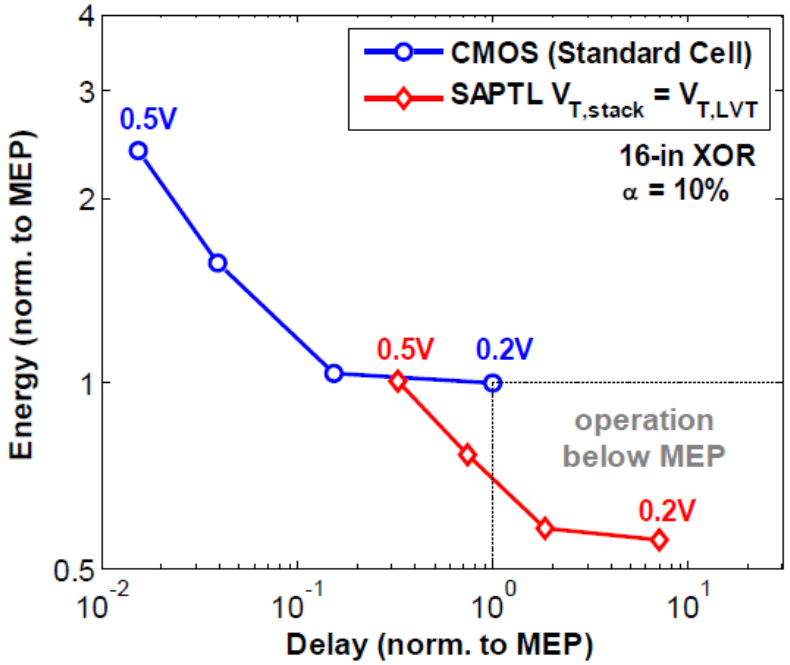
Nominal datarate	100 kbps
Sensitivity	-72 dBm
Total power dissipation	52 µW

Enabled by innovative use of scaled CMOS and MEMS technology

Transmitter and Baseband Logic



- Transmitting 1mW (0 dBm) with an efficiency of close to 50 % utilizing MEMS

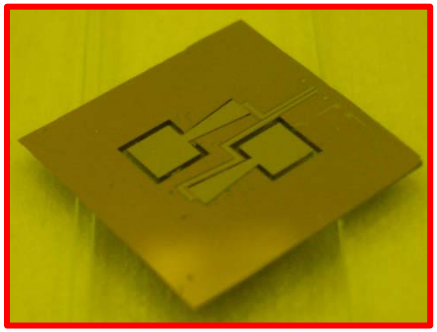


- Novel logic family to extend region of operation below minimum energy/operation point of conventional CMOS

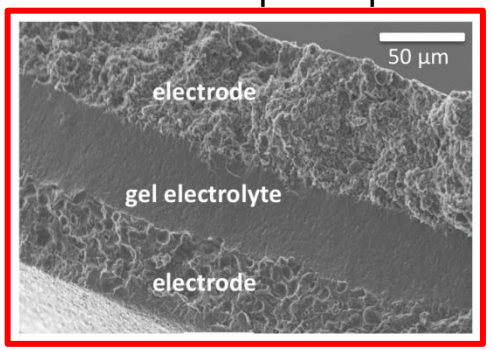
Ultimate Integration: Active RFID

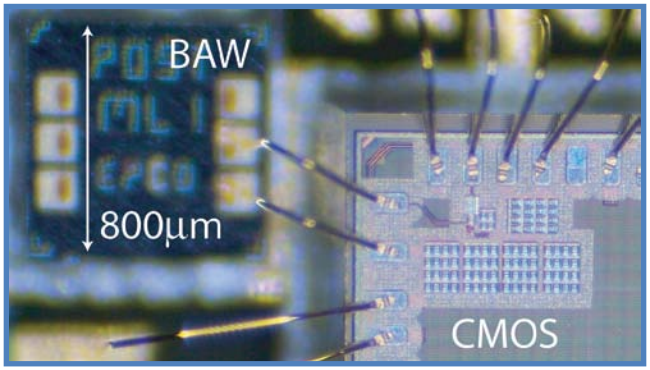
A fully integrated, self-powered active RFID tag based on our low power receivers and transmitters, low-voltage logic, innovative power management, efficient integrated energy harvesting and conversion, as well as thick-film printed energy storage technologies

Microfabricated energy harvester

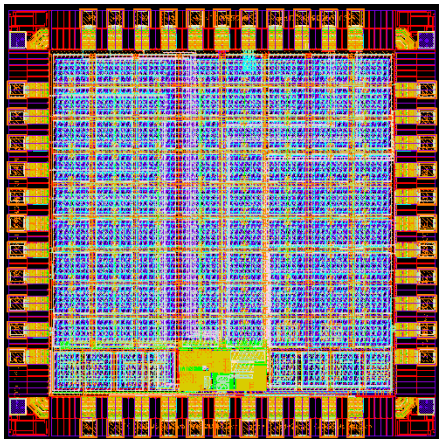


Printed super-cap



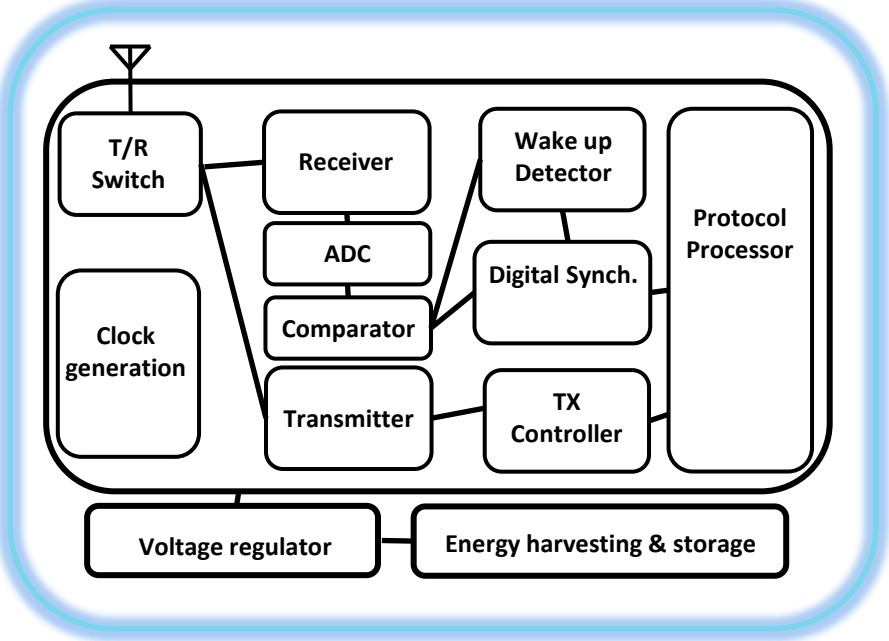


Low power radio



Voltage converter and regulator

Specifications (Target)



- Fully integrated
- Postage stamp size
- Communication range >10 m
- Datarate of 100 kbps
- Fully compatible with RFID link and MAC specification

- Can operate indefinitely (for 24 hours/day) from single solar cell – average power dissipation on the order of µWs

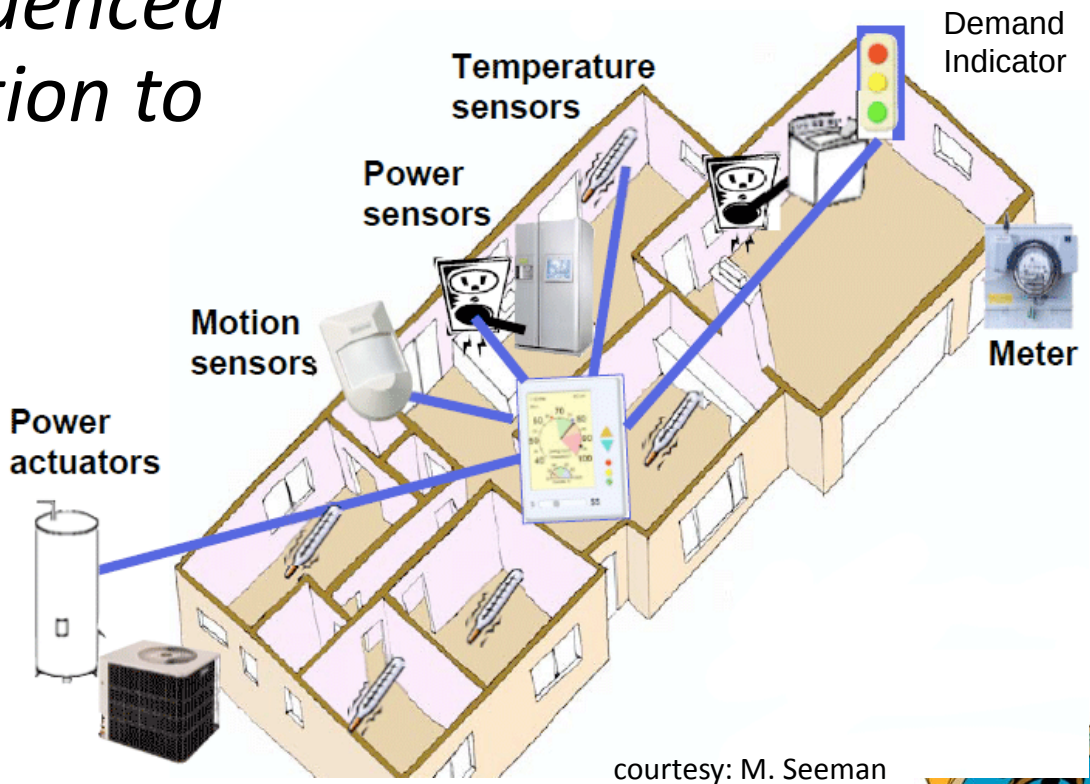
Enables querying from portable mobile devices (e.g. cell phones), or from a deployed network (such as WiFi)

Applications: Smart Buildings

- *"Nearly 70% of the average household utility bill could be influenced by WSN application to temperature and lighting"*

  WSN Technology
  Trends Report July 2009

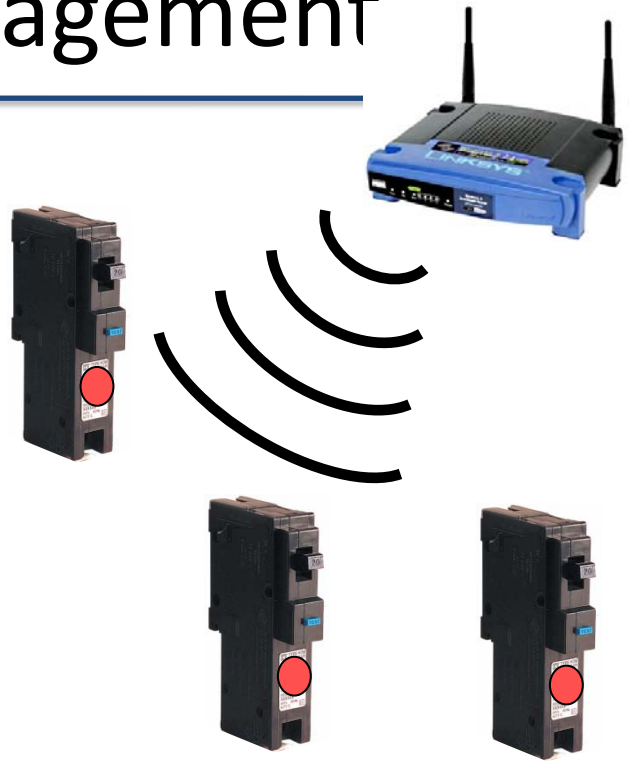
- Huge potential to reduce peak energy demand

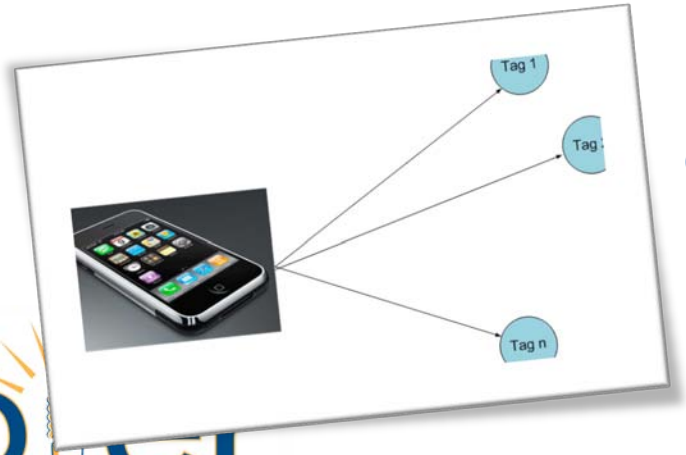


courtesy: M. Seeman

Utilities Asset Management

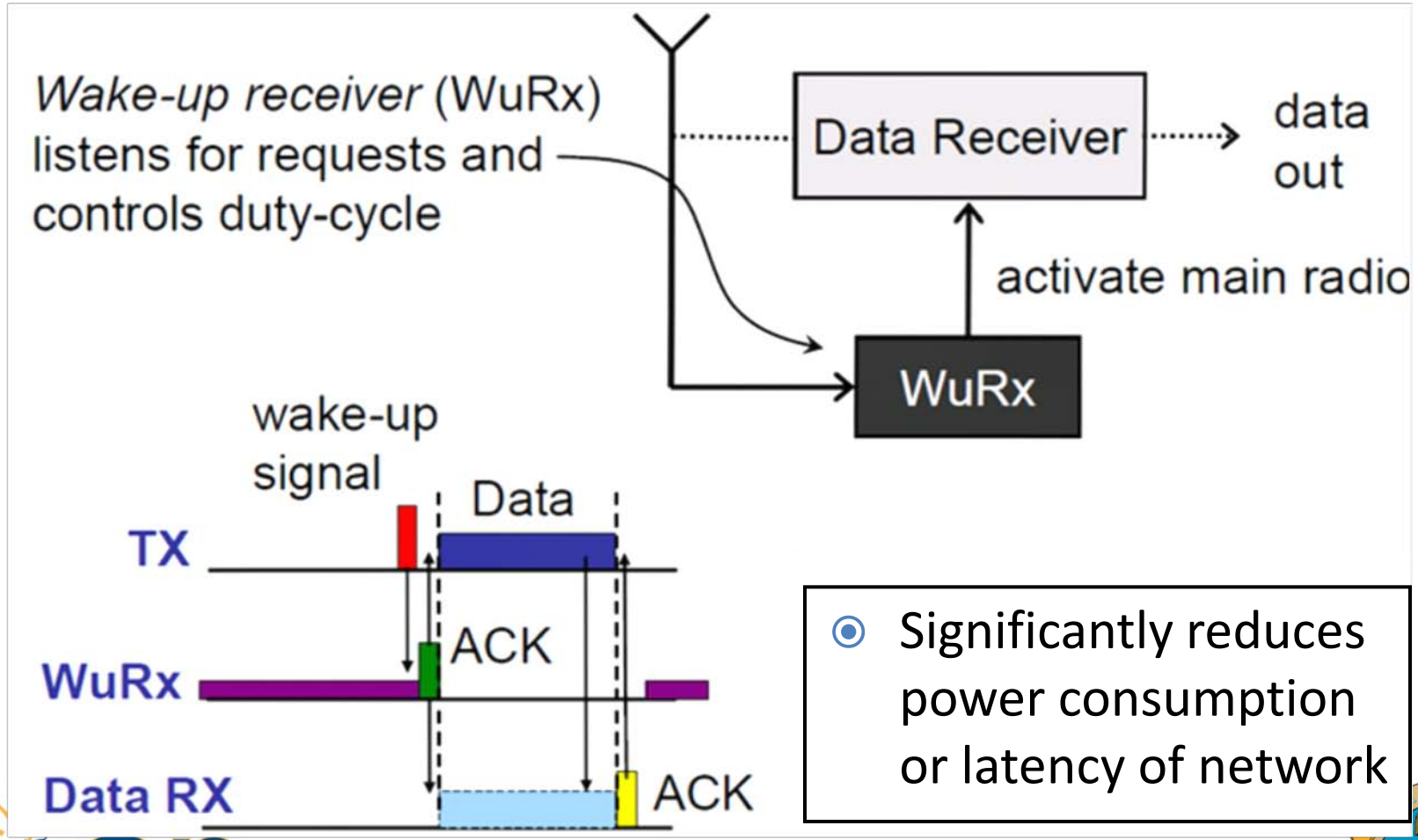
- Monitor devices and infrastructure
  - fuses, fault indicators, etc.
- Retrofitting existing equipment using self–powered active RFID tags
  - easy to deploy
  - utilize existing infrastructure and / or low power handheld devices to poll tags
  - smaller and cheaper than WSN nodes





- Obviously applicable to asset management in the broad sense (warehouses, stores, containers, etc)

Wake-up Receiver:
Lower Power - Lower Latency



- Significantly reduces power consumption or latency of network

courtesy: N. Pletcher

We have developed Ultra-Low Power Radios that

- Enable small wireless sensing nodes powered purely by energy scavenging
- Are easy to deploy and can use existing infrastructure
- Can communicate over more than 10 m indoors
- Are perfectly suitable for Wireless Sensor Network and active RFID – like applications

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Acknowledgements

- California Energy Commission
- STMicroelectronics
- Avago Technologies
- GSRC
- BWRC Member Companies
- NSF Infrastructure Grant No. 0403427

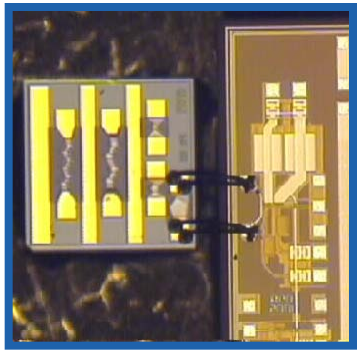
Back-up

Summary

- Receiver (Uncertain IF)
  - 50 µW @ 0.5 V (100 kbps, < - 80 dB Sensitivity)
- Transmitter (Active Antenna)
  - P_{TX} ≈ 0 dBm (1 mW) @ 46 % efficiency (330 kbps, 50% OOK data)
  - < 2 µW in sleep mode
- Active RFID (target)
  - self-powered (no need to replace batteries)
  - average power consumption < 10 uW

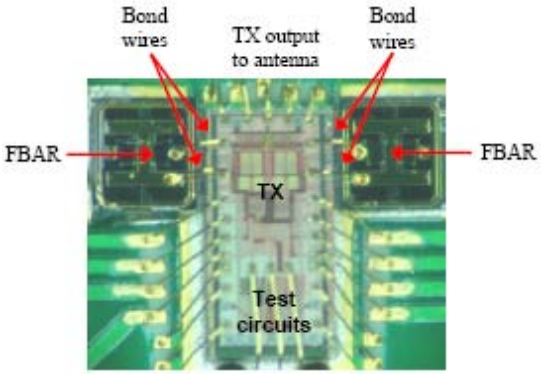
(Condensed) Radio History in Our Group

FBAR-based low power oscillator



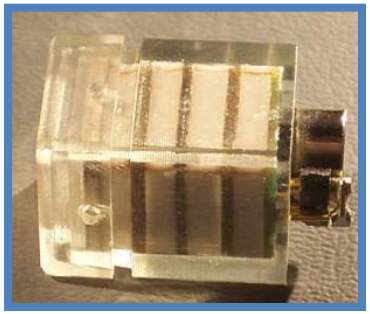
ESSCIRC 2002 (Otis)

Active Antenna Transmitter



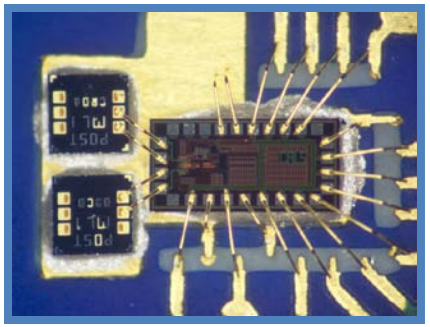
VLSI 2006 (Chee)

PicoCube



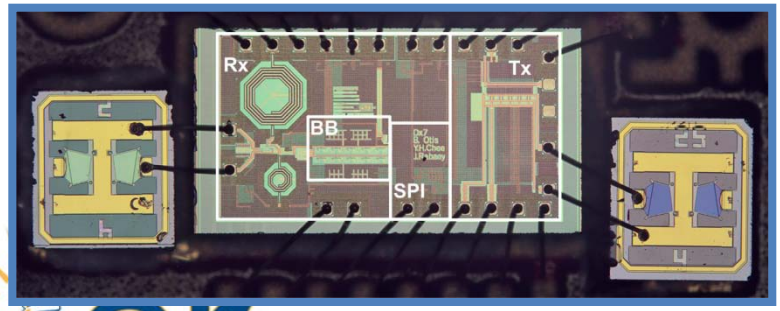
ISSCC / DAC 2008 (Burghardt et al)

Interpolative FBAR VCO



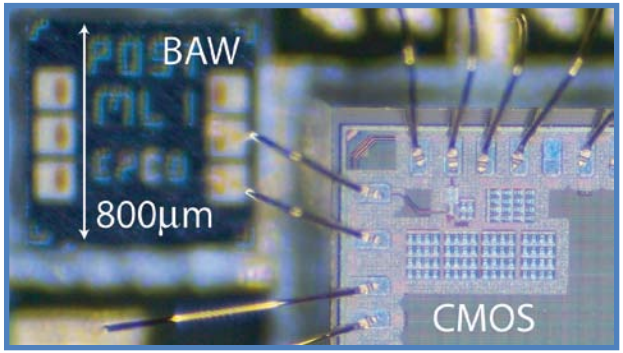
ISCAS 2009 (Mark)

Super-Regenerative Transceiver



ISSCC 2005 (Otis /Chee)

Wakeup Receiver



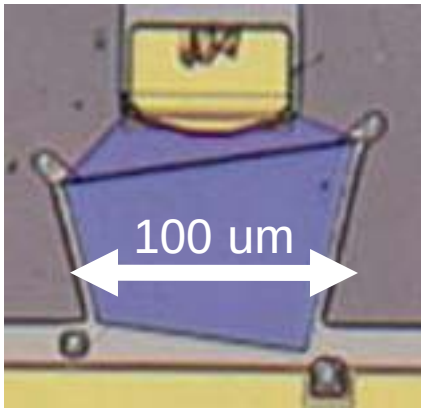
ISSCC 2008 (Pletcher)

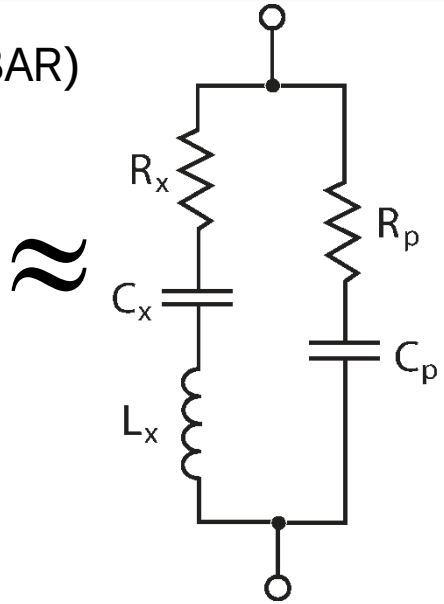
PUBLIC INTEREST ENERGY RESEARCH
"Research Powers the Future"

STATE OF CALIFORNIA ENERGY COMMISSION

Bulk Acoustic Wave Resonator (BAW)

Avago 1.9 GHz BAW (FBAR)

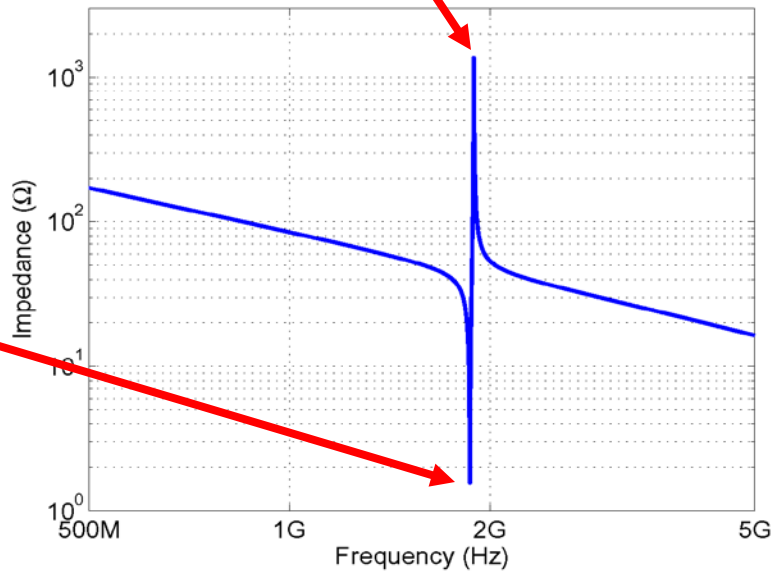




$$f_{parallel} = f_s \times \sqrt{1 + \frac{C_x}{C_p}}$$

$$Q_{parallel} = Q_s \times \frac{R_x}{R_x + R_P}$$

Simulated BAW impedance response



$$f_{series} = \frac{1}{2\pi\sqrt{L_x \times C_x}}$$

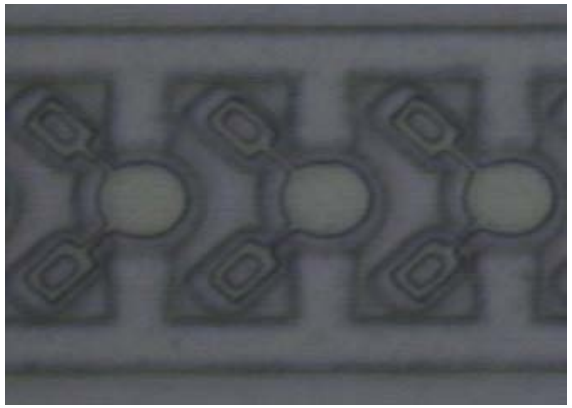
$$Q_{series} = \frac{2\pi \times f_{series} \times L_x}{R_x} = \frac{1}{2\pi \times f_{series} \times R_x C_x}$$

PUBLIC INTEREST ENERGY RESEARCH
"Research Powers the Future"

Pushing the Limits Even Further

- Moving towards 2.4 GHz ISM band

- Novel MEMS resonators
  - electrostatic resonators
  - -90 dBm sensitivity at 50 uW



- Microscopic radios
  - 1x1 mm passive, high data-rate radios (incl. antenna)