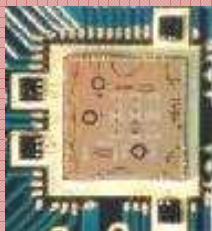


Next Generation of Fully Integrated Ultra-Low Power Radios

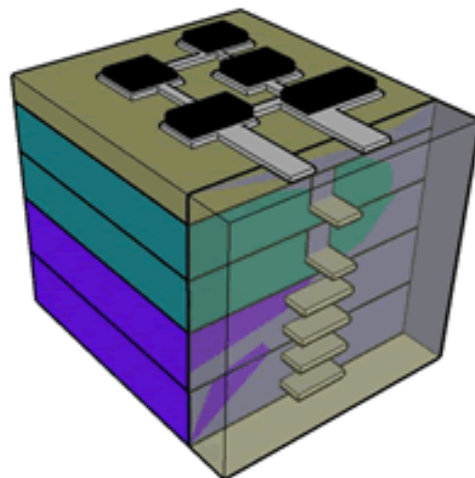
Michael Mark, Wenting Zhou, Wen Li,
Jesse Richmond, Jan Rabaey

Wireless Sensor Node

Low Power Radio



Power Storage



"Picocube"

Sensor



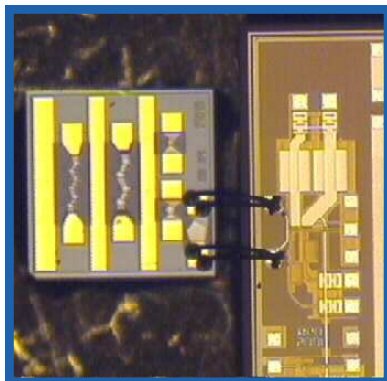
Renewable Power



Supply

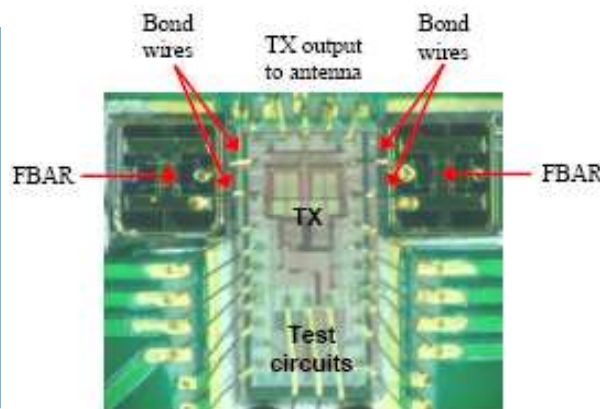
(Condensed) Radio History in Our Group

FBAR-based low power oscillator



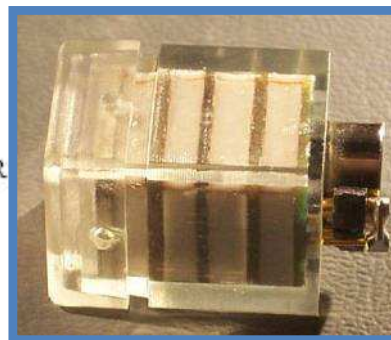
ESSCIRC 2002 (Otis)

Active Antenna Transmitter



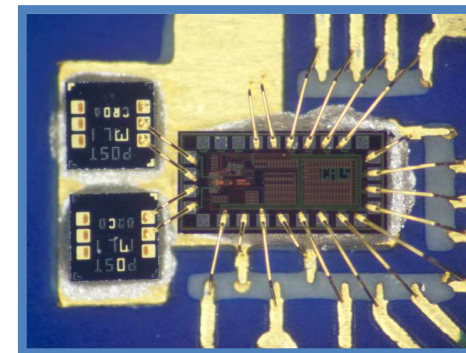
VLSI 2006 (Chee)

PicoCube



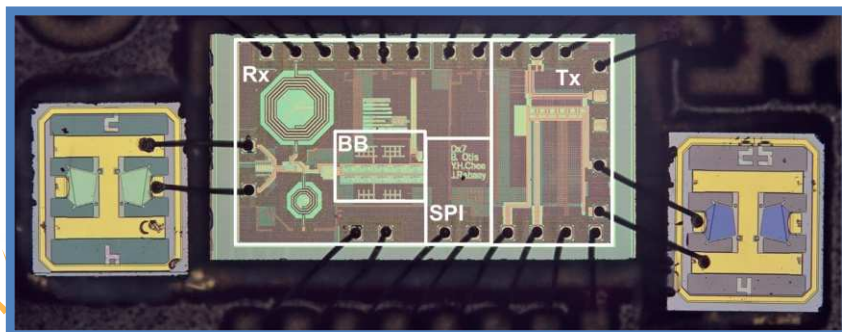
ISSCC / DAC 2008 (Burghardt et al)

Interpolative FBAR VCO



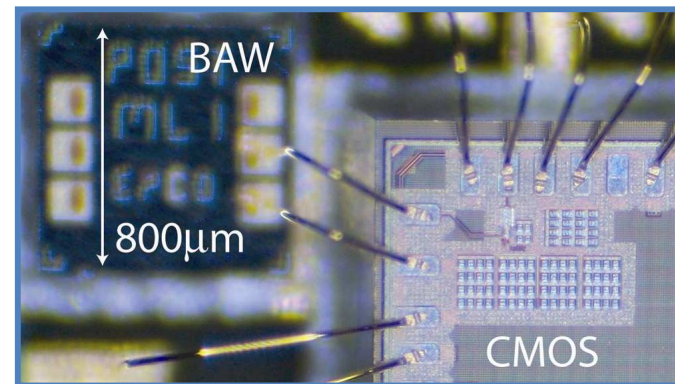
ISCAS 2009 (Mark)

Super-Regenerative Transceiver



ISSCC 2005 (Otis /Chee)

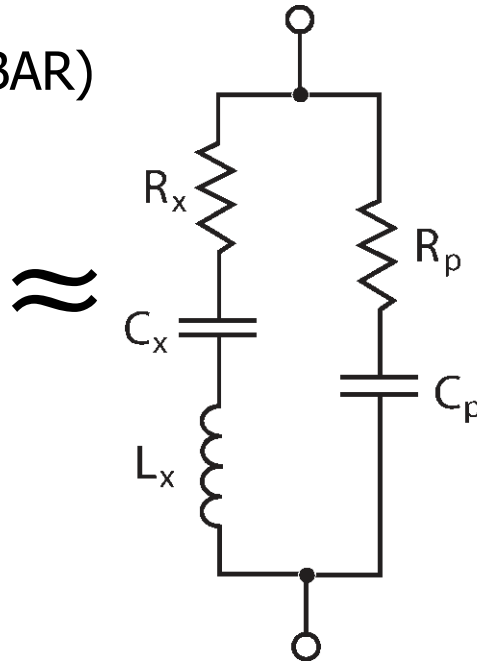
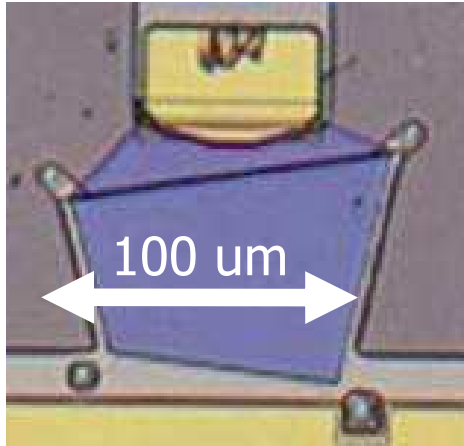
Wakeup Receiver



ISSCC 2008 (Pletcher)

Bulk Acoustic Wave Resonator (BAW)

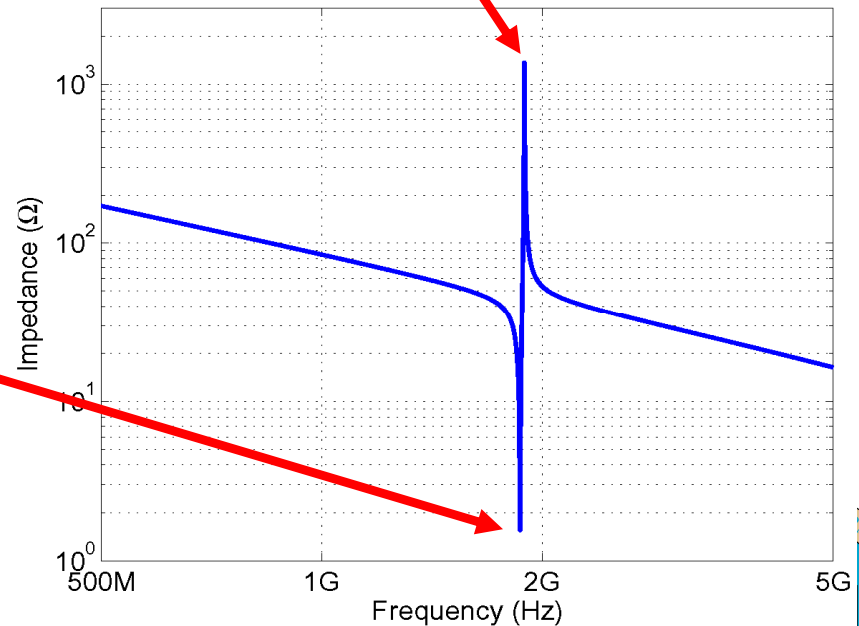
Avago 1.9 GHz BAW (FBAR)



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

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

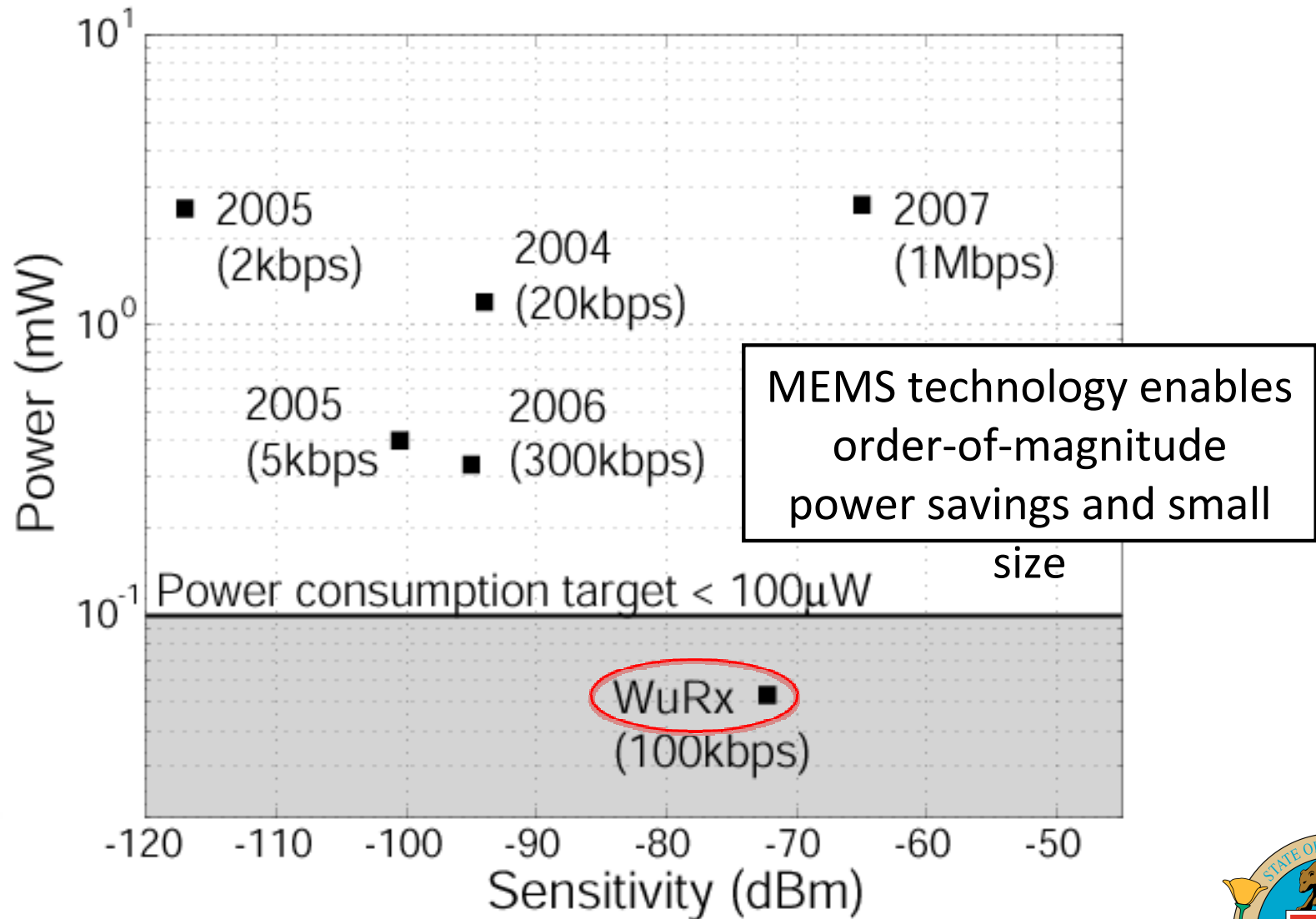
Simulated BAW impedance response



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

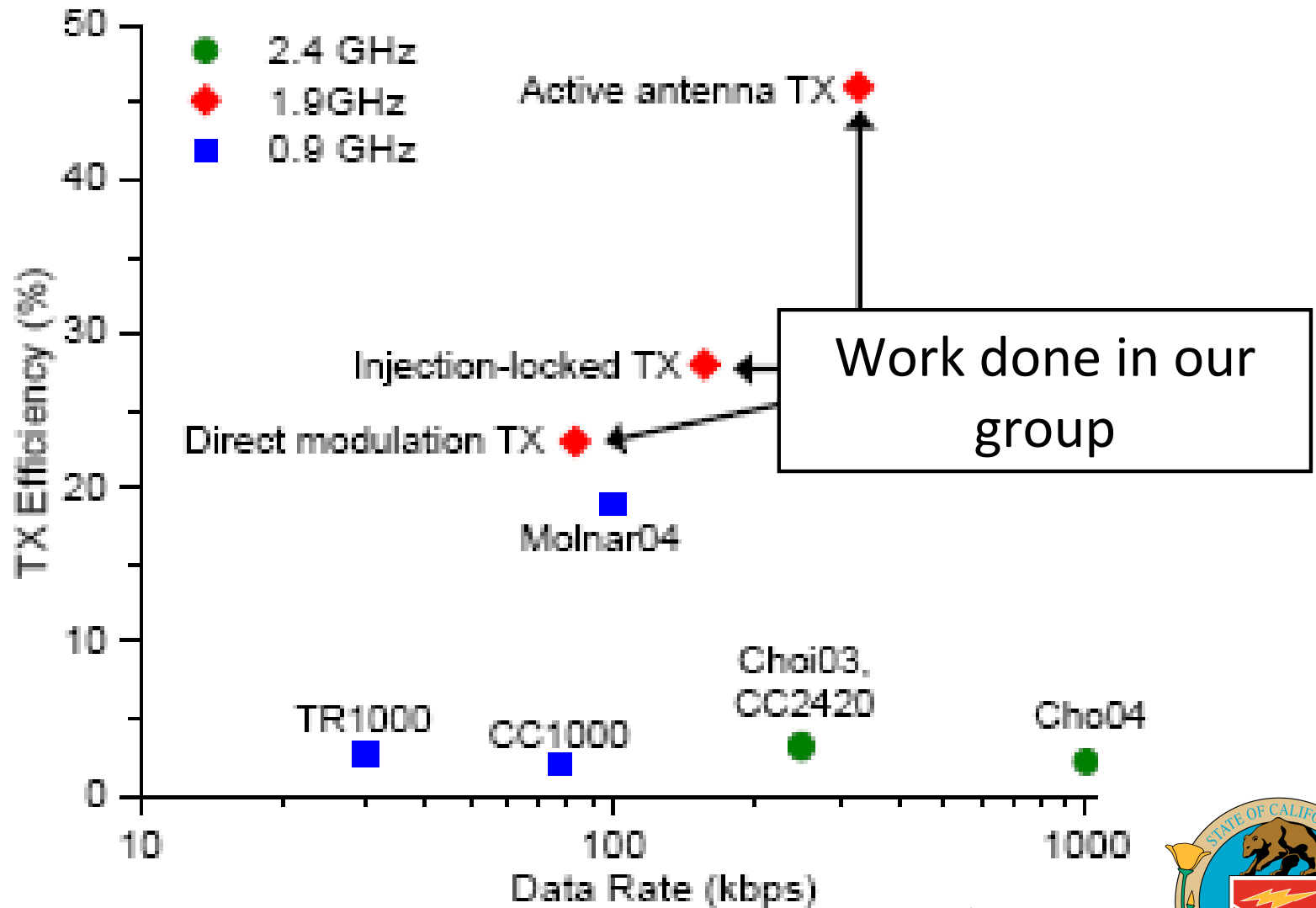
$$Q_{series} = \frac{2\pi \times f_{series} \times L_x}{R_x} = \frac{1}{2\pi \times f_{series} \times R_x \times C_x}$$

Breaking New Ground in ULP Receivers ...



N. Pletcher 2008

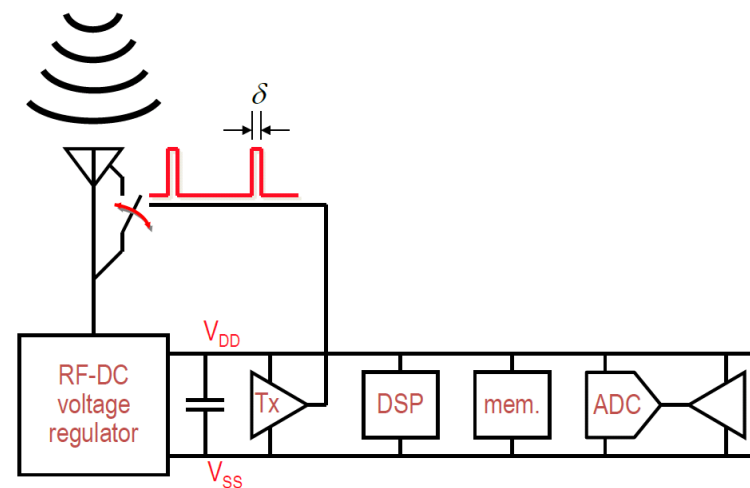
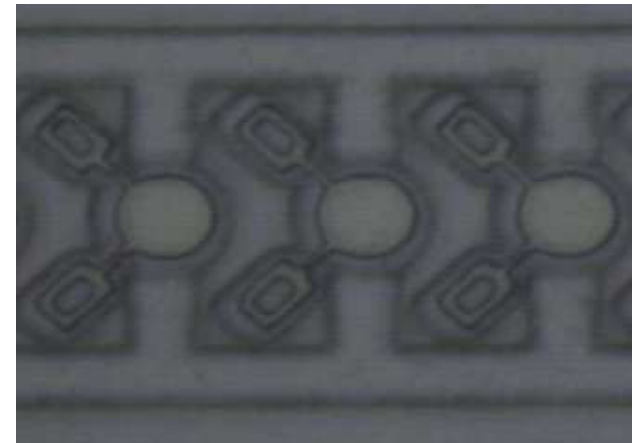
... and Transmitters



Y. Chee 2006

Pushing the Limits Even Further

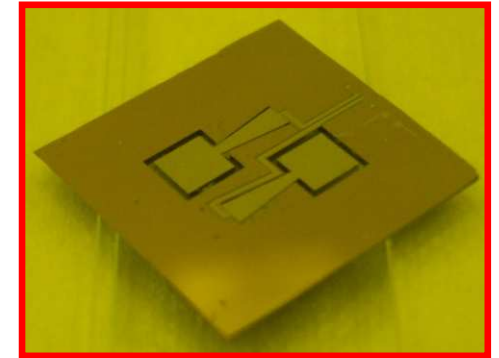
- Moving towards 2.4 GHz ISM band
- Novel MEMS resonators
 - electrostatic resonators
 - -90 dBm sensitivity at 50 μ W
- Microscopic radios
 - 1x1 mm passive, high data-rate radios (incl. antenna)



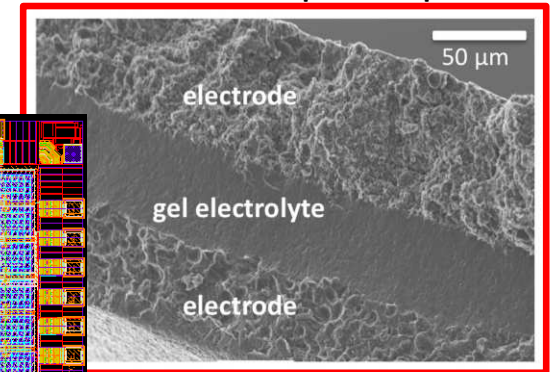
Ultimate Integration: Active RFID

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



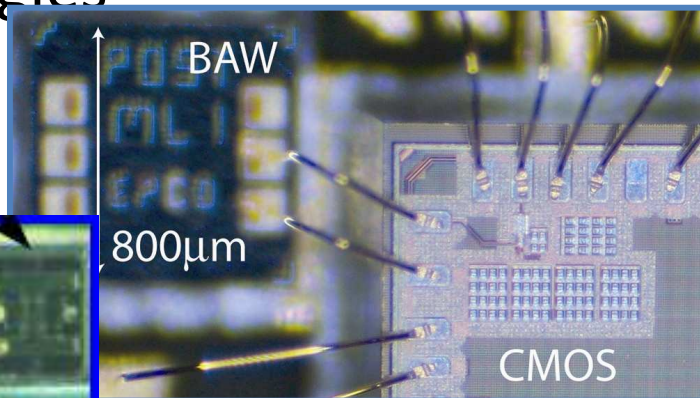
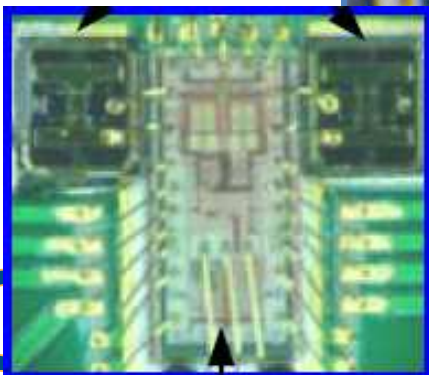
Printed super-cap



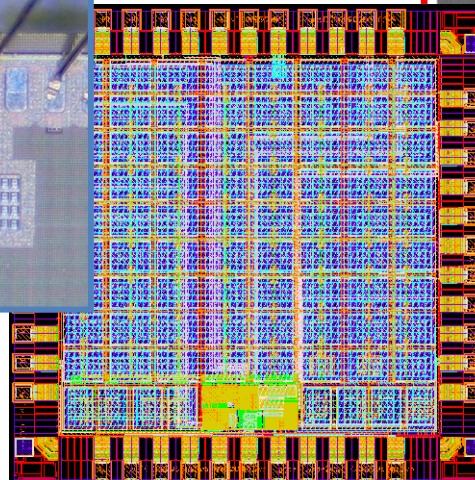
Voltage converter and regulator



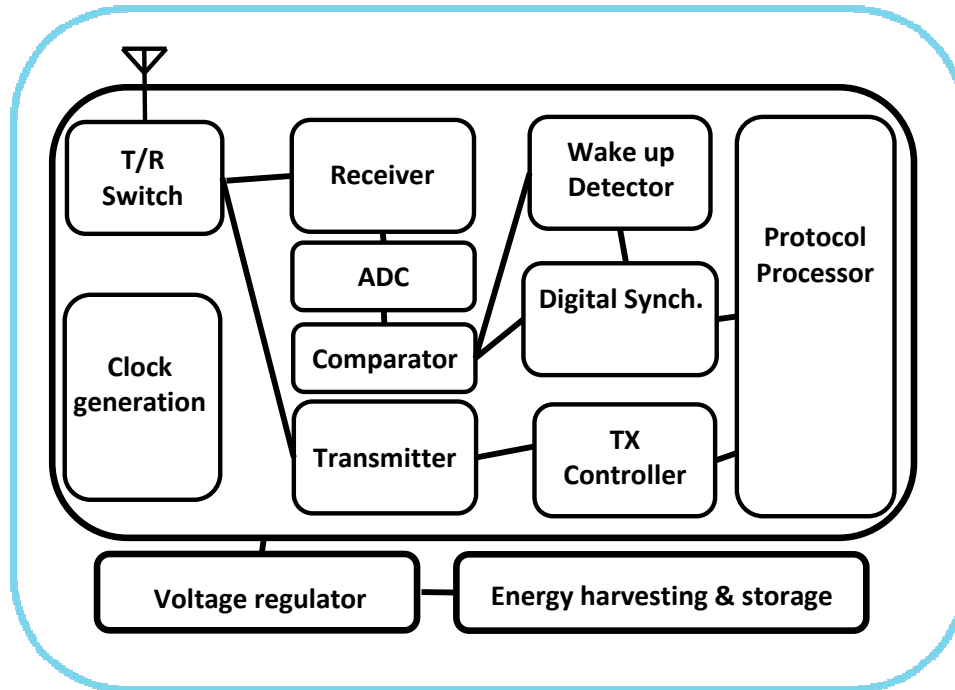
TX



WuX RX



Specifications (Target)



- Fully integrated
 - Postage stamp size (while only mm's thick)
 - Operates in 2.4 GHz ISM band
 - 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 μ Ws**

Summary

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

Acknowledgements

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