Reducing Communication Cost in Demand Response Systems

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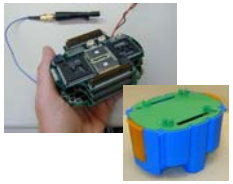
PicoRadio Evolution

Radio (Rabaey/BWRC)

Traditional Radio

PicoRadio - 2002



PicoRadio - 2003

PicoRadio - 2004

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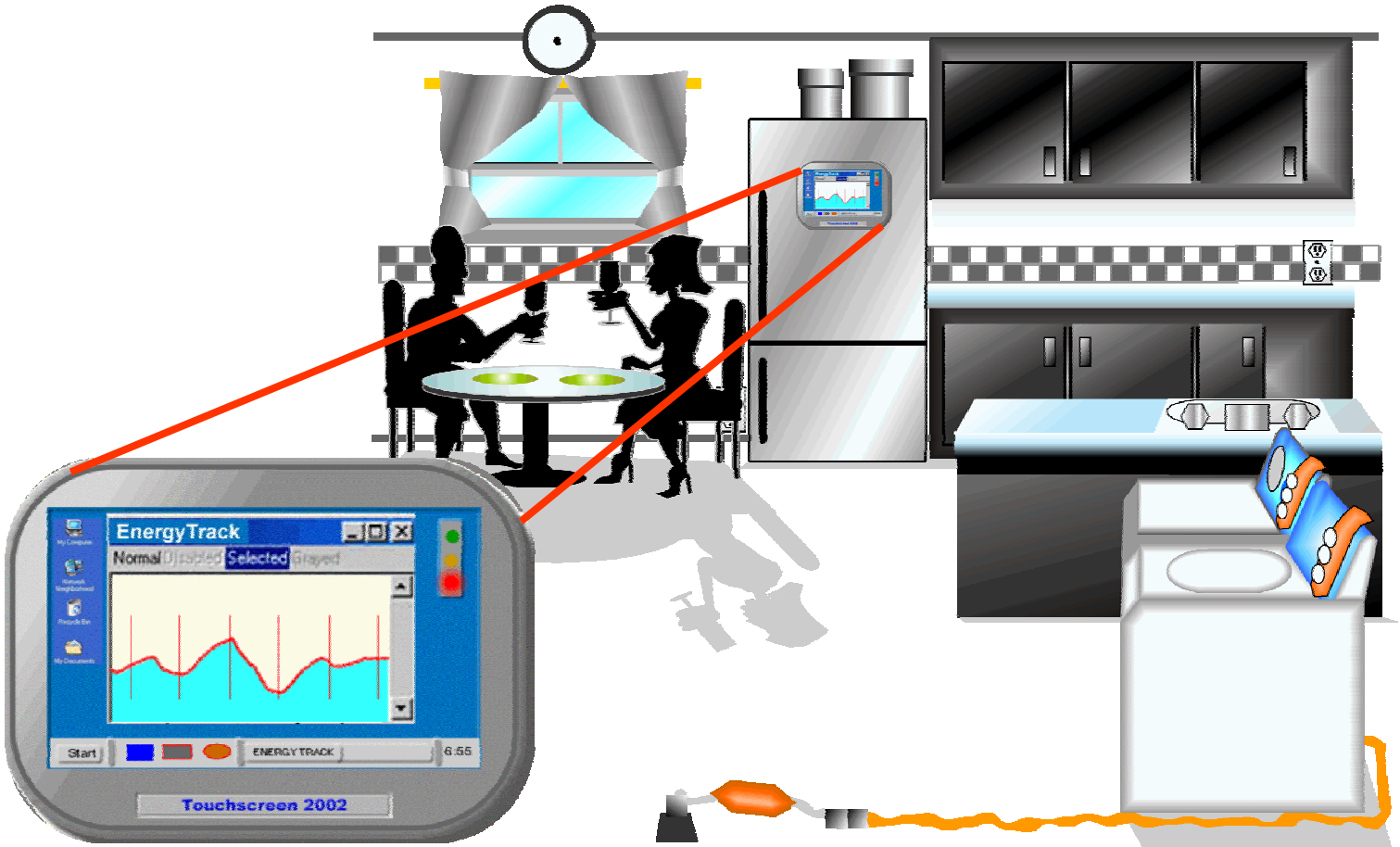
The Energy-Aware Home (Demand Response)



At the core: network of low-cost low-power wireless nodes

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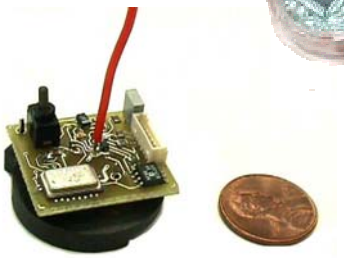
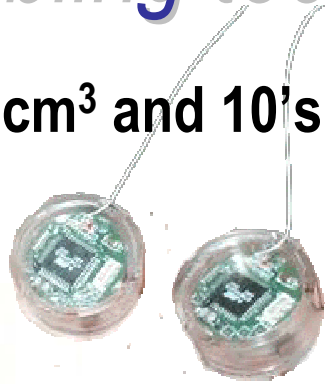
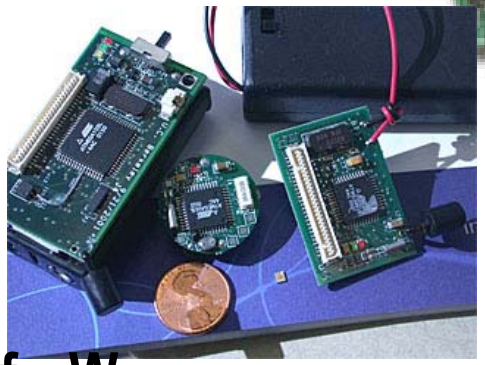
The enabling technology is or will be there

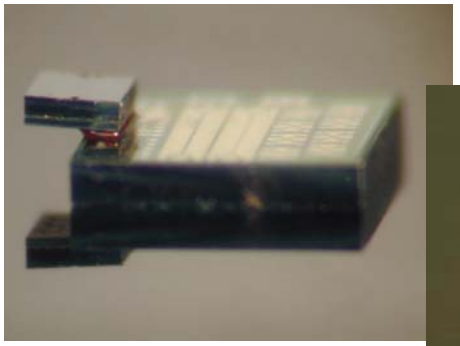
From 10's of cm^3 and 10's to 100's of mW

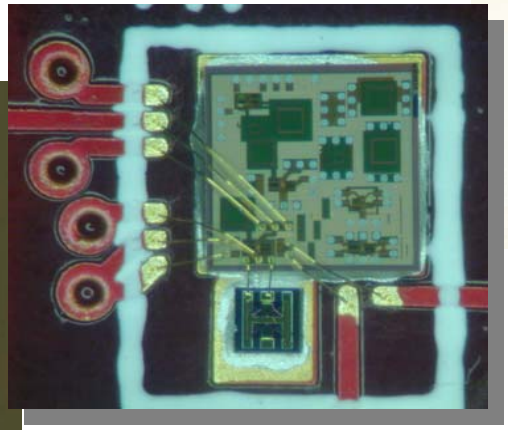


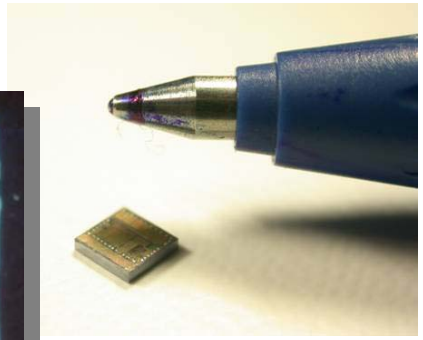




To 10's of mm^3 and 10's of μW







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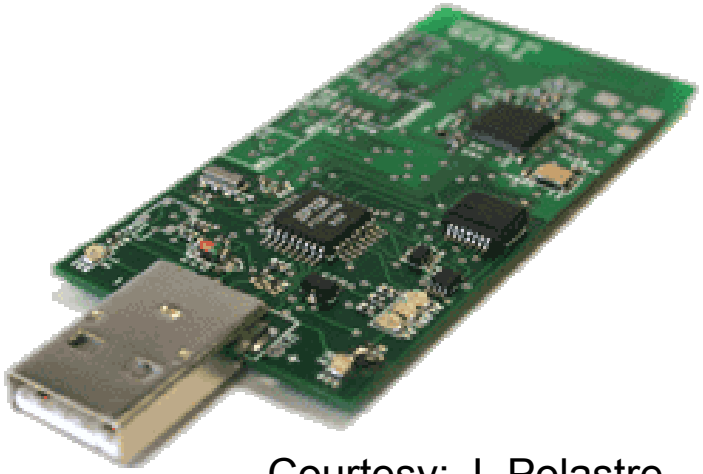
Telos: A Platform for Prototyping

Developed by D. Culler group (NEST)

- **A new platform for low power research**
  - Monitoring applications:
    - Environmental
    - Building
    - Tracking
- **Long lifetime, low power, low cost, integrated sensors**
- **Adavnatages over current Mica platform?**
  - Oscillator start up times, oscillator noise, and operating/sleep current too high
  - Instead leverage 802.15.4 low power operation and new MCUs

- **Standards Based**
  - IEEE 802.15.4
  - USB
- **IEEE 802.15.4**
  - CC2420 radio
  - 250kbps
  - 2.4GHz ISM band
- **TI MSP430**
  - Ultra low power
    - 1.6μA sleep
    - 460μA active
    - 1.8V operation
- **TinyOS support**



Courtesy: J. Polastre

Currently used for real-world prototypes of protocol stacks and applications

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PicoRadio's — The Mission

Meso-scale low-cost radio's for ubiquitous wireless data acquisition that

- are fully integrated
  - –Size smaller than 1 cm^3
- are dirt cheap
- minimize power/energy dissipation
  - – Limiting power dissipation to 100 μW enables energy scavenging
- and form self-configuring ad-hoc networks containing 100's to 1000's of nodes

Pushing the limits ever further!

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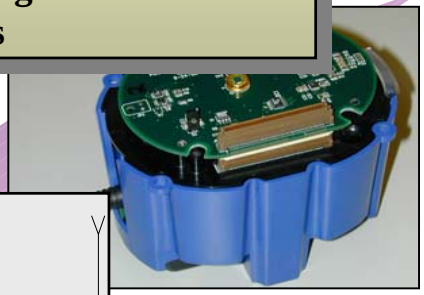
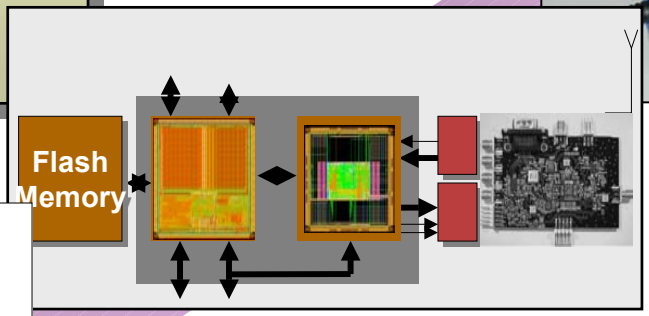
PicoRadio Past Roadmap

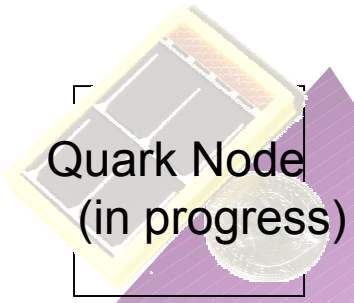
PicoNode I: 450 mW Baseline
- StrongArm/FPGA trade-off
- Dynamic voltage scaling and multiple power modes



PicoNode II: 20 (+ 50) mW
- System-on-a-chip integration
- State-of-the-art embedded IP
- "just-the-right-performance"
- extensive concurrency
- Aggressive clock-gating
- Advanced design methodology



PicoBeacon ~ 3 mW
- Energy-aware system design
- Reactive inter-chip and intra-chip communication
- Automatic power-down and leakage control
- Chip-Supervisor/Power manager
- "Mostly" passive RF front-end



300 cm^3

Size

10 cm^3

1mW

Avg. Power

500 mW

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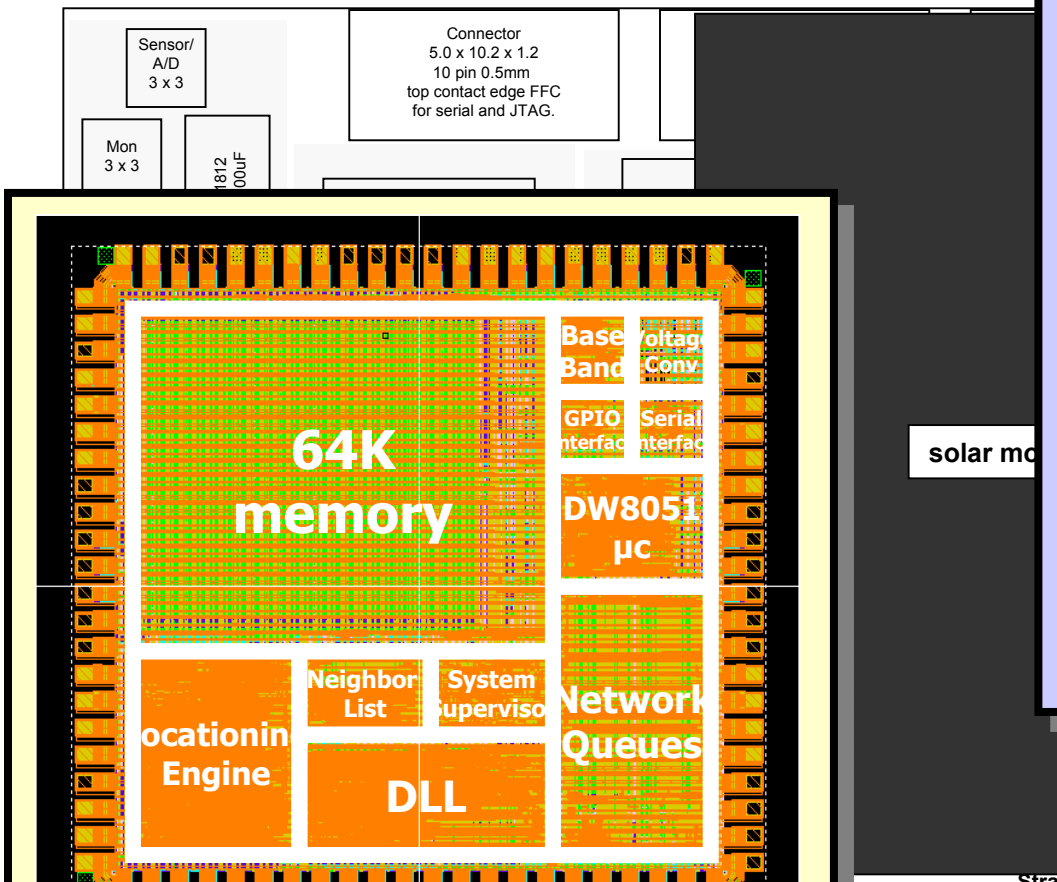
The Quark Node (expected late summer)

Board under design

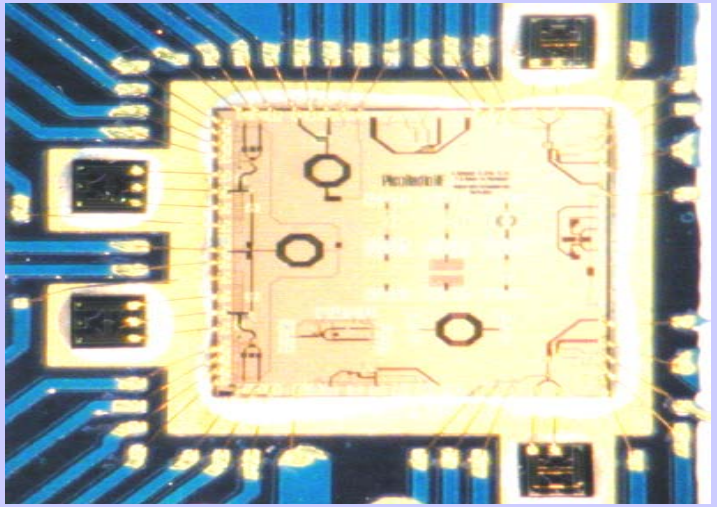
58 x 33 mm

Scale: 0.15” = 1mm



Charm: due back from fab

Fully integrated sensor processor (< 1 mW)

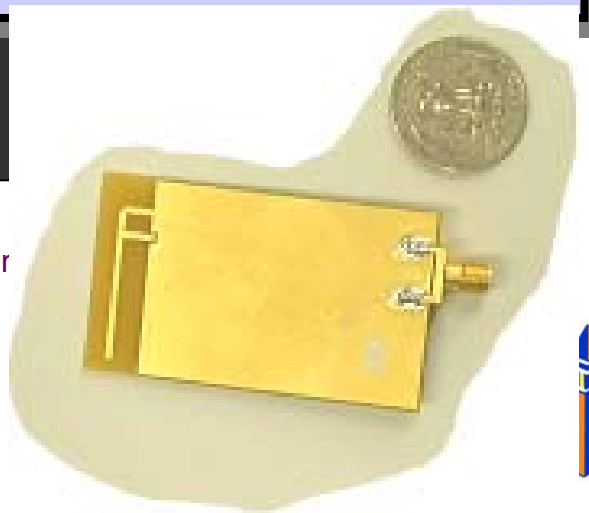


Strange: 2 channel 50 kBs radio

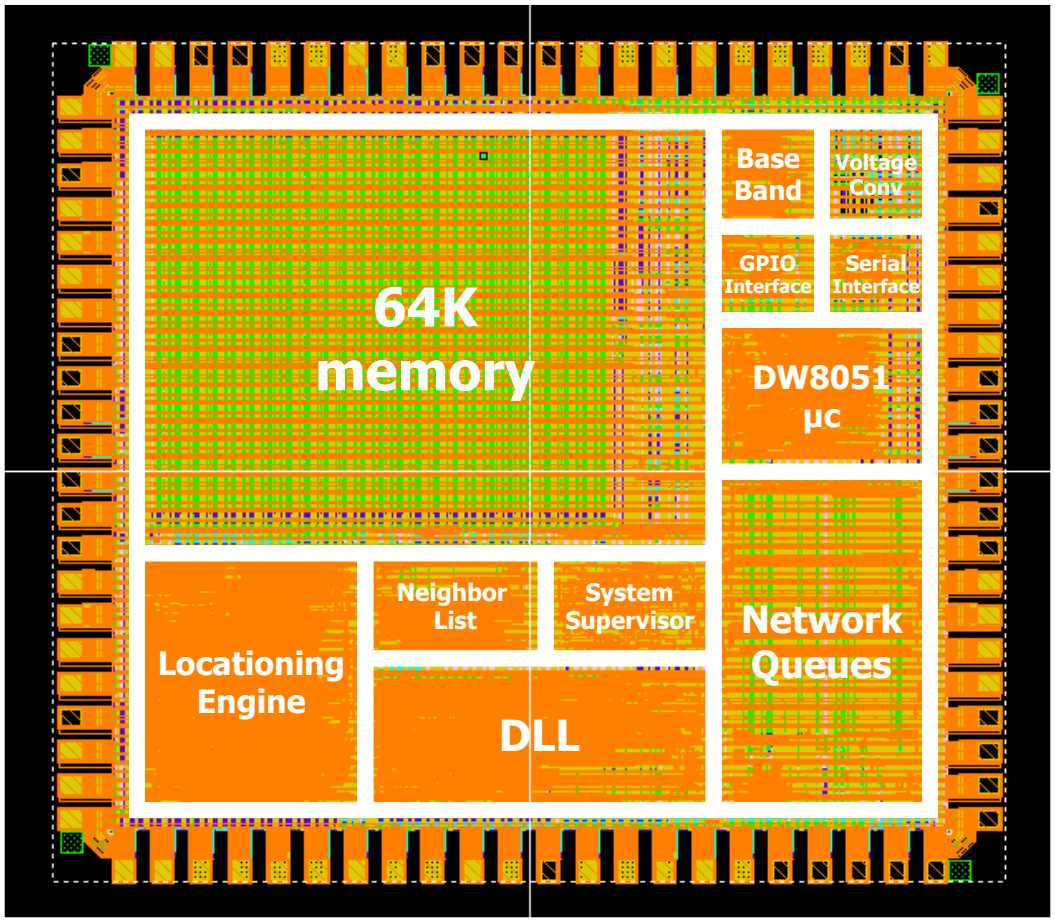
More then order of magnitude more power efficient than Zigbee

Strange Subsystem and Switch Block

into one chip in next iteration



Wireless Sensor Network Protocol Processor



Technology	0.13µ CMOS
Chip Size	3mm x 2.75mm = 8.2 mm^2
Transistor Count	3.2M
Gate Count	62.5K gates
Clocks Freqs	16MHz(Main), 1MHz(BB)
On Chip memory	68Kbytes
Core Supply Voltages	1V(High) –0.3V(Low)
Pad Supply Voltage	1.8V
On_Power	< 1 mW
Pad Count	88

In fab (Jan 04)

Integrates all digital protocol and applications functions of wireless sensor node

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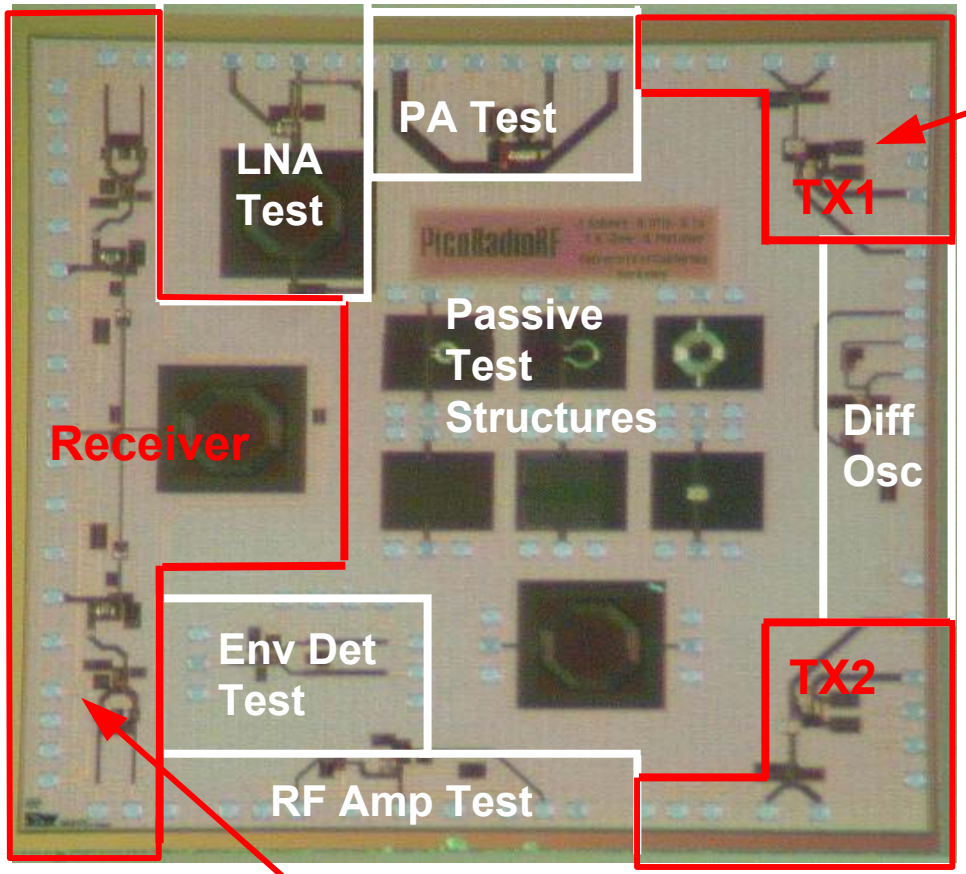
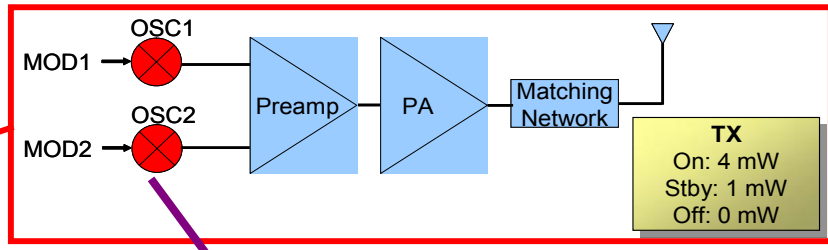
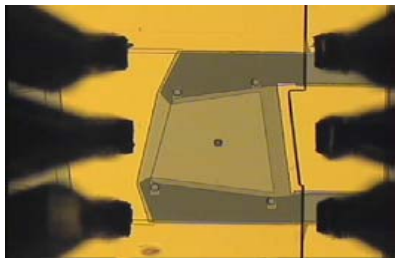
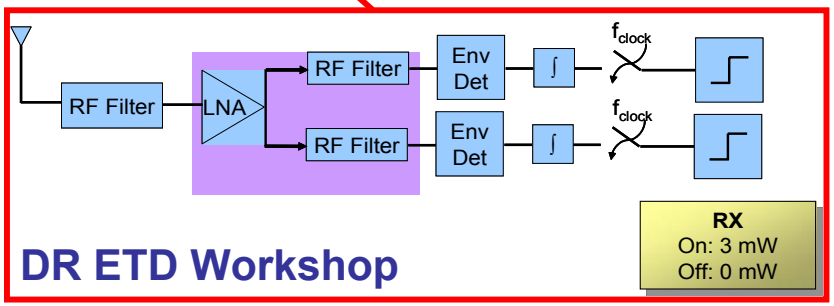
The Incredibly Shrinking Radio





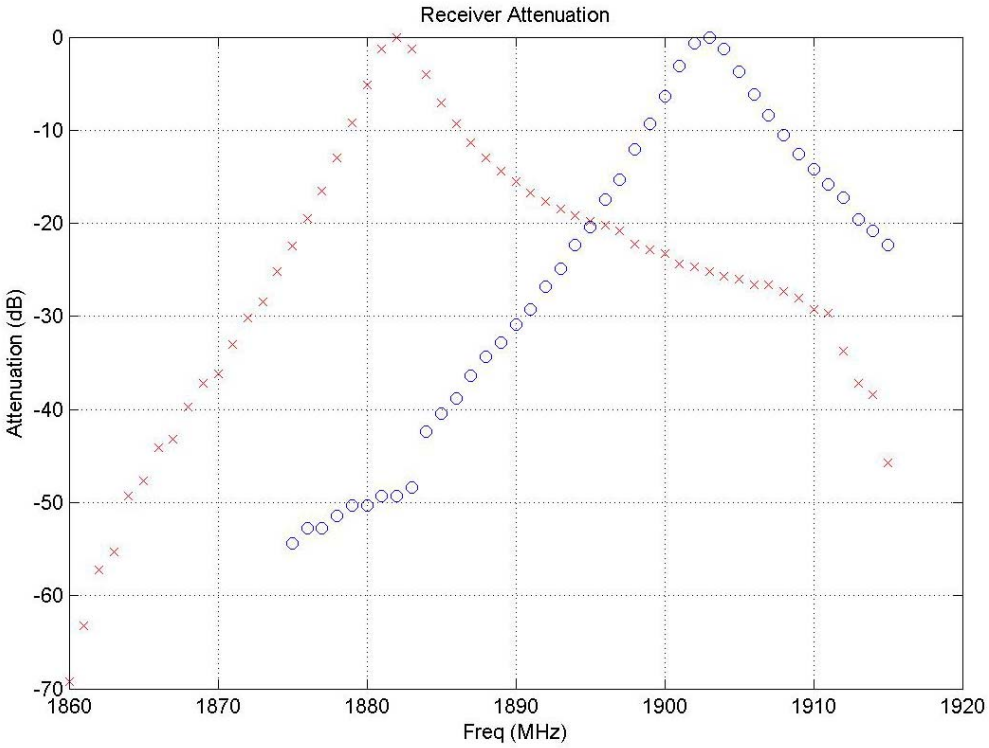
Thin-Film Bulk Acoustic Resonator

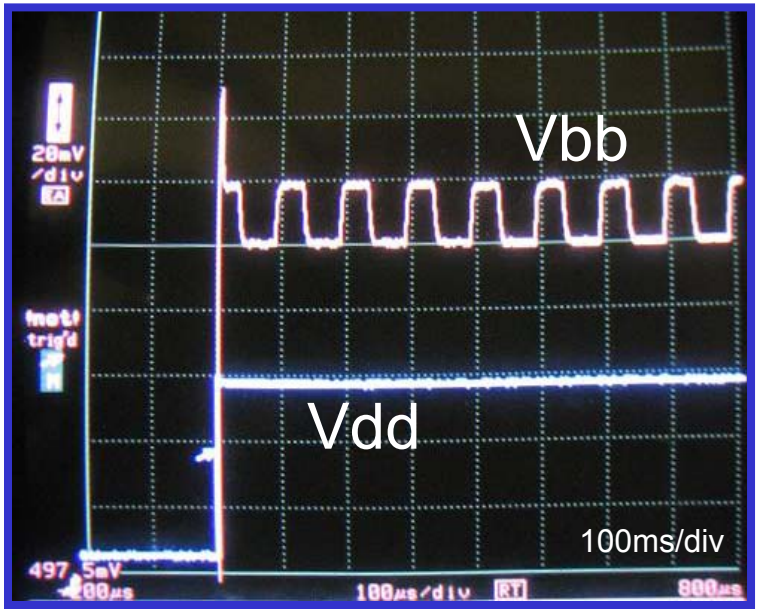


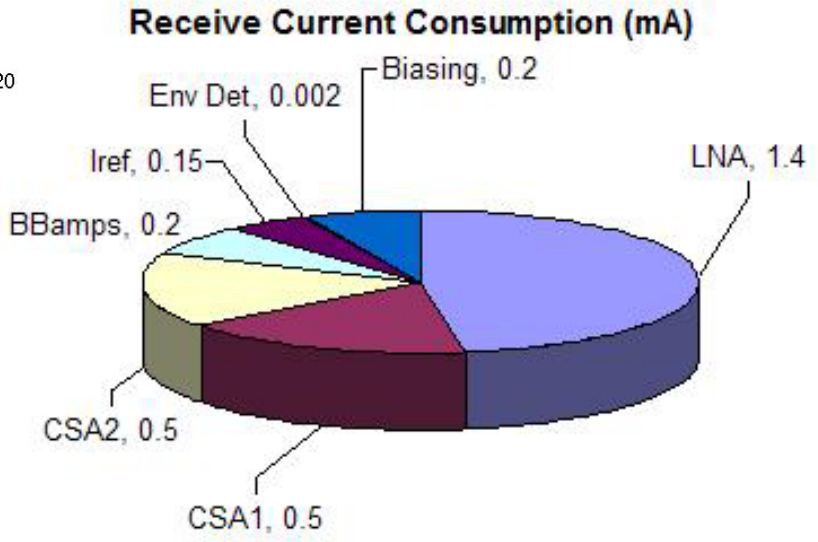


- Technology: 0.13 μm CMOS combined with off-chip FBARs
- Carrier frequency: 1.9 GHz
- 0 dBm OOK
- Two Channels
- Channel Spacing ~ 50MHz
- 40 kbps/channel
- 2-4 mW (when on)
- Total area < 4 mm^2

Receiver Results

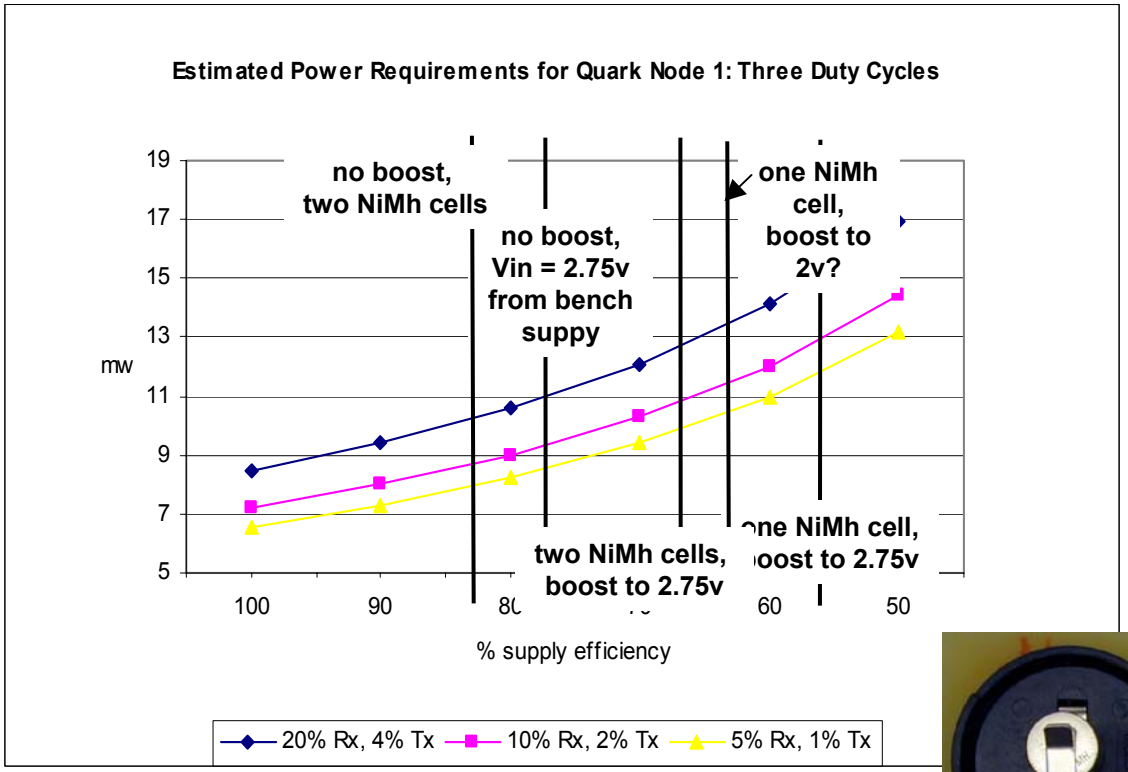


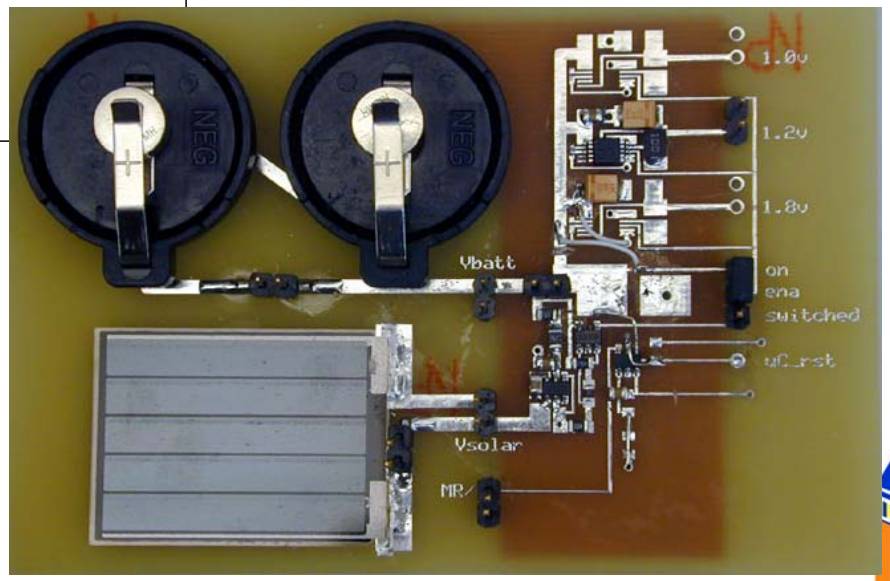




- **-78dBm sensitivity (12dB SNR)**
- **10μs turn-on time**
- **3mA @ 1.2V supply**

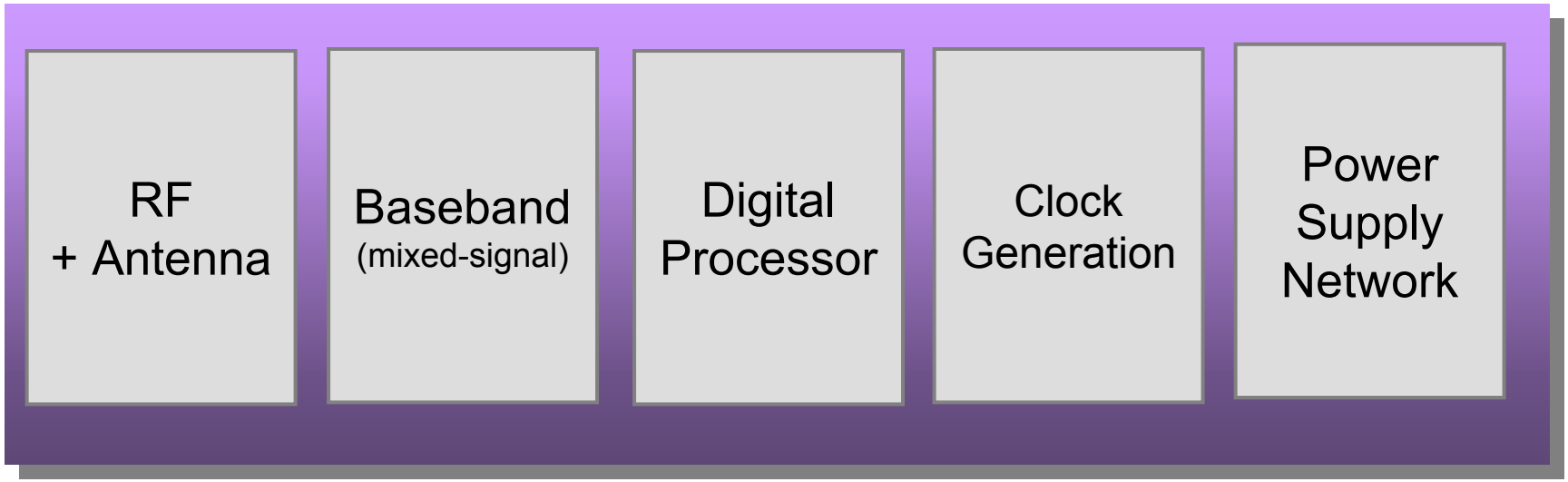
Optimizing the supply network





Where are we going from here?

Towards a sub-100 μW integrated node



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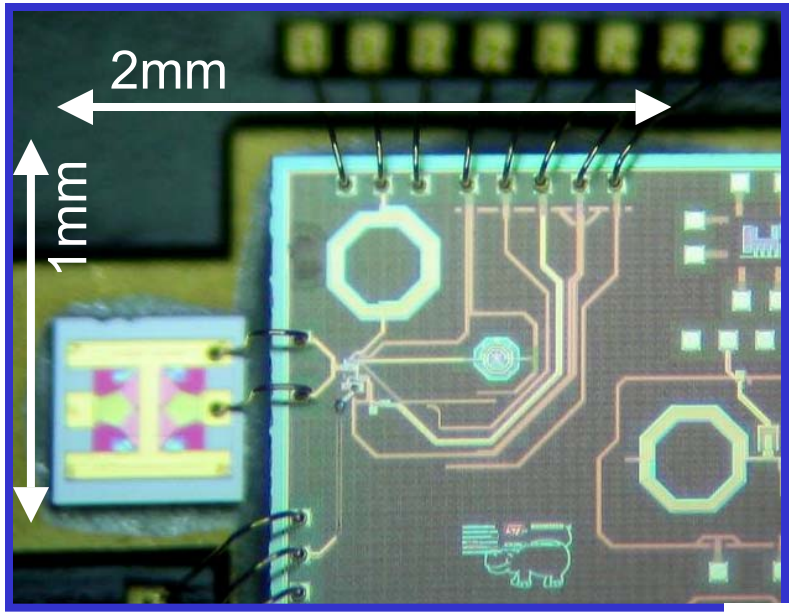
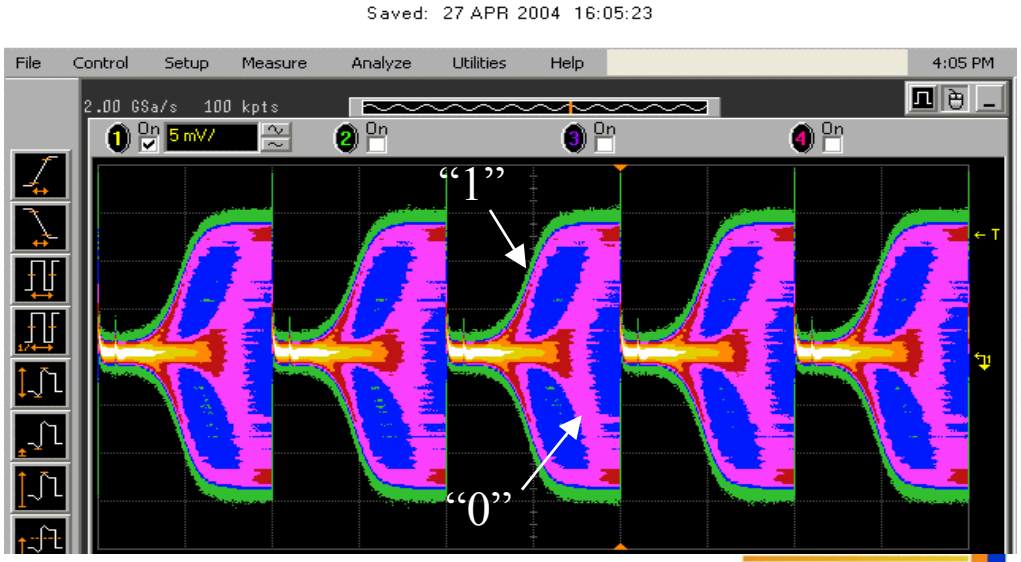
Operational Super-Regenerative Receiver

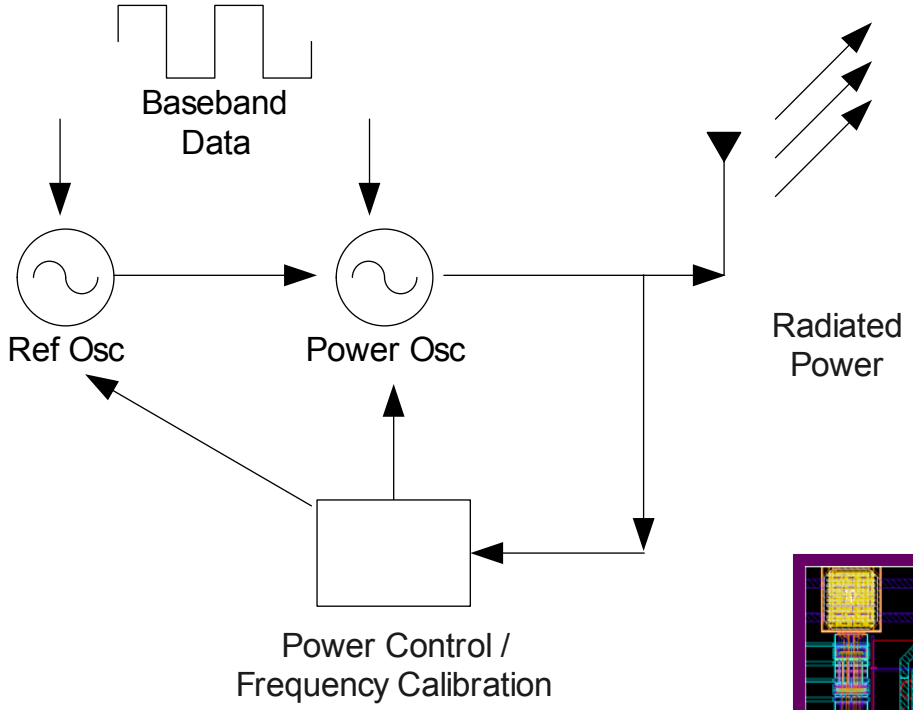


- Fully Integrated: no crystal or off-chip inductors
- P_{rx}<400μW
- Sensitivity: -100dBm

f_q=100kHz



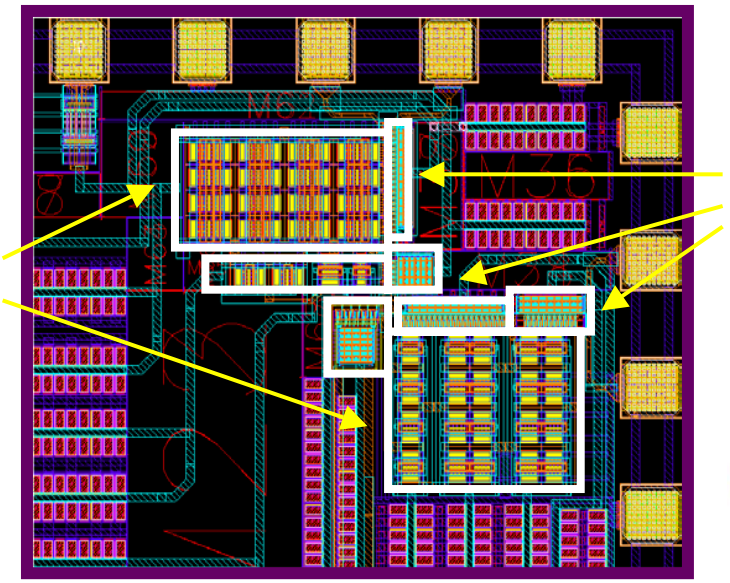
Energy-efficient Transmitters



Power Oscillator to deliver power efficiently and reduce driver power (self-driven)

- FBAR Reference Oscillator
- Concurrent Antenna/Power Oscillator design to provide optimal load termination
- Power Control for optimal radiated power
- Frequency Calibration to minimize locking power

Injection-locked transmitter



TX at 2 mW or less (when on)

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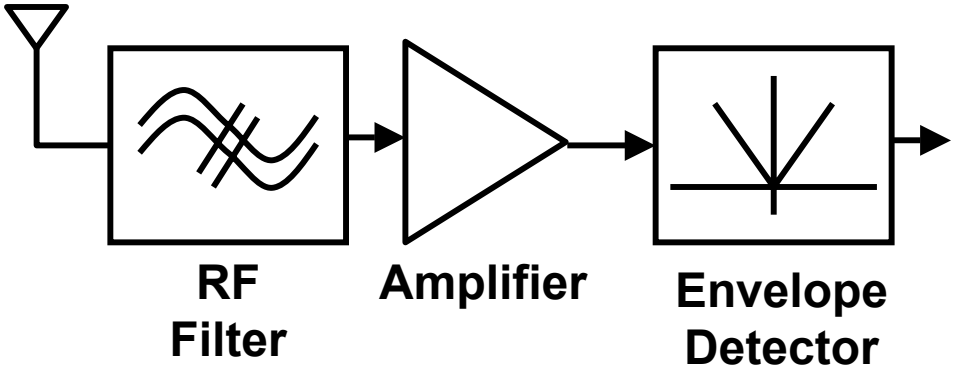
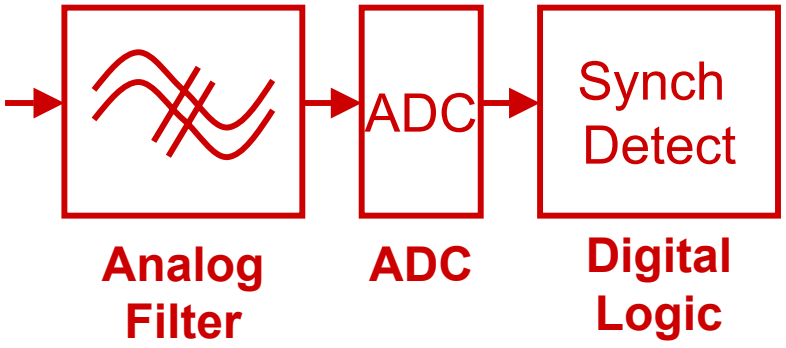
Baseband Processing



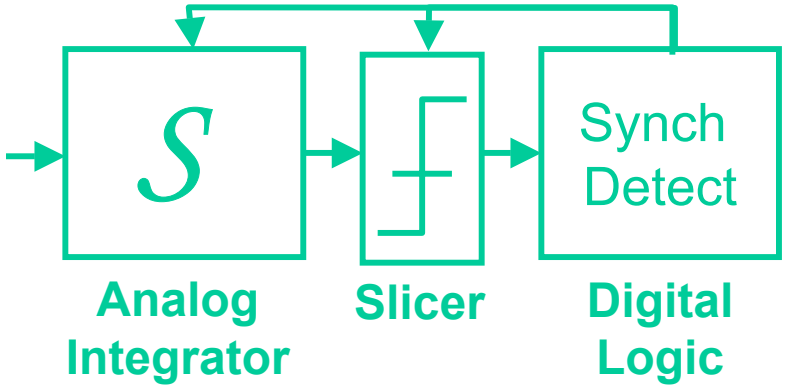
Mostly Digital



Preliminary Data!

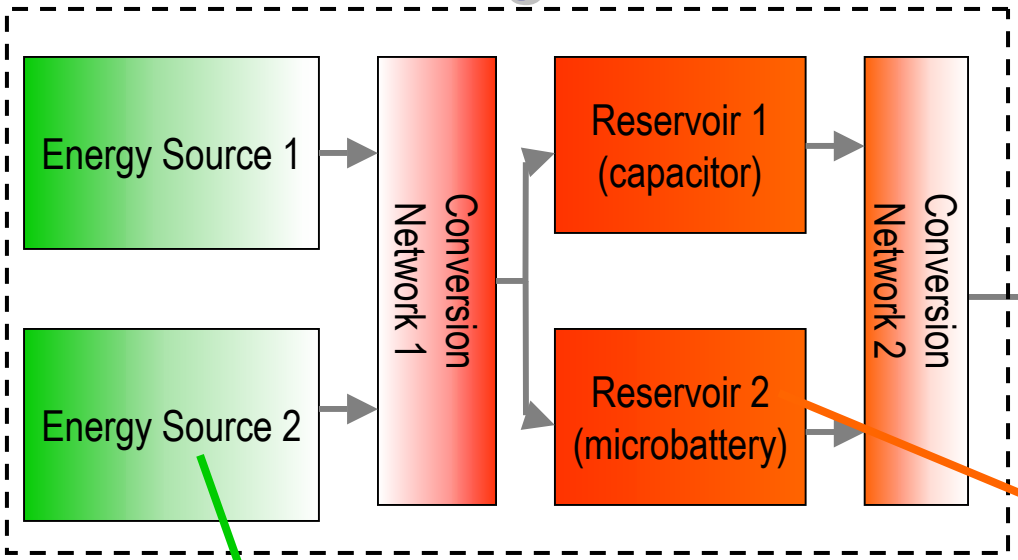
	Mostly Analog	Mostly Digital
Digital Power (uW)	**17 (control)**	**49 (correlate, control)**
Analog Power (uW)	**200 (integrators, comparators)**	**125 (8-bit ADC @ 500KHz)**
Total Power (uW)	217	174
Header Length (symbs)	23	17

Mostly Analog



with Fernando De Bernardinis, Yanmei Li, and Brian Otis

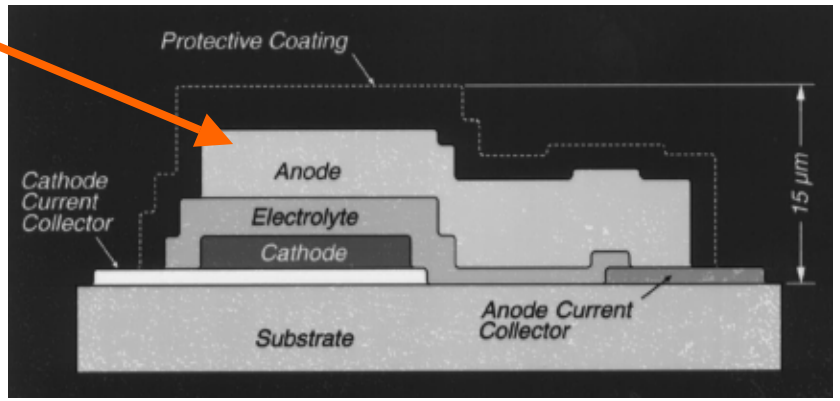
Powering Ultra-Dense Networks

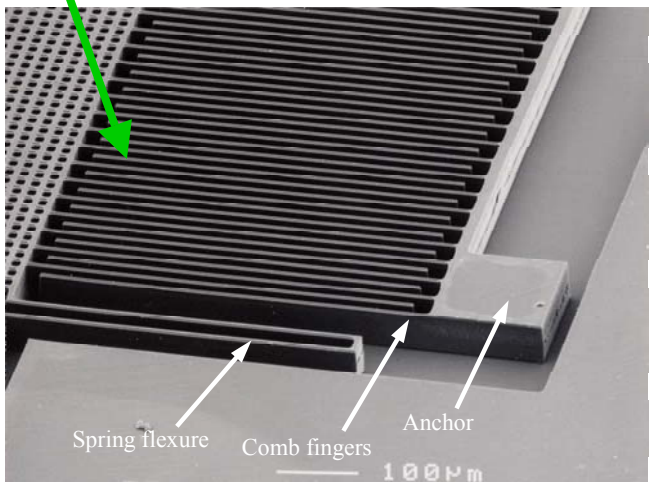


Energy generation and conversion network

Needs integrated meso-scale energy train

Micro-battery





Electrostatic MEMS vibration converters

Proposal submitted to NSF (PIs: Rabaey, Wright, Sanders, Steingard, Roundy)

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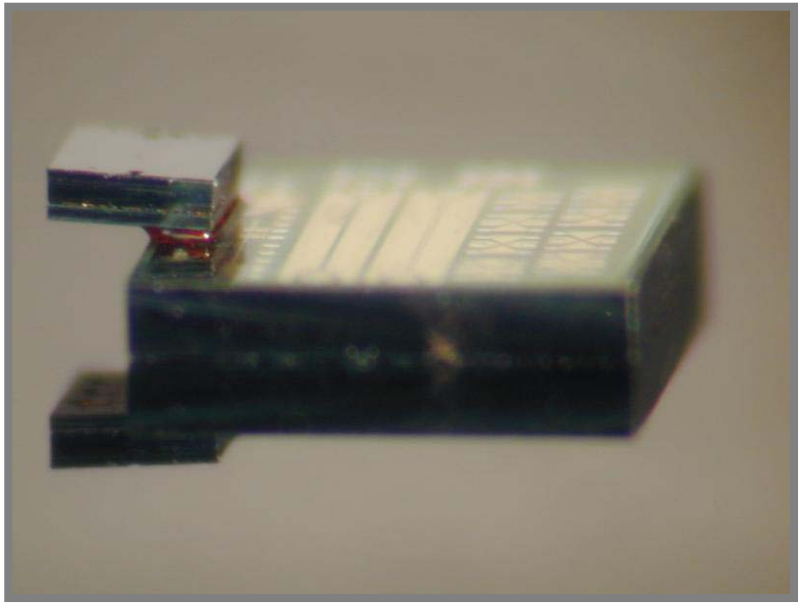
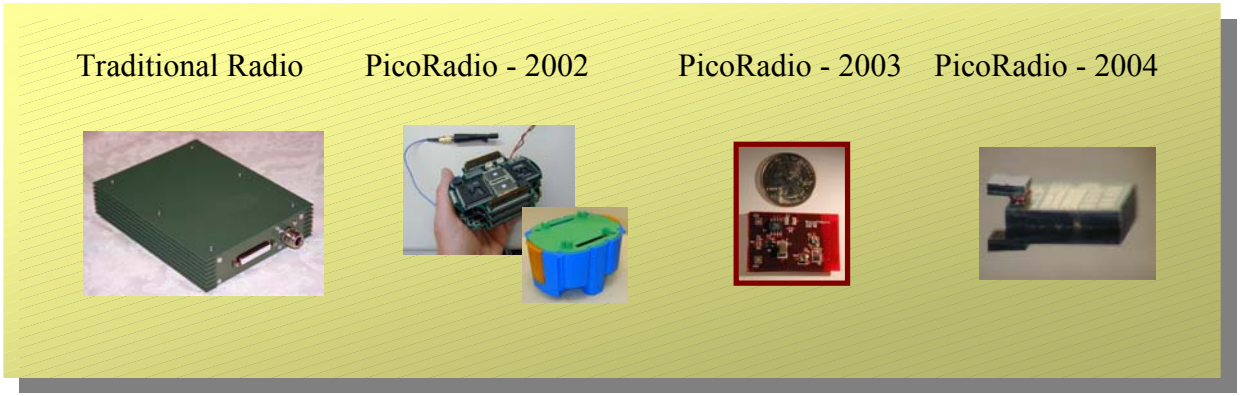
Summary and Perspectives

- **Energy-scavenging wireless sensor and actuation nodes are within reach**
- **Use of aggressive and innovative manufacturing techniques can (ultimately) lead to sub-1$ solutions**
- **PicoRadio technologies are ready for prime time!**
- **Towards the future: another factor 10 in size and power**





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