Passive Radio Technologies from the University of Washington Sensor Systems Lab

Passive Wireless Sensor Technology Workshop, WiSEE
Montreal, October, 2017

Joshua R. Smith
Professor
Computer Science and Engineering
Electrical Engineering
University of Washington, Seattle

Co-Founder
Jeeva Wireless Inc

Sensor Systems Lab --- Graduated PhDs

Alanson Sample 2011
Disney Research

LT Jiang 2014
Airbnb

Ben Waters 2015
CEO WiBotic

Vamsi Talla 2016
CTO, Co-Founder, Jeeva Wireless

Yi “Eve” Zhao, 2016
Occulus / FB

Aaron Parks, EE

Graduated PhDs

Sensor Systems Lab --- Current Students


Saman Naderiparizi, EE


Brody Mahony, EE

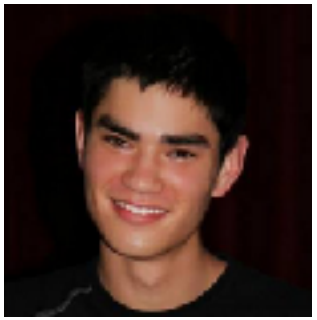

Vaishnavi Ranganathan, EE


Jim Youngquist, CSE


Xingyi Shi, EE


Gregory Moore, EE


Zerina Kapetanovic, EE


Patrick Lancaster, CSE

Current Graduate Students

Internet of Things

Smart connected electronic devices

EVERYWHERE

Even inside the human body!

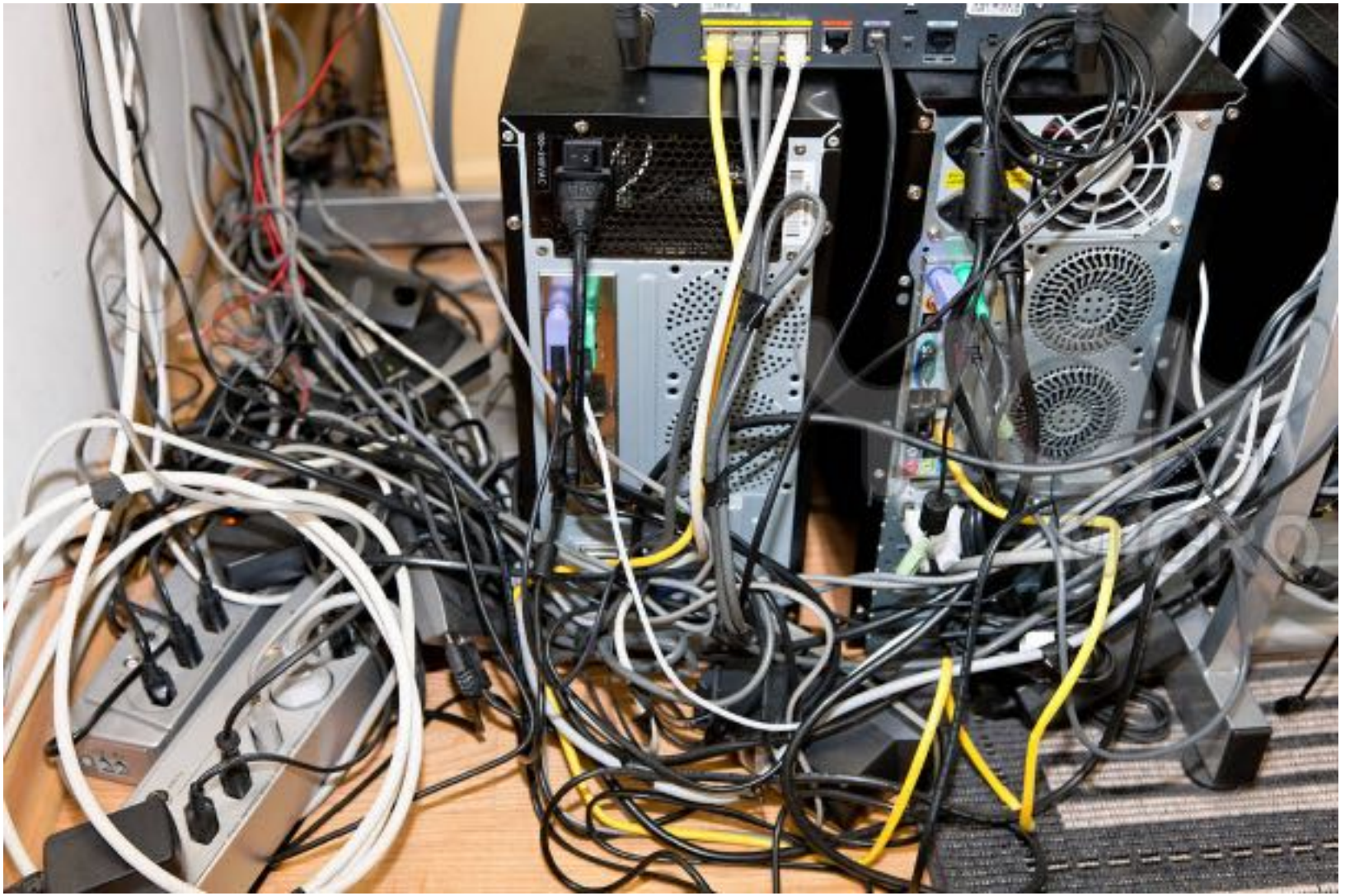
The Problem

If we're going to put electronic devices everywhere

even inside the body

How are we going to power them?

Cords?



Batteries?

Lifetime
Size
Weight

RF-powered digital sensing-computing system

WISP: Wireless Identification and Sensing Platform

Video

2006
First UHF-powered accelerometer

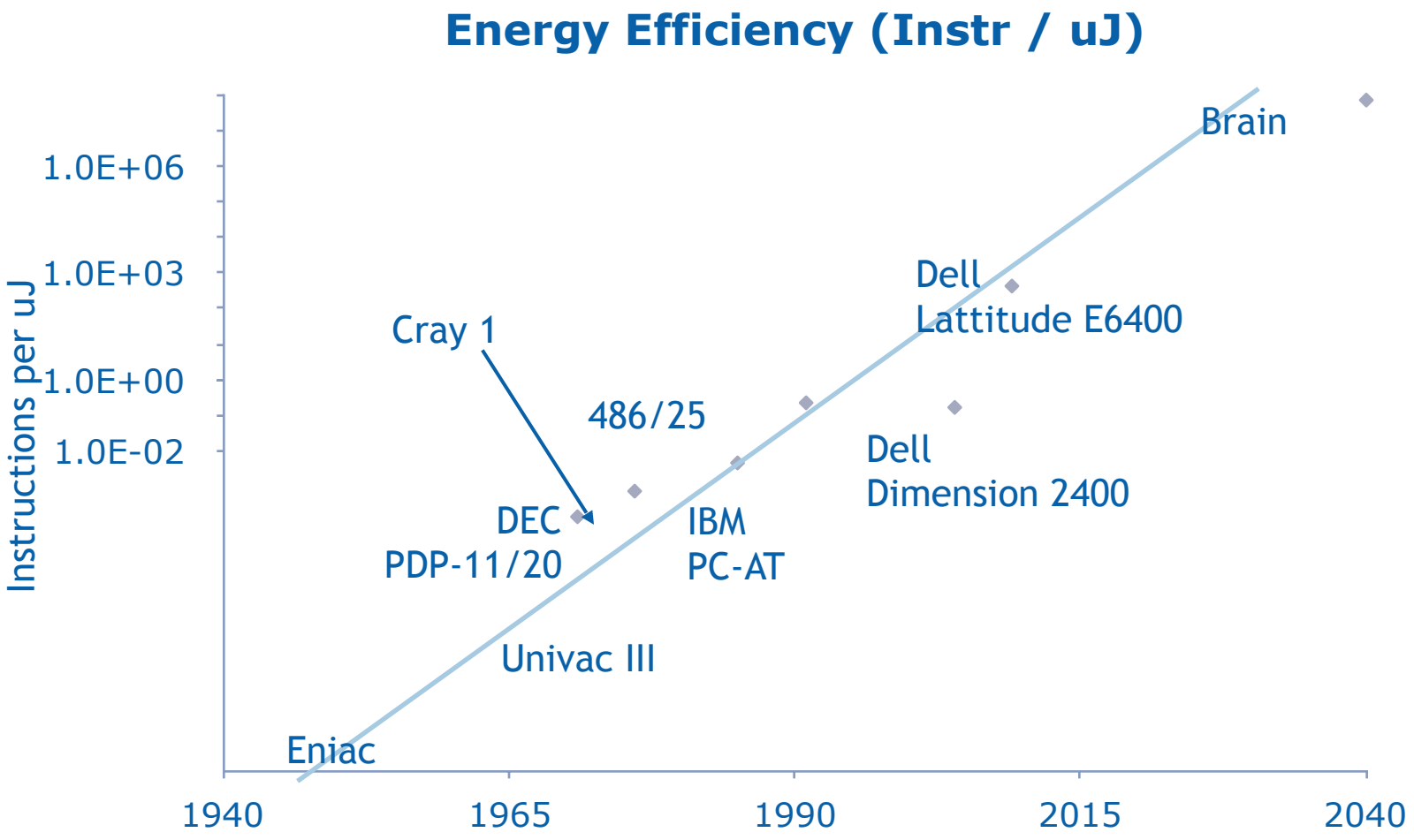
Backscatter to UHF RFID reader
~10 updates per sec

Design of an RFID-based battery-free programmable sensing platform, *AP Sample, DJ Yeager, PS Powledge, AV Mamishev, JR Smith, IEEE Trans. Instrumentation and Measurement, 57 (11), 2608-2615, 2008*

A wirelessly powered platform for sensing and computation, JR Smith, AP Sample, P Powledge, A Mamishev, S Roy. *Ubicomp 2006*

Why Now?

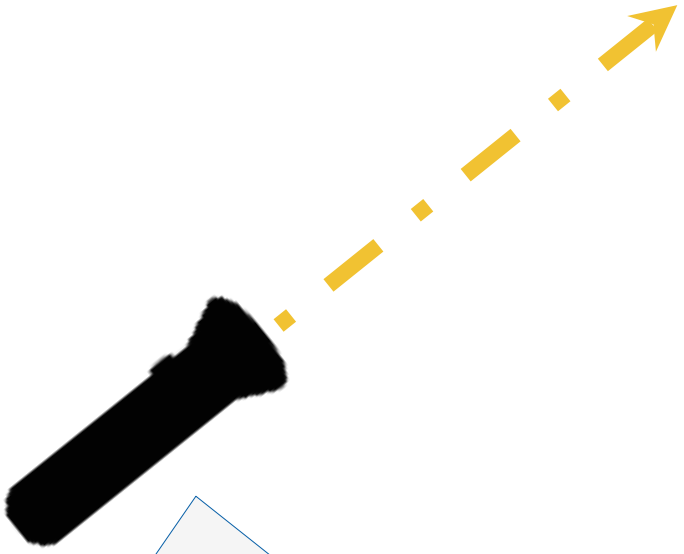
Energy Efficiency Scaling



Data: ***Implications of Historical Trends in the Electrical Efficiency of Computing***
Koomey, Berard, Sanchez et al, IEEE Annals of the History of Computing, 2011

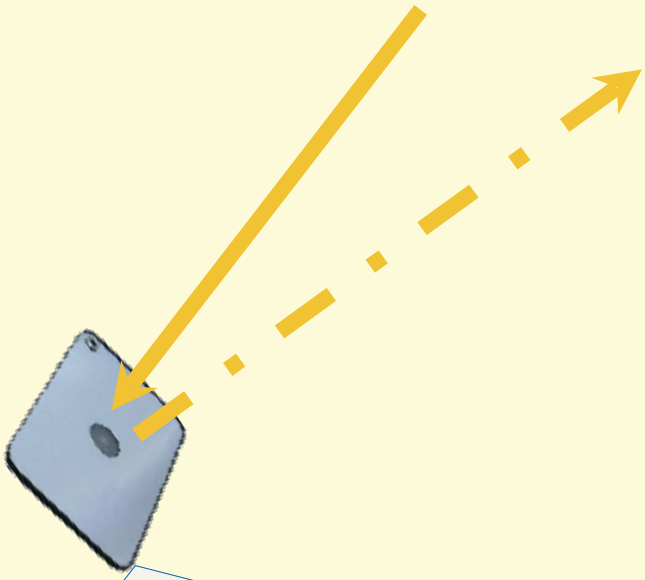
Backscatter Communication

Conventional radio



Generates and emits signals. **Uses lots of energy.**

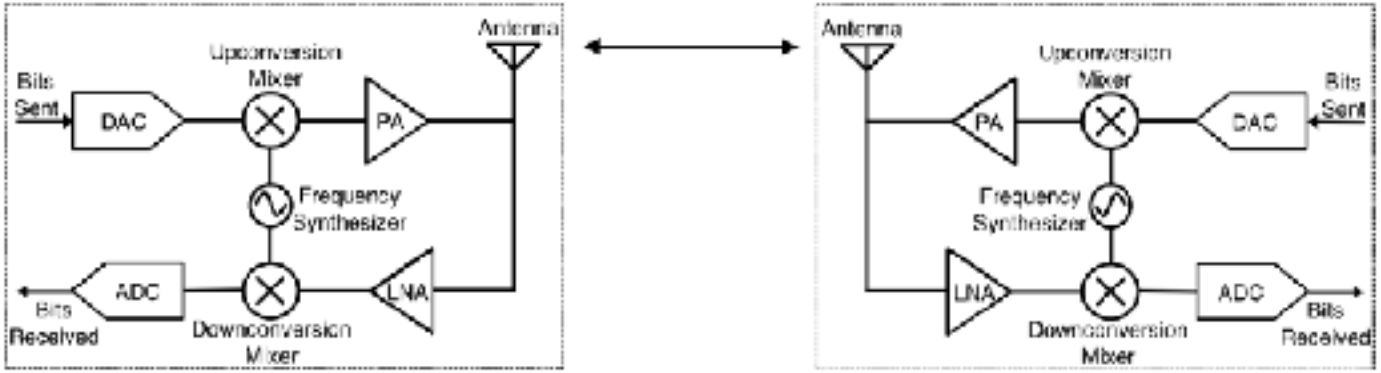
Backscatter (Jeeva passive radio)



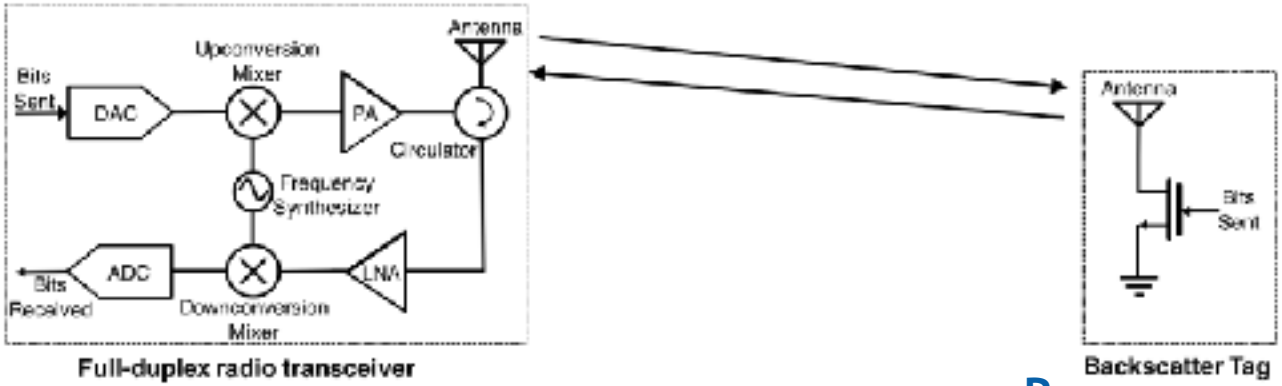
Reflects existing signals. **1000x-10000x less energy per bit**

Backscatter Communication: Design for Asymmetry

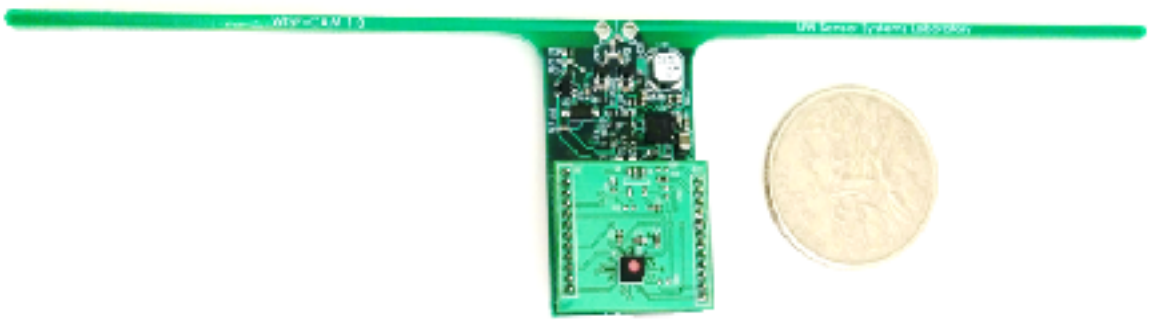
Ordinary Symmetric System



Backscatter: Design for asymmetry of mobile + fixed



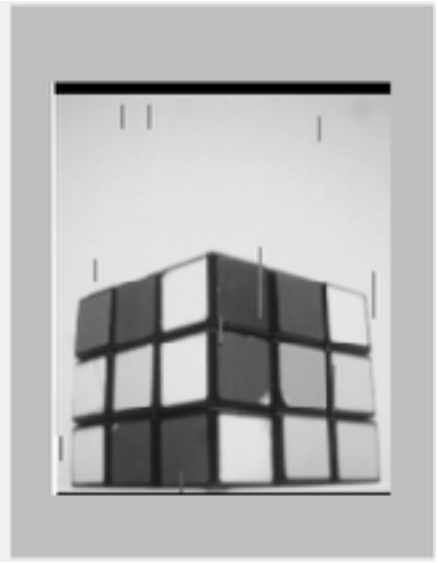
Battery-Free Wireless Camera

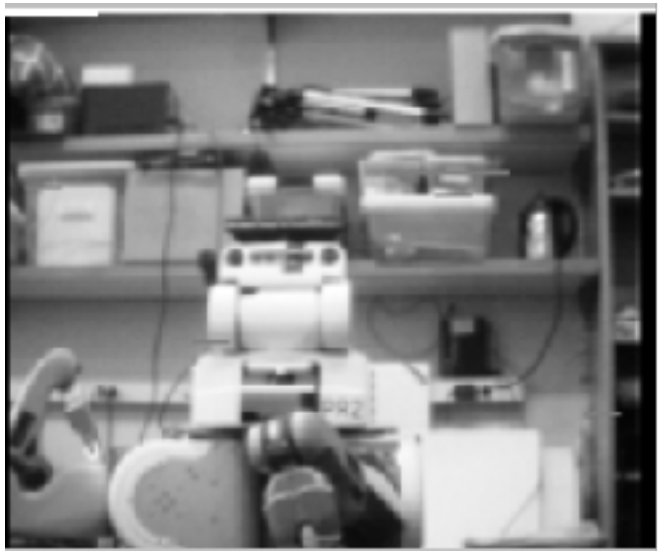


1 picture every 20 sec at 1m
1 picture every 3.5 min at 4m

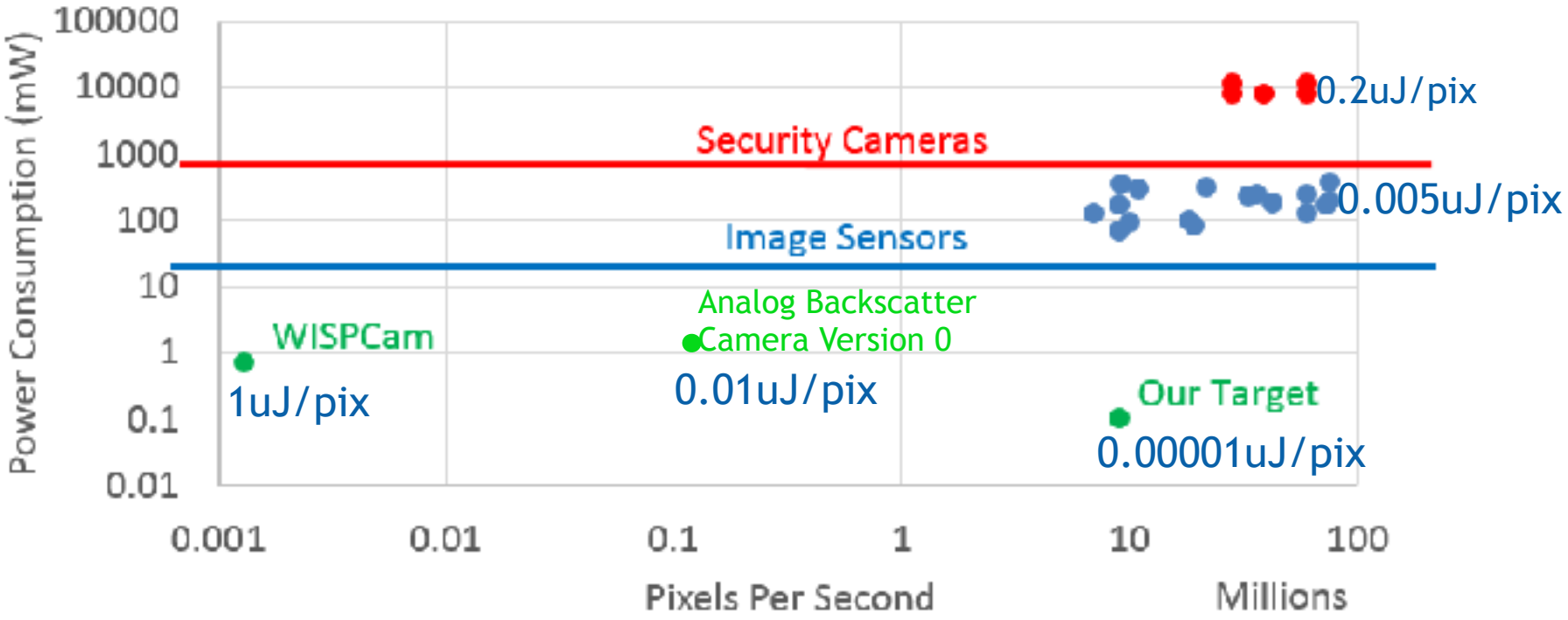
Useful for metering, inspection, surveillance, …

20mJ / frame
Harvested RF power stored on capacitor until there is enough to take picture and upload

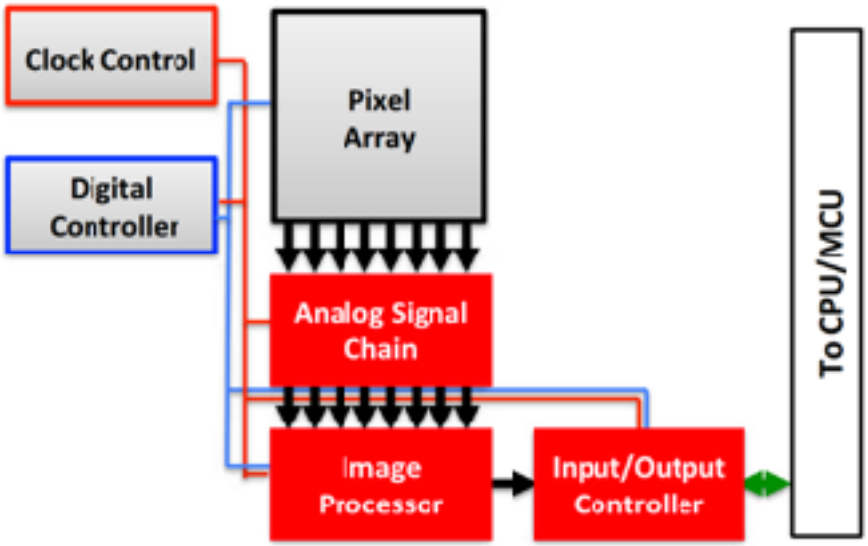




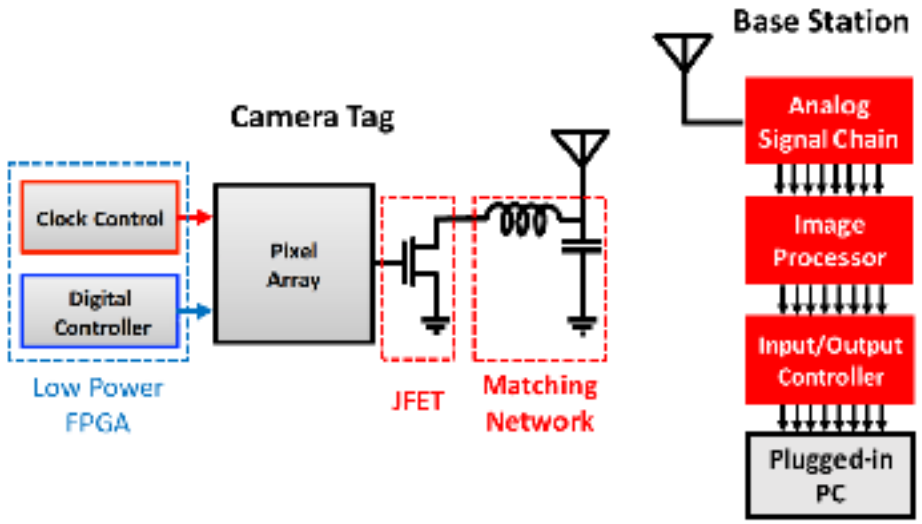
Camera power-performance



Analog backscatter camera



Conventional Camera Design



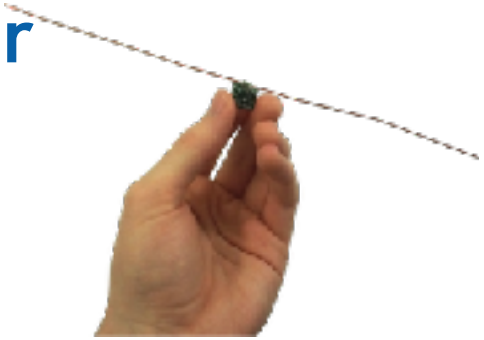
Analog Backscatter Camera Design
Move power hungry portions to wired

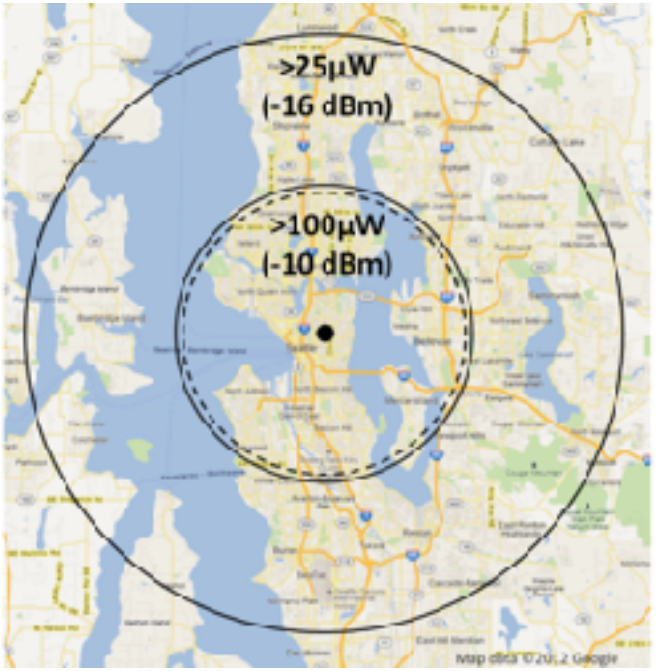
Explore neurally-inspired sensory coding techniques

Analog backscatter for low power streaming video

Video

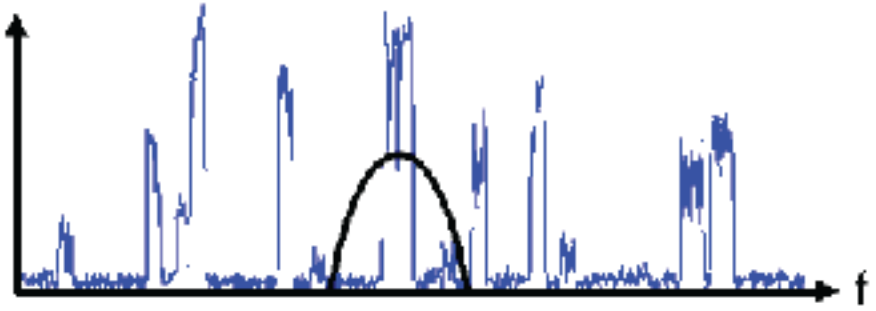
WARP: Wireless Ambient Radio Power

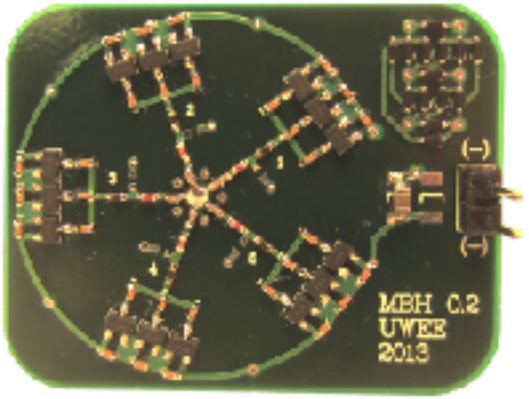


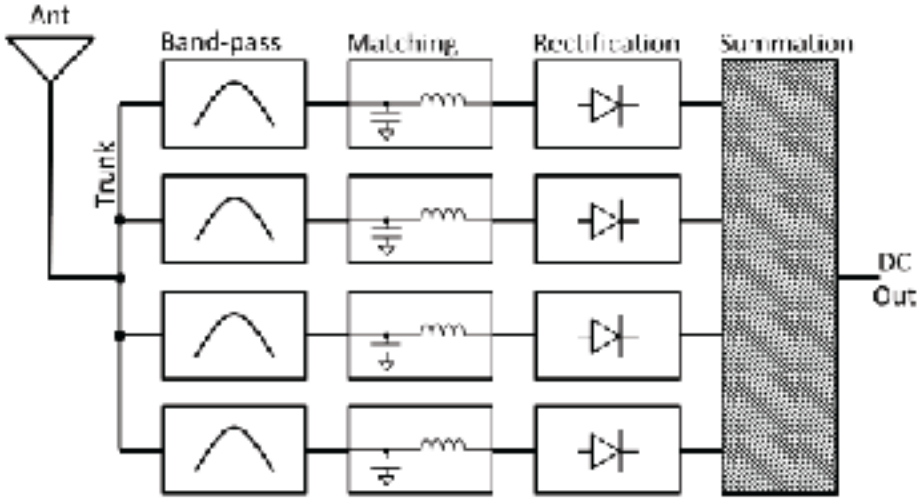


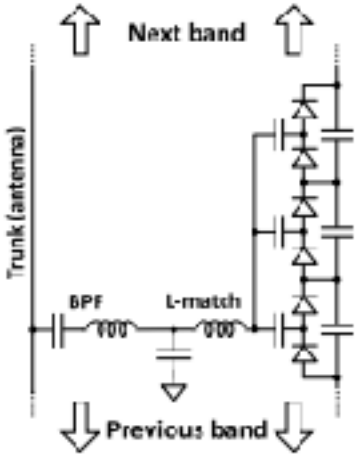
Experimental results with two wireless power transfer systems, A.P. Sample and J.R. Smith, Proceedings RAWCON 2009

Multi-band harvesting





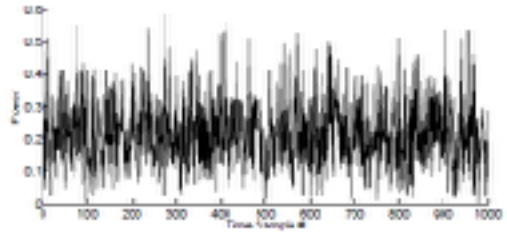




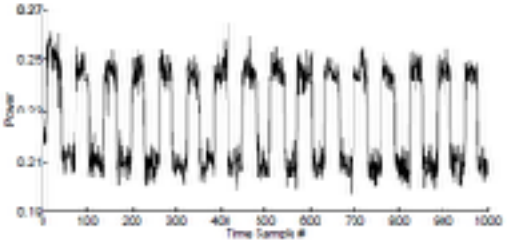
Sifting Through the Airwaves: Efficient and Scalable Multiband RF Harvesting,
Aaron Parks, Joshua R. Smith, IEEE RFID 2014 ***Best Paper***

ABC: Ambient Backscatter Communication

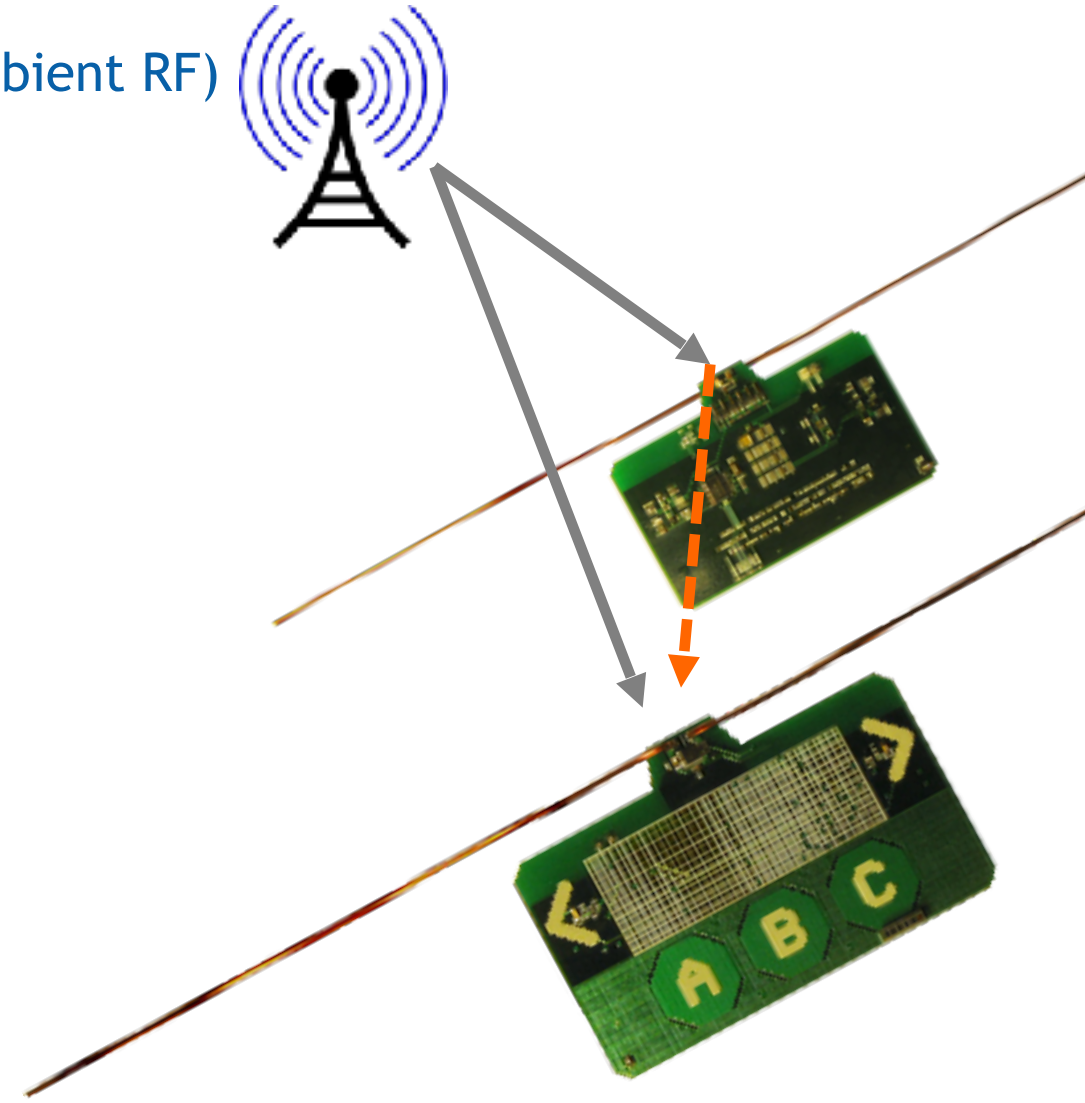
WISP (backscatter) x WARP (ambient RF)
Or, “RFID with no RFID reader”



(a) Original TV plus Backscatter signal



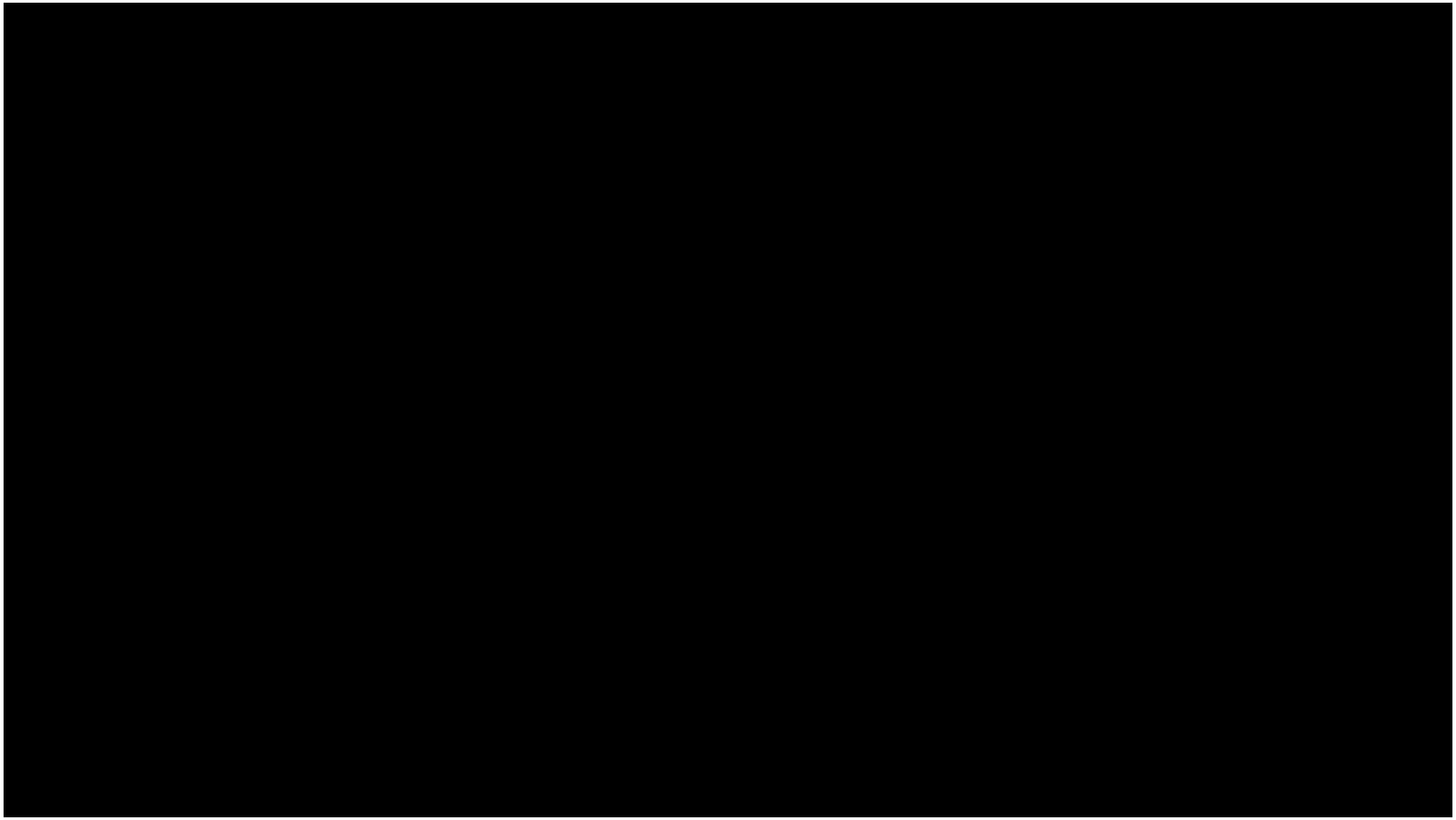
(b) Signal After Averaging



Ambient Backscatter: Wireless Communication out of Thin Air, Vincent Liu, Aaron Parks, Vamsi Talla, Shyam Gollakota, David Wetherall, Joshua R. Smith, SIGCOMM 2013 ***Best Paper***

Card to Card funds transfer

Video

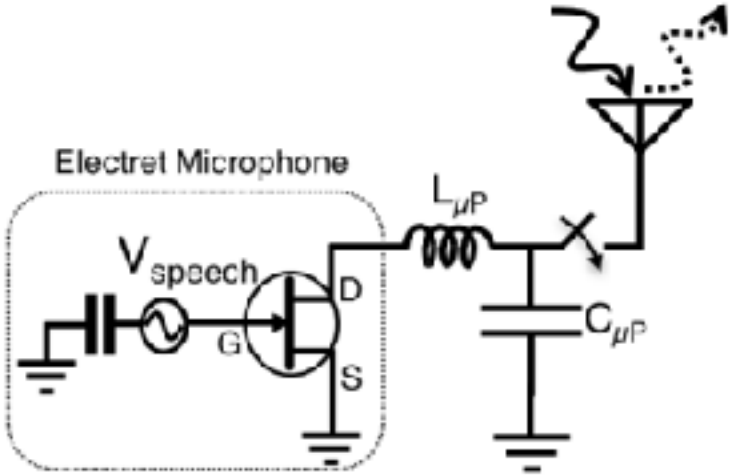


Ambient Backscatter: Wireless Communication out of Thin Air, Vincent Liu, Aaron Parks, Vamsi Talla, Shyam Gollakota, David Wetherall, Joshua R. Smith, SIGCOMM 2013 ***Best Paper***

Can we get high data rate passive wireless sensing?

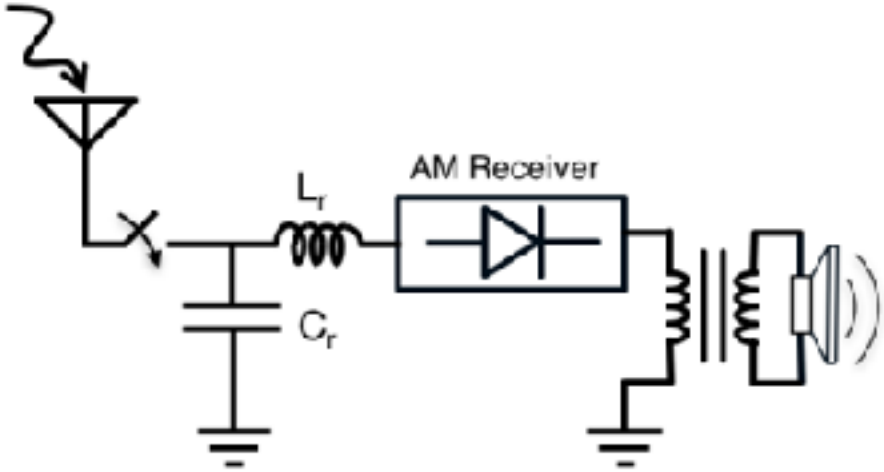
Battery-free phone

Sending speech



(a) System architecture for transmitting speech at the battery-free phone

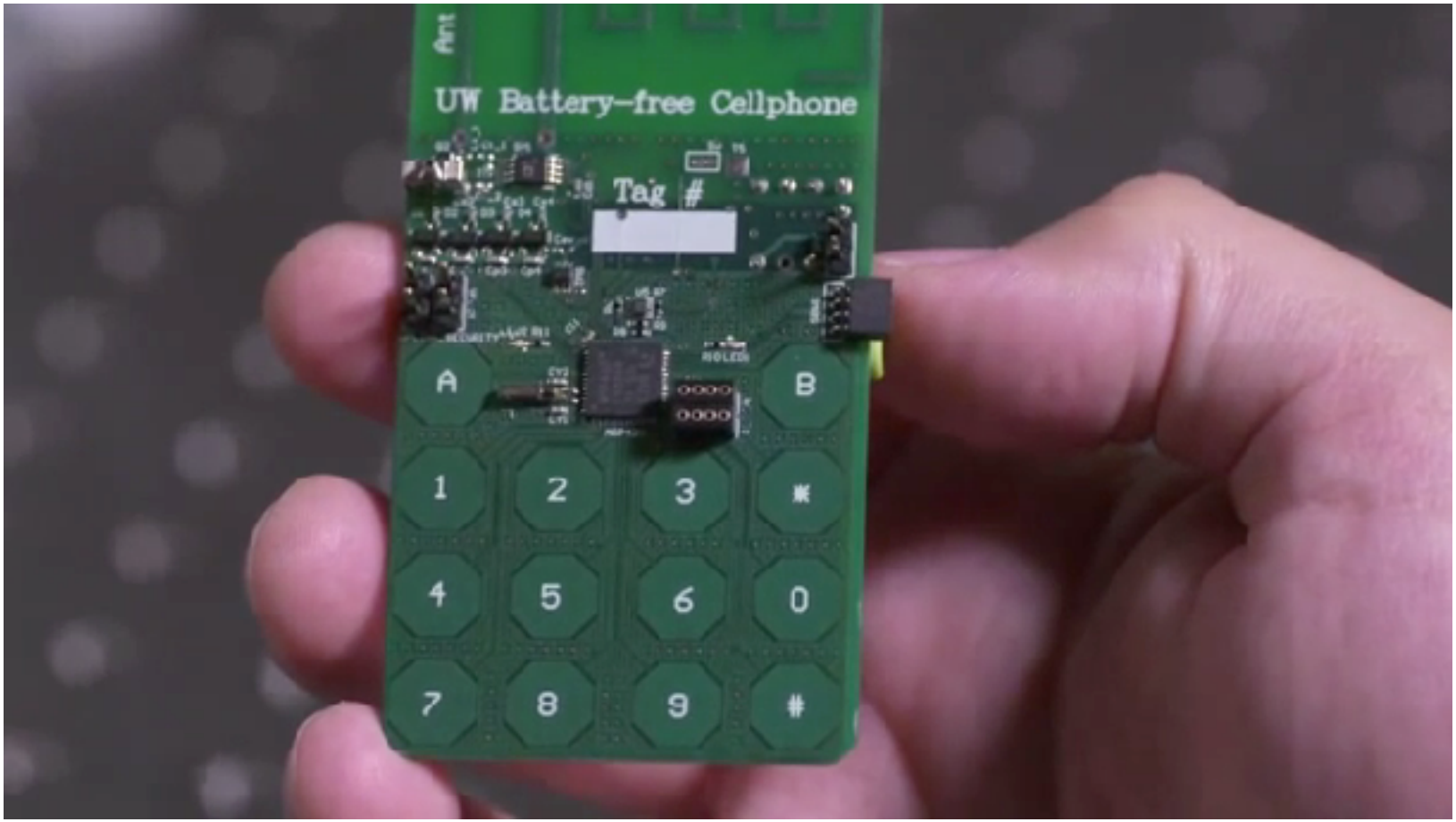
Receiving speech



(b) System architecture for receiving speech from the battery-free phone

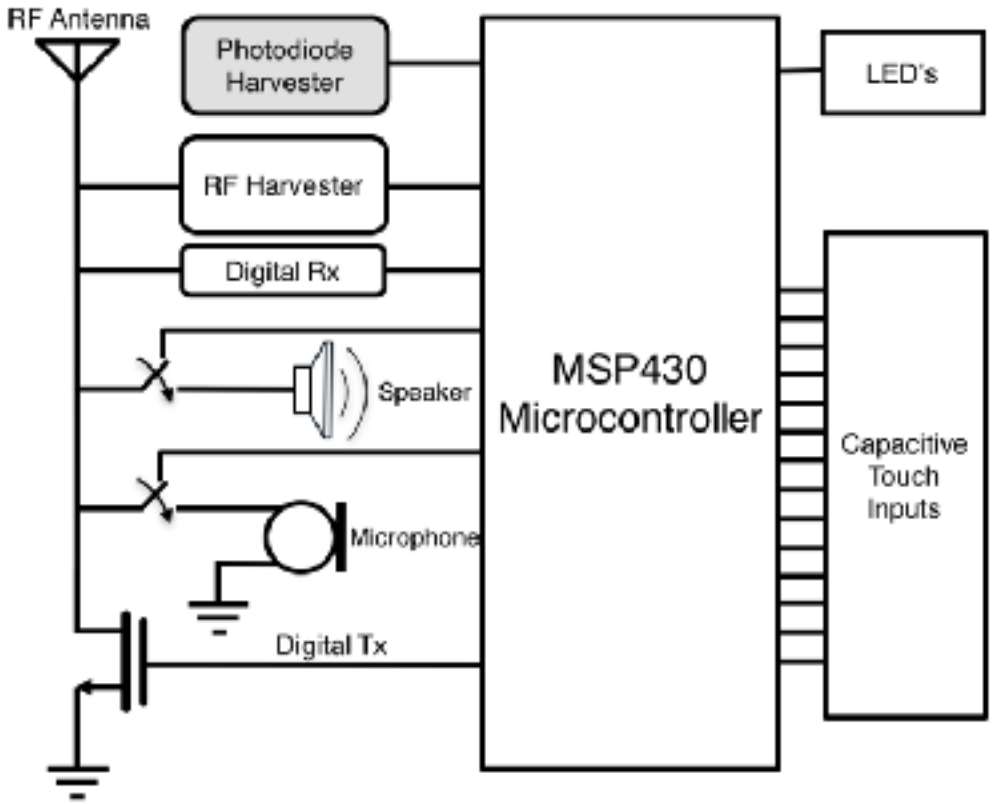
Battery Free Cellphone

Video

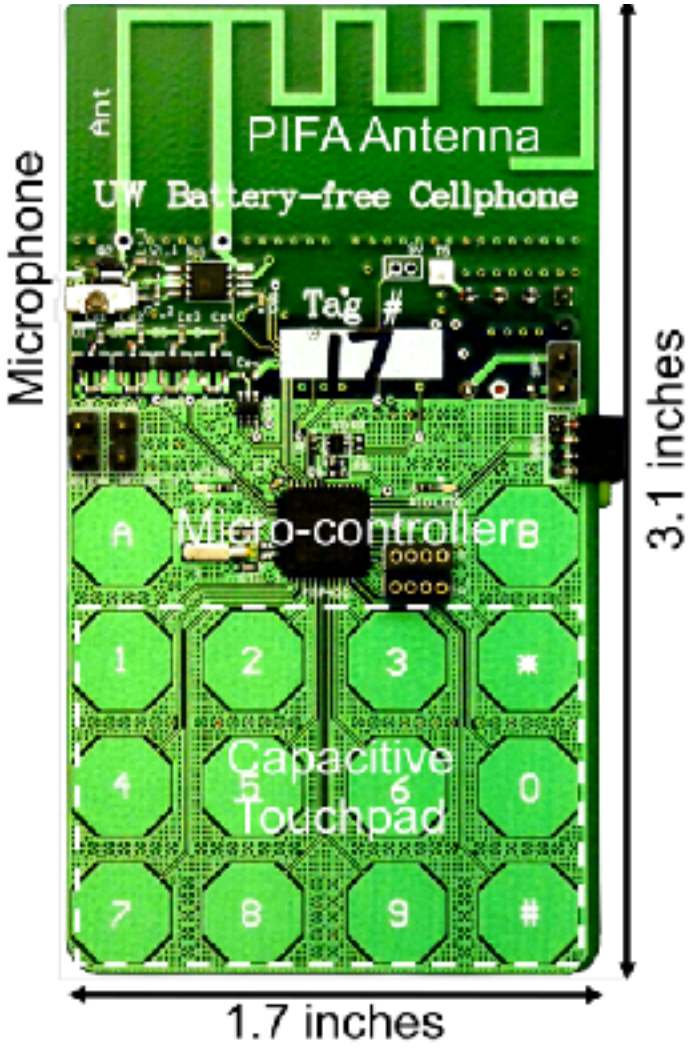


Battery Free Cellphone, V Talla, B Kellogg, S Gollakota, J Smith, PACM IMWUT, Vol 1, No 2, Article 25, June 2017

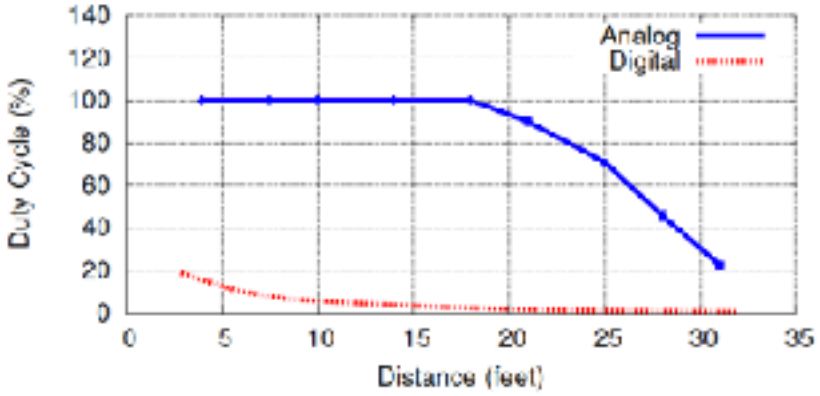
Battery Free Cellphone Blocks



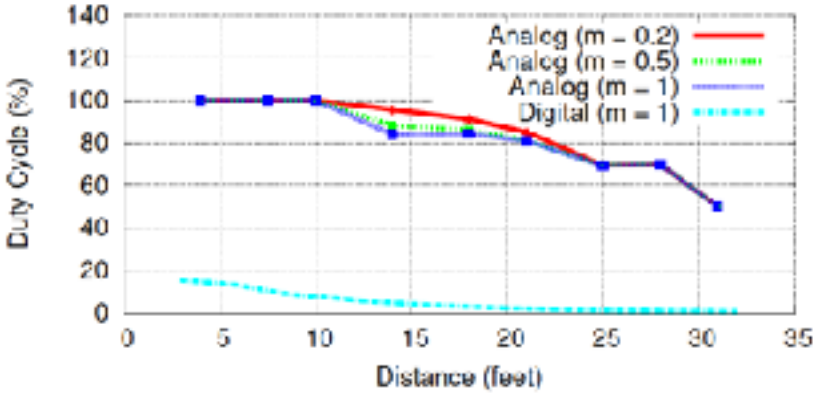
Battery Free Cellphone Photo



Duty Cycle vs Range

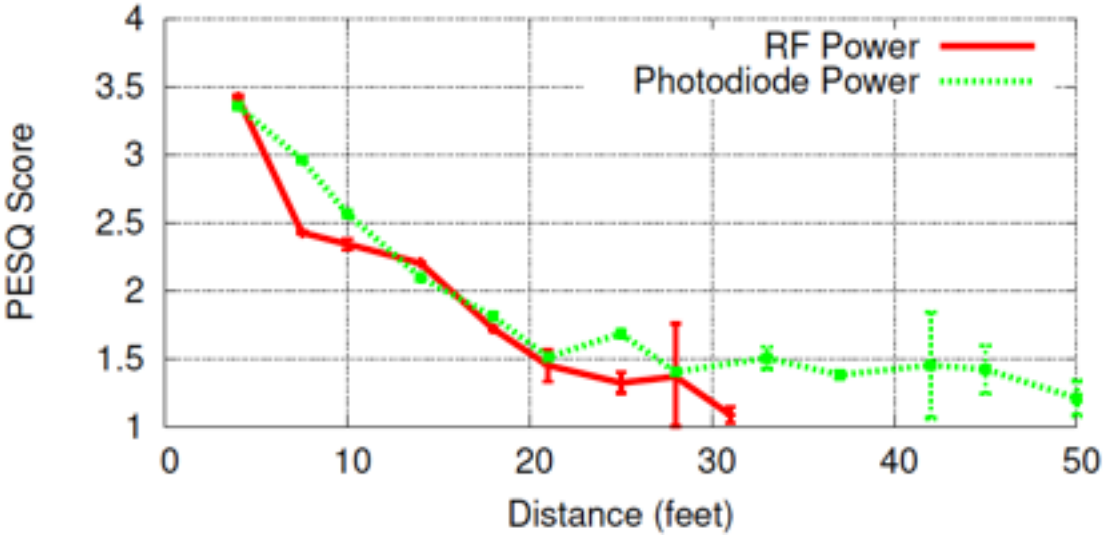


(a) Duty cycle while transmitting speech

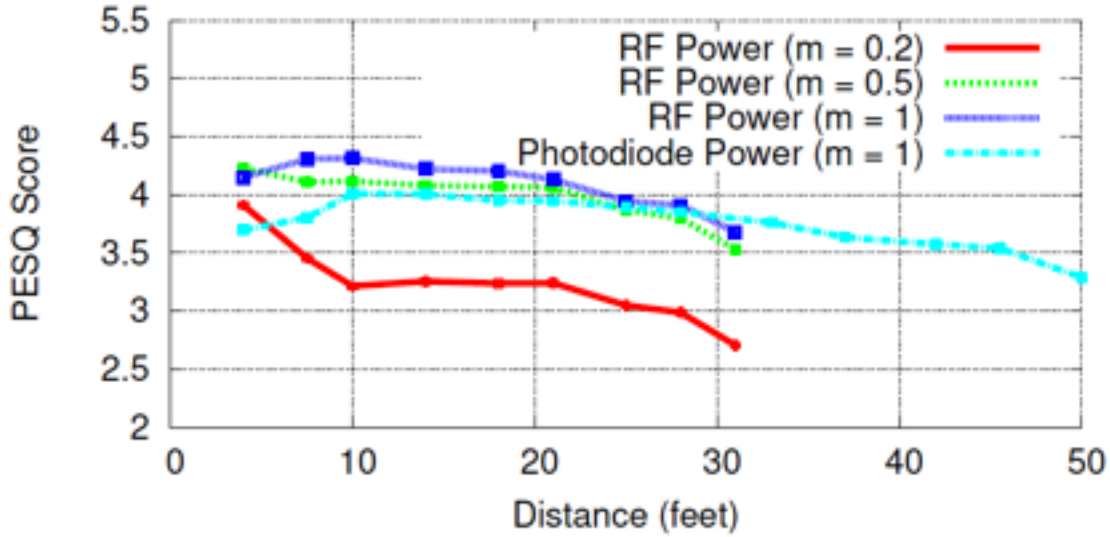


(b) Duty cycle while receiving speech

Speech Quality vs Range



Quality of speech sent from phone



Quality of speech received at phone

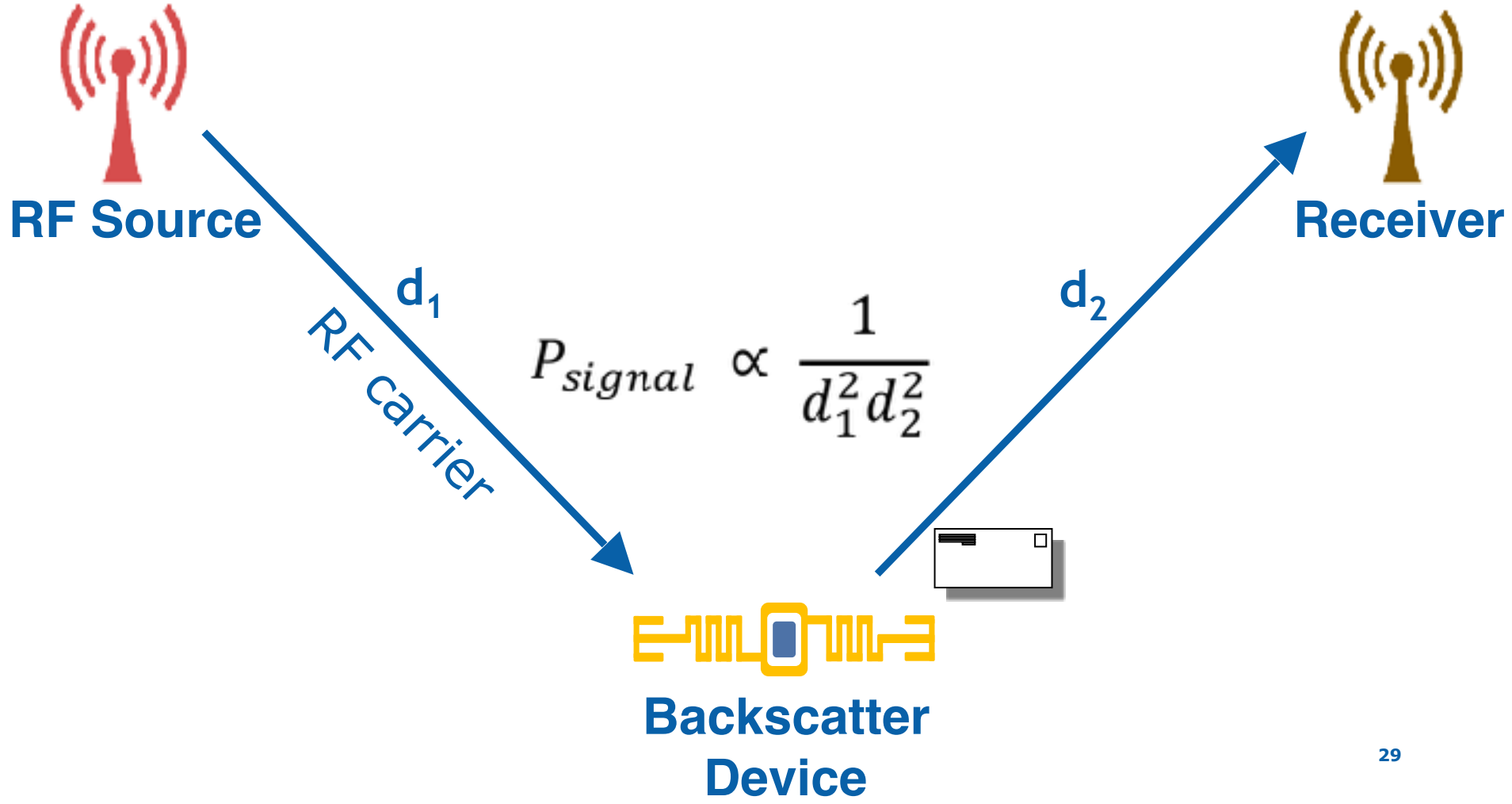
PESQ: Perceptual Evaluation of Speech Quality

Power consumption

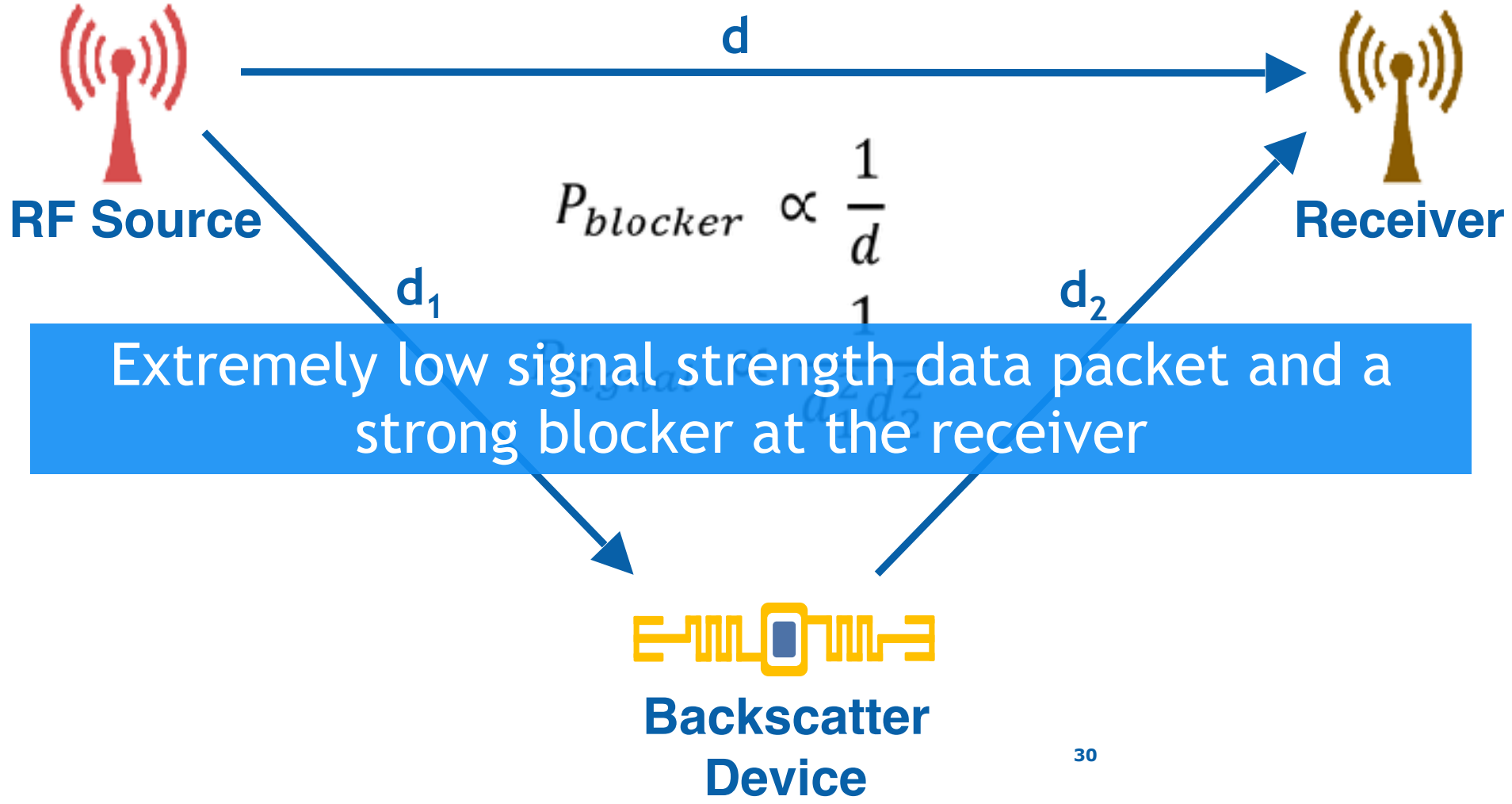
Component	Power Consumption
Harvester & Power Management	2.15 μW
MSP430 micro-controller (LPM3)	0.86 μW
RF switch	0.86 μW
Total	3.55 μW

Can we get long range?

Challenge: Signal Propagation in Backscatter Systems



Challenge: Signal Propagation in Backscatter Systems



Extremely low signal strength data packet and a strong blocker at the receiver

Our Solution: Clean slate design of backscatter system

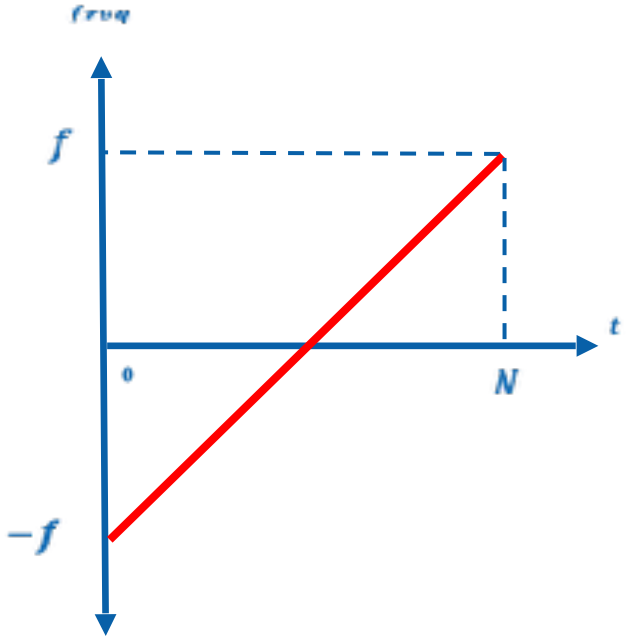
- Use coding to achieve optimal tradeoff between sensitivity and data rate
- Modulation scheme resilient to single tone interference

Chirp Spread Spectrum Modulation

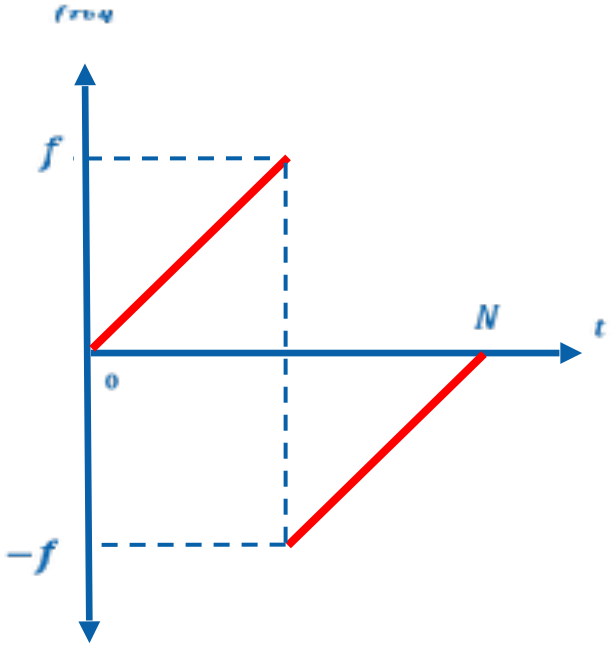
- Decode signals down to -148 dBm
- 50 bps to 32.5 kbps data rates
- Blocking immunity of 90 dB

Chirp spread spectrum modulation

Linearly vary the frequency of the carrier with time



Bit ‘0’

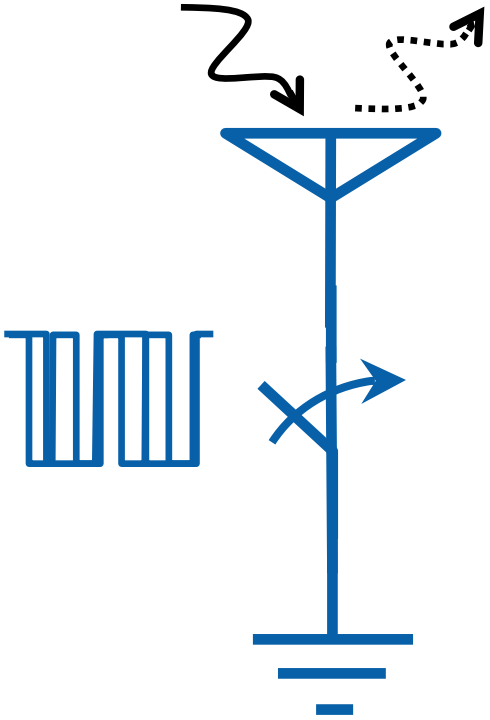


Bit ‘1’

Data is encoded in cyclic shifts of frequency

Synthesize CSS using backscatter

Linearly vary the frequency of the square wave at the backscatter switch

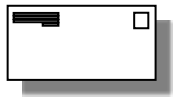


Synthesize CSS using backscatter

RF Source

Receiver

Extremely small, low power and cheap long range connectivity solution which can be embedded in every object



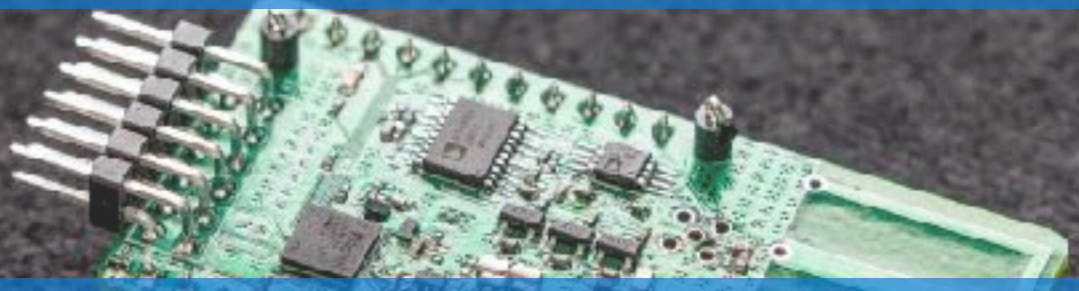
CSS Modulated Data packet

Backscatter Device

Implementation

COTS Prototype:

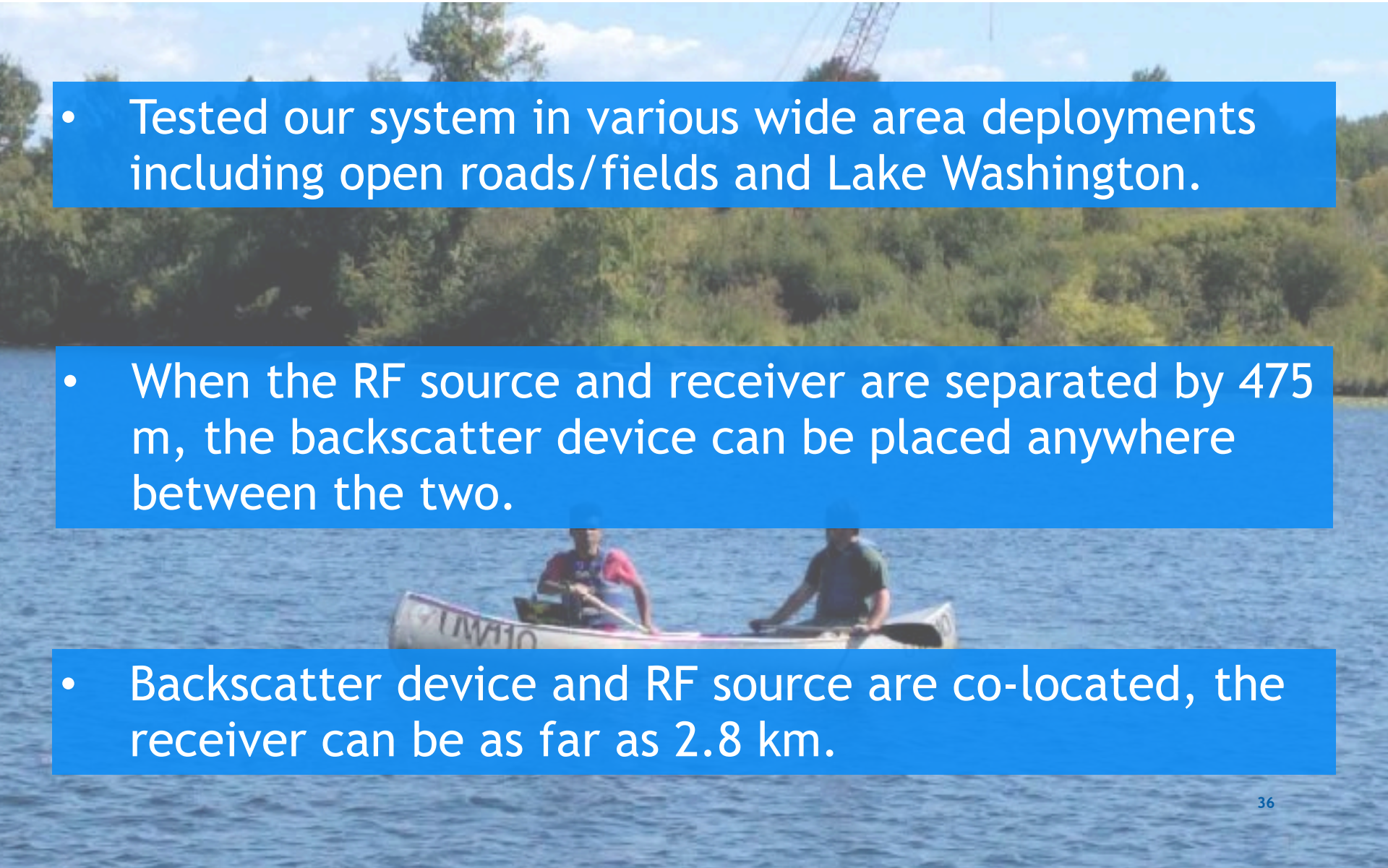
- MicroSemi Igloo Nano FPGA
- Custom RF backscatter switch



IC Implementation:

- TSMC 65nm LP Process
- Verilog baseband, RF switch & PLL
- Consumes 9.5 µW during transmission

Synthesize CSS using backscatter



- Tested our system in various wide area deployments including open roads/fields and Lake Washington.
- When the RF source and receiver are separated by 475 m, the backscatter device can be placed anywhere between the two.
- Backscatter device and RF source are co-located, the receiver can be as far as 2.8 km.

In Home evaluation

- Communicate @ µWs across a 3 floor, 5000 ft^2 home
- Expand by adding additional Companion devices

Discussion

Is battery-free sensing/computing practical now or soon?

- Now…and increasing cell density & energy efficiency working in our favor

What does it mean?

- Eliminating wires ➔ Lower weight
- Eliminating batteries ➔ Perpetual sensing even w/ servicing impossible
- Battery-free "recovery/config" mode for every device?
- More sustainable (no batteries)

Where to from here?

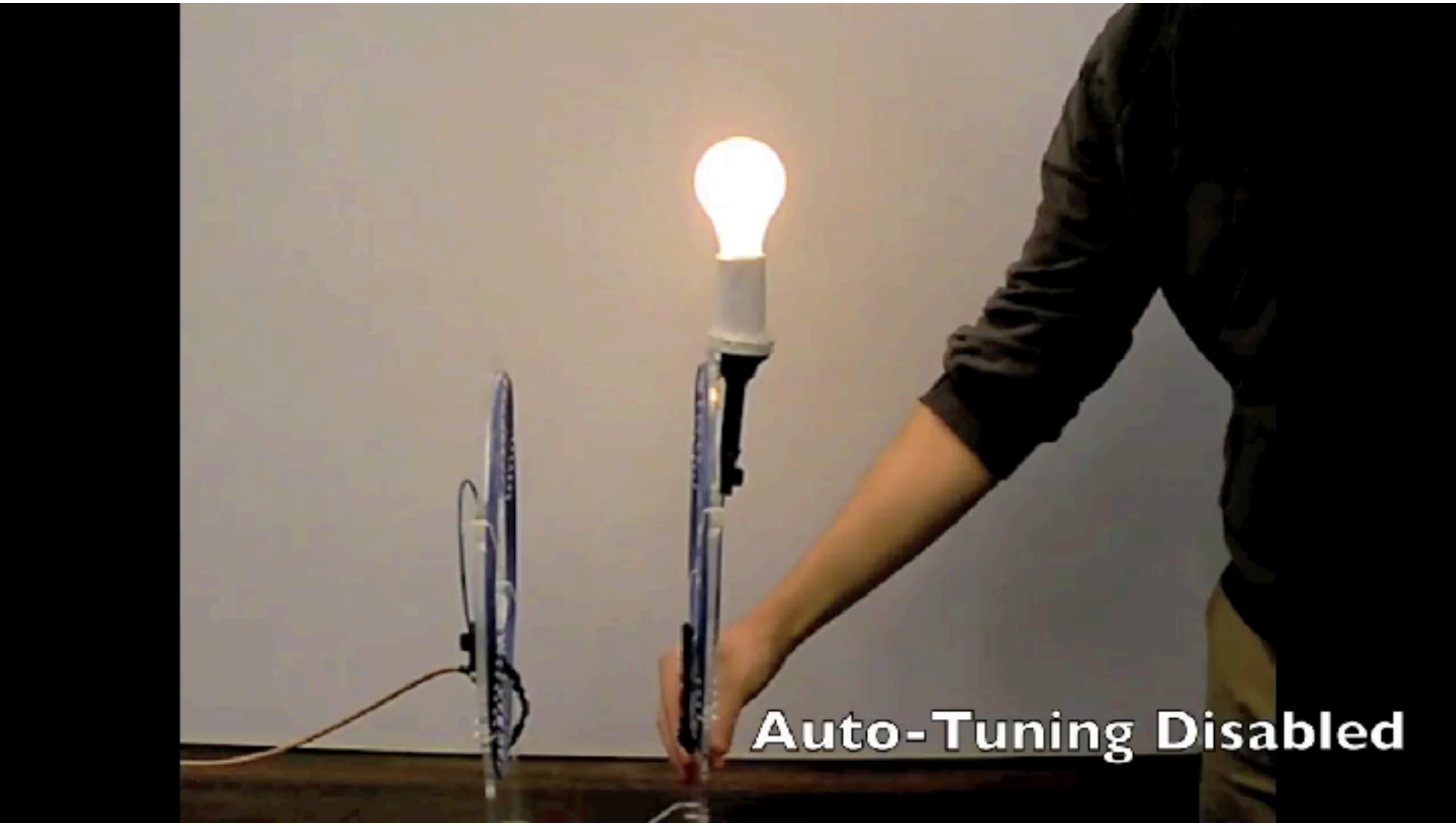
- Find the applications where it can become real first…Jeeva Wireless

info@jeevawireless.com

Backup: Near field wireless power

Range and orientation adaptation

Video

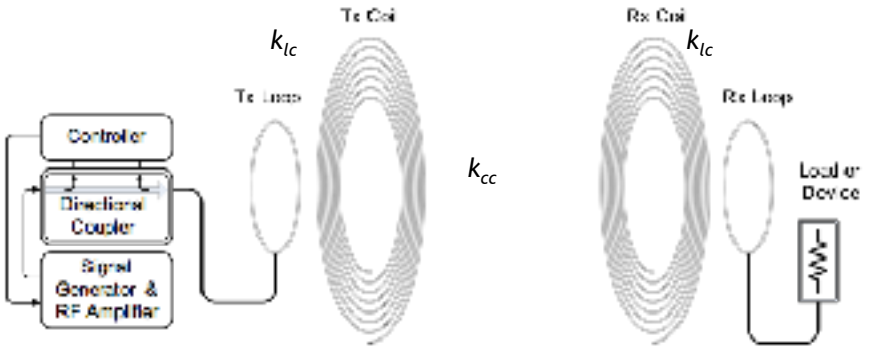


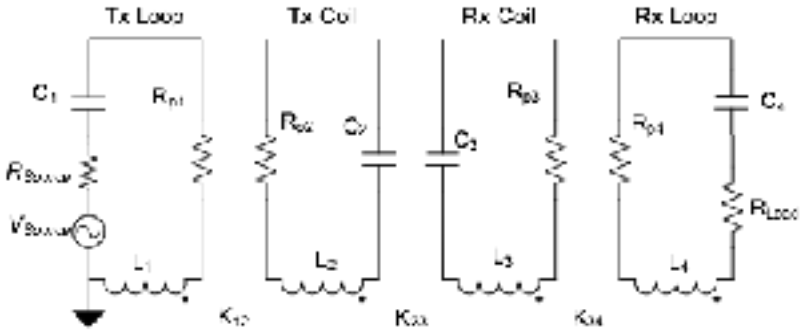
Analysis, Experimental Results, and Range Adaptation of Magnetically Coupled Resonators for Wireless Power Transfer, A.P. Sample, D.T. Meyer, J.R. Smith, *IEEE Transactions on Industrial Electronics, Feb 2011, vol.58, no.2*

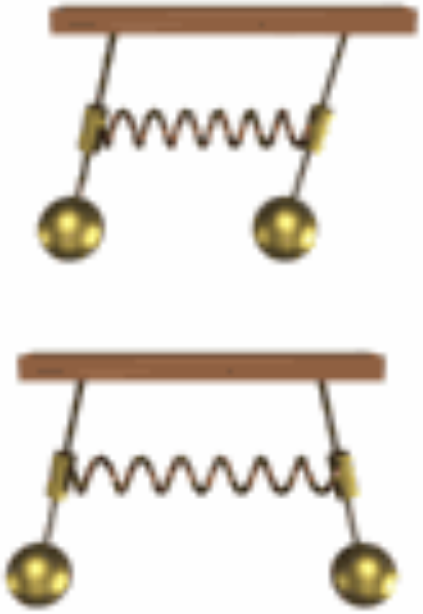
WIBOTIC

Ben Waters, Co-Founder, CEO

WREL System

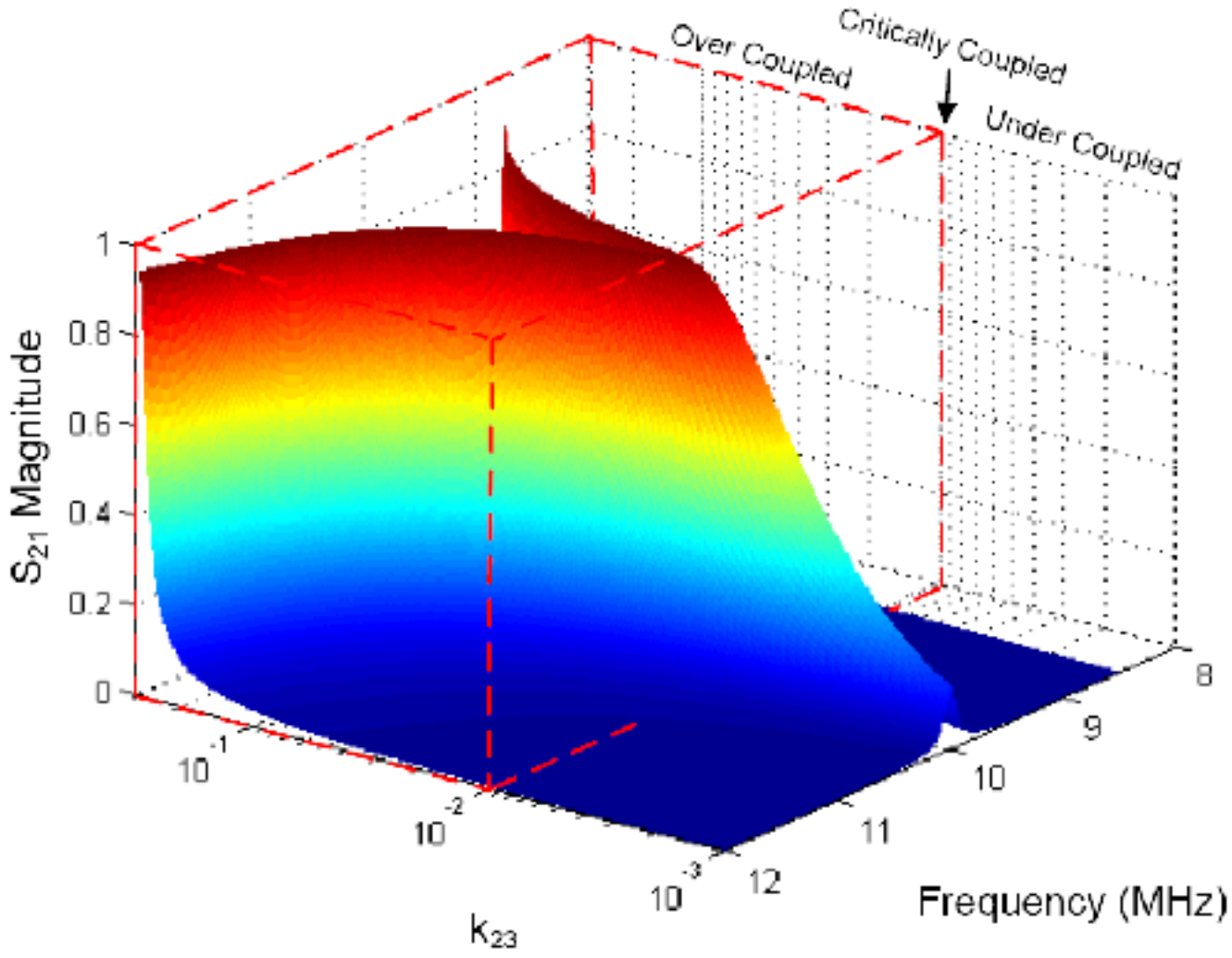




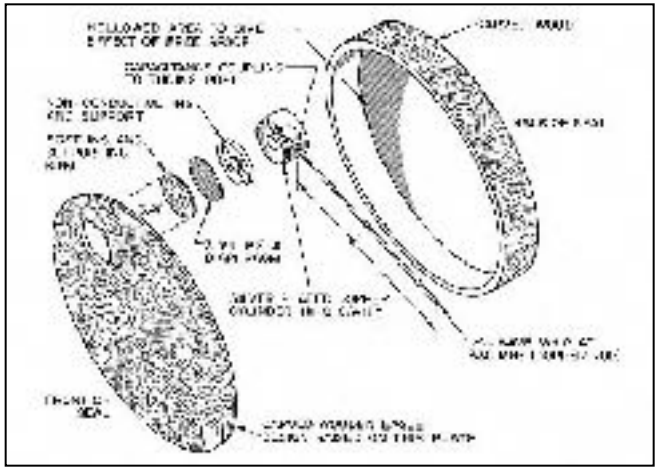


Analysis, Experimental Results, and Range Adaptation of Magnetically Coupled Resonators for Wireless Power Transfer, A.P. Sample, D.T. Meyer, J.R. Smith, *IEEE Transactions on Industrial Electronics, Feb 2011, vol.58, no.2*

Wireless Resonant Energy Link --- Theory



Battery-free Wireless Microphone



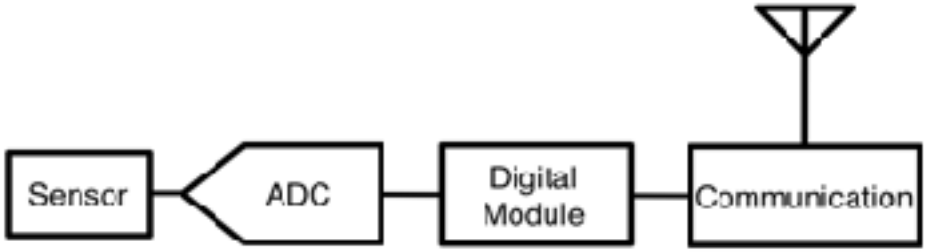
0.7m

7m

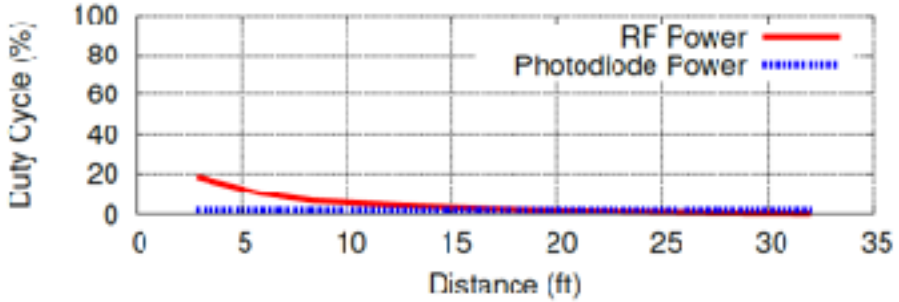
Hybrid Analog-Digital Backscatter: A New Approach for Battery-Free Sensing, V. Talla, J.R. Smith, IEEE RFID 2013.

Hybrid Analog-Digital Backscatter Platform for High Data Rate, Battery-Free Sensing, V. Talla, M. Buettner, D. Wetherall, J.R. Smith, WiSNET 2013

Could we use digital backscatter to make a phone?



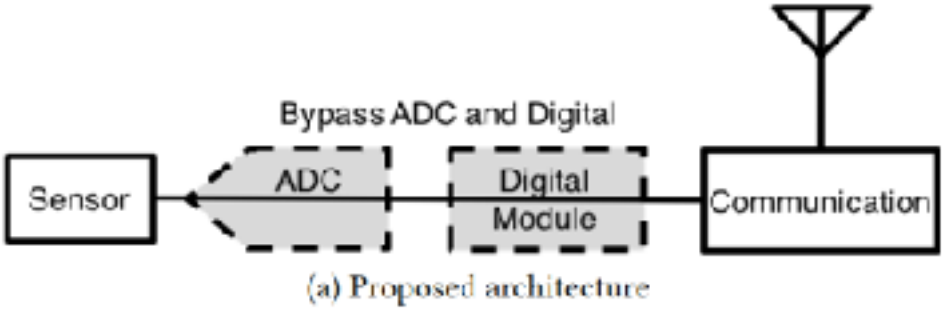
(a) System architecture for existing digital approach.



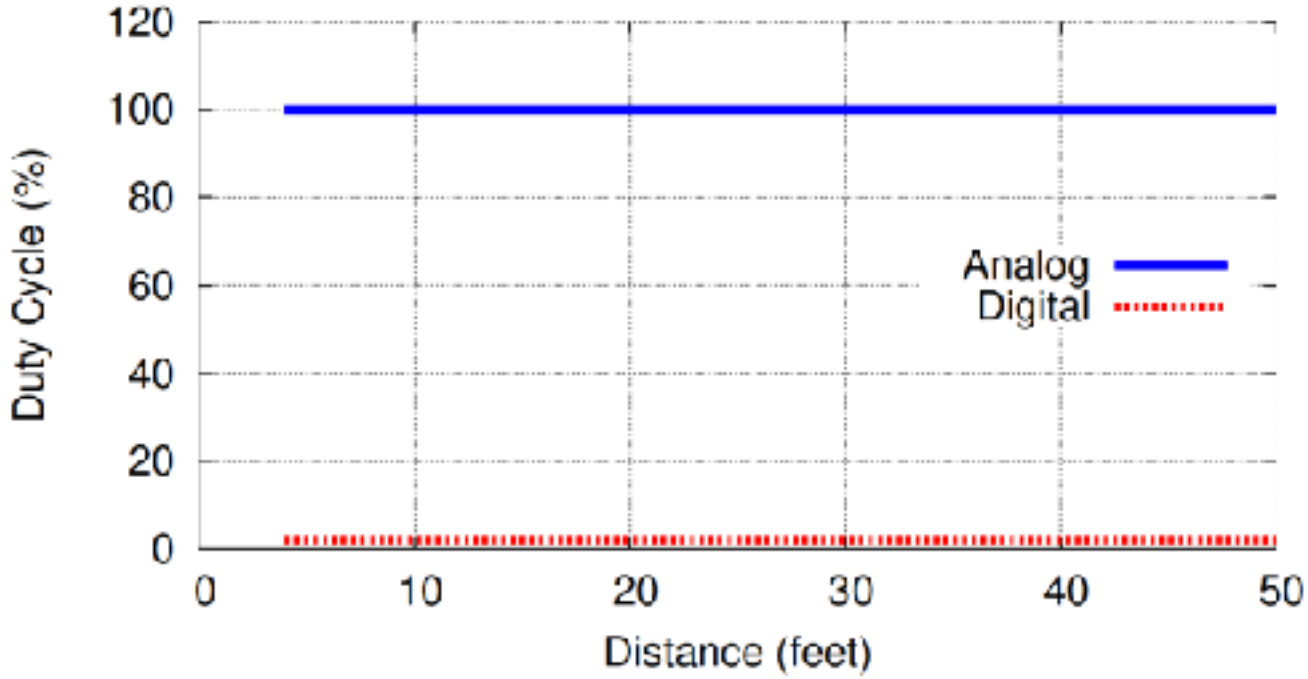
(b) Duty cycle while transmitting speech on RF power using existing digital approach.

It would not work very well…low duty cycle
Shift more functionality from endpoint to powered infrastructure

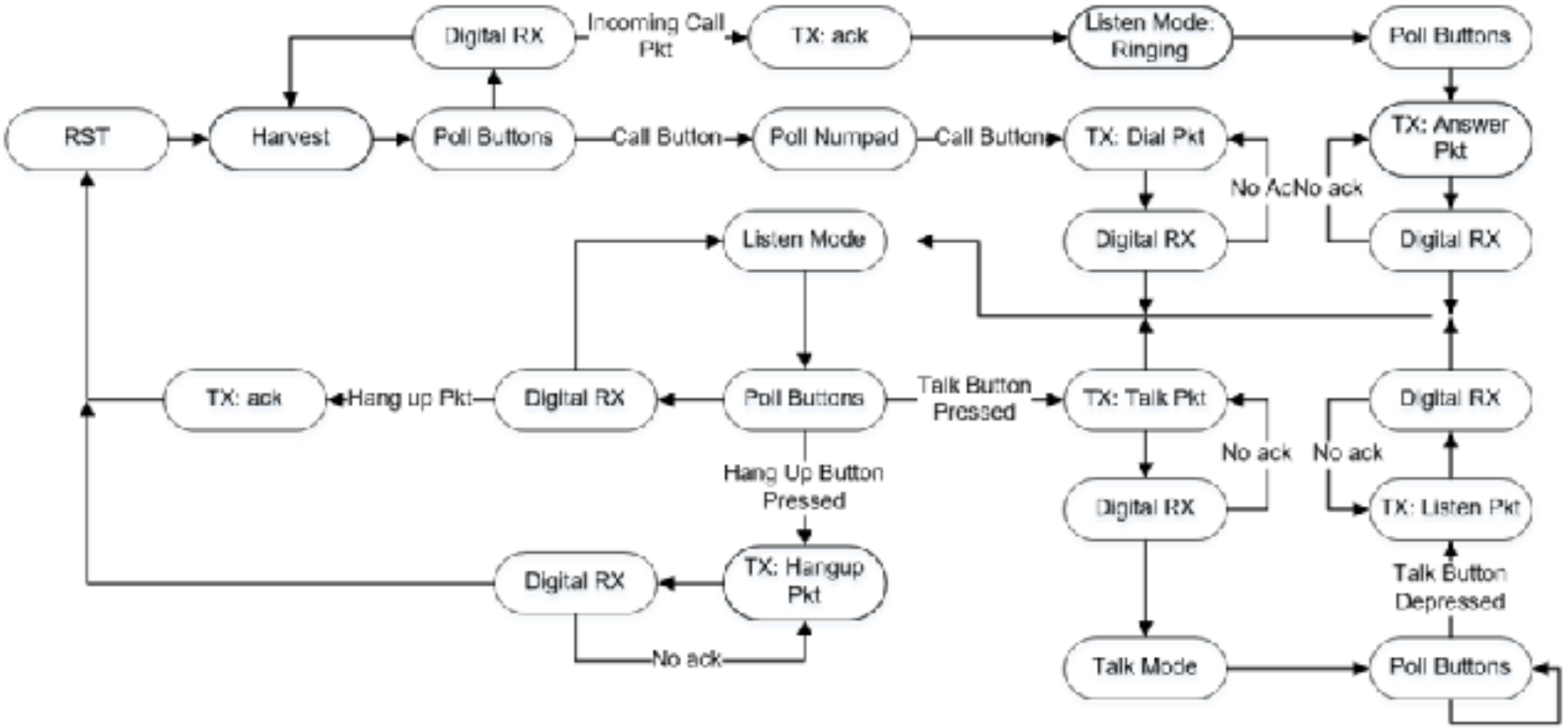
Analog backscatter has power benefit over digital



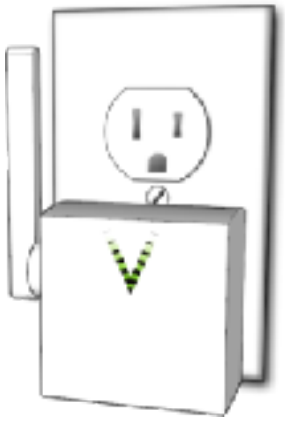
(a) Proposed architecture



Phone state machine

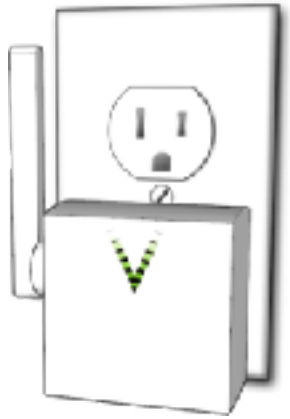


Long Range System



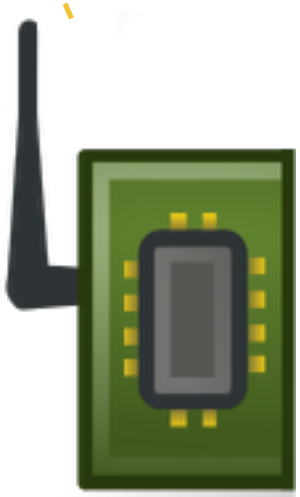
Companion

200m+ range between Companions and Endpoints, 30kbps data rates



Companion

In the Long-Range system, **Multiple Companions** are used to both generate signals and pick up the Endpoint's reflected packet



Companions automatically coordinate to form a network. They **bridge** to enterprise or home Wi-Fi or wired LAN