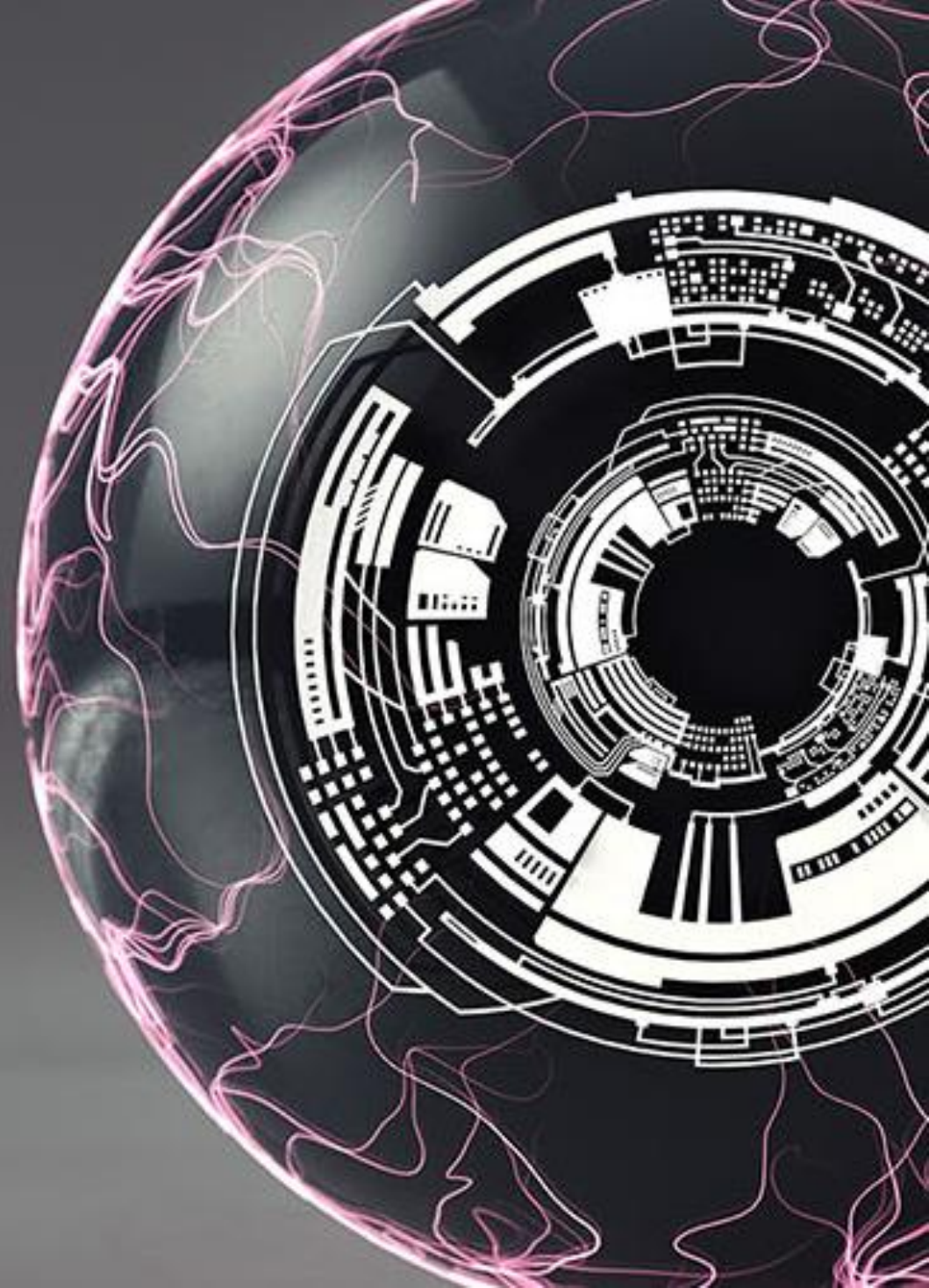




Battery-free, RF-powered cameras

Joshua Smith
Associate Professor
Computer Science and Engineering
Electrical Engineering
University of Washington



WISP: Wireless Identification and Sensing Platform



First UHF-powered
accelerometer

Battery-Free Wireless Identification and Sensing, M.Philipose, J.R. Smith, B. Jiang, K. Sundara-Rajan, A. Mamishev, S. Roy. *IEEE Pervasive Comp.*, V4 N1, 2005
A wirelessly powered platform for sensing and computation, J.R. Smith, A. Sample, P. Powledge, A. Mamishev, S. Roy. *UbiComp 2006*
RFID Sensor Networks with the Intel WISP Best Demo, Sensys, M. Buettner, B. Greenstein, R. Prasad, A. Sample, J.R. Smith, D. Yeager, D. Wetherall, 2008

Sensor Systems Lab Students



Saman Naderiparizi



Zerina Kapetanovic



Vaishnavi Ranganathan

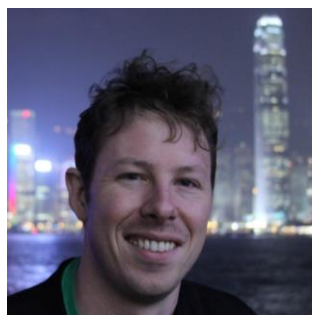


Yi "Eve" Zhao

Microsoft Interns
this summer!



Xingyi Shi



Gregory Moore



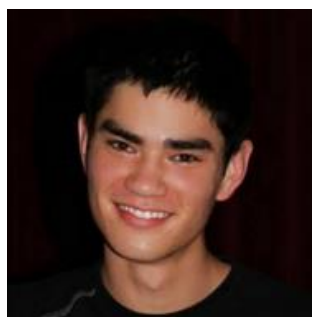
Aaron Parks



Brody Mahony



Jim Youngquist



Patrick Lancaster



Vamsi Talla

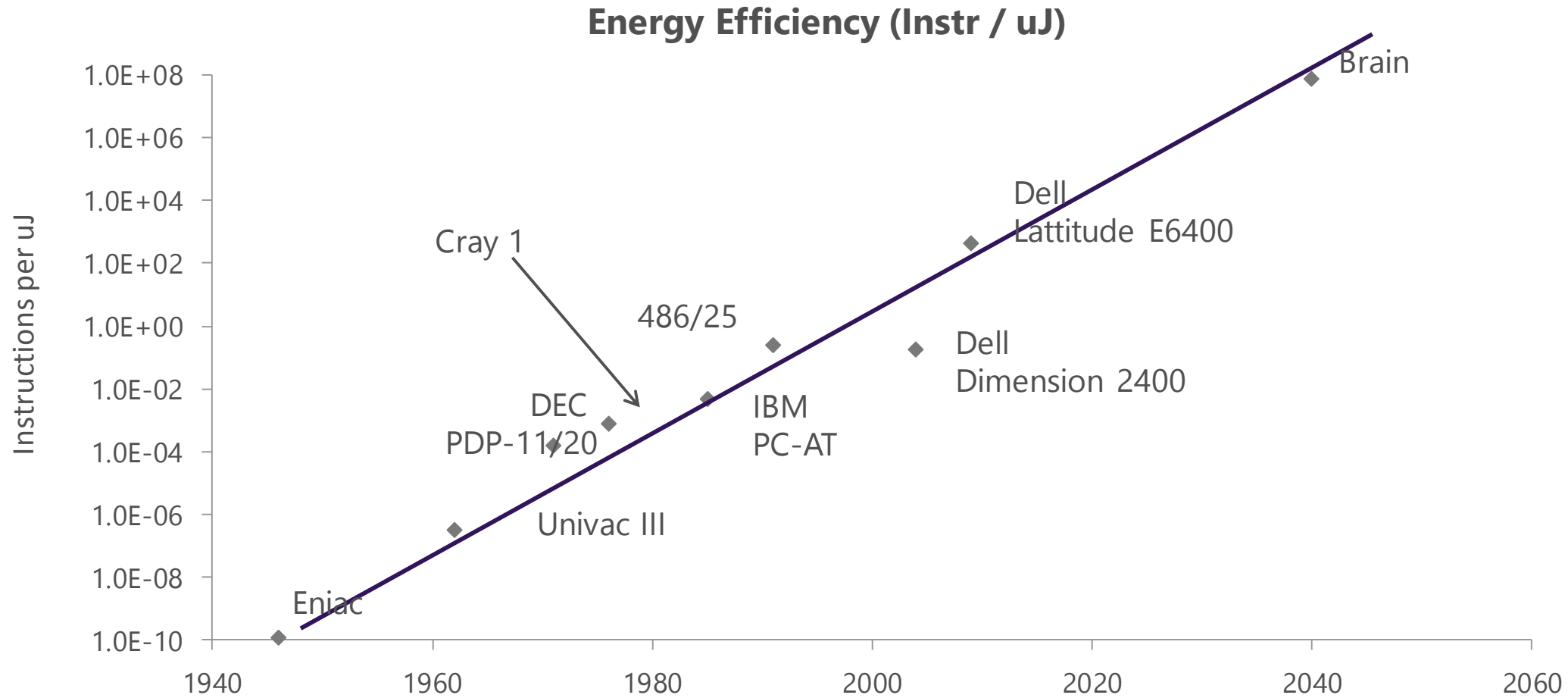


Ben Waters, EE

PhD alums

Enabling trend

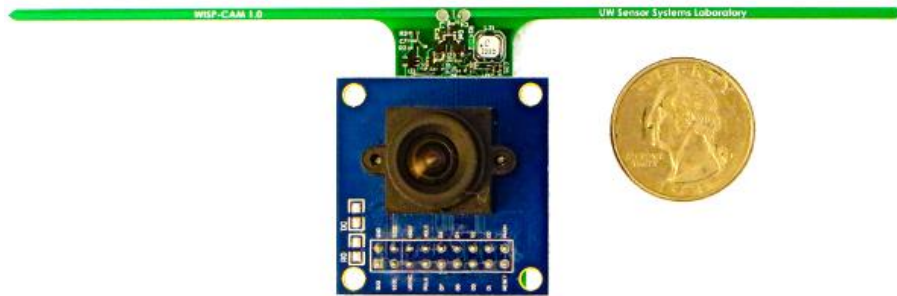
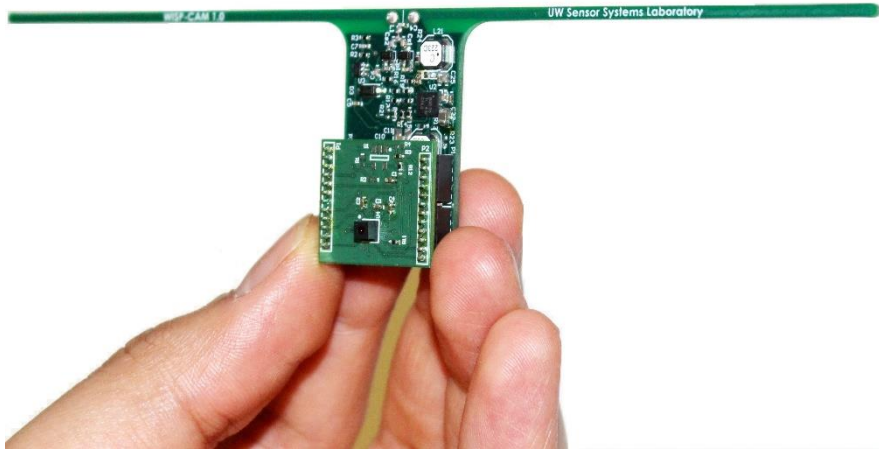
Energy Efficiency Scaling



Data: *Implications of Historical Trends in the Electrical Efficiency of Computing*

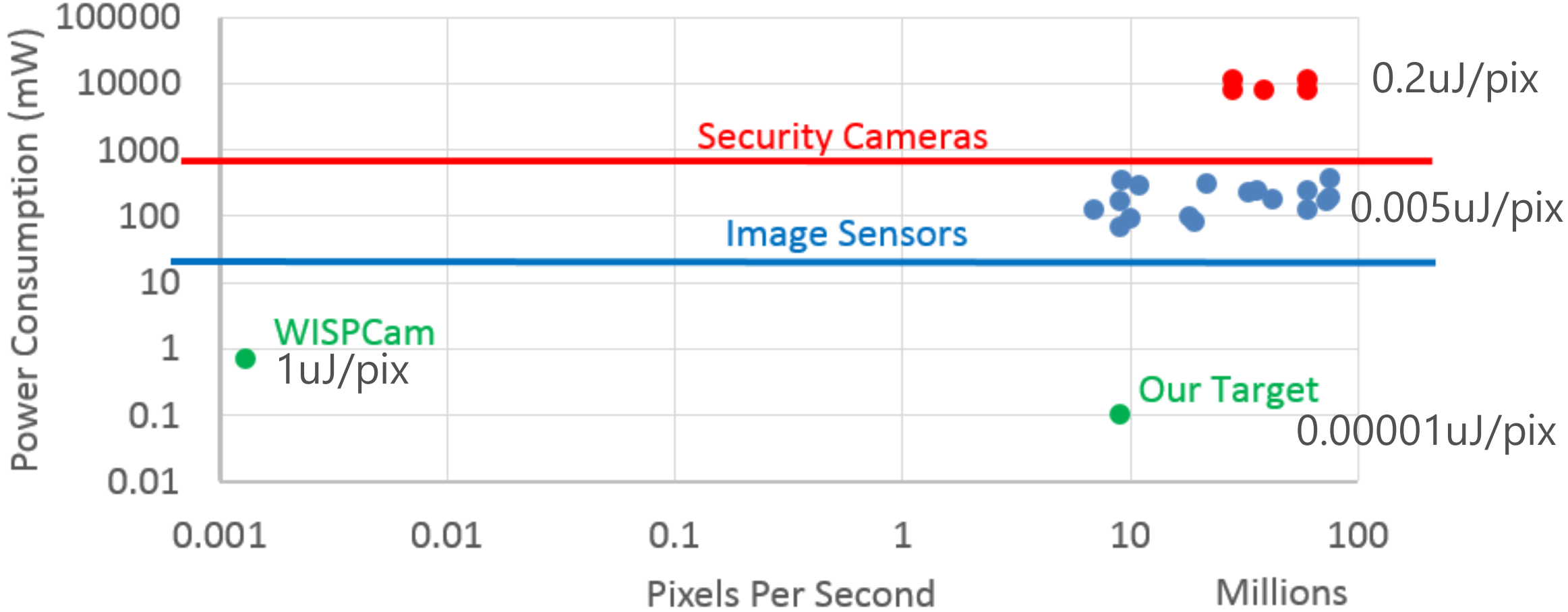
Koomey, Berard, Sanchez et al, IEEE Annals of the History of Computing, 2011

WISPCam: A Battery-Free RFID Camera



Saman Naderiparizi, A. N. Parks, Z. Kapetanovic, Y. Zhao, J. Youngquist, B. Ransford and J. R. Smith,
IEEE RFID 2015, ACM UbiComp 2015, GetMobile Magazine 2016

Camera power-performance scaling

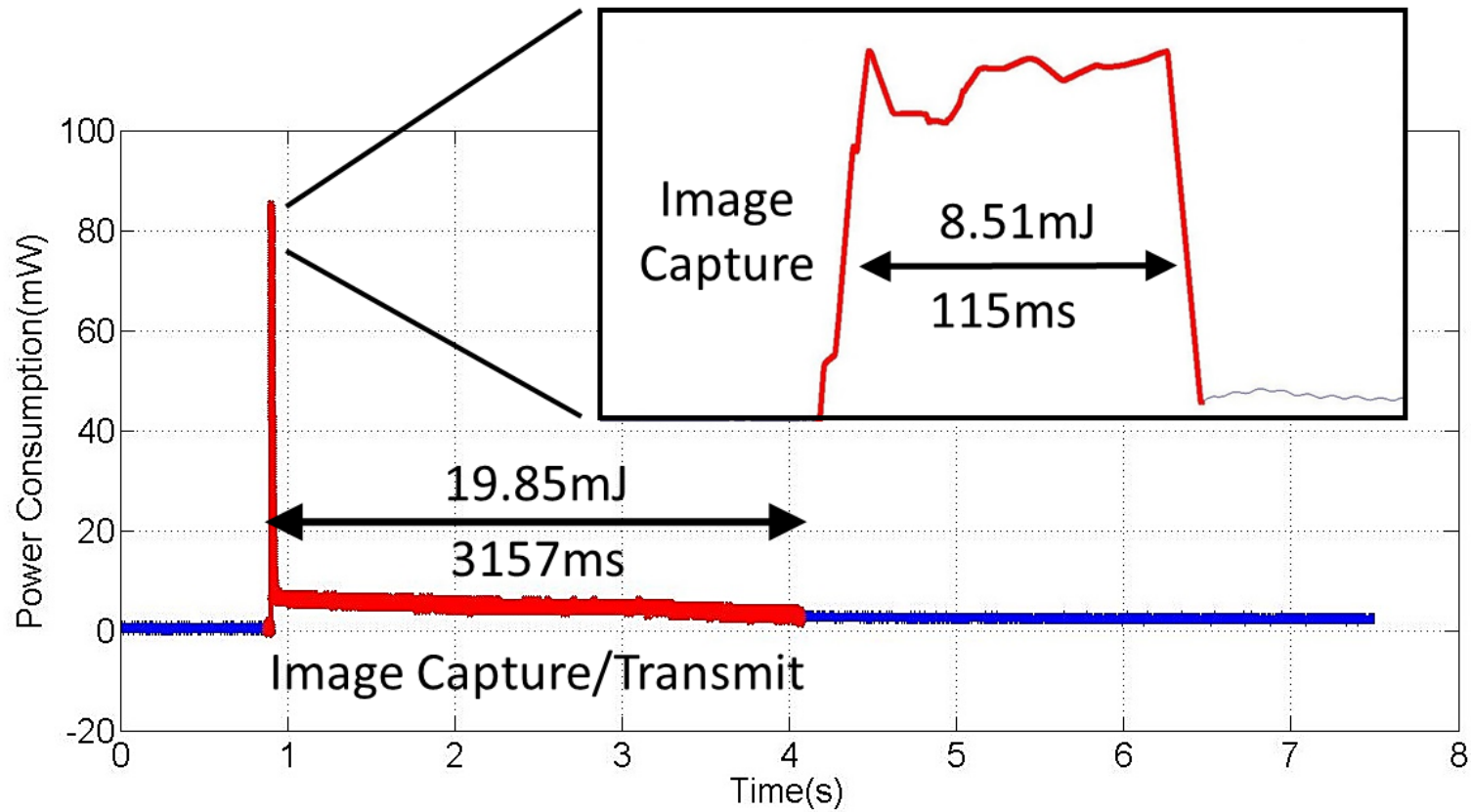


Battery-free sensing overview

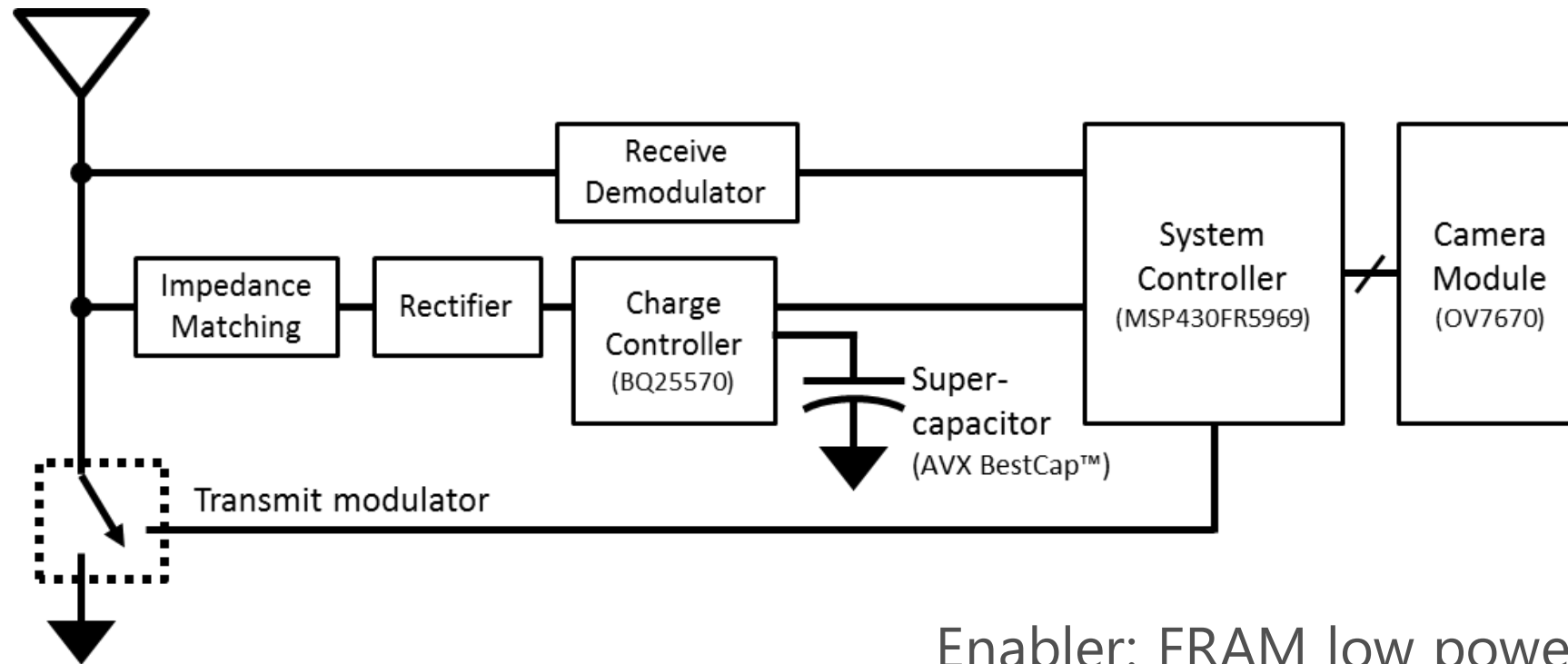
We have previously shown battery-free sensing using simple sensors such as temperature, acceleration, ...



WISPCam Energy Consumption

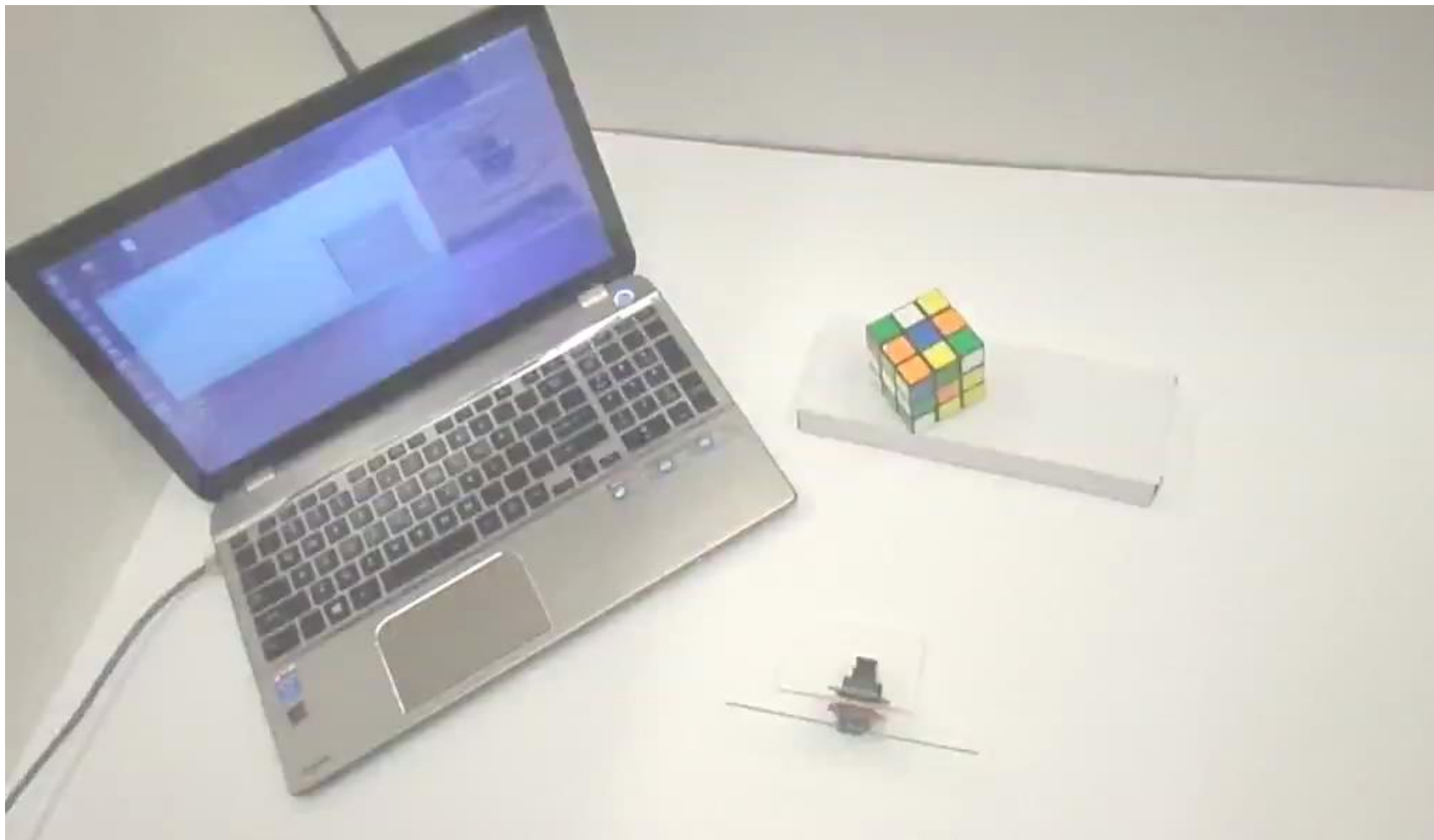


WISPCam System Overview



Enabler: FRAM low power, non-volatile storage of image

WISPCam demo video

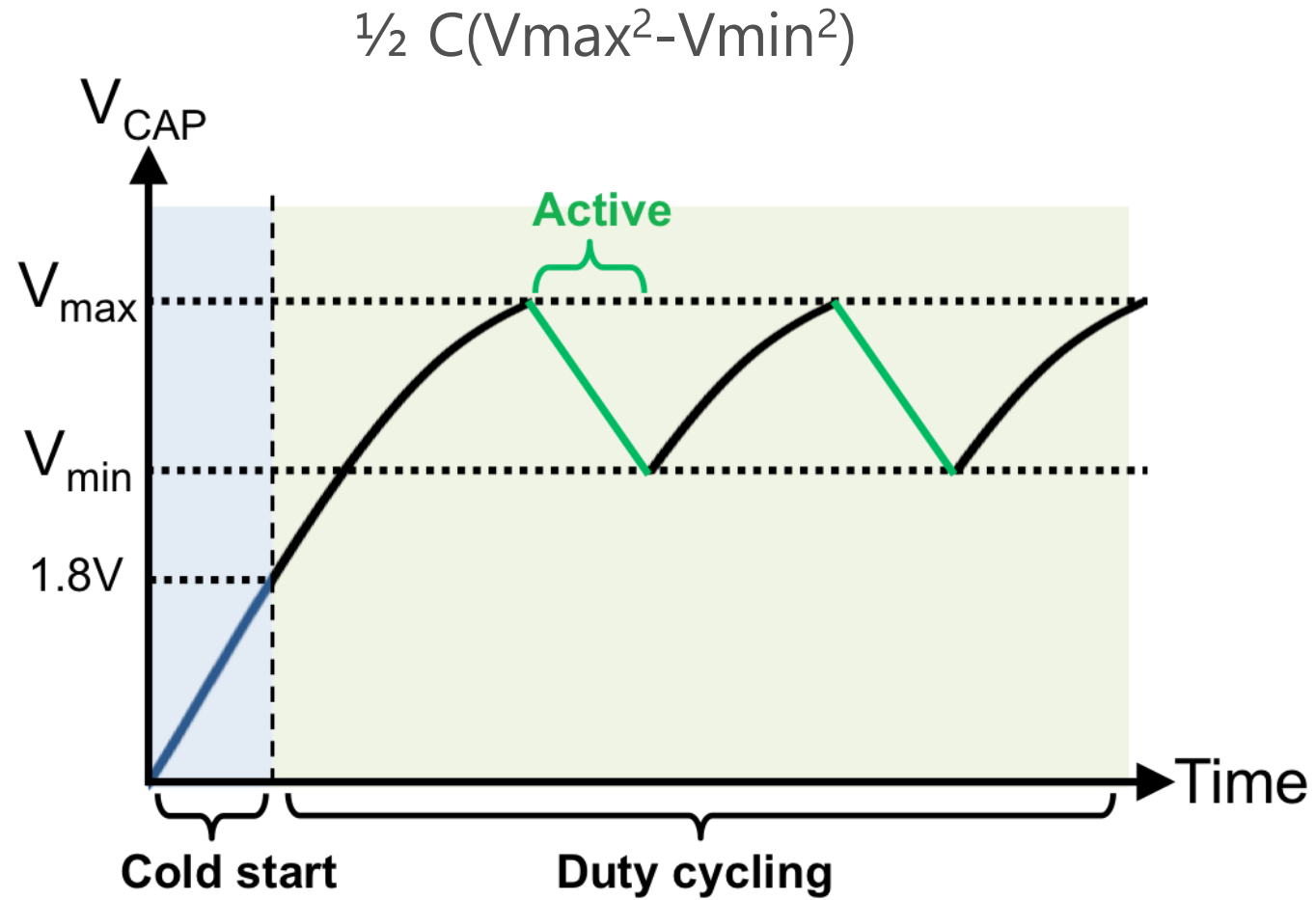


Enabling a battery-free camera

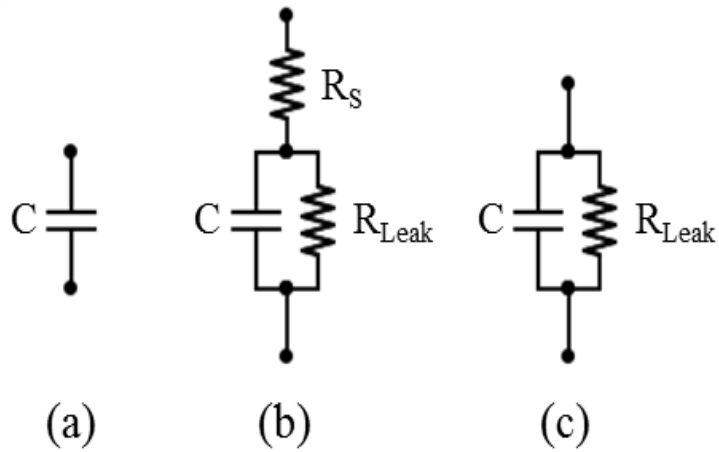
Efficient on-board large energy storage.

Large data storage and transmission on an energy-constrained system

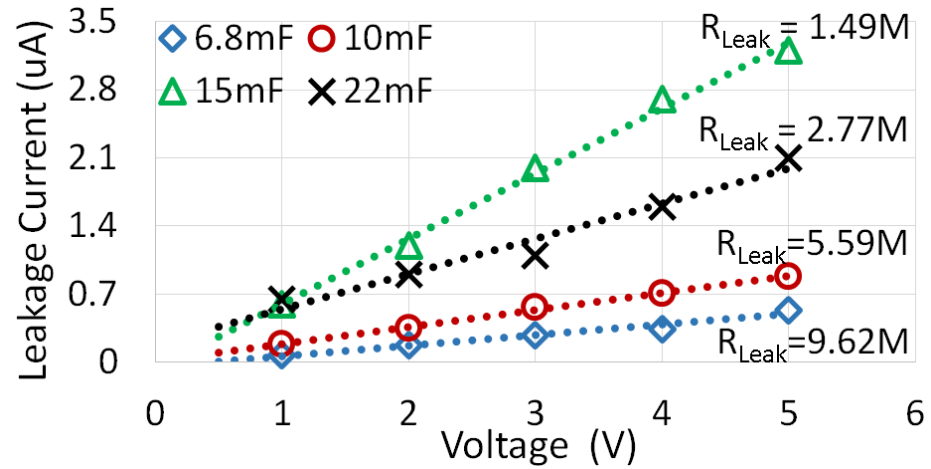
Efficient Charge Storage



Leakage



Super capacitor electrical model



Leakage of various super capacitors

Generally the higher the C the higher the leakage current

Usable Power While Charging

Required Energy

Minimum voltage threshold

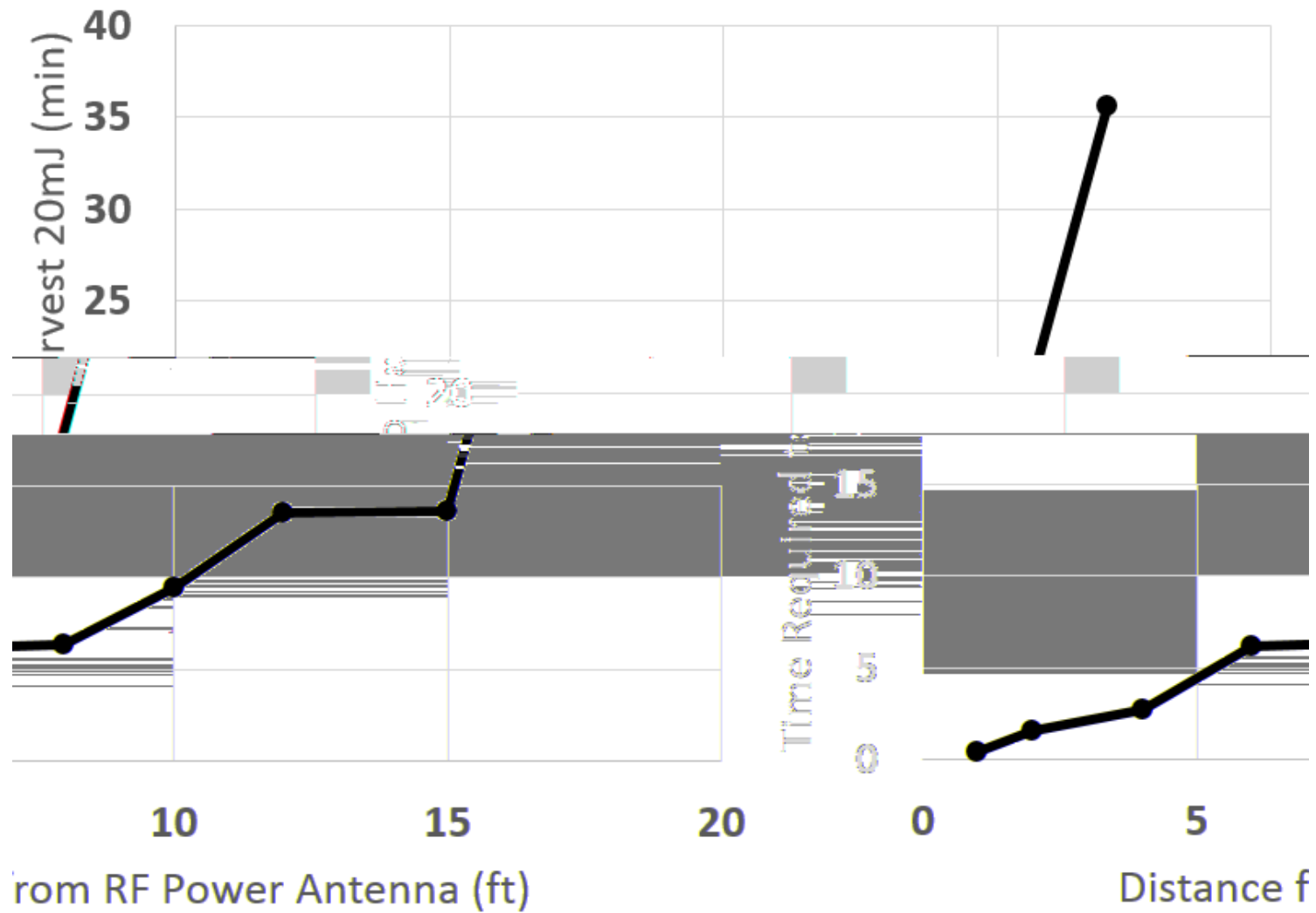
Leakage resistance

Charging power

Usable Power

Input Power	6.08mF	11.24mF	21.98mF	17.45mF
10uW	8.8uW	8.3uW	6.8uW	3.9uW
100uW	99uW	98uW	97uW	95uW

WISPCam Update Rate



WISPCam Applications

Inaccessible / difficult to access locations

Gauge/meter monitoring

Security

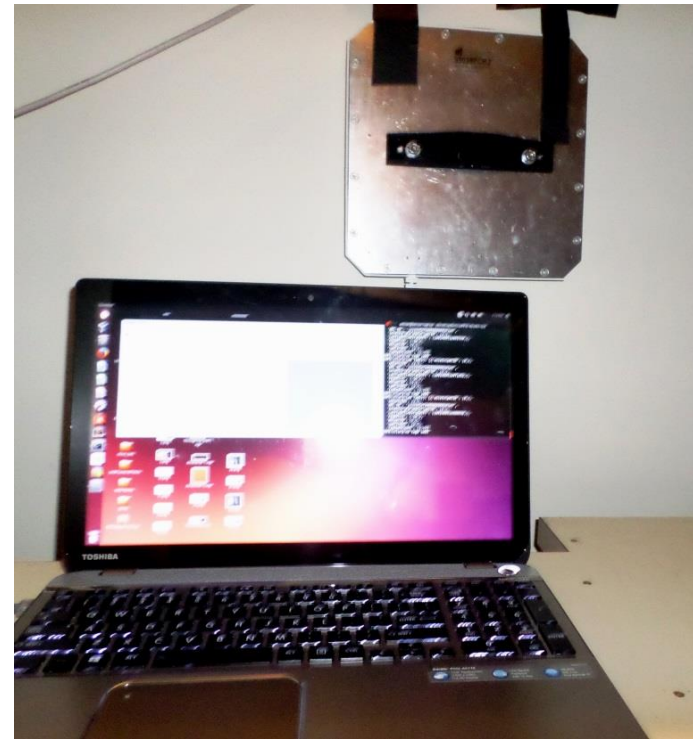
...

Through-Wall Imaging

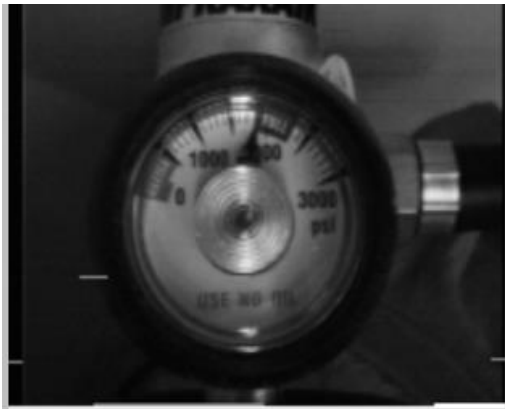
Scene



Interface software



Gas Pressure Gauge



Metering Application Example



Motion Triggered Camera



Computation in WISPCam

WISPCam Limitations:

- Communication Speed

- Computational Capabilities

- Memory

How to do more than just image capture?

Smart Task Categories

Computationally light

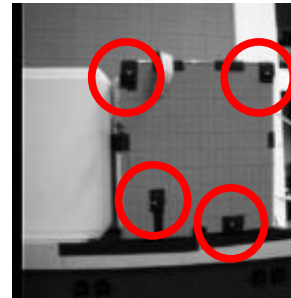
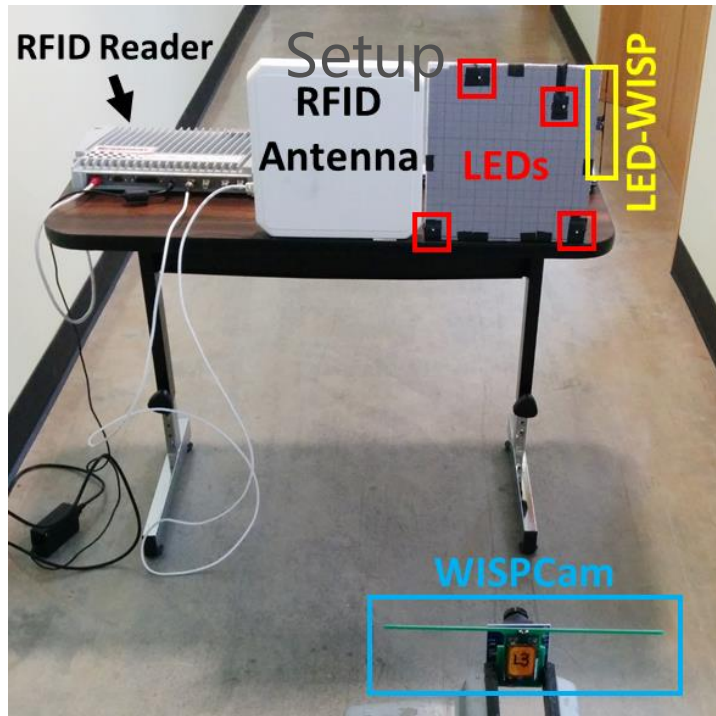
Image subtraction

Computationally Demanding

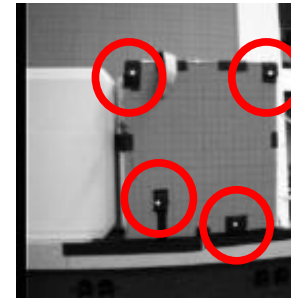
Face Detection

Computationally Light Tasks

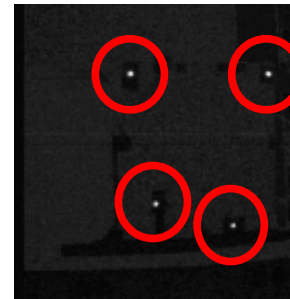
Optical localization



Background

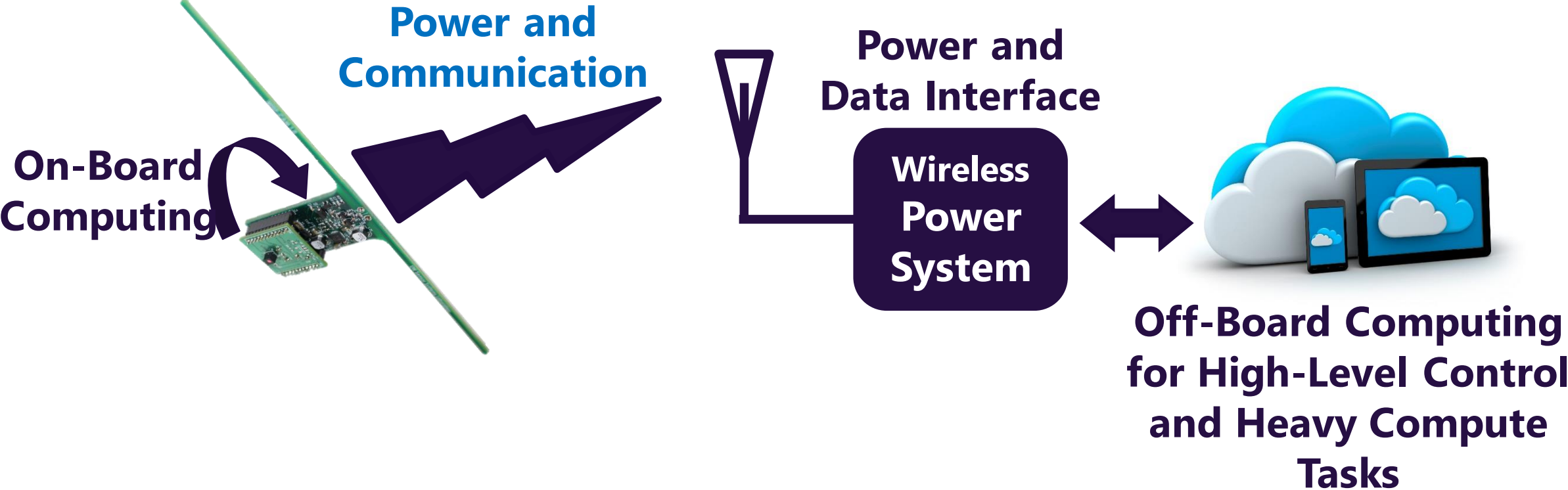


Foreground



Subtracted

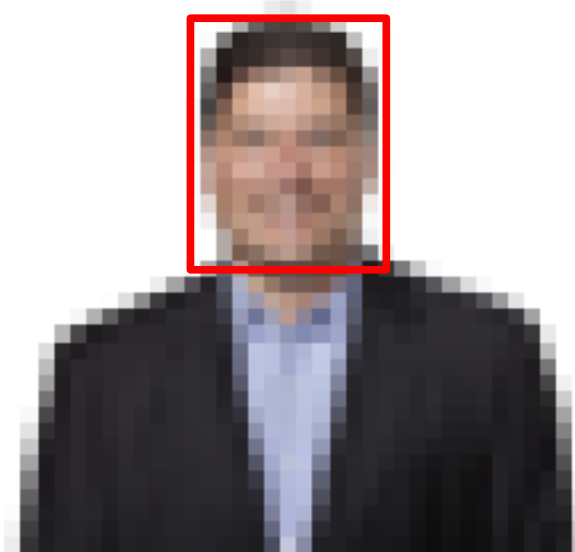
Computationally Demanding Tasks



Face Detection/Recognition Example



Impossible



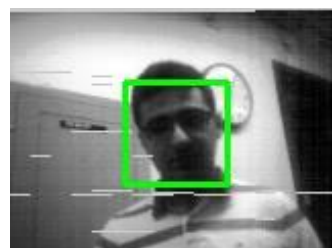
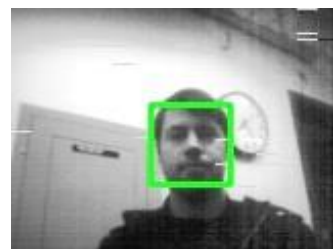
Possible



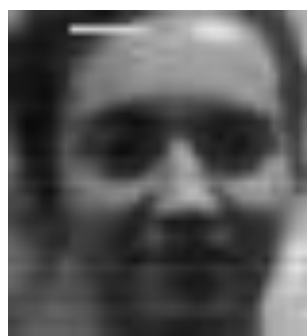
Possible

Face Recognition on a Battery-Free
Camera

Low resolution Window



Low resolution Faces

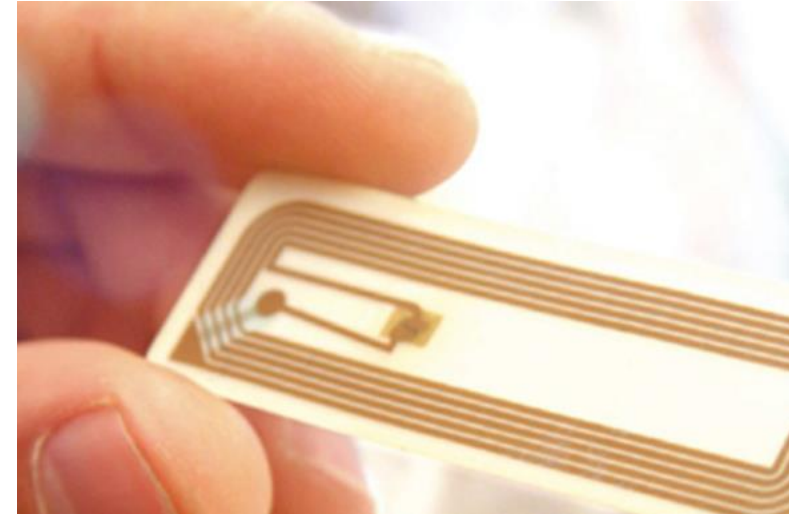
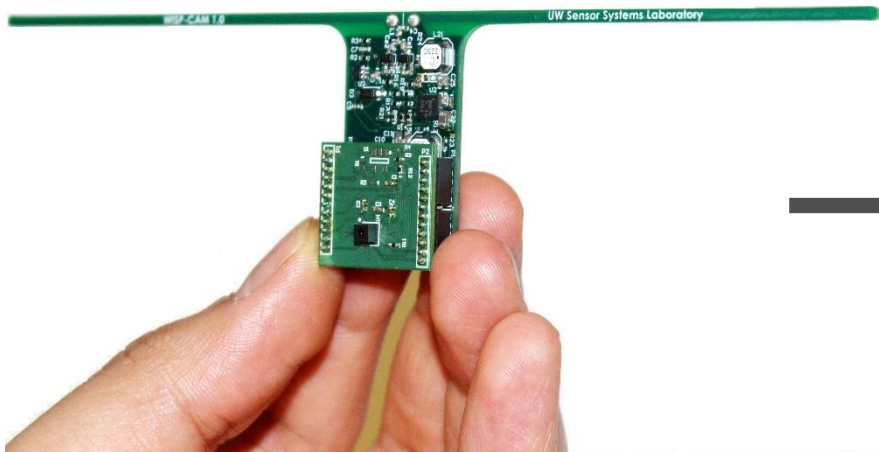


High resolution Faces



Specific-face triggered image capture?

Implications



Cameras can evolve to sticker form factor, with no wires or batteries
Sticker cameras can have substantial computation...trigger on person, event,...
Can deploy them much more widely than would be possible today
 Inside walls, containers, gutters, trash cans, ...
Will create new privacy "gray areas"...making it easy to see things that in principle are public, but in practice are hard to view



THE PAUL G. ALLEN
FAMILY FOUNDATION



NSF Engineering Research
Center on Sensorimotor
Neural Engineering (CSNE)



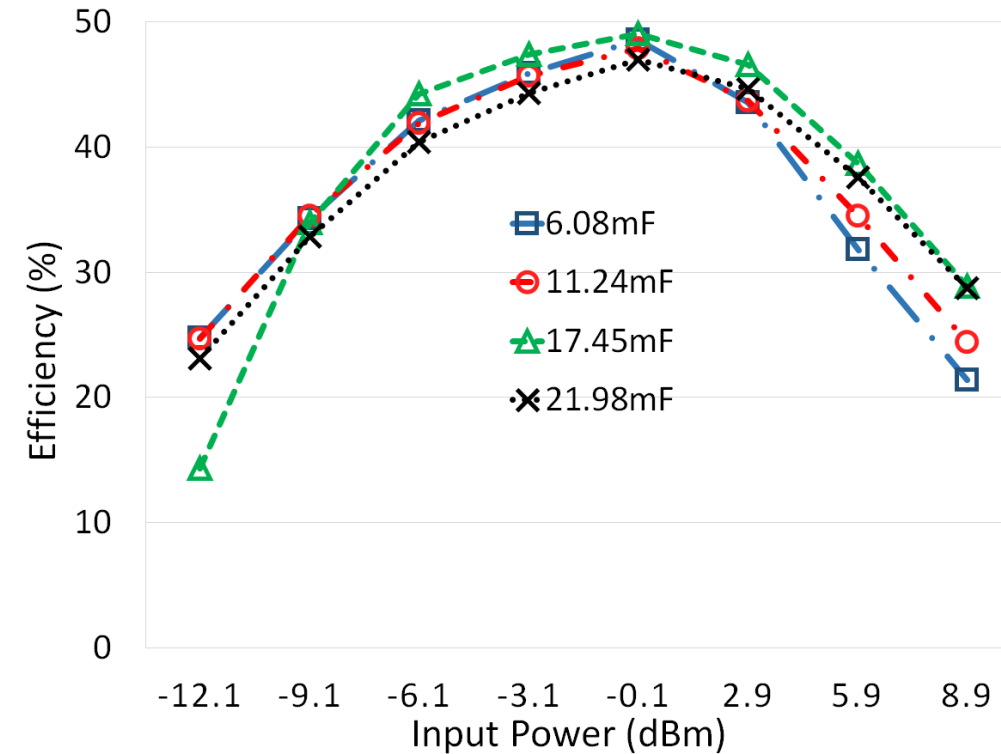
Intel Science and Technology Center for
Pervasive Computing (ISTC-PC)

Thank you

WISPCam Harvester Efficiency

WISPCam power harvester efficiency past cold-start

For 17.45mF, efficiency drops faster at lower power levels



How Many Security Cameras are Out There?

- 44ZB data generation per year by 2020
- 50B internet connected devices
- 1.1ZB is security cameras
 - 2.5% of all data !
 - **245M active security cameras in 2014**



Security Camera Limitations

Severe power problem:

Image Sensor @4K and 15fps (~200mW)

Video Compression Module and off-chip Image Processor (~1500mW)

Wireless Communication (~1100mW)

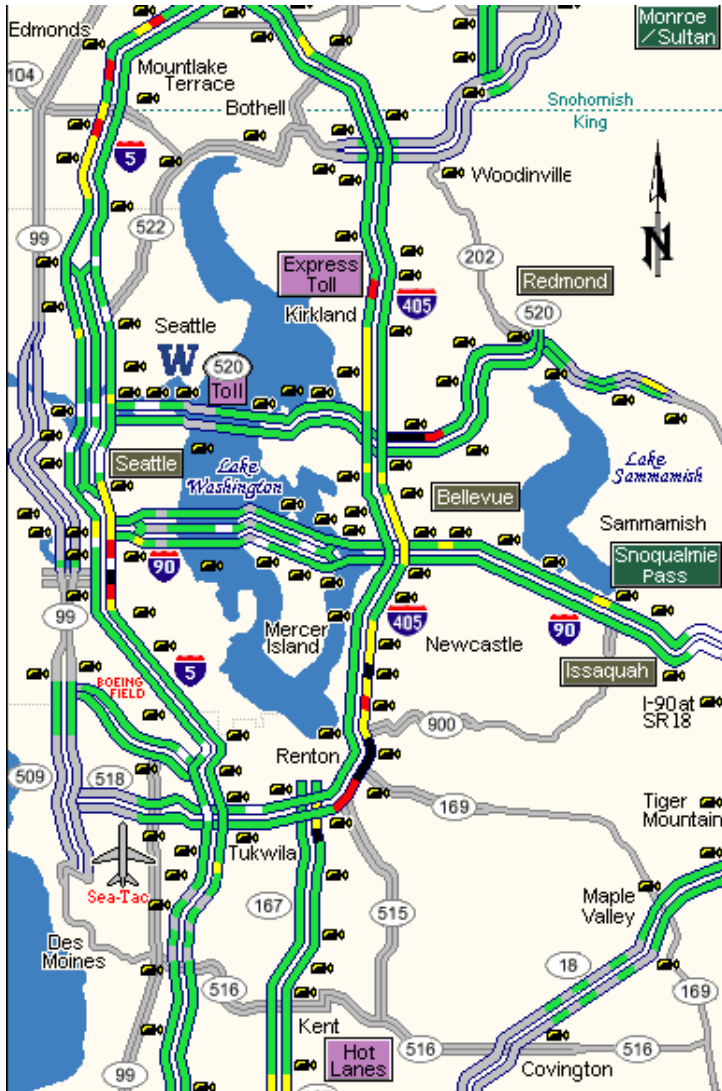
Total about 2800mW.

Need to be plugged-in.

Thus limited location usage.



Despite the Limitations ...



Security cameras are deployed widely

Eliminating all wires---power and data---will make security cameras even more widespread and enable new applications