Towards Battery-free HD Video Streaming

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Snap Spectacle

- Batteries add weight
- Has heating issues
- No video streaming

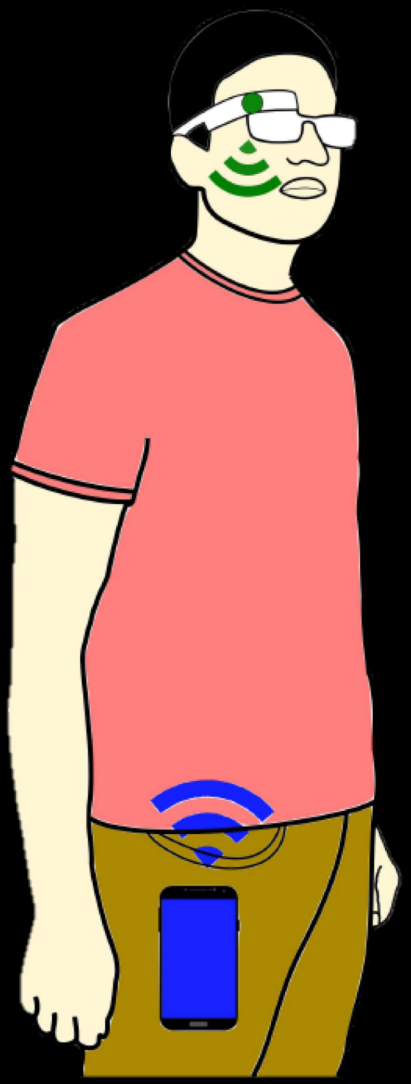
Nest Camera

Needs to be plugged into power

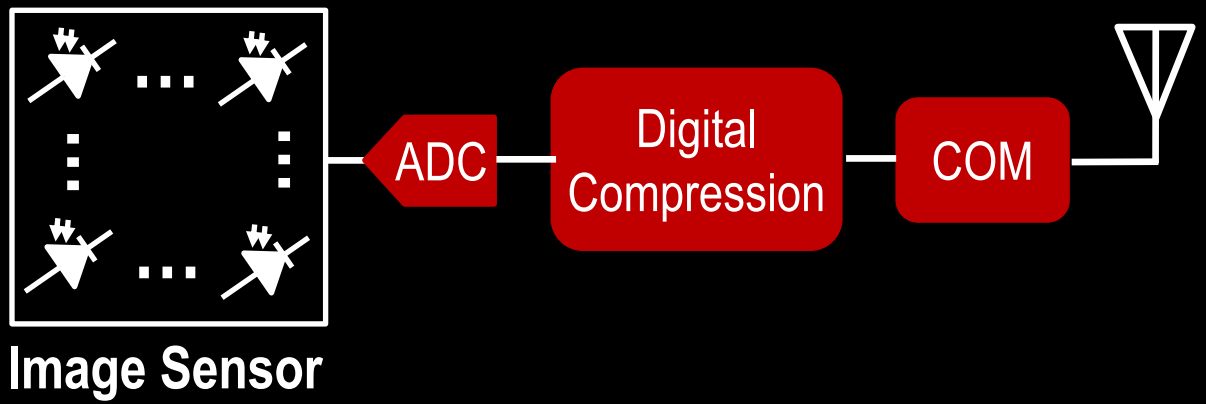
Grand Challenge

Design sticker form-factor battery-free camera tags

Our Vision of Battery-free Cameras



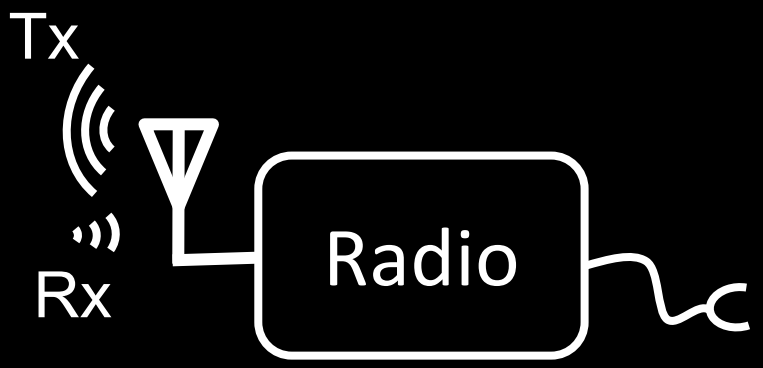
Challenge: Video Streaming is Power Hungry



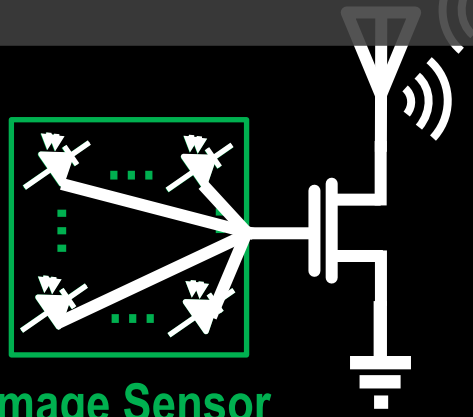
At 720p 30fps grayscale

- Image sensor: 85uW
- ADC: 2mW
- Digital Compression: 1W
- Radios: 100mW
- Total >1W

We Take Inspiration from the Great Seal Bug



Achieve Low-power Video Streaming

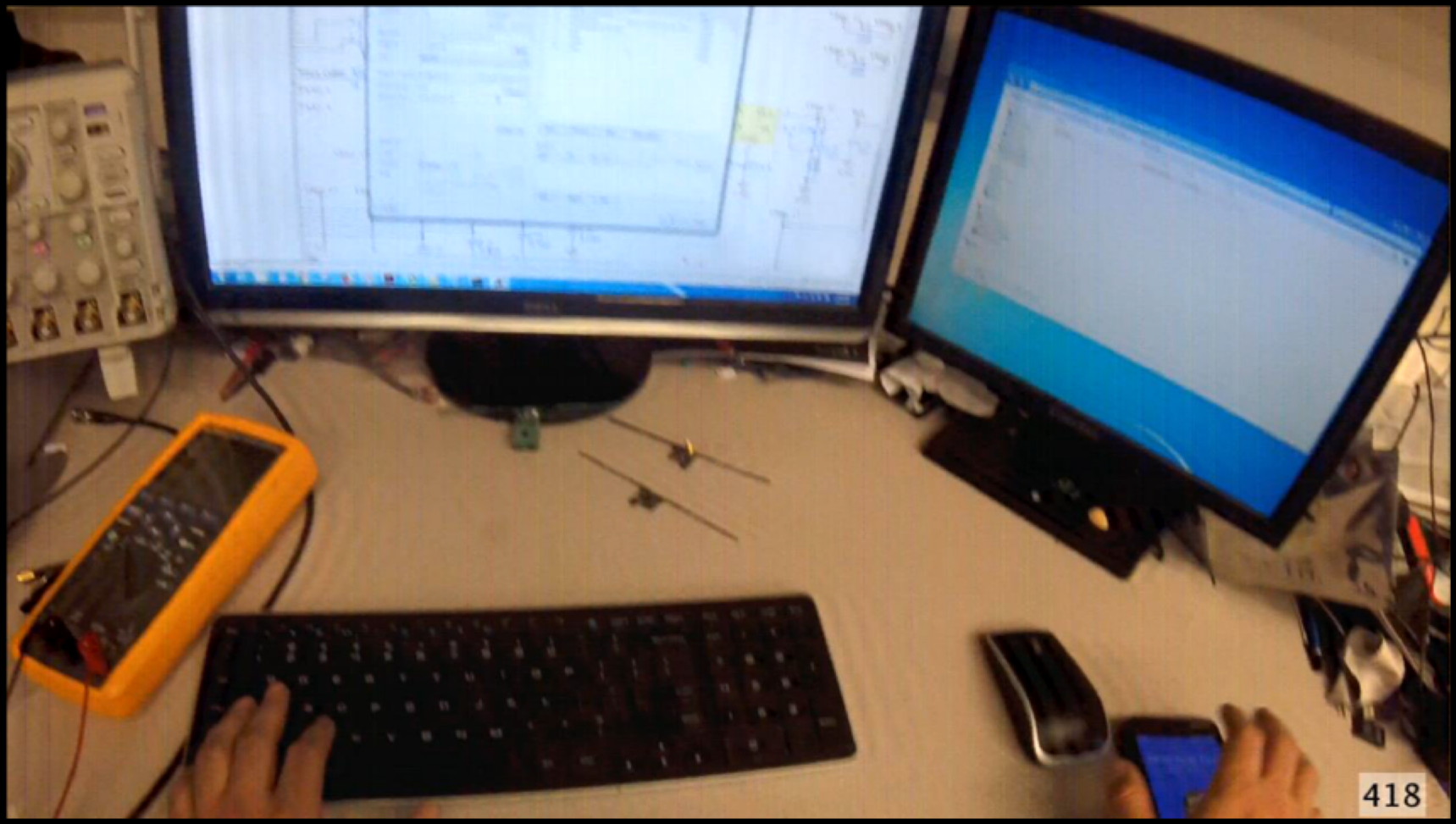


Contributions

- First demonstration of analog video backscatter that sends pixels directly to the antenna

- Evaluated with multiple prototypes & simulations
  - HD prototype with offline processing of 10fps grayscale 720p analog video backscatter at up to 14ft
  - Spec out an IC that shows 30fps 720p and 1080p video at 252uW and 560uW respectively
  - Live prototype of a 112x112 13fps video stream at 27ft

Recorded Demo

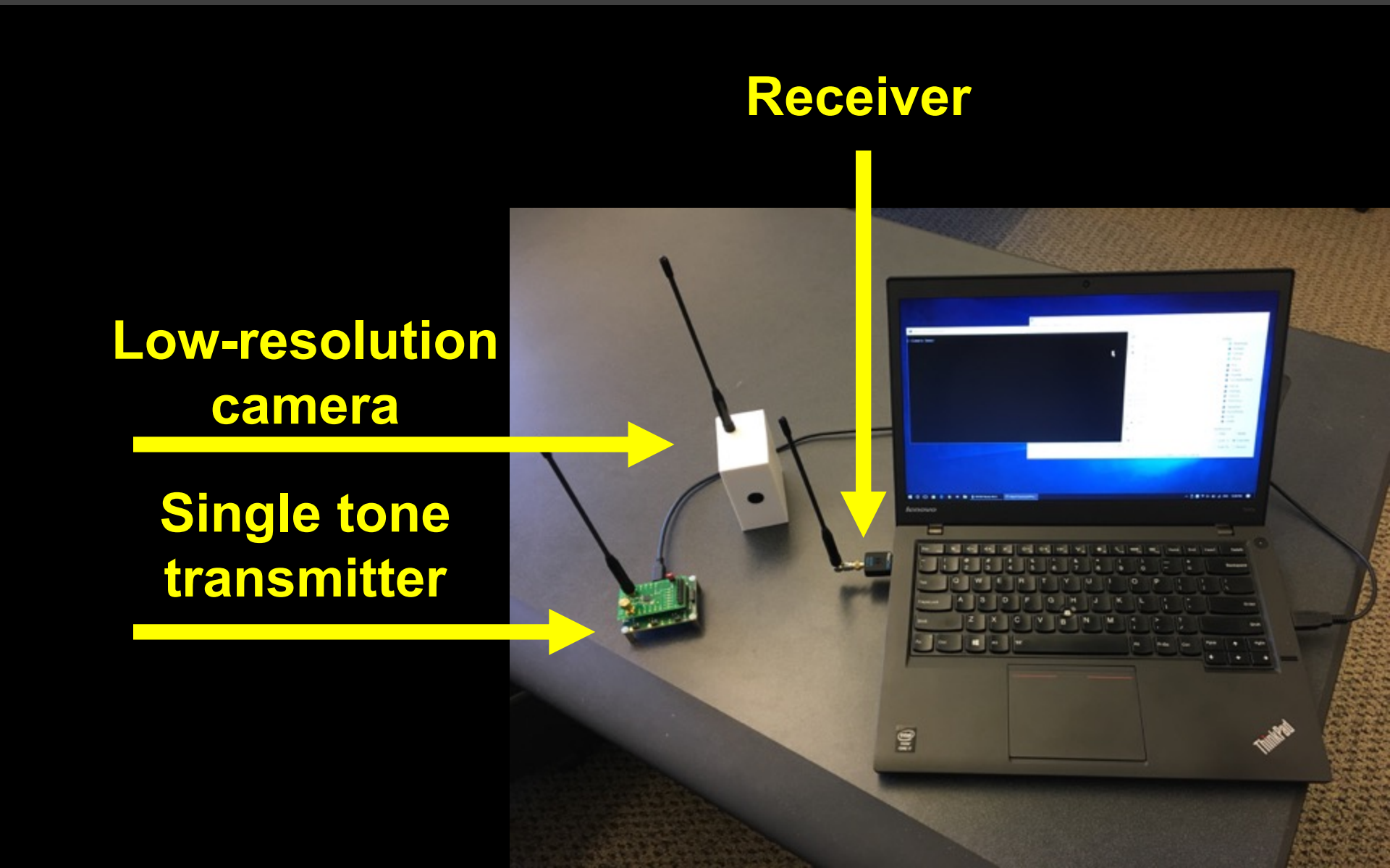


Ultra Low Power HD Video Streaming

Real-Time Demo

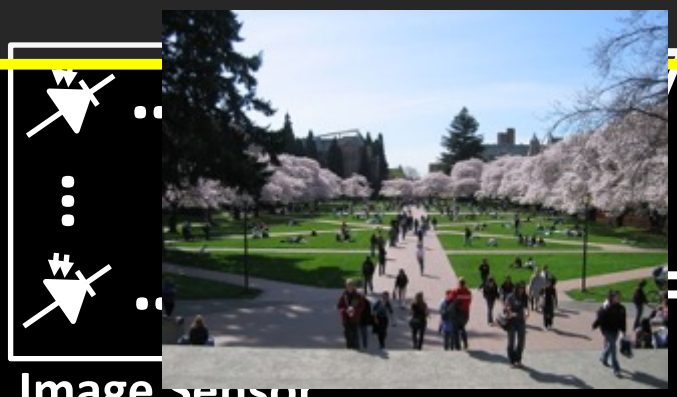
112 X 112 Resolution Video Streaming

Demo 2



Technical Challenges

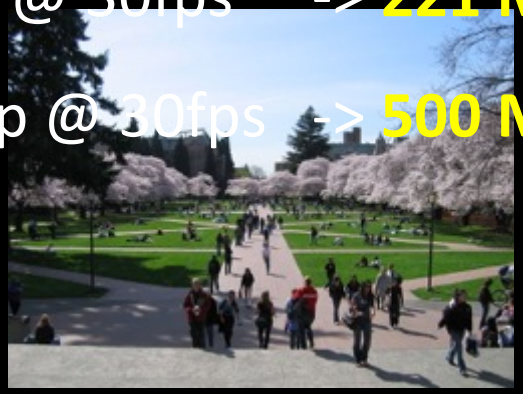
1. Analog video has lower quality than digital video

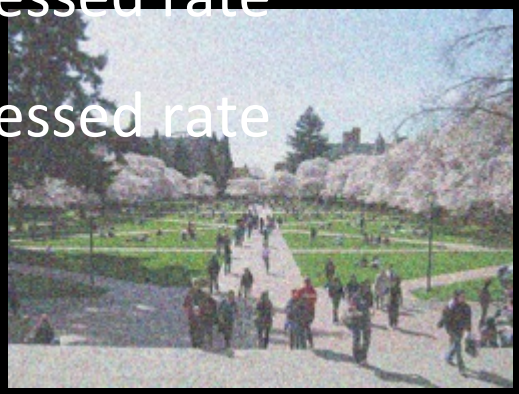


2. Benefits of digital compression are lost in analog

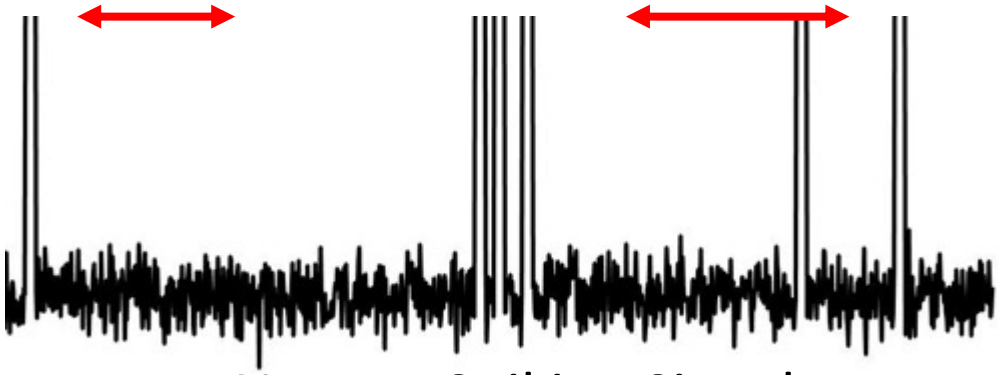
➢ 720p @ 30fps -> **221 Mbps** uncompressed rate

➢ 1080p @ 30fps -> **500 Mbps** uncompressed rate





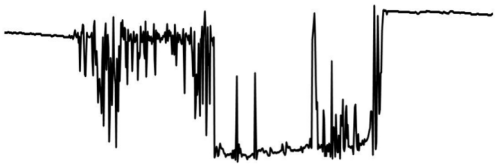
Solution 1: Inspiration from Human Brain Signals

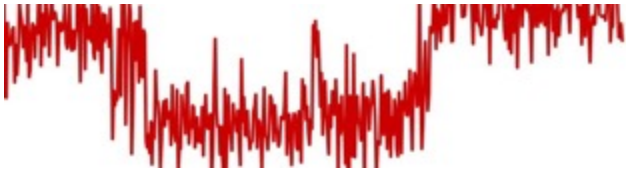


Neuron Spiking Signal

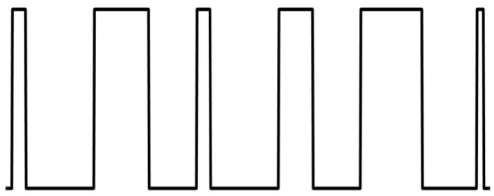
Received Signal **Received Image**

Analog Pixels



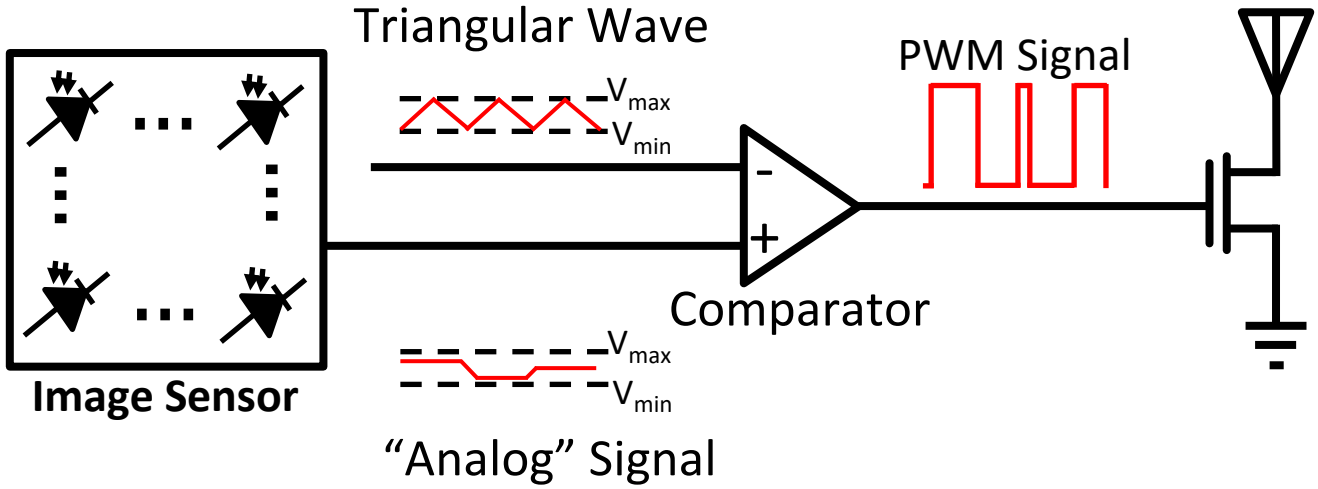


Pulse-width Modulation



Solution 1: Inspiration from Human Brain Signals

We create pulse width modulated pixels using analog hardware



Overcome the curse of analog video

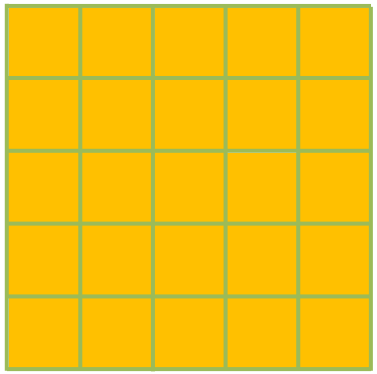
Technical Challenges

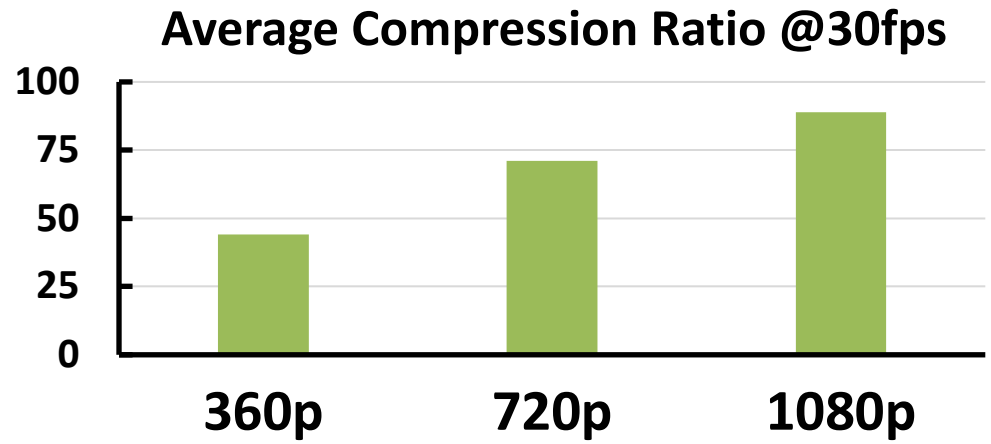
1. Analog video has lower quality than digital video

2. Benefits of digital compression are lost in analog

Our Intra-Frame Compression

- Adjacent pixels are fairly similar
- We send video in zig-zag manner
- Reduces average wireless bandwidth





Across 100 HD-resolution YouTube videos

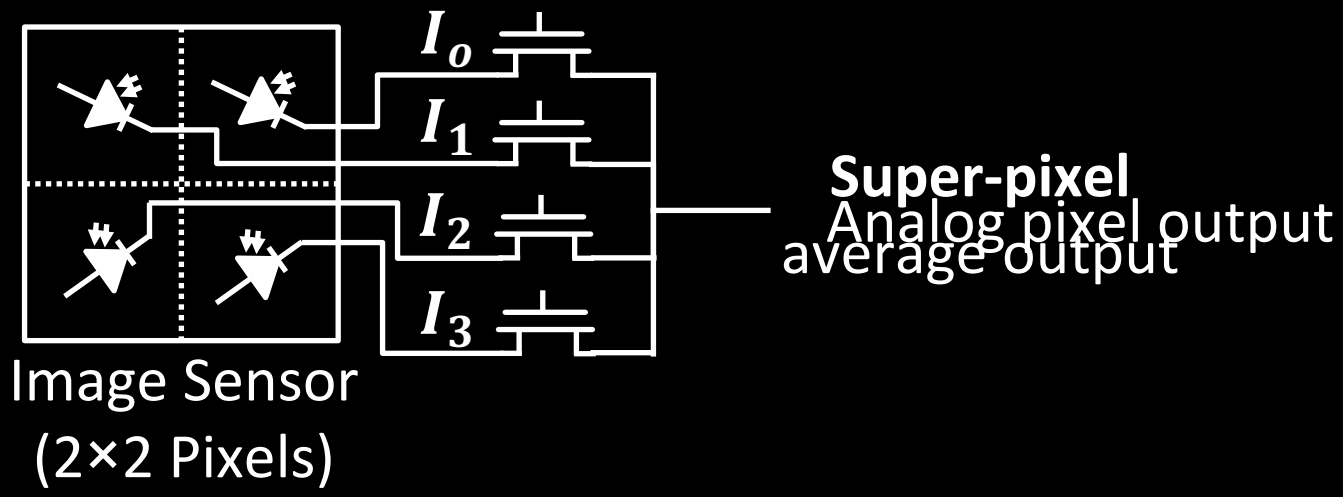
Reduces BW for 720p@30 analog video 70x

Our Inter-Frame Compression Algorithm

What kind of operation can we perform?

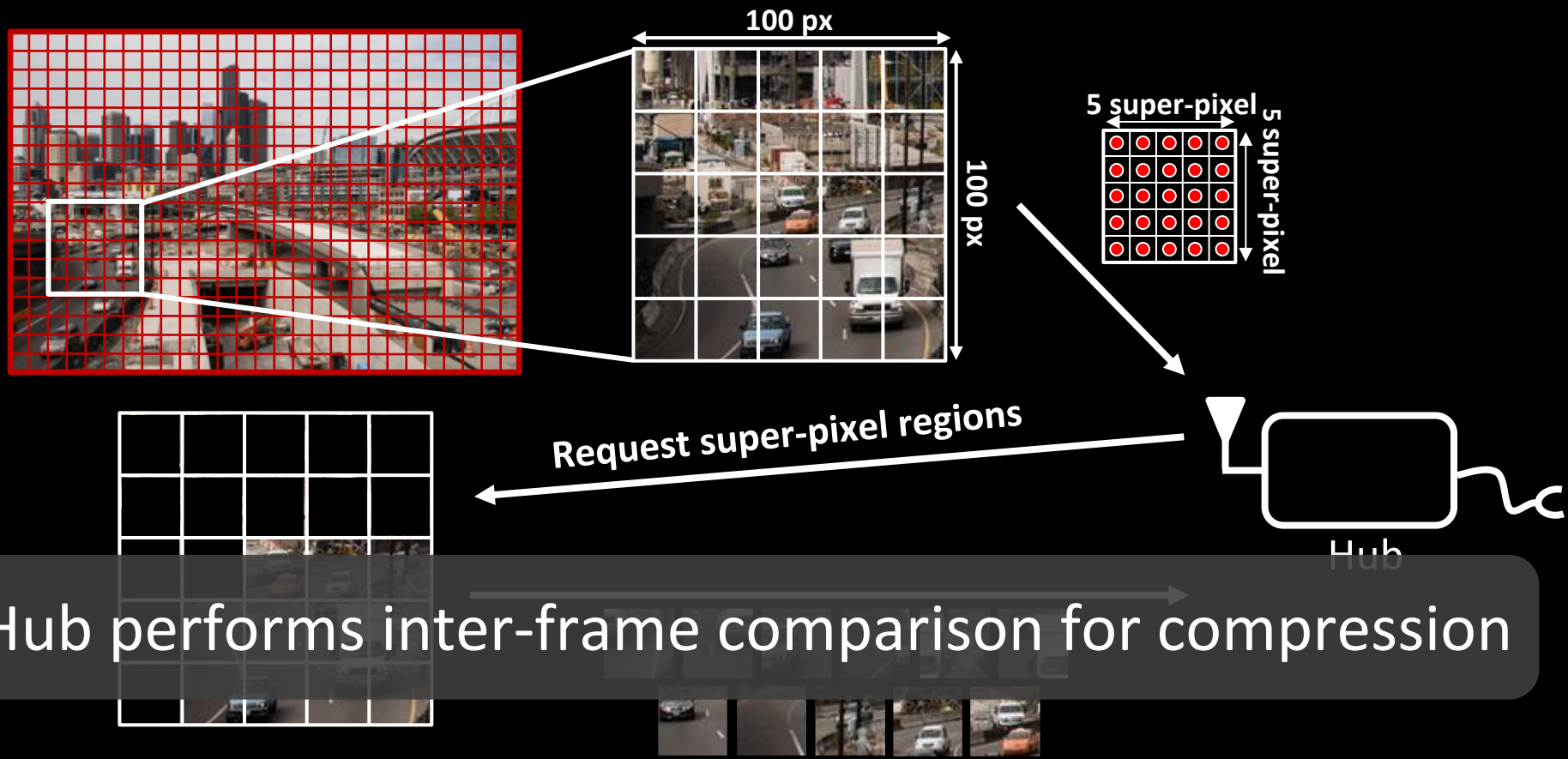
- Analog Domain
- Low-power

→ Averaging Operation



Our Inter-Frame Compression Algorithm

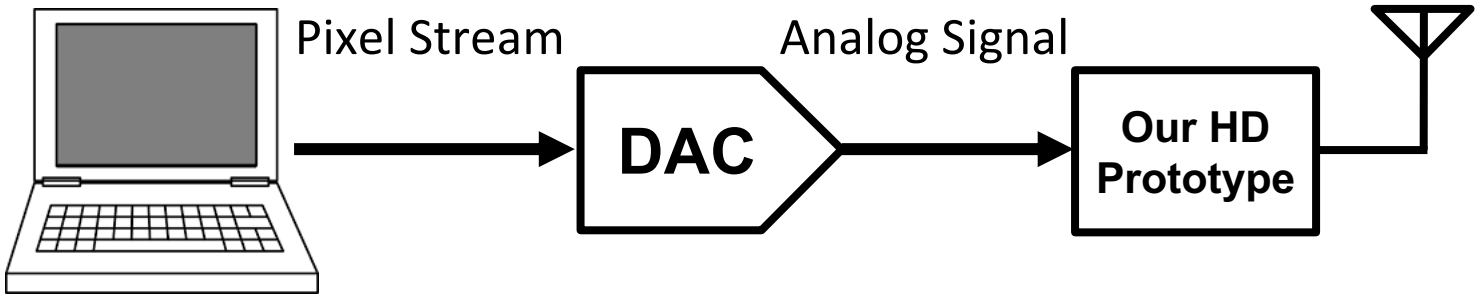
- Low-power analog computation → super-pixel
- Distributed compression algorithm



Implementation

HD video streaming prototype

- Play HD videos from a PC to a DAC
- Custom backscatter switch



Low-resolution video streaming prototype

- 112×112 grayscale low-power camera
- Low-power Igloo Nano FPGA

Evaluation

We evaluate three main aspects

- Quality of received videos
- Our compression algorithm
- Power consumption

Evaluation: HD Video Quality

Effective Number of Bits (ENOB)

We achieve about ~6 bits at distance of 10 feet

Evaluation: HD Video Quality (Mobility)

Effective Number of Bits (ENOB)

- Put our prototype antenna on a participant head
- We asked participant to perform different poses

We achieve ENOB greater than 5 for all poses

Evaluation

We evaluate three main aspects

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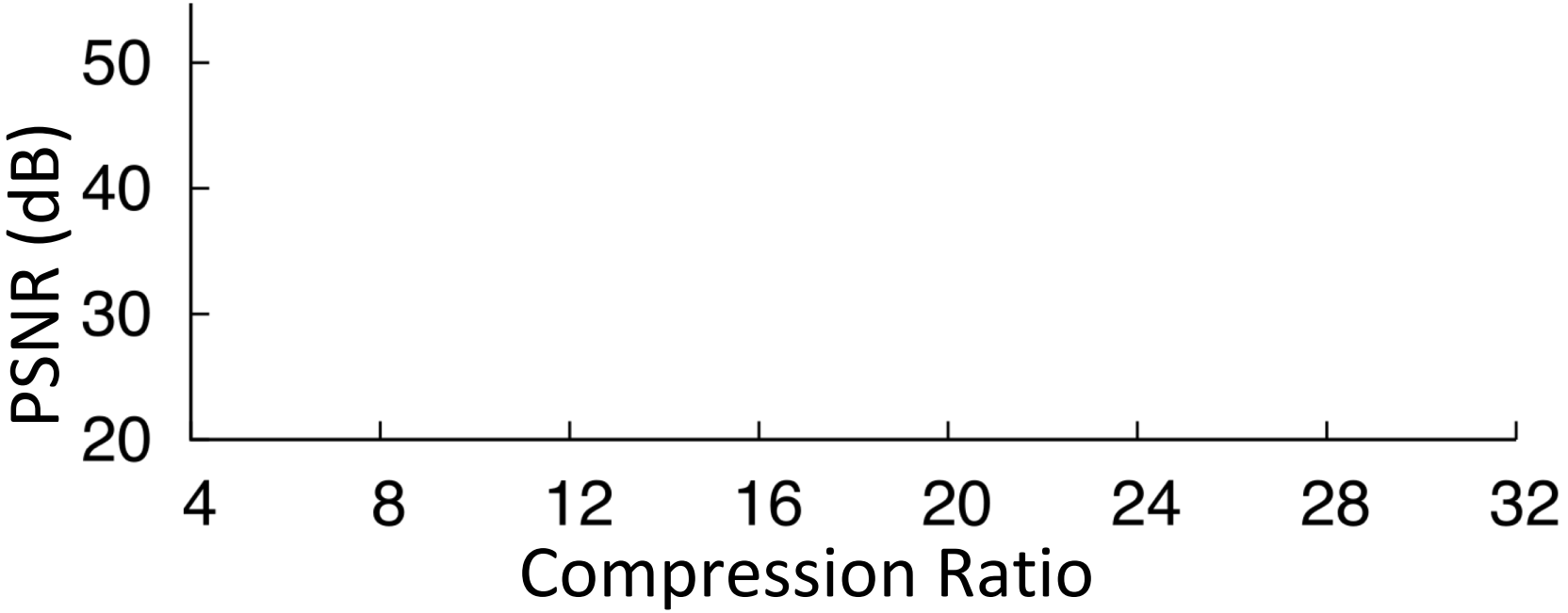
Evaluation: Inter-Frame Compression Algorithm

We record videos from a normal lab space

We change super-pixel size to evaluate our algorithm



Evaluation

We evaluate three main aspects

- Quality of received videos
- Our compression algorithm
- Power consumption

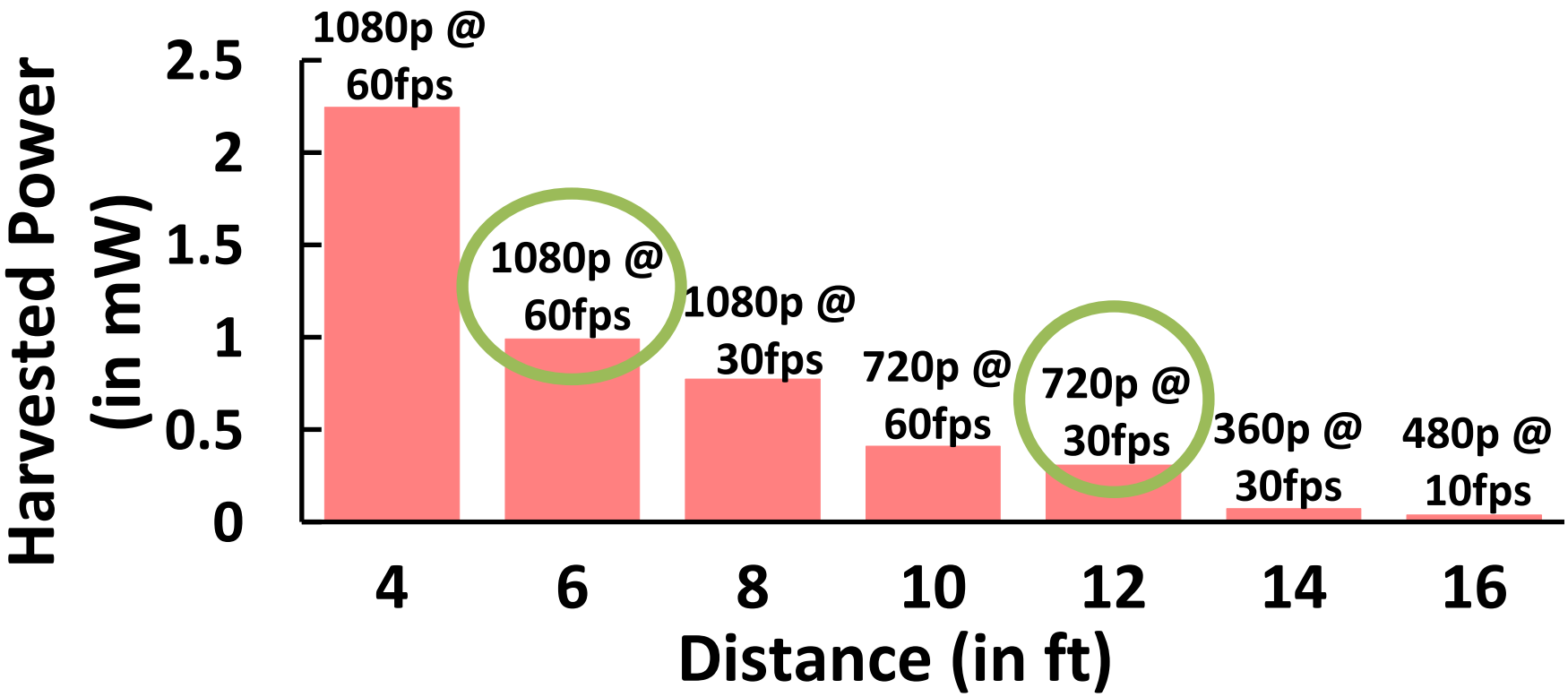
Evaluation: Power Consumption

We spec out an IC to emulate power consumption

- Verilog camera interface, PWM converter, & RF switches
- TSMC 65nm LP Process

Frame Rate	60 fps	30 fps	10 fps
Video Quality	Power (μW)	Power (μW)	Power (μW)
1080p (1920×1080)	806.50	560.63	167.77
720p (1280×720)	320.94	252.10	78.31
480p (640×480)	126.88	106.78	36.71
360p (480×360)	75.63	65.68	25.11

Evaluation: Power Consumption



Potential for battery-free video streaming

Grand Challenge

Design sticker form-factor battery-free camera tags

Trade-off and Road Ahead

- Tradeoff between video quality and range
- Explore advanced inter-frame compression
- Build battery-free video streaming ASIC

Contributions

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