Ambient Backscatter

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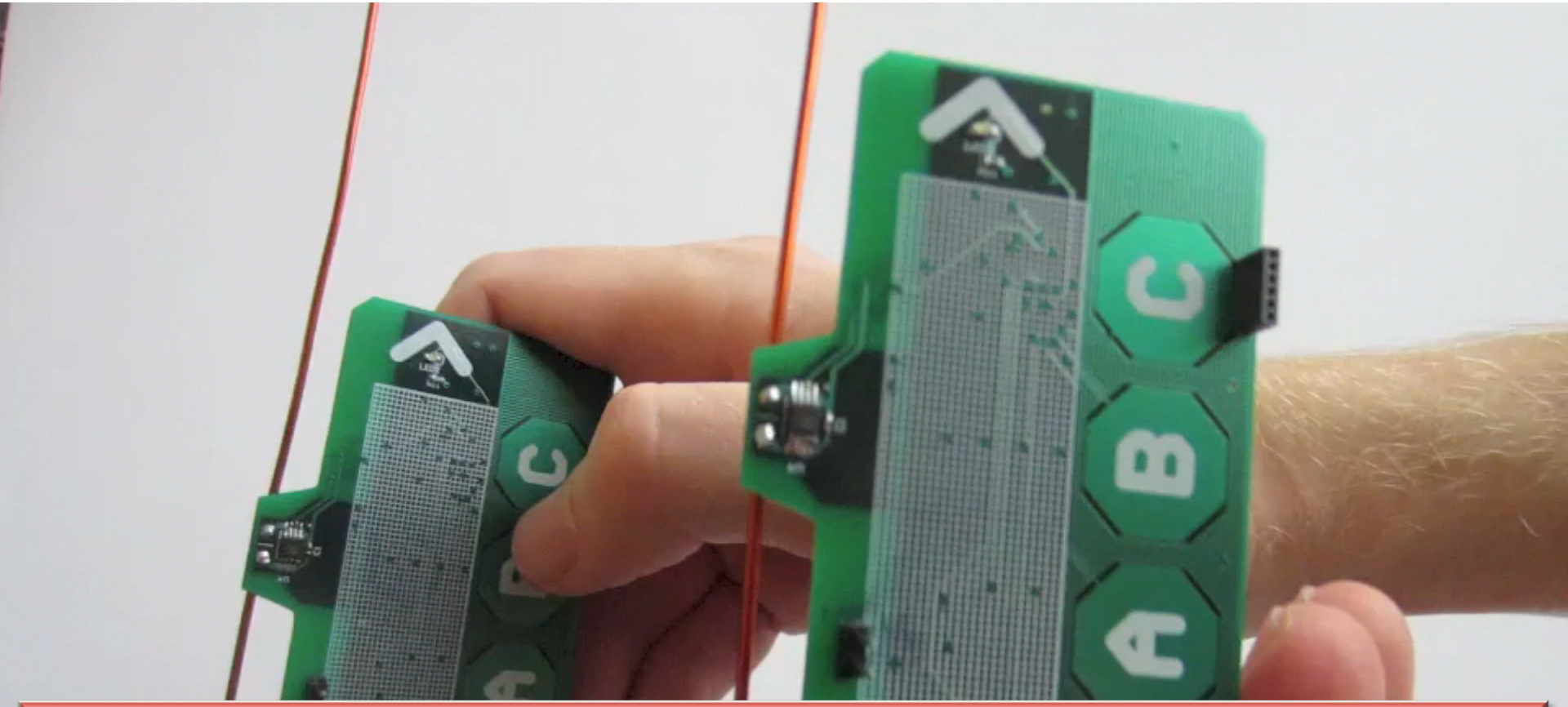
Our Goal

Interactive devices that compute and communicate without batteries

What We Are After



How to power computation, sensing, and communication?

Leverage Existing Wireless Signals

TV

Cellular

Wi-Fi

Available at almost any time and place, rain or shine

Recent Work Harvests 10s of µW [‘09]

- Enough for computation and sensing

- Orders of magnitude less power than needed for radio communication [‘13]

Challenge: Communication Between Battery-Free Devices

- Generating radio signals is expensive
- Could duty cycle
  - Limits interactive applications

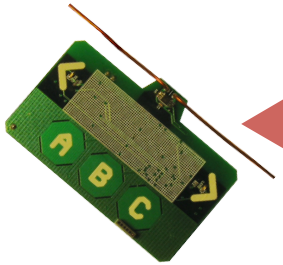
Can we communicate without either device generating radio signals?

Ambient Backscatter

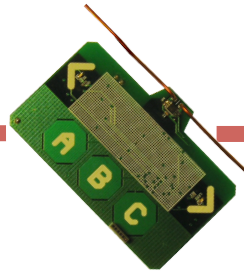
Use existing signals instead of generating our own

TV Tower

Works with only ~5% of the harvested power!



Bob



Alice

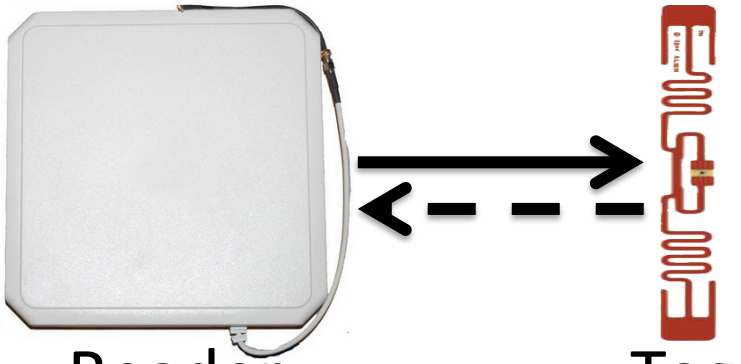
Additional Multipath

‘0’ bit – Absorb TV Signals

‘1’ bit – Reflect TV signals

Challenges

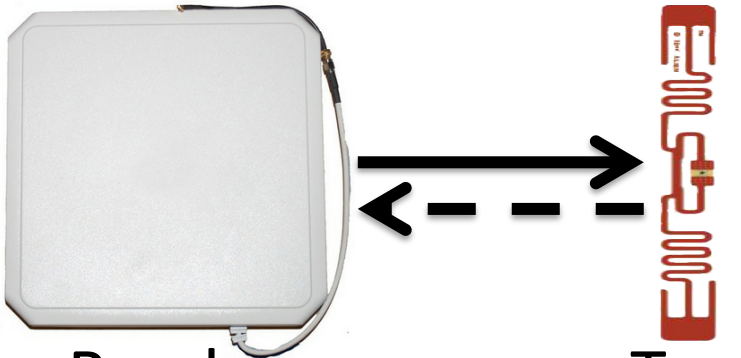
RFID



- Reader sends constant wave
- Receive chain: 100s of mW
- Reader centrally coordinates

Ambient Backscatter

RFID



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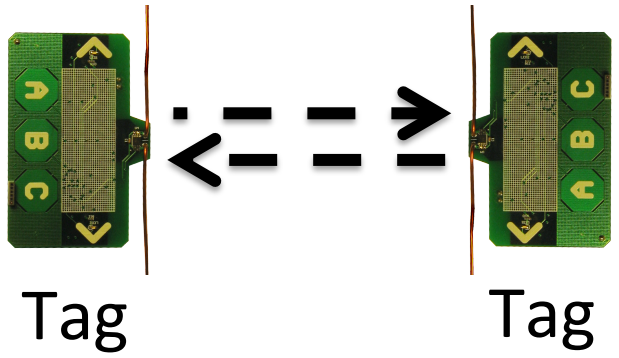
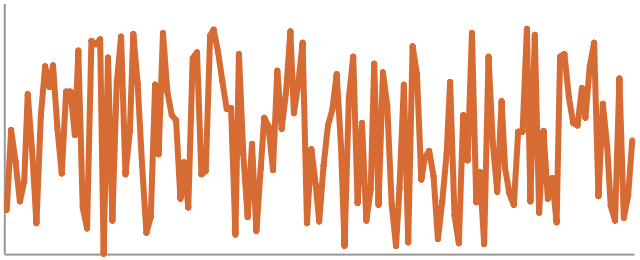
Ambient Backscatter





- Uses uncontrollable signals
- Receive chain: 0.5 µW
- Need distributed MAC

Challenges

- Extracting backscattered signals from ambient signals we don't control
- Decoding on a battery-free device
- Designing distributed MAC for battery-free devices

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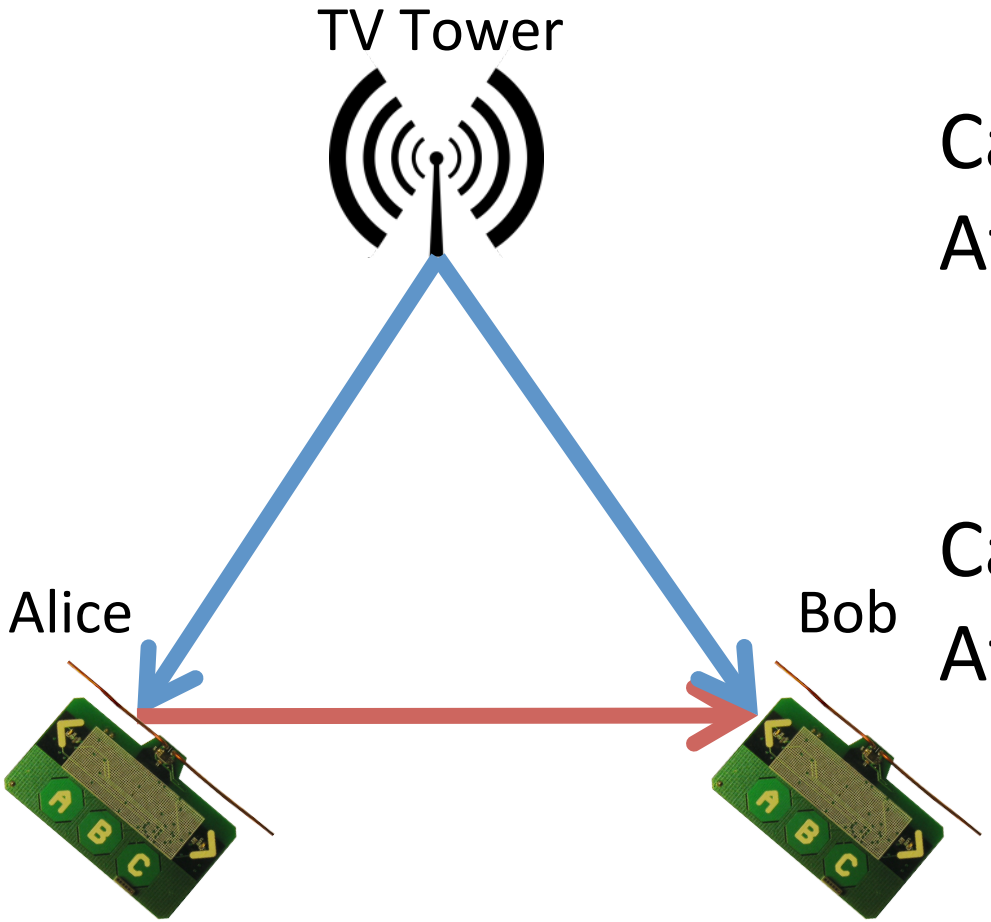
How Do We Extract The Backscattered Signals?



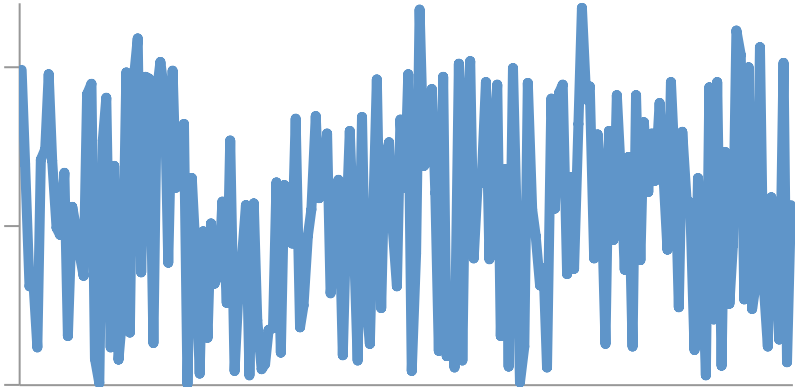
Case 1: Alice absorbs
At Bob: TV signal

Case 2: Alice reflects
At Bob: TV signal
+ Weak Reflection

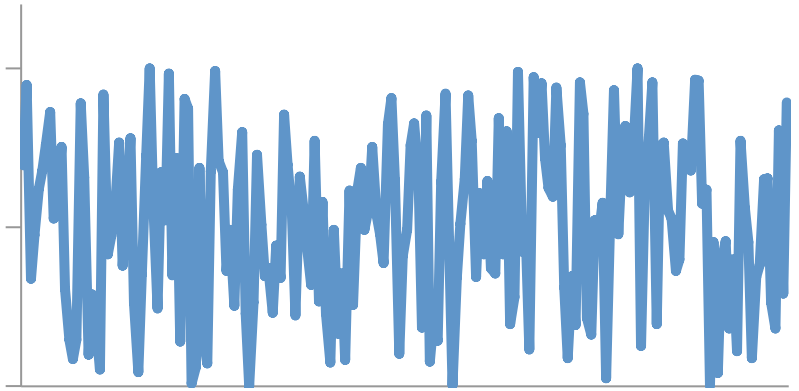
Alice's reflections change the average amplitude

Solution: Detect Changes in Average Amplitude

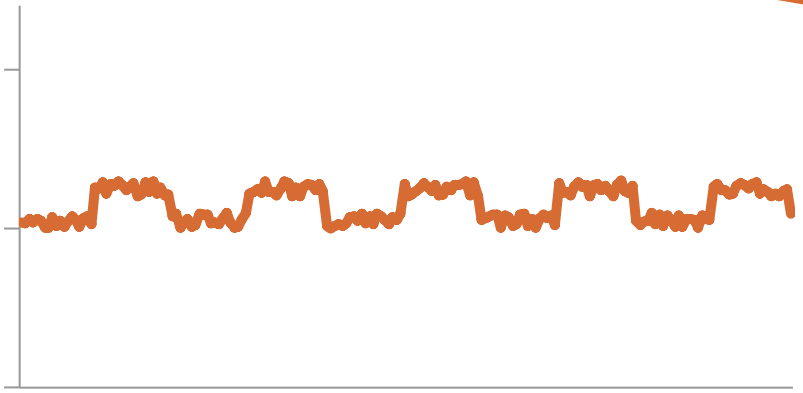
Alice Sends 1010…

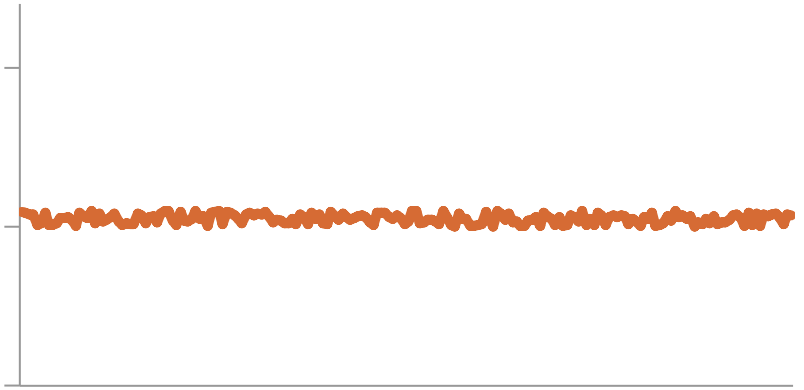


Alice Inactive

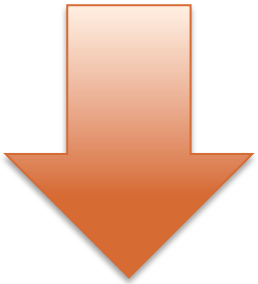


Moving Window Average





If we had digital samples, averaging would be easy

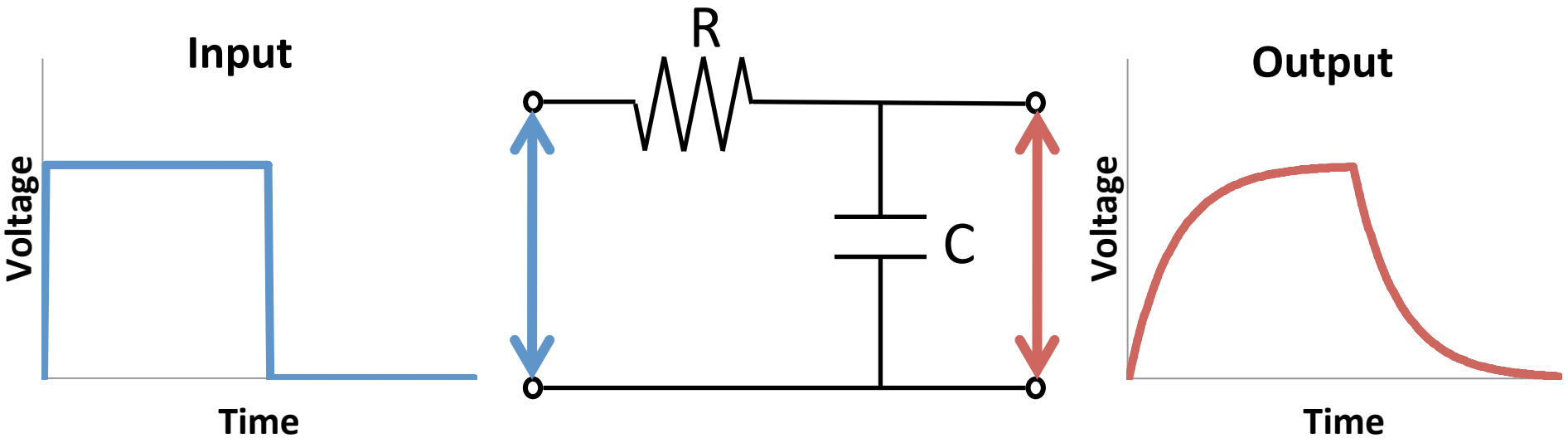


Need power-hungry analog-to-digital converters

Challenges

- Extracting backscattered signals from ambient signals we don't control
- Decoding on a battery-free device
- Designing distributed MAC for battery-free devices

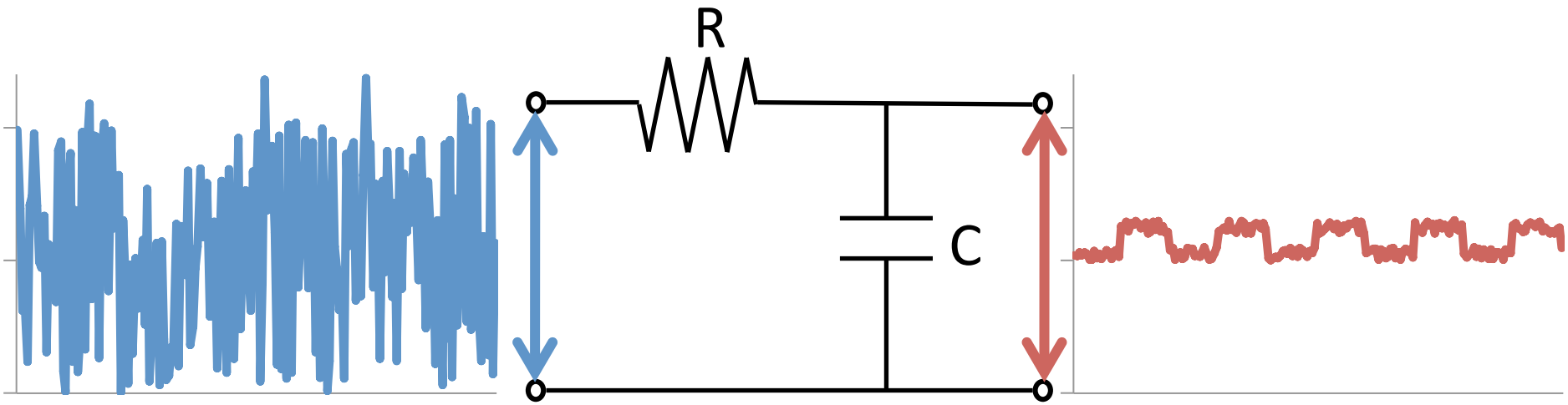
Use RC Circuits to Average



- Capacitor slowly charges/discharges when voltage is applied/removed

Provides a cheap, analog, exponential moving average

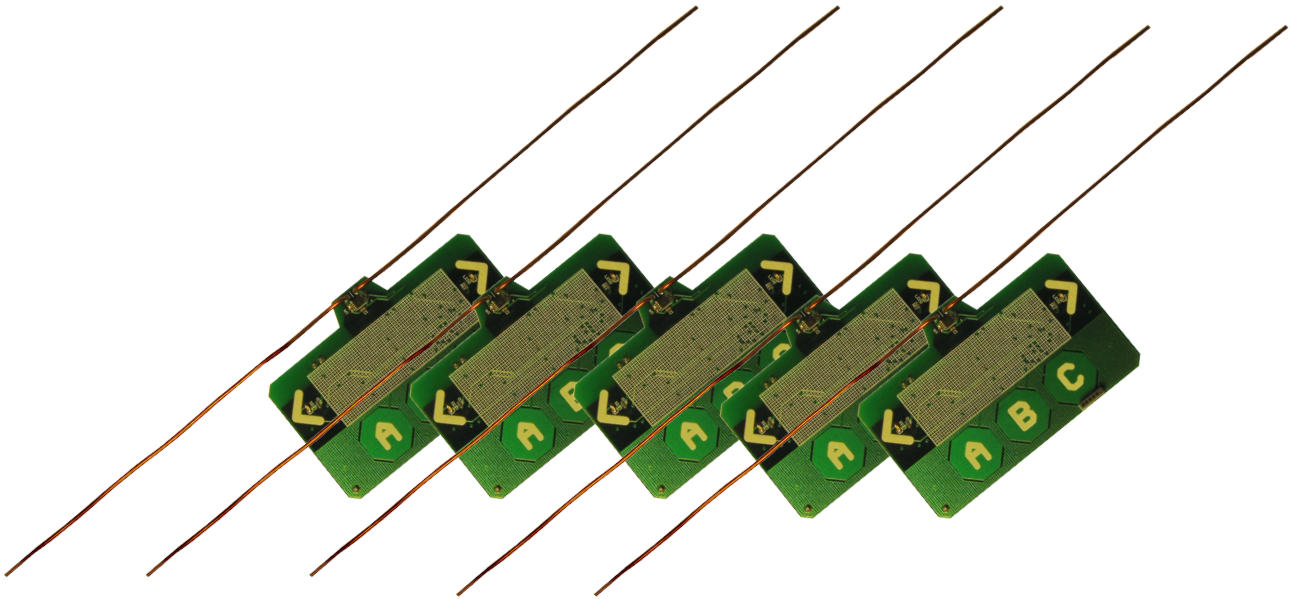
Use RC Circuits to Average



- Capacitor slowly charges/discharges when voltage is applied/removed

By picking the right RC values,
we can selectively filter out the high TV frequencies

Now that we can decode bits…



Link Layer
Physical Layer

Distributed MAC?

Challenges

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We Use CSMA

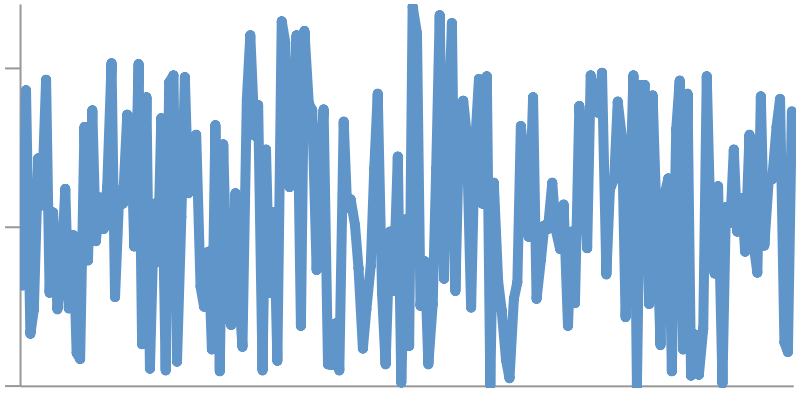
- CSMA uses carrier sense, i.e. energy detection
- Battery-free devices do not have energy levels
  - Requires power-hungry ADCs

Challenge: Energy detection without access to the energy levels

Solution: Leverage Hardware Properties for Energy Detection

1. RC circuit filters out the TV signals
   → Removes high-amplitude variations

In the absence of backscattering, we see a constant output



Solution: Leverage Hardware Properties for Energy Detection

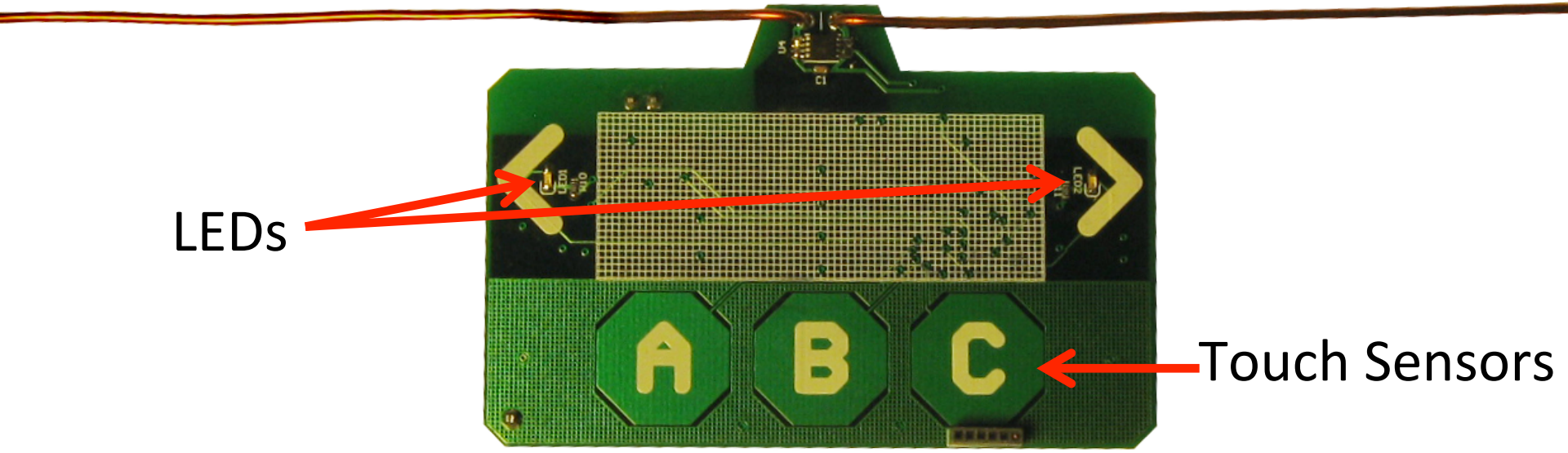
- No backscatter → See all 0s or all 1s
- Backscatter → See many transitions

Use bit transitions as proxy for energy detection

Evaluation

Prototype Using Off-the-Shelf Components

- Battery-free
- Harvests and backscatters TV signals at 539 MHz
- Microcontroller performs computation



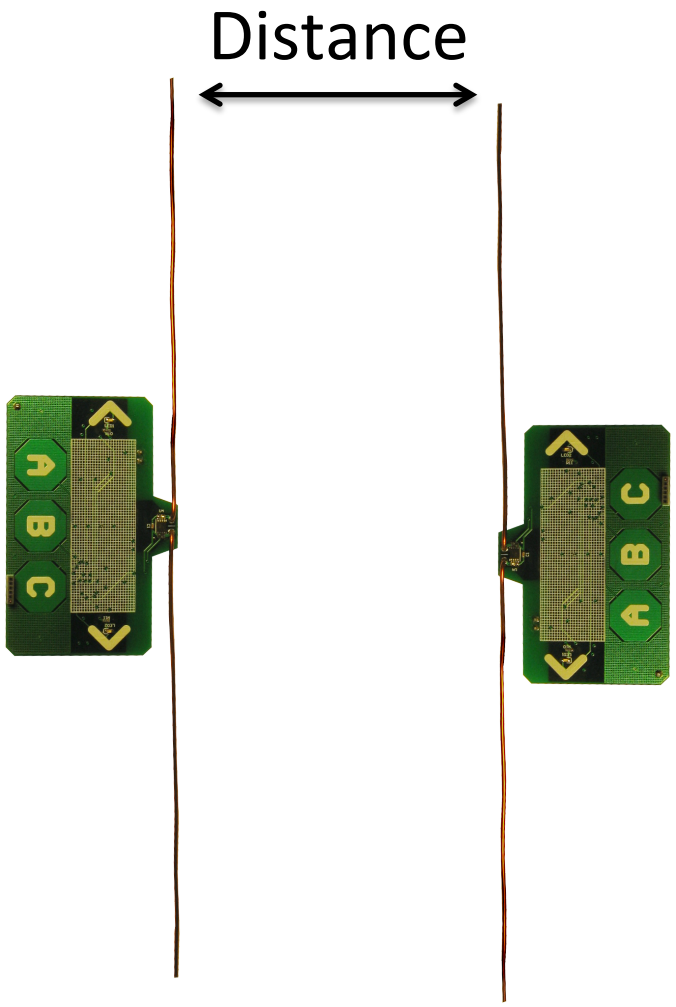
Tested Locations

- Seattle area with a 1MW TV tower at 539 MHz
- Indoor and outdoor environments
- Distances up to 10.5 km from the TV tower
  - TV power ranged between -24dBm and -8dBm

What Bit Rates Can We Achieve?

- Three bit rates:
  10kbps, 1kbps, 100bps

- BER versus distance
  between two devices



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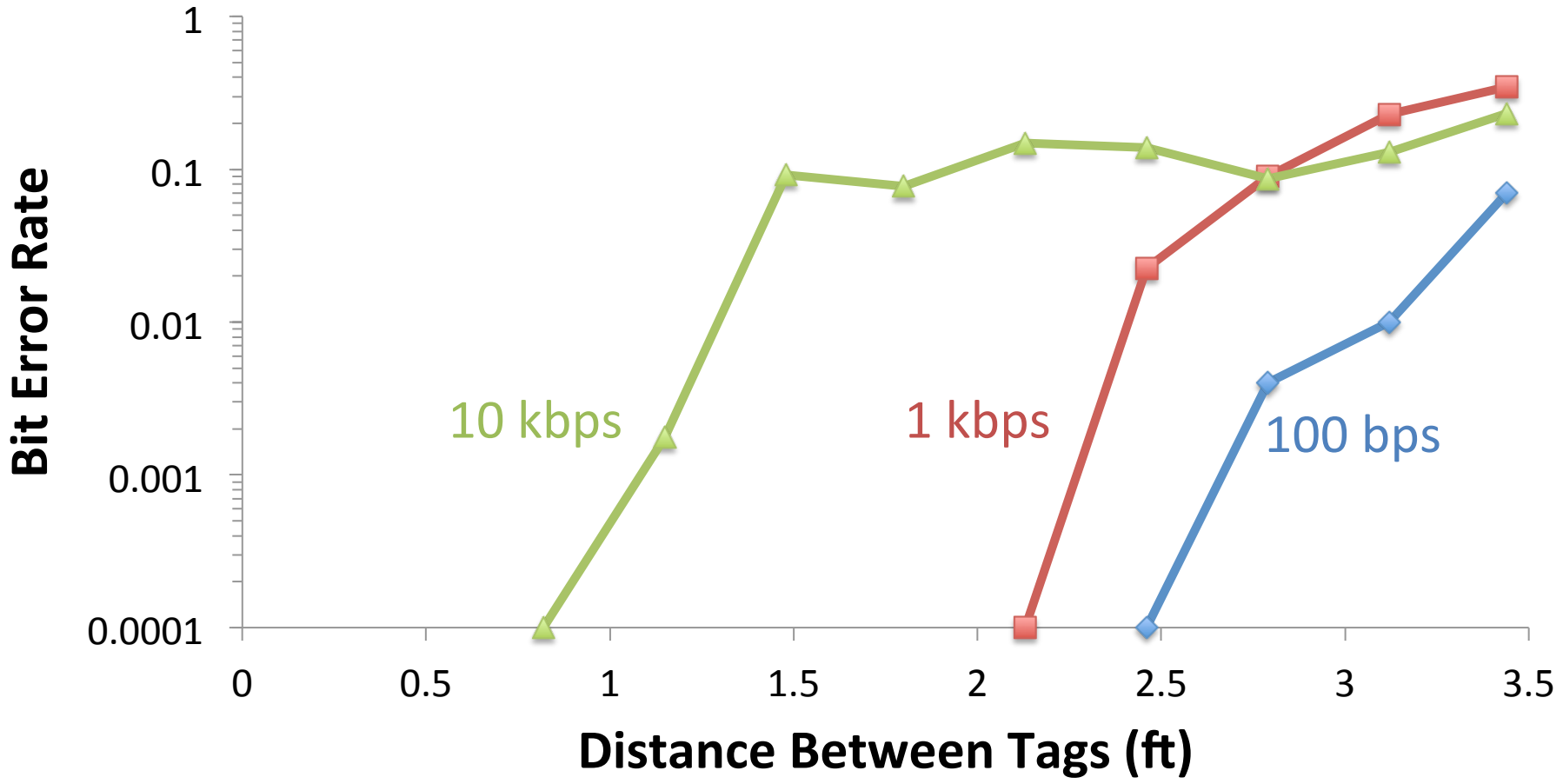

These results show the feasibility of Ambient Backscatter

Applications

Identifying Misplaced Items

In Grocery stores or Warehouses (e.g., Amazon)

- With ambient backscatter, devices can figure out they are misplaced on their own

- We built a preliminary system with cereal boxes

Identifying Misplaced Items

In Grocery stores or Warehouses (e.g., Amazon)

Works even if not all tags are in range of a reader

Conclusion

- We develop
  - The first primitive that enables communication without either device generating RF signals
  - A battery-free hardware prototype that computes and communicates using only TV signals

- We transform existing signals into both a power source and a communication medium
  - Opens up new research opportunities

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