Turbocharging Ambient Backscatter Communication

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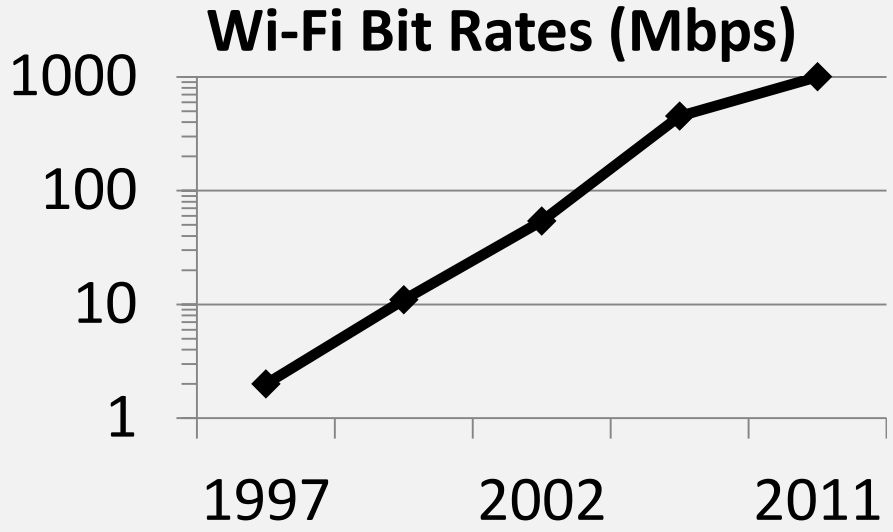
Radio Communication Trends

Then

Multi-Antenna

Now



Then

Coding

Now

- Range (10s of km)
- Reliability

Our Work

Can we achieve these techniques on battery-free devices?

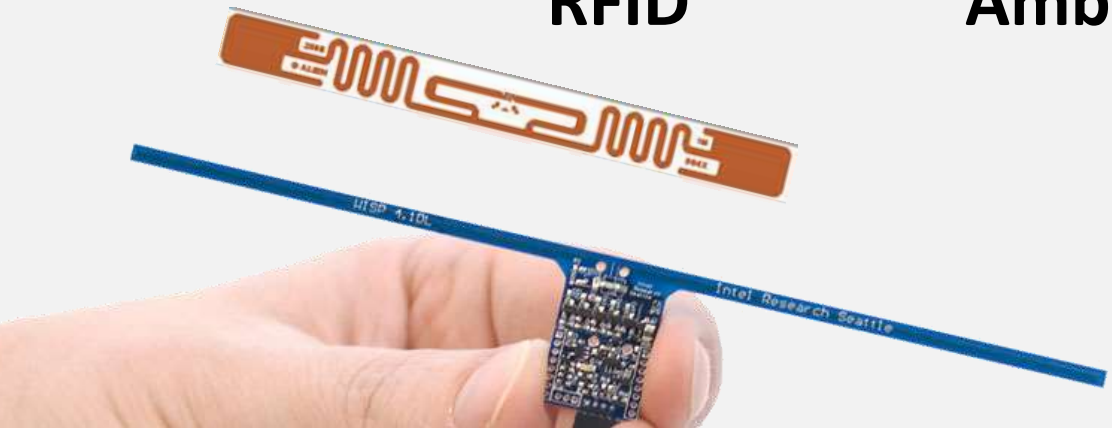
If Possible, Benefits New Classes of Devices

Wearables

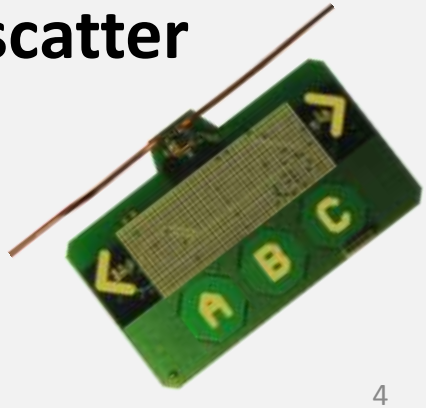
Localization

Severe power constraints

RFID



Ambient Backscatter



Challenge: Expensive Digital Computation

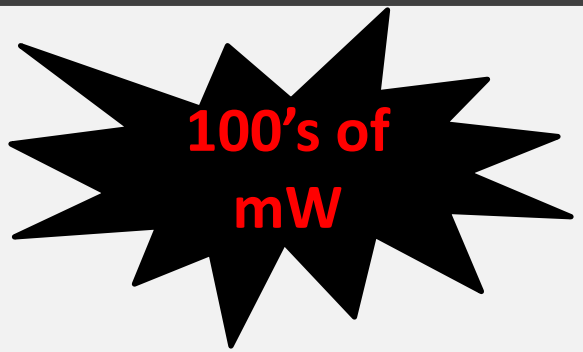
Multiple antennas

- Channel estimation
- Matrix inversion, etc.

Coding (e.g., CDMA)

- Expensive correlation
- Synchronization, etc.

Battery-free devices have orders of magnitude less power



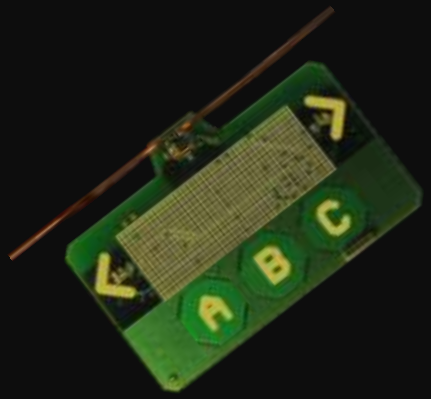
Requires power-intensive ADCs

Our Design Principle

Perform computation in the analog domain

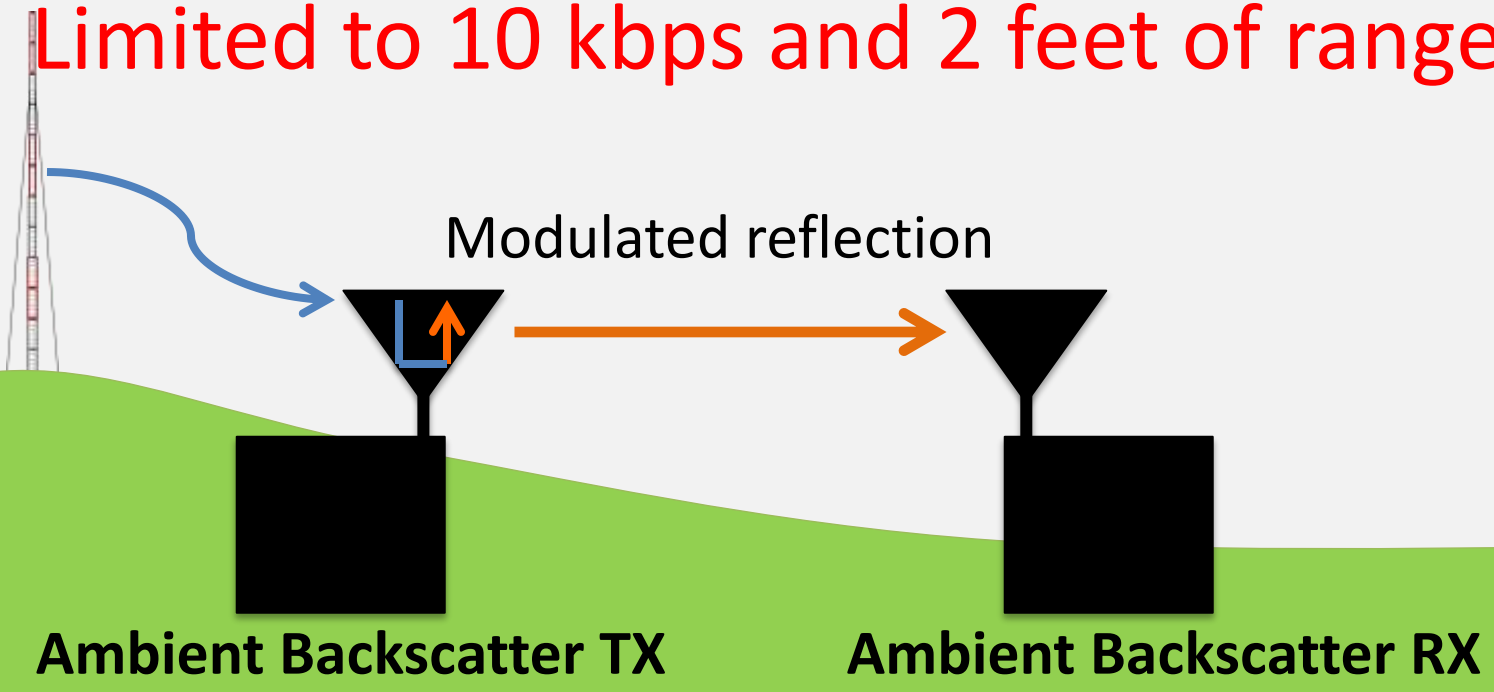
Contributions

- Introduce the first multi-antenna cancellation design for battery-free backscatter devices
  - 10 kbps → 1 Mbps
- Introduce first analog coding technique for long-range backscatter communication
  - 2 feet → 20 meters



Ambient Backscatter Communication

Limited to 10 kbps and 2 feet of range



No additional power
No additional spectrum

Contributions

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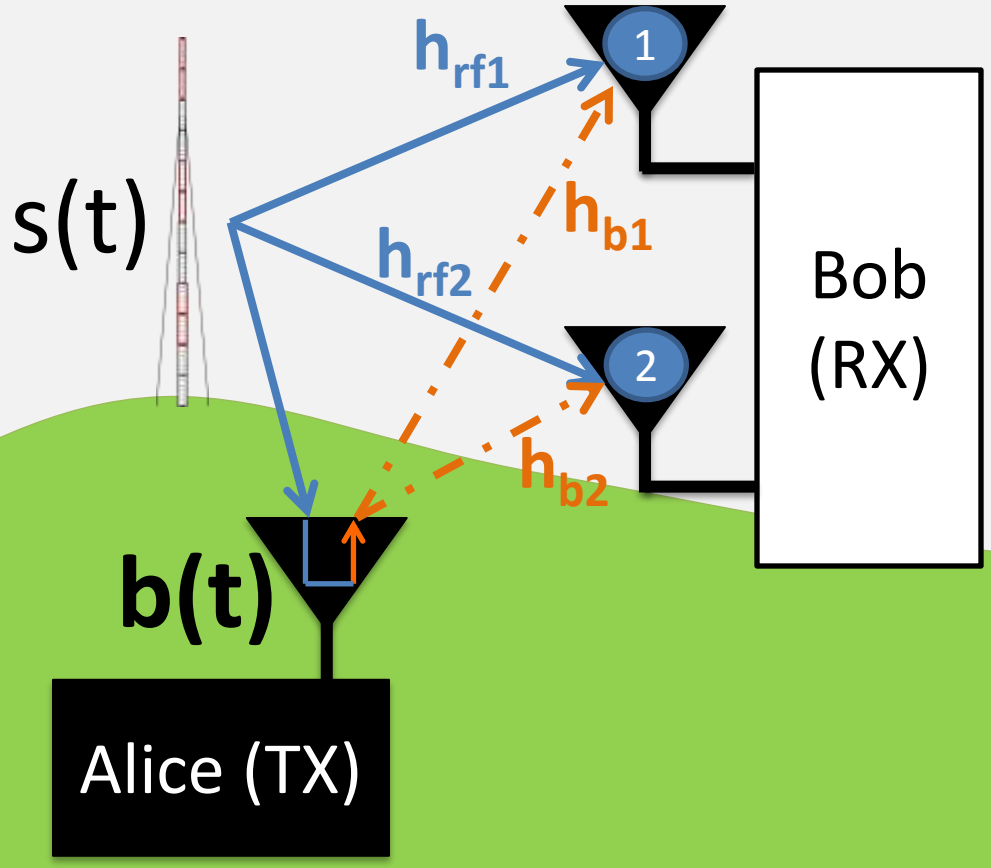
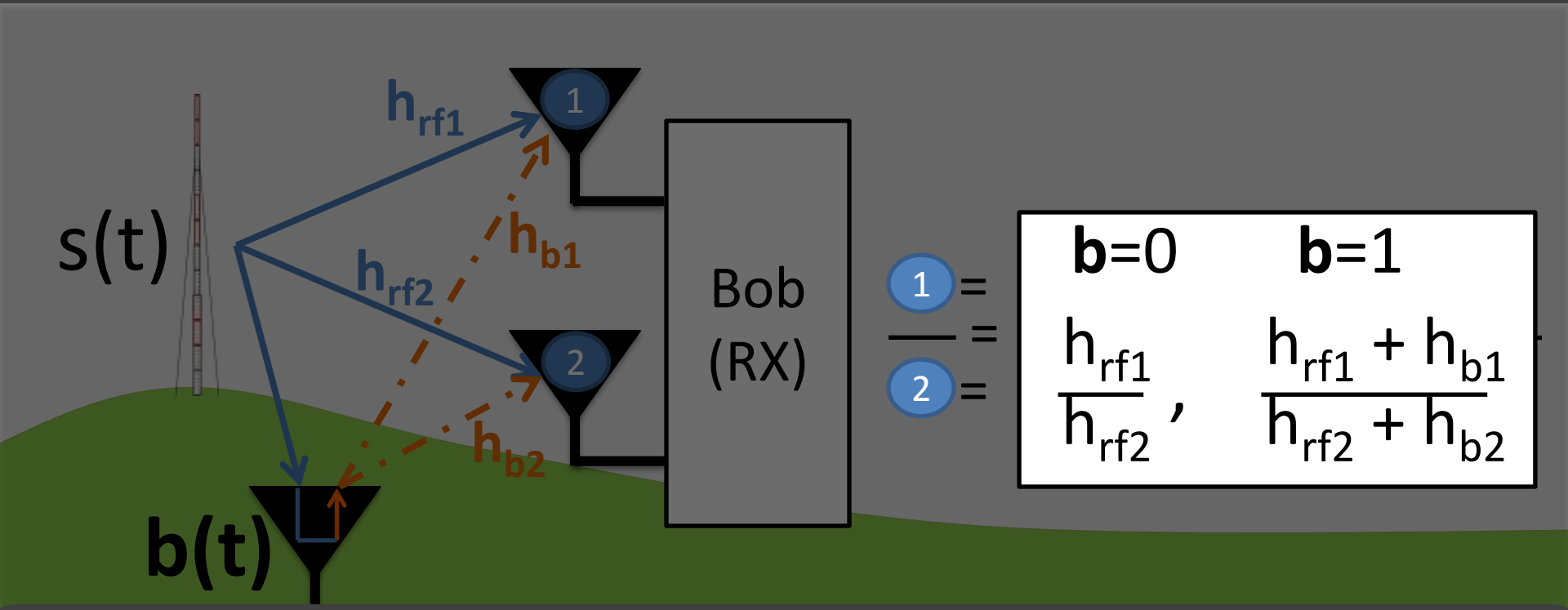
Multi-Antennas Without Digital Computation



$$1 = h_{rf1}s(t) + h_{b1}s(t)\,b(t)$$

$$2 = h_{rf2}s(t) + h_{b2}s(t)\,b(t)$$

Multi-Antennas Without Digital Computation

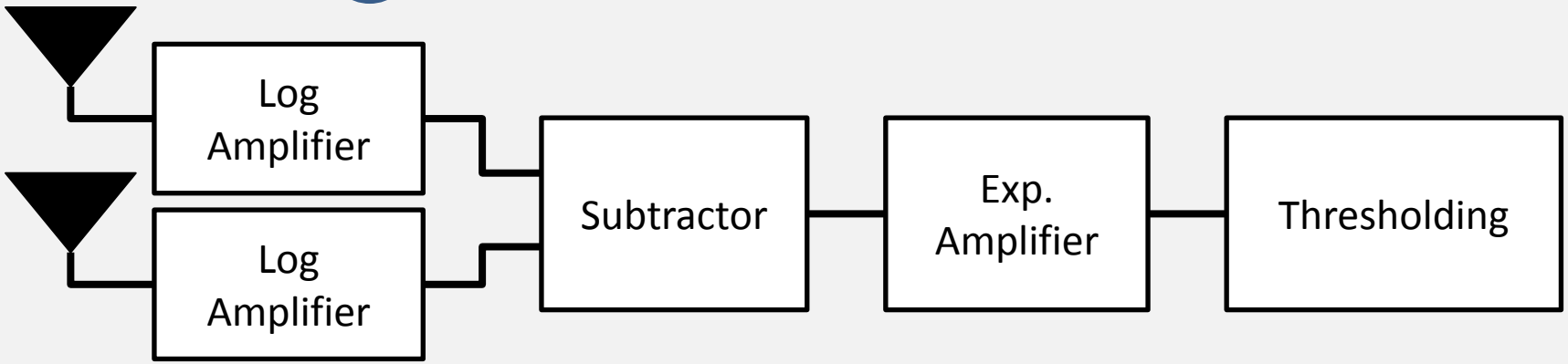


Decode b(t) using changes in $\frac{1}{2}$

Division in the Analog Domain

- Commercial analog dividers are power hungry!
  - Build our own.

$$\frac{1}{2} = \exp(\log(1) - \log(2))$$



Multi-antenna design without digital computation

Contributions

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How do we Increase Range?

- Add redundancy to data for easier decoding

Cross-correlating is too expensive

How do we Increase Range?

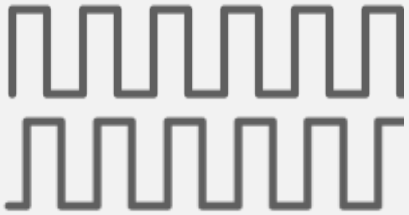
- Use periodic code

Pattern for ‘1’ bit

Pattern for ‘0’ bit

000000…

Receiver simply correlates with:



No shift → Gives I component

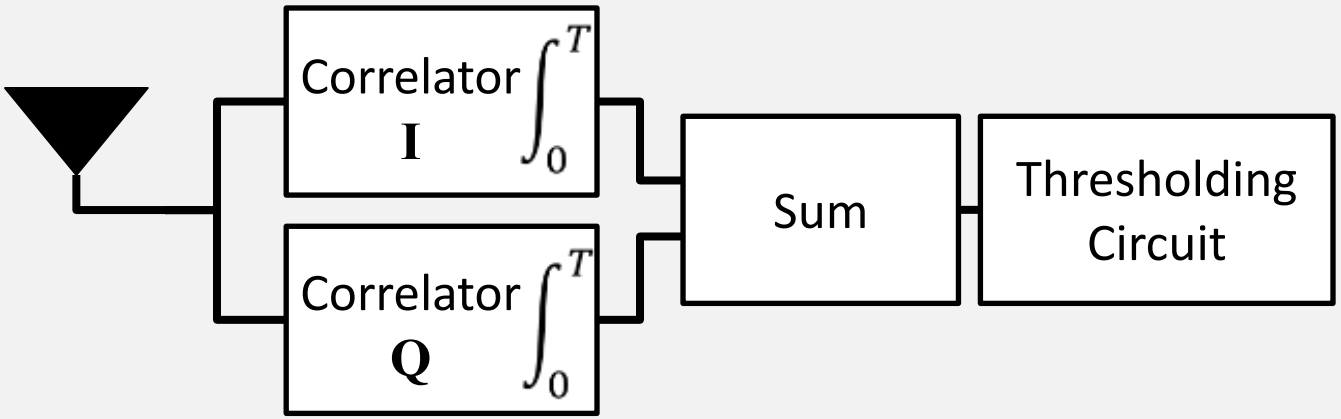
½ symbol delay → Gives Q component

$$|I| + |Q| = N$$

No synchronization required

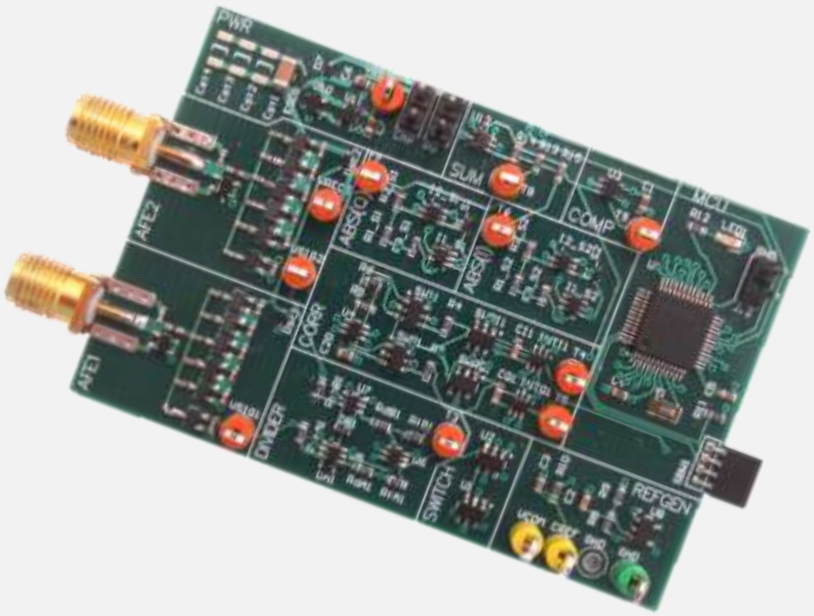
How do we Increase Range?

- Analog implementation



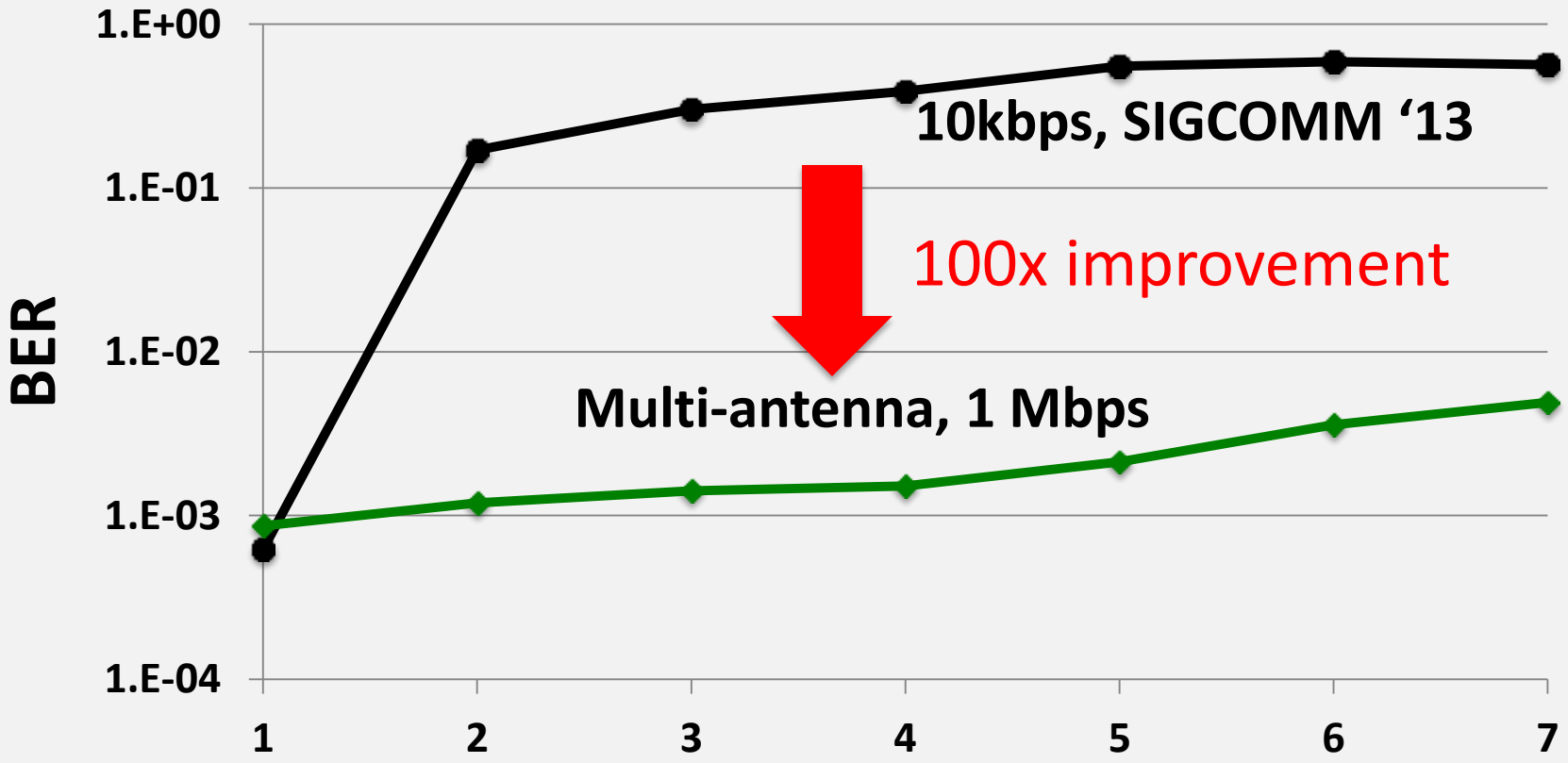
Simple analog implementation → Low Power

Our Hardware Prototype



- Integrated multi-antenna and coding implementation
  - 422 uW for multi-antenna
  - 8.9 uW for coding circuit
- Software-defined behavior
  - 0.3 bps to 1 Mbps
- TV , RFID, and solar harvesting

What Gains Can Multiple Antennas Provide?



Incident TV power is -20dBm

What Gains Can Multiple Antennas Provide?

- How do we get orders of magnitude gains by adding an antenna?
- Last year (SIGCOMM '13)
  - Average to eliminate big TV signal

$$\log_2\left(1+\frac{P_{TAG}}{P_{TV}+P_{NOISE}}\right)$$

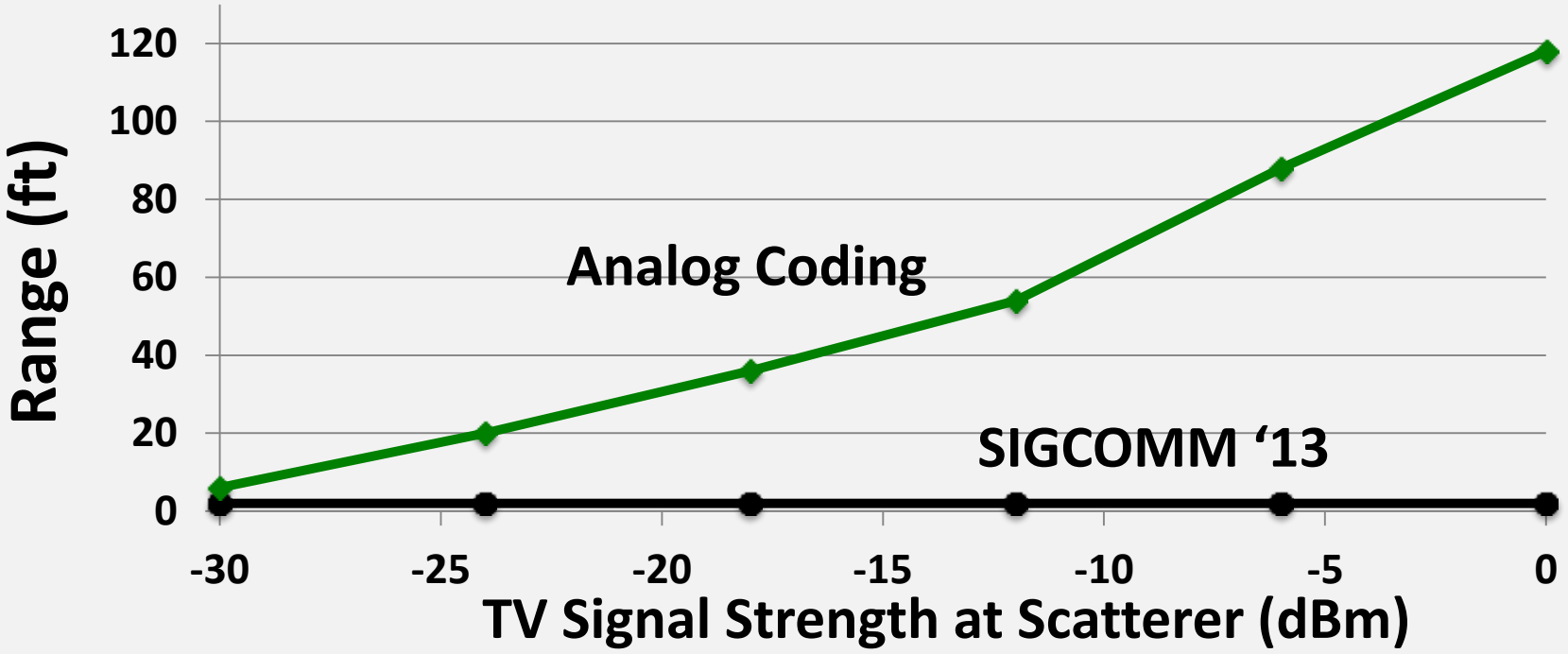
- Multi-antenna design
  - Completely cancel TV signal

$$\log_2\left(1+\frac{P_{TAG}}{P_{NOISE}}\right)$$

Orders of magnitude increase in rate

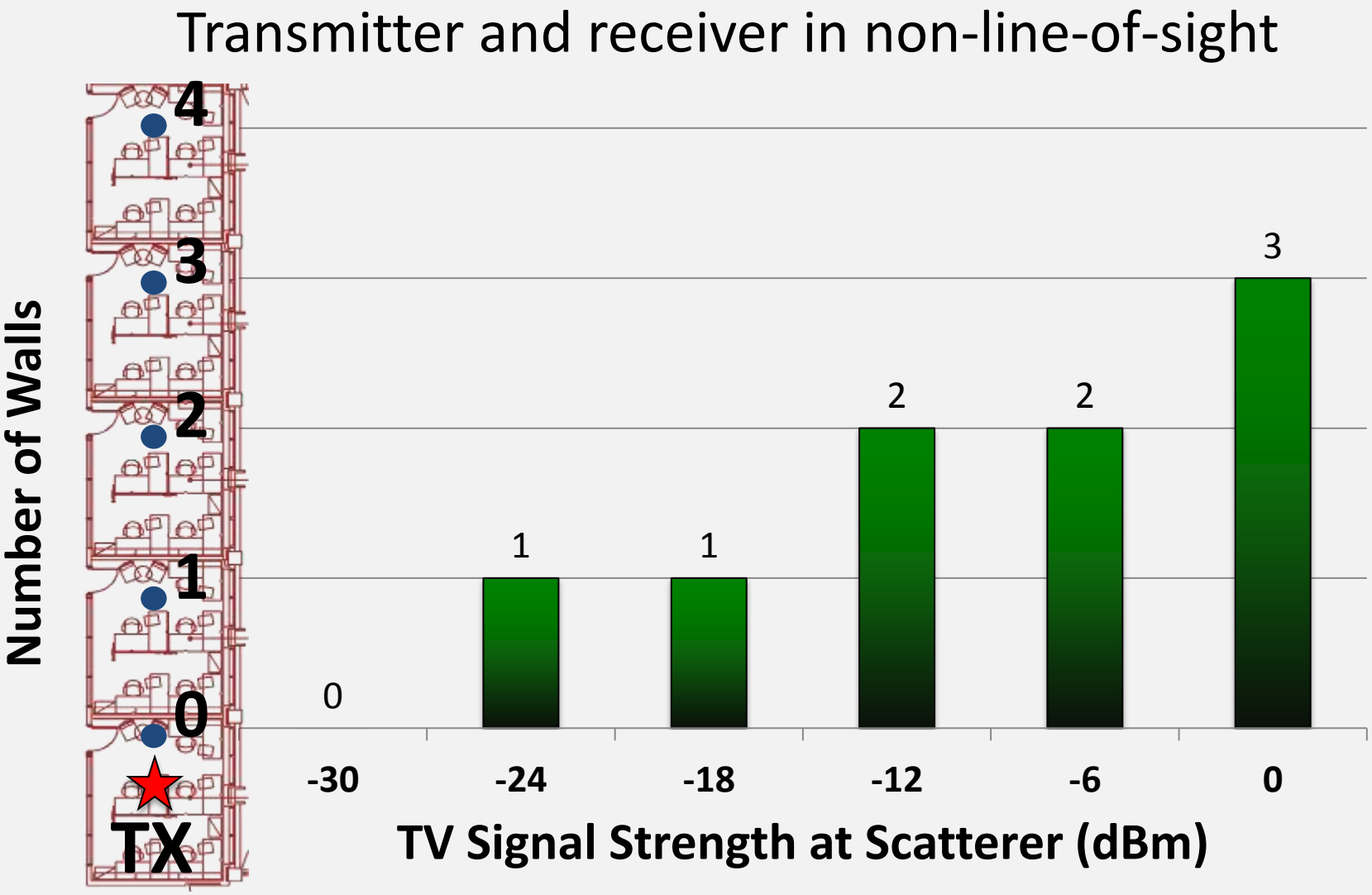
Can our Analog Code Increase the Range?

Transmitter and receiver in line-of-sight



10-100x improvement across all power levels

Can our Analog Code Increase the Range?



Conclusions

- Introduce the first multi-antenna and coding designs for battery-free backscatter devices
- Provide orders of magnitude increase in rate and range of ambient backscatter
- Re-design networking primitives with power as a first class citizen
  - Full-duplex (MOBICOM'14), UWB (?), Random access (?), TCP/IP (?), …