

Turbocharging Ambient Backscatter Communication

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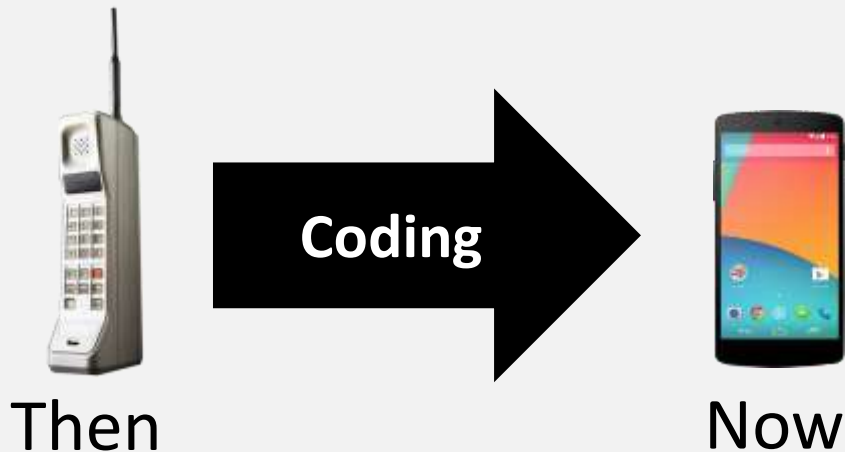
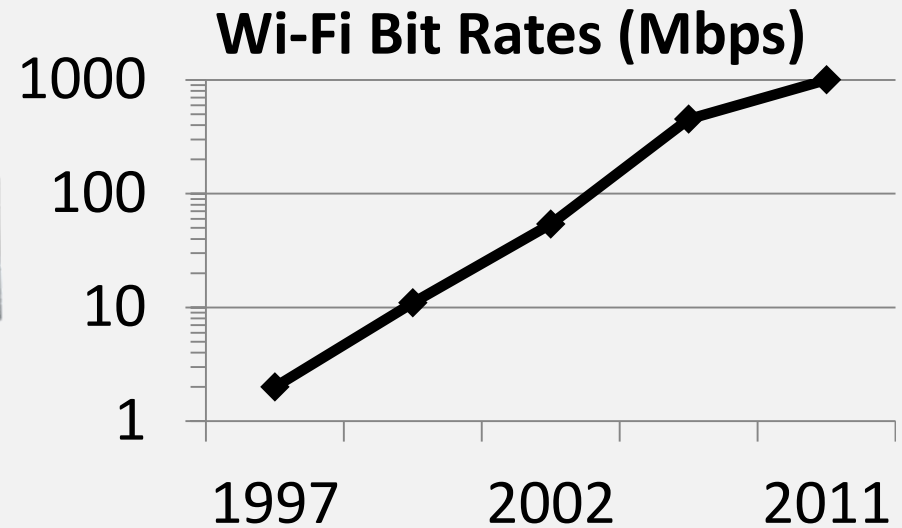
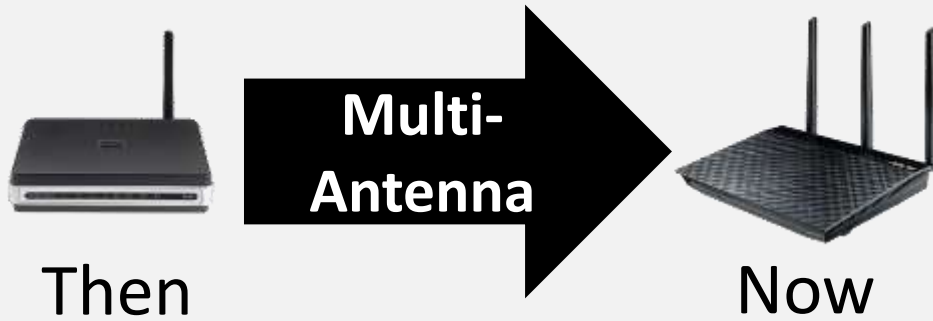
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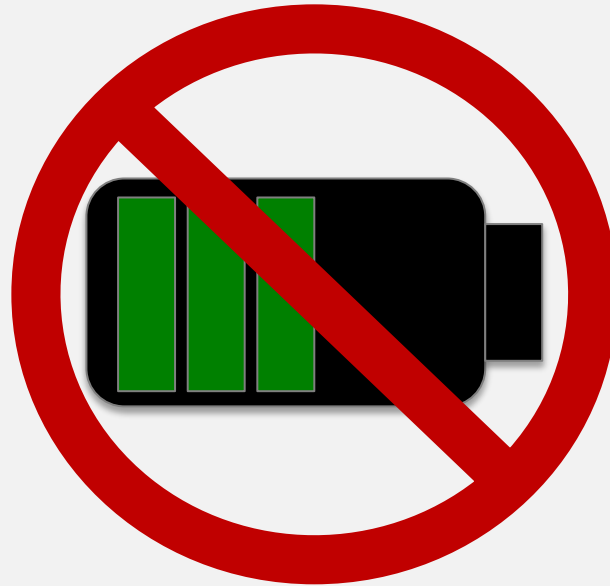


Radio Communication Trends



- Range (10s of km)
- Reliability

Our Work



Can we achieve these techniques
on battery-free devices?

If Possible, Benefits New Classes of Devices



Wearables



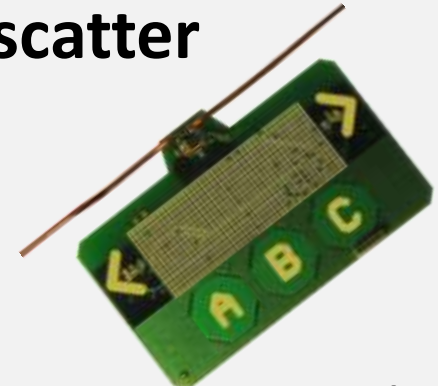
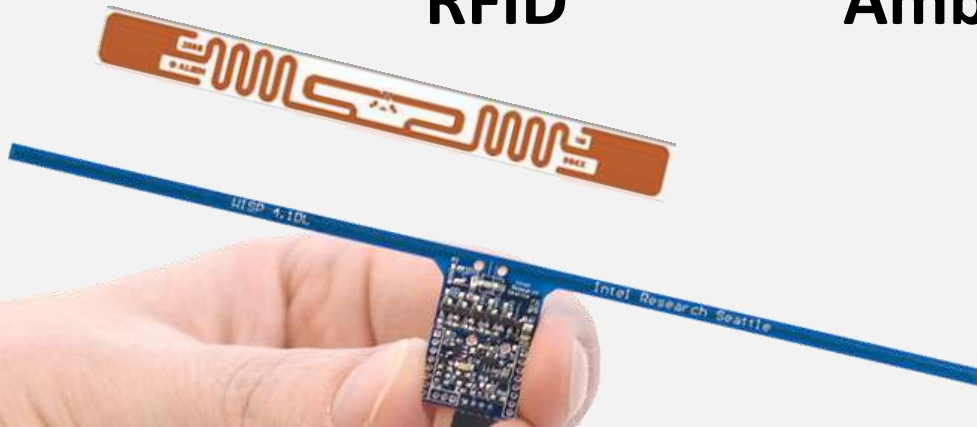
Localization



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**

**100's of
mW**

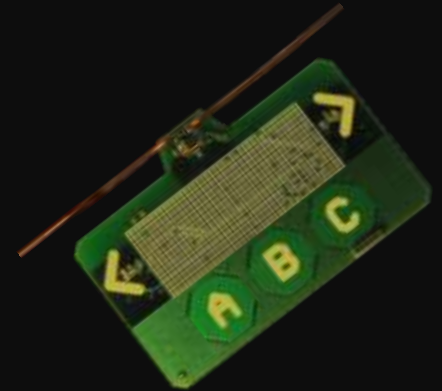
Requires power-
intensive ADCs

Our Design Principle

Perform computation in the **analog domain**

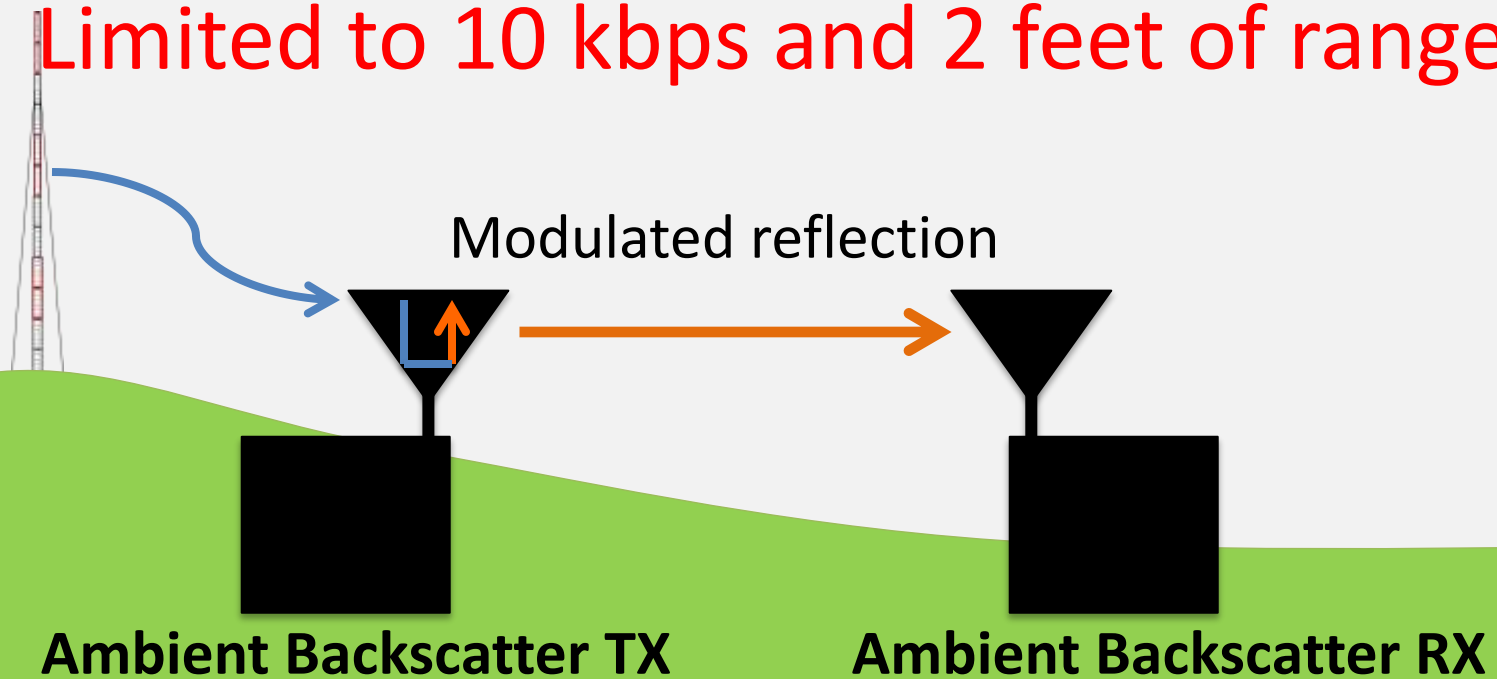
Contributions

- 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

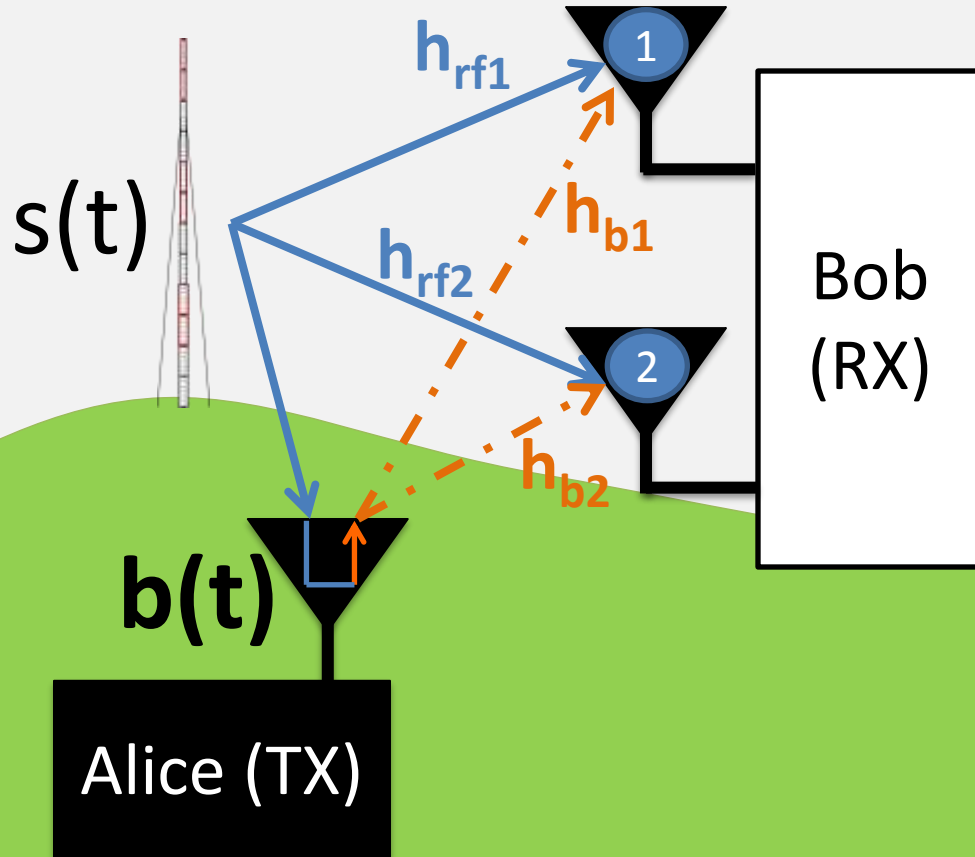


No additional power
No additional spectrum

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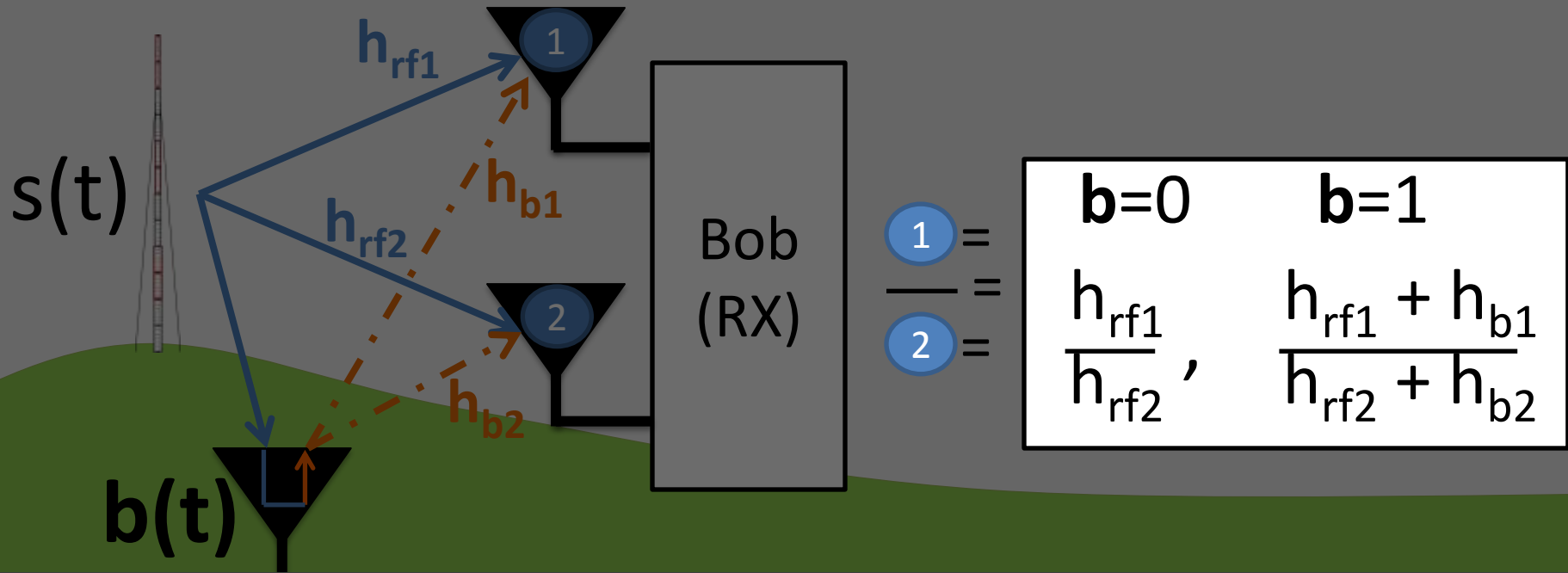
Multi-Antennas Without Digital Computation



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

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

Multi-Antennas Without Digital Computation

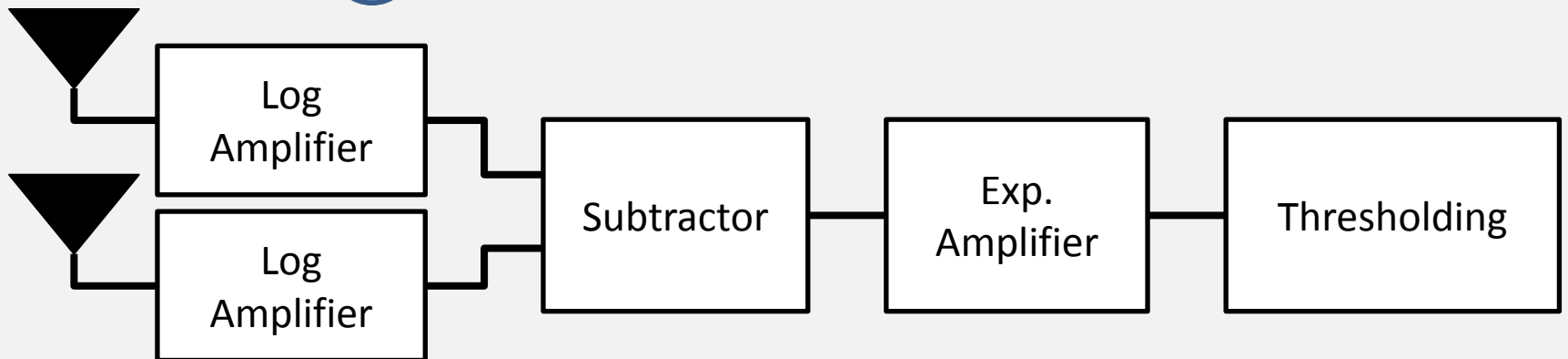


Decode $b(t)$ using changes in $\frac{1}{2}$

Division in the Analog Domain

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

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



Multi-antenna design **without digital computation**

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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

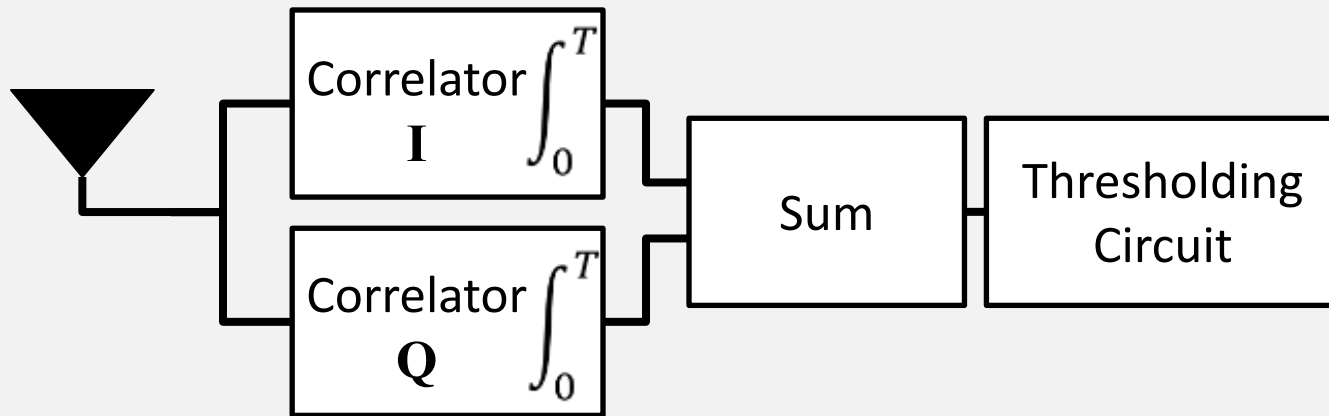
→ Gives Q component

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

No synchronization required

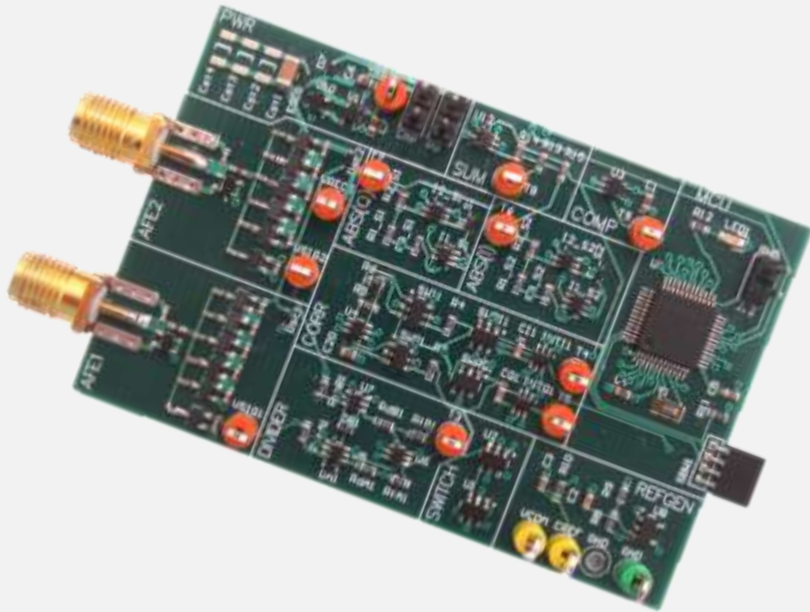
How do we Increase Range?

- Analog implementation



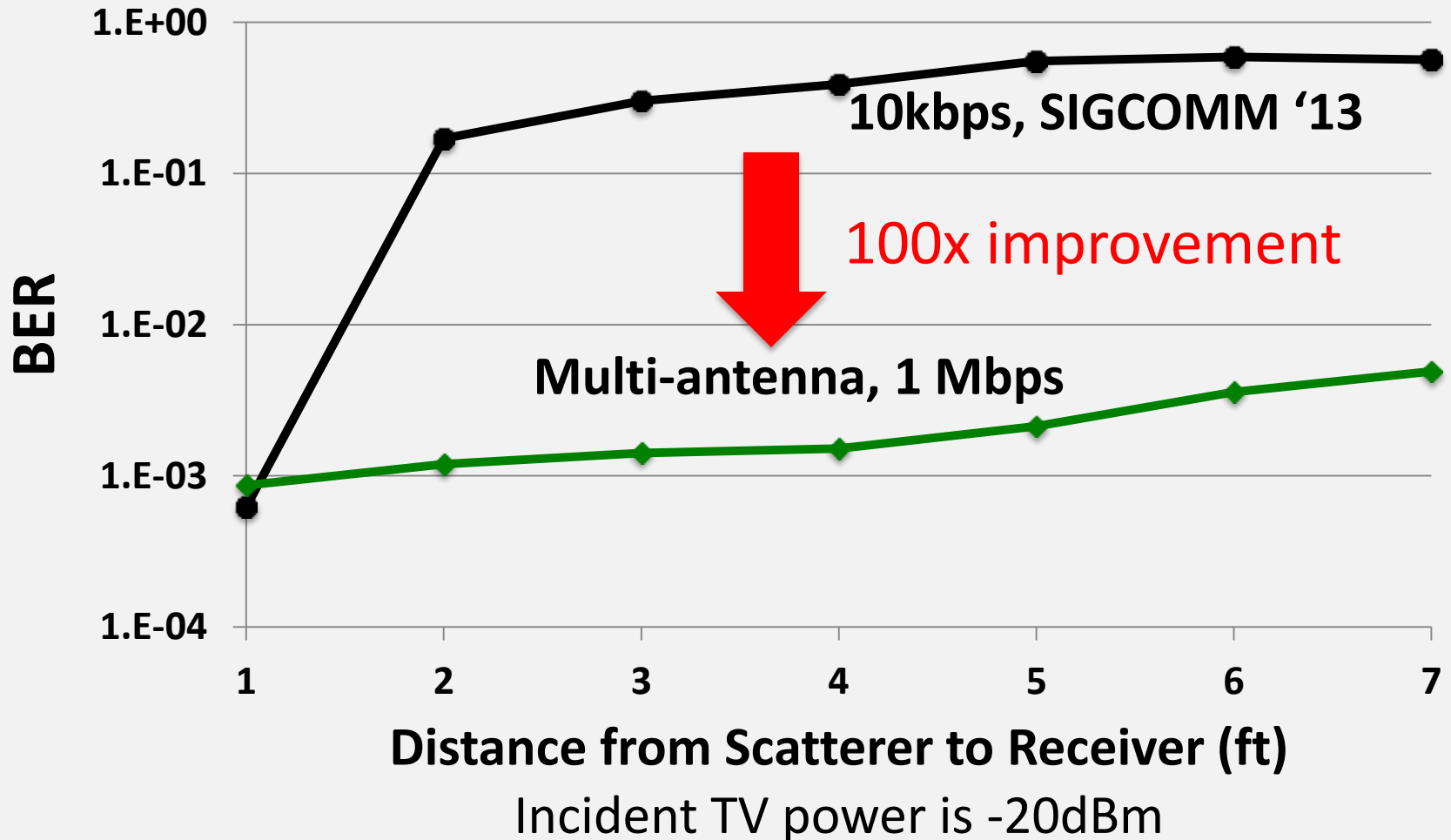
Simple analog implementation → Low Power

Our Hardware Prototype



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

What Gains Can Multiple Antennas Provide?



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

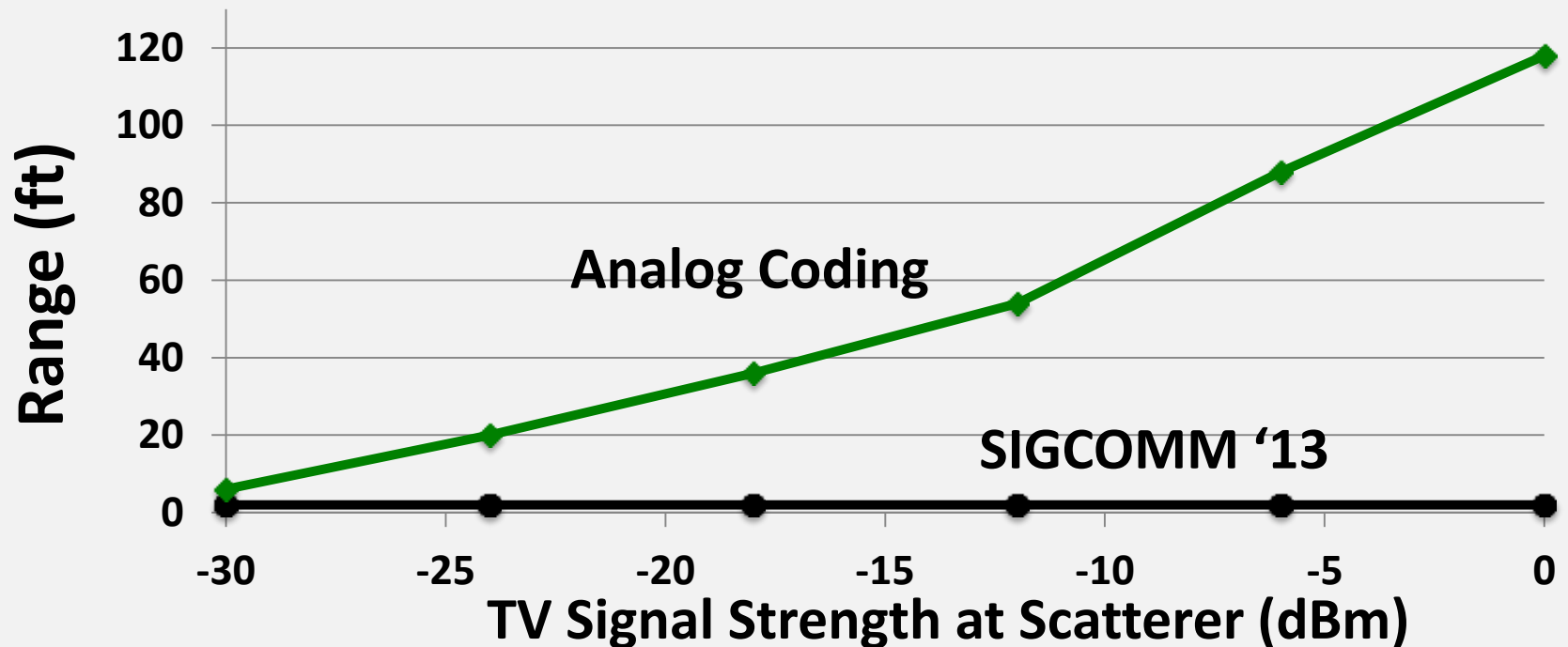
- Completely cancel TV signal

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

Orders of magnitude increase in rate

Can our Analog Code Increase the Range?

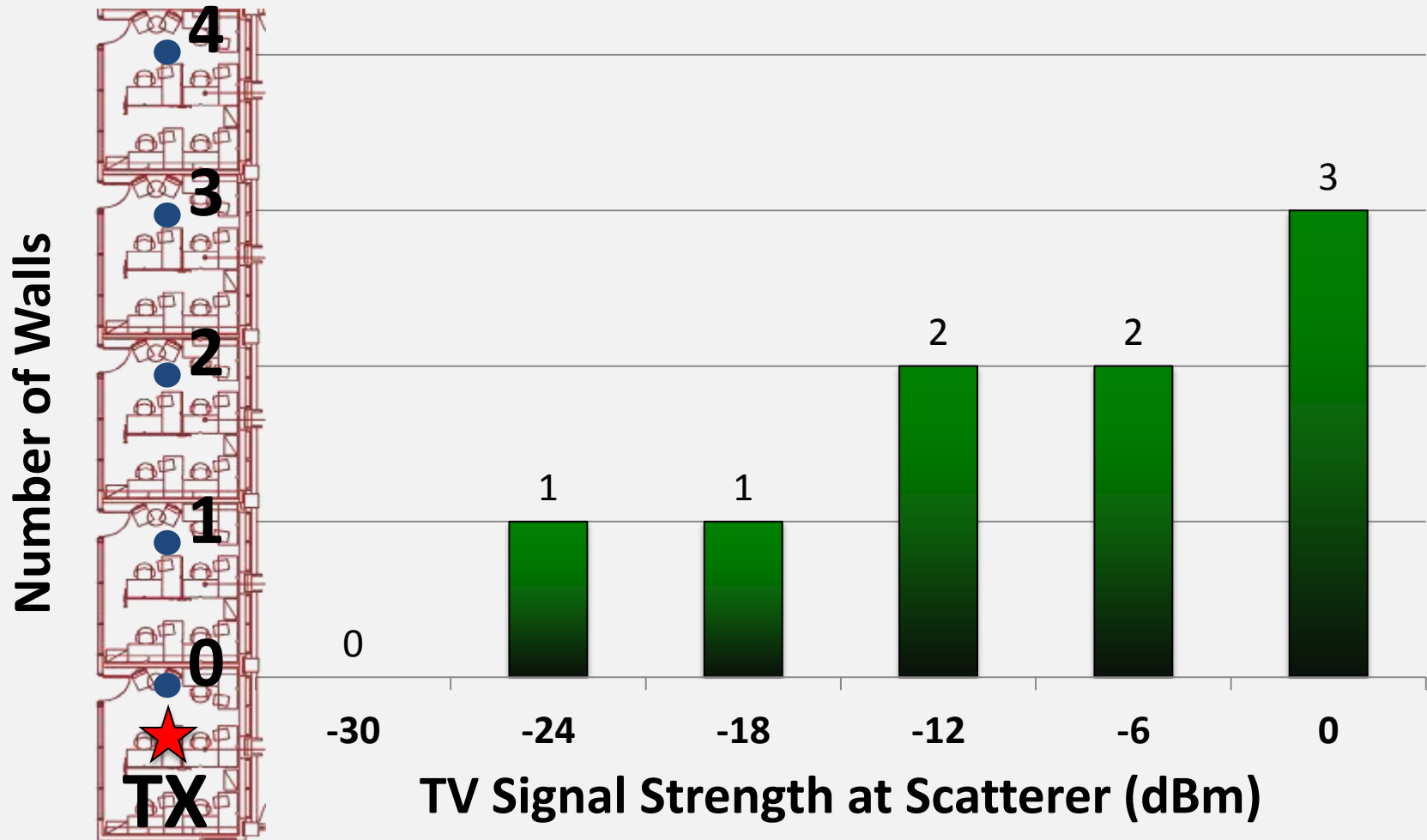
Transmitter and receiver in line-of-sight



10-100x improvement across all power levels

Can our Analog Code Increase the Range?

Transmitter and receiver in non-line-of-sight



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 (?), ...