LiveTag: Sensing Human-Object Interaction Through Passive Chipless WiFi Tags

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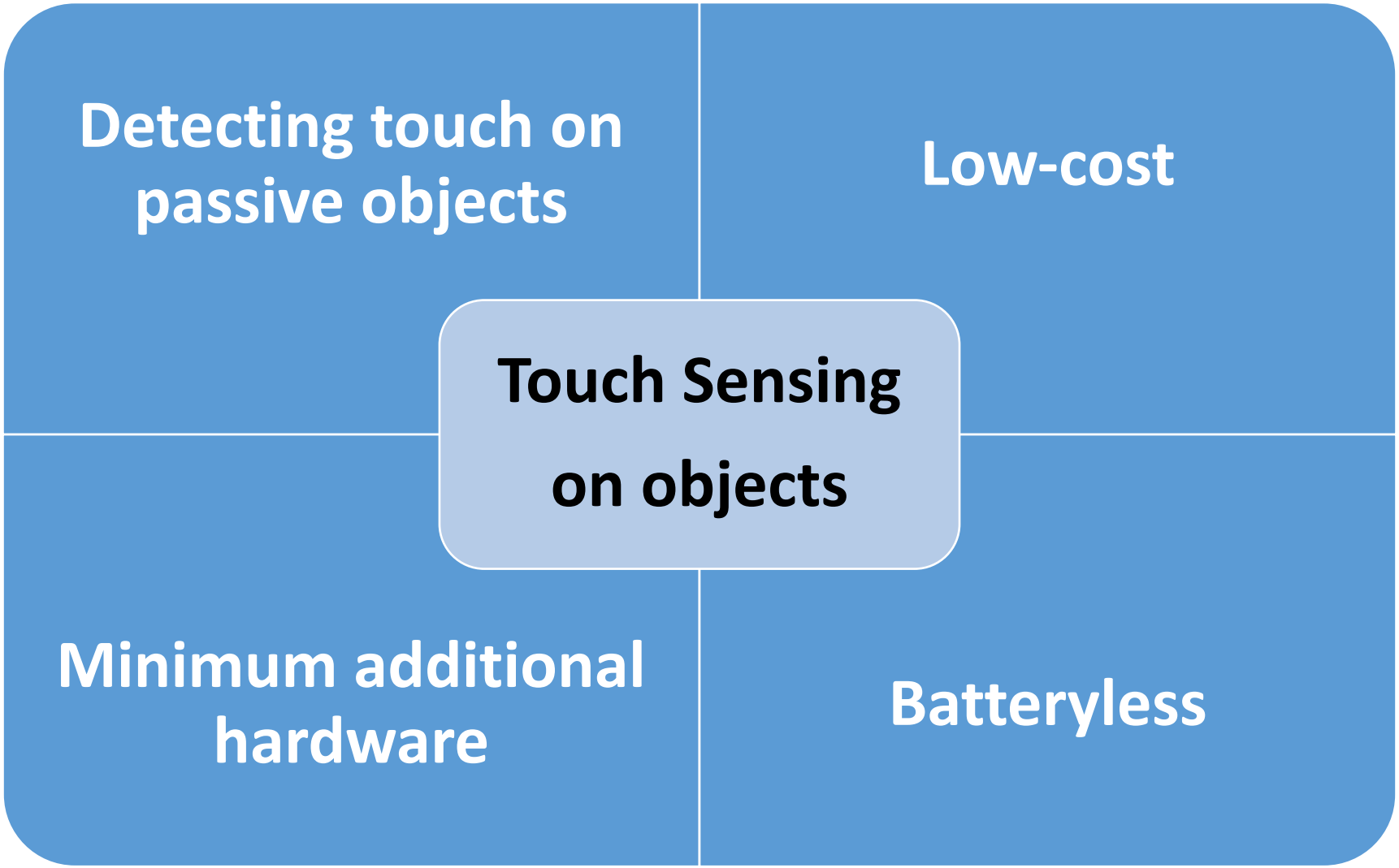
Sensing Human-Object Interaction

- **Human activity involves interaction with physical objects**
  - Inferring human activities
  - Using objects as command-and-control interface

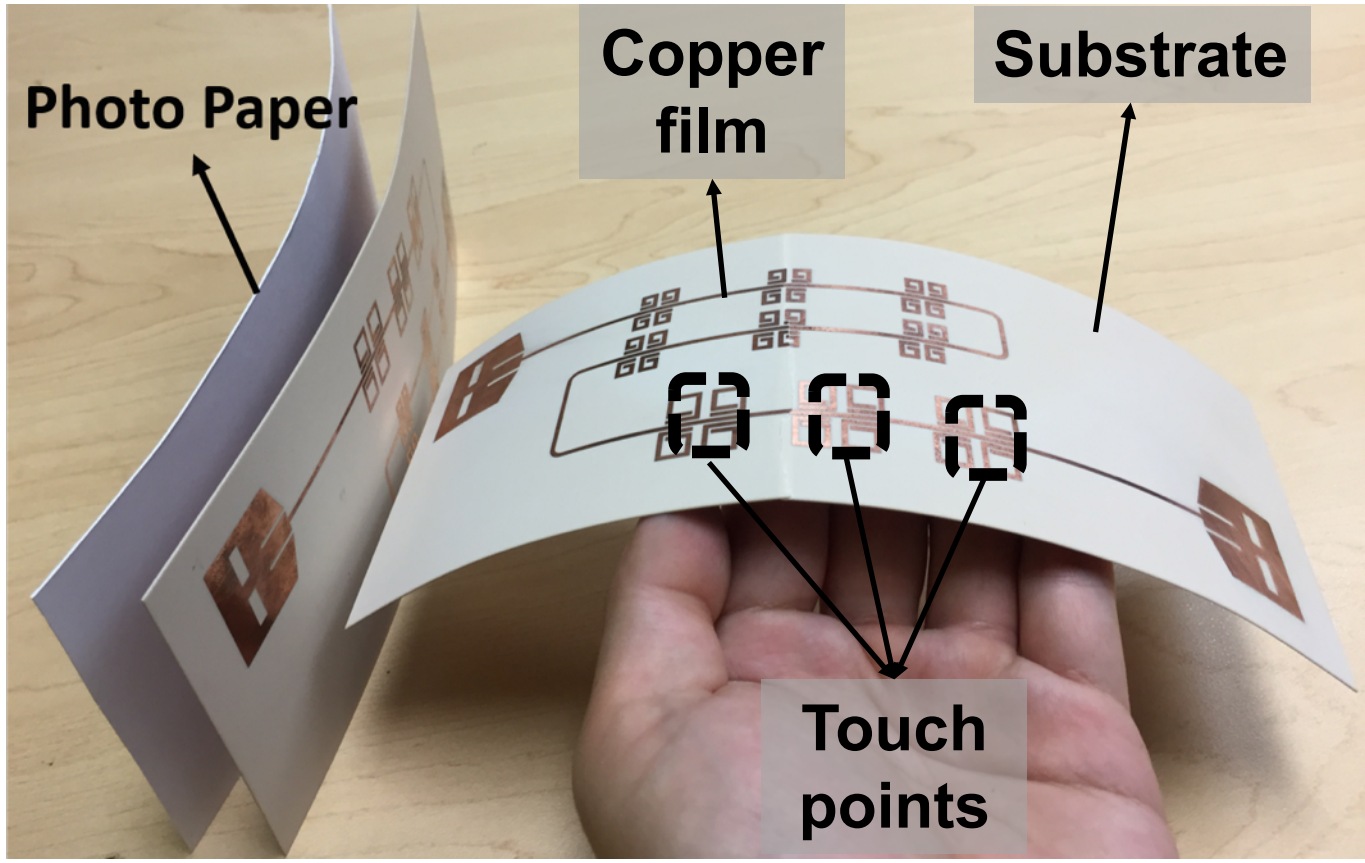
Can we detect touch interaction on everyday objects?

Design Goals



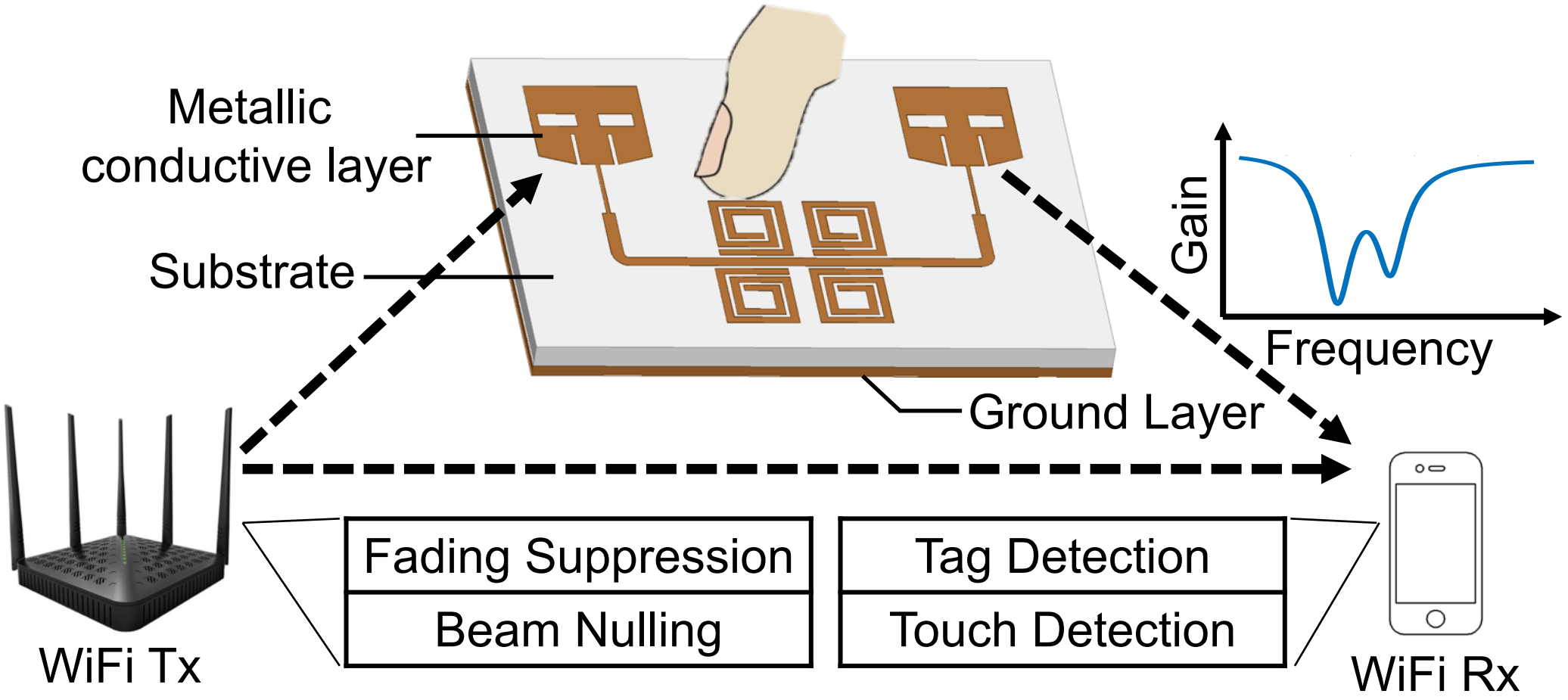
LiveTag Basics

- **Chipless, passive WiFi tag**
- **Attached to objects**
- **Serve as touch interfaces**
- **Detectable by WiFi devices**



A Smart Home Enabled by LiveTag

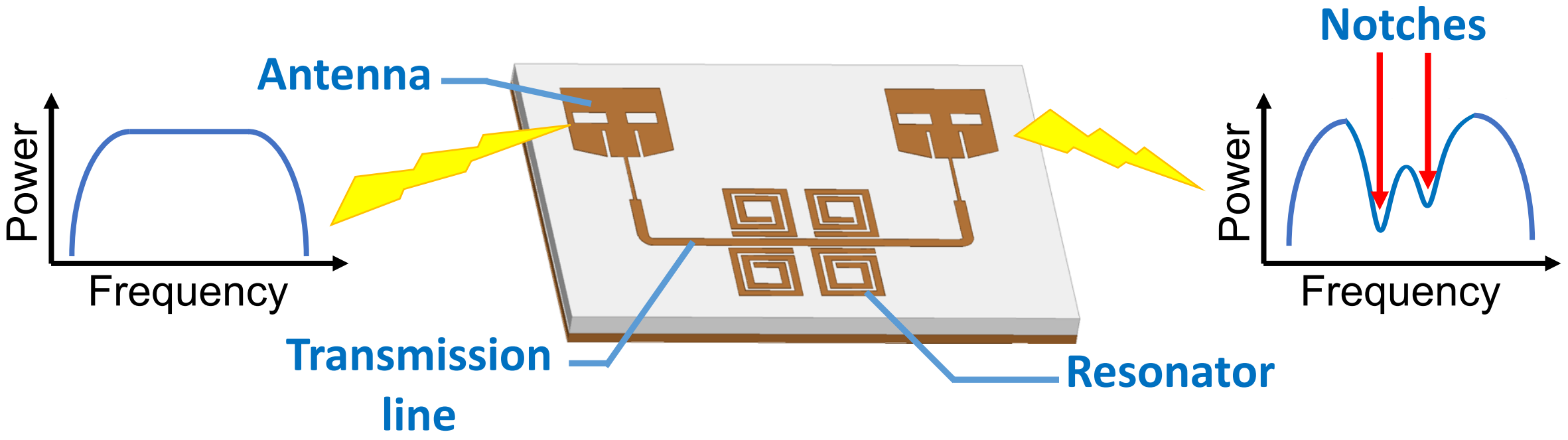
LiveTag Basics



LiveTag Solution

- **Tag design**
  - Creating WiFi detectable feature with resonator
  - Enabling multiple touch points on the tag
- **Detecting tags and touches with WiFi**
  - Combating multipath fading with beamforming
  - Suppressing self-interference
  - Robust touch detection mechanism

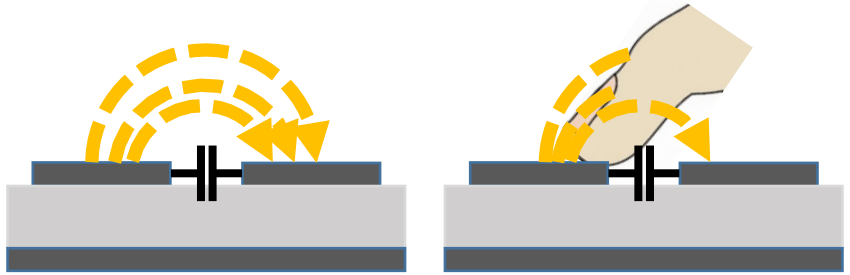
Creating WiFi Detectable Features



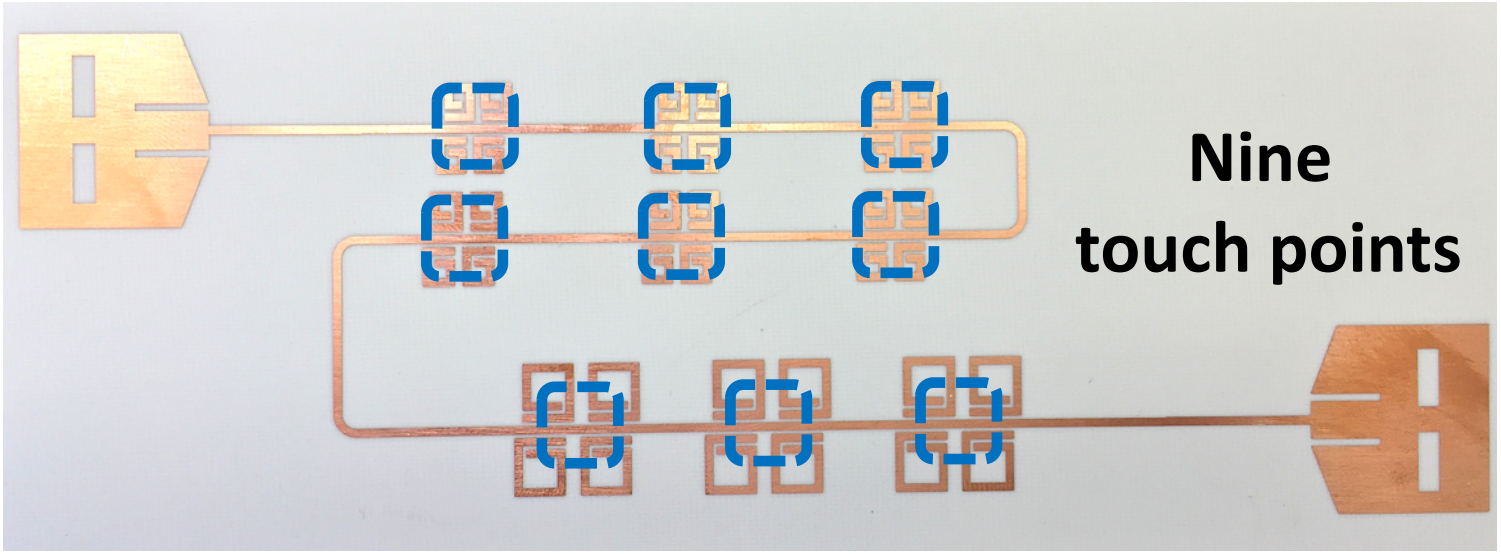
- WiFi signal PSD “modulated” by resonators
- Each resonator creates a notch at a certain frequency
- Notch frequencies serve as tag signature

Enabling Multiple Touch Points

- Resonators are “detuned” when touched

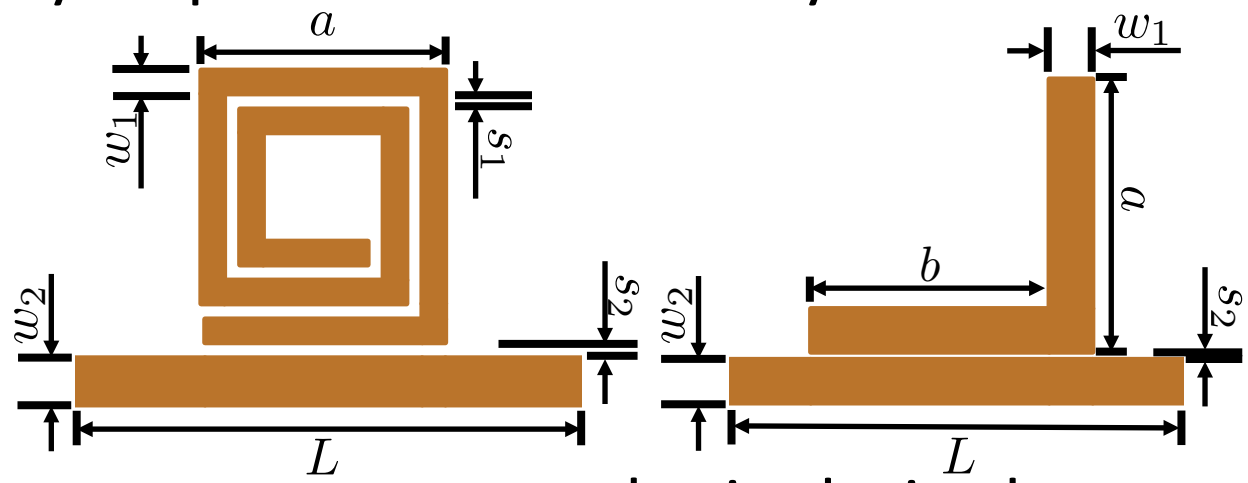


- Multiple touch points on a single tag



Optimizing Tag Structure in LiveTag

- Tag frequency response determined by resonator shape



- Optimize shape parameters to obtain desired prosperities
  - Notch center frequency
  - Deep & narrow notches
  - Independent notches
  - …

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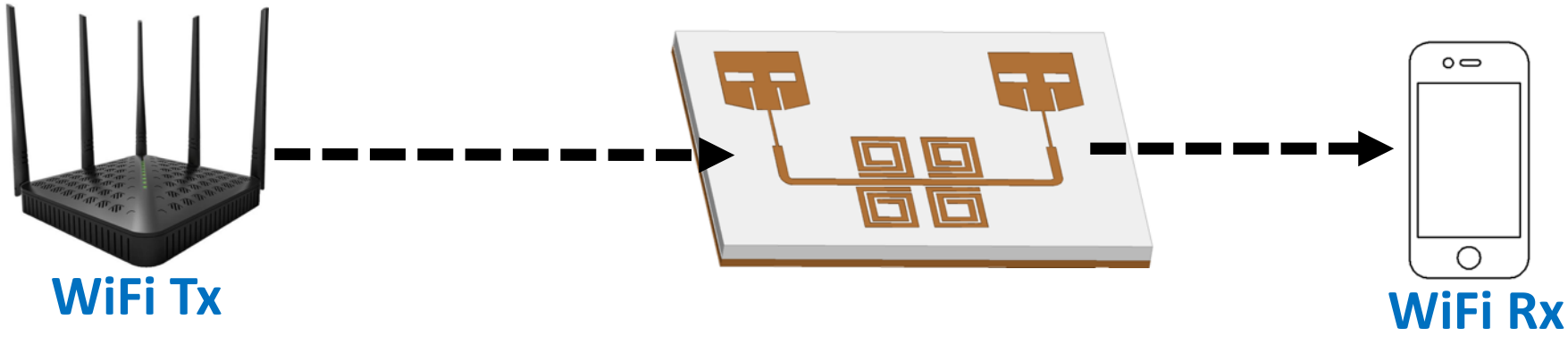
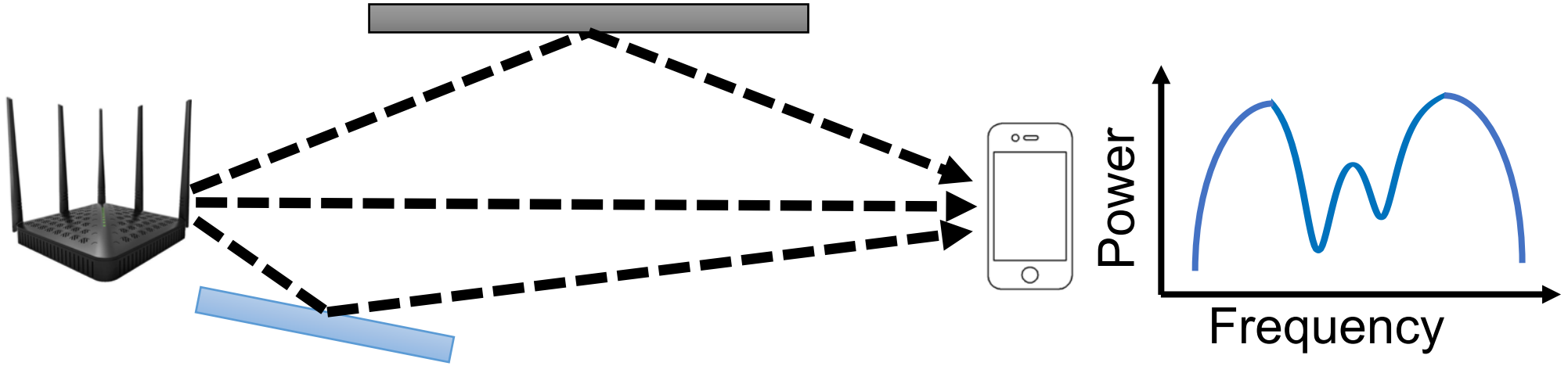
Extracting Tag Signature with WiFi Devices

- WiFi transmitter sends packets across all WiFi channels
- Receiver extracts CSI on each channel
- Stiches CSI to obtain complete PSD



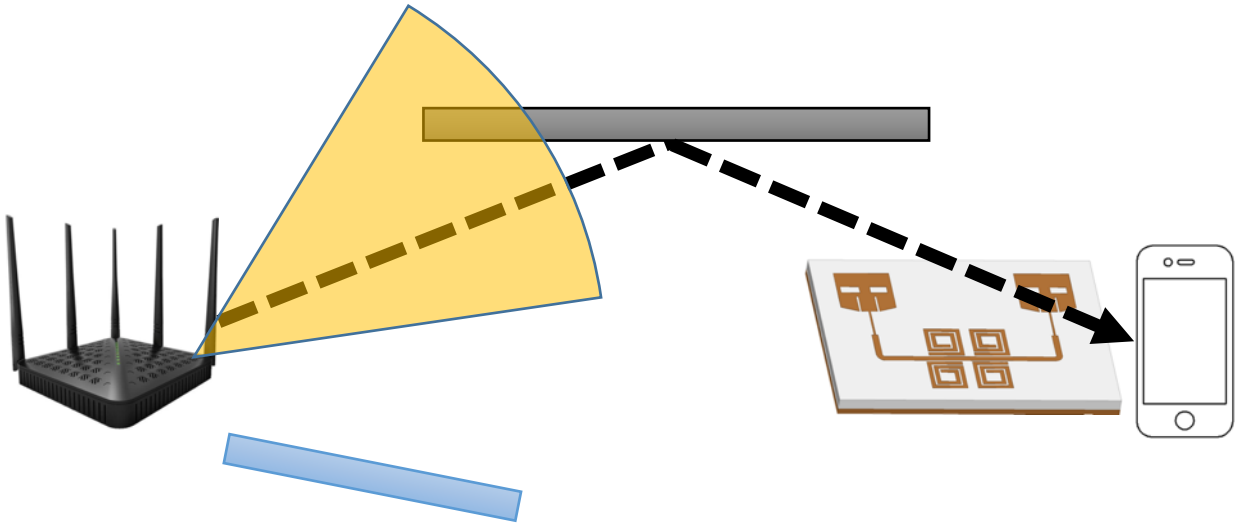
Suppressing Multipath Fading

- Multipath facing also creates deep frequency notches
- Signal travels through direct and multiple reflection paths
- Constructively/Destructively combined depending on path lengths
- **Properties of fading notches depend on reflectors**



Suppressing Multipath Fading

- Solution: Let signal hit different reflectors
  - Fading notches varies, but tag notches persist
- Use multiple antennas to steer beam towards different directions
  - Beamforming creates directional transmission “beams”



Beam	Detected Notches
1	f_1, f_2

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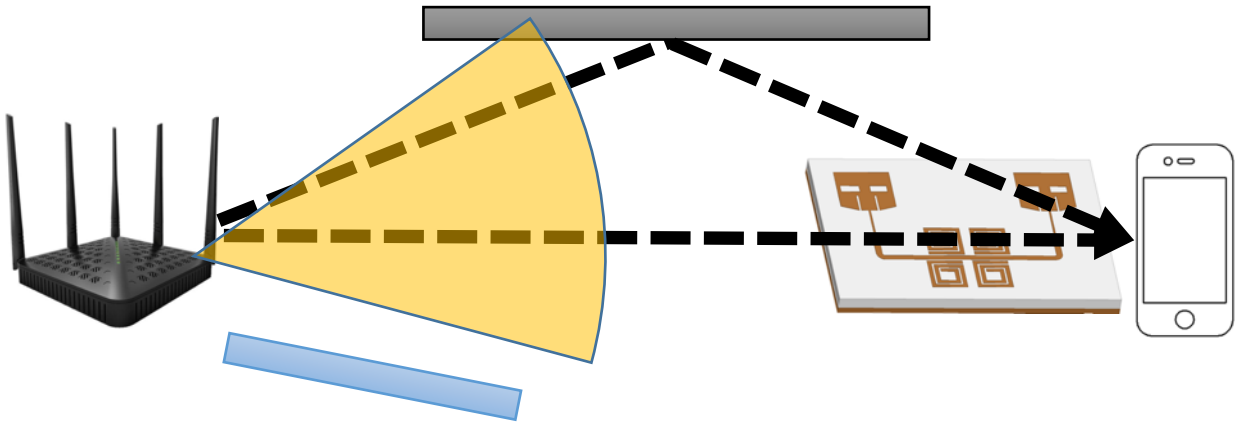

Beam	Detected Notches
1	f_1, f_2
2	f_1, f_2, f_3

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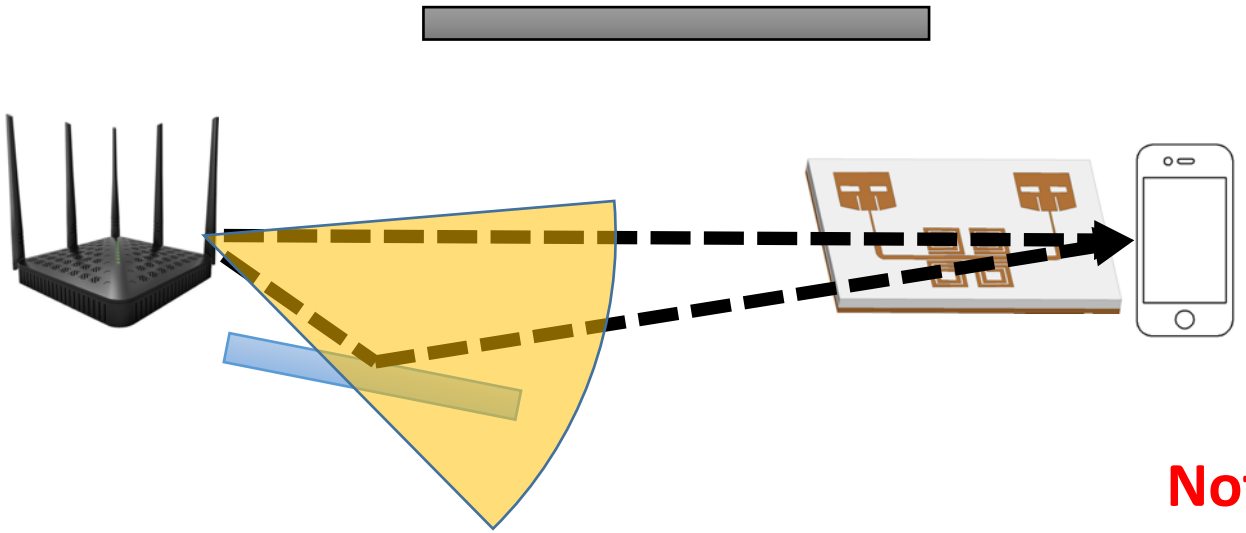

Beam	Detected Notches
1	f_1, f_2
2	f_1, f_2, f_3
3	f_2, f_4

Notch at f_2 is consistent: We find a tag notch!

Self-Interference Cancelation

- Measure Line-of-Sight (LOS) direction
- WiFi transmitter creates a null along LOS direction

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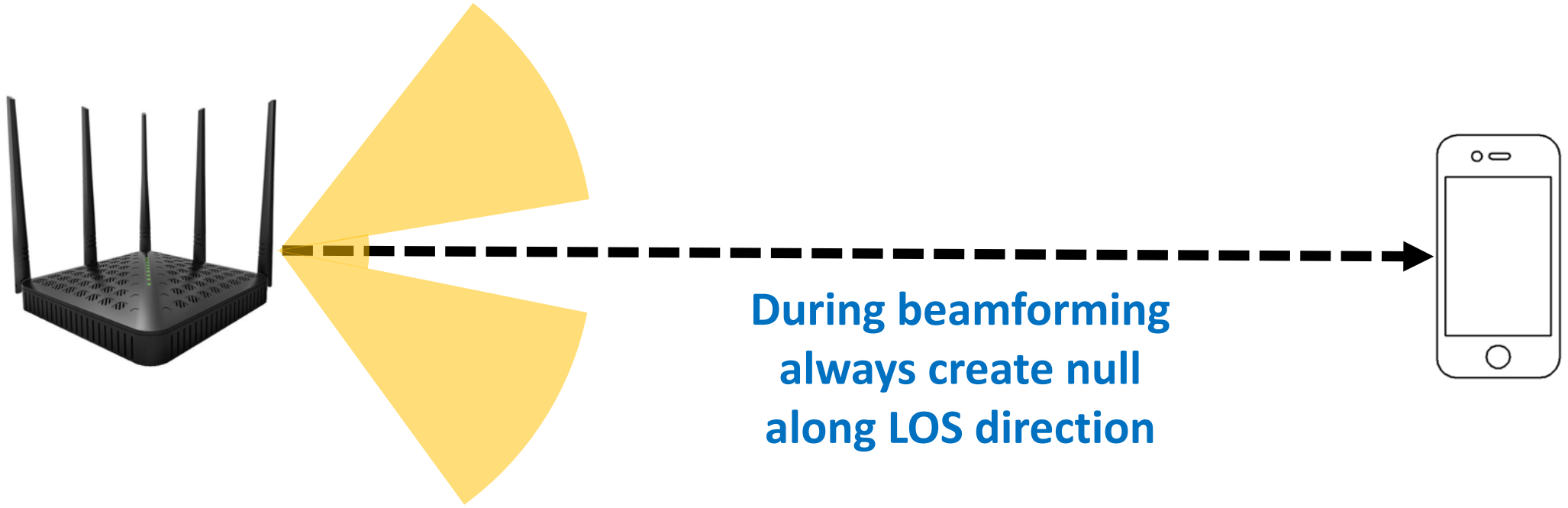

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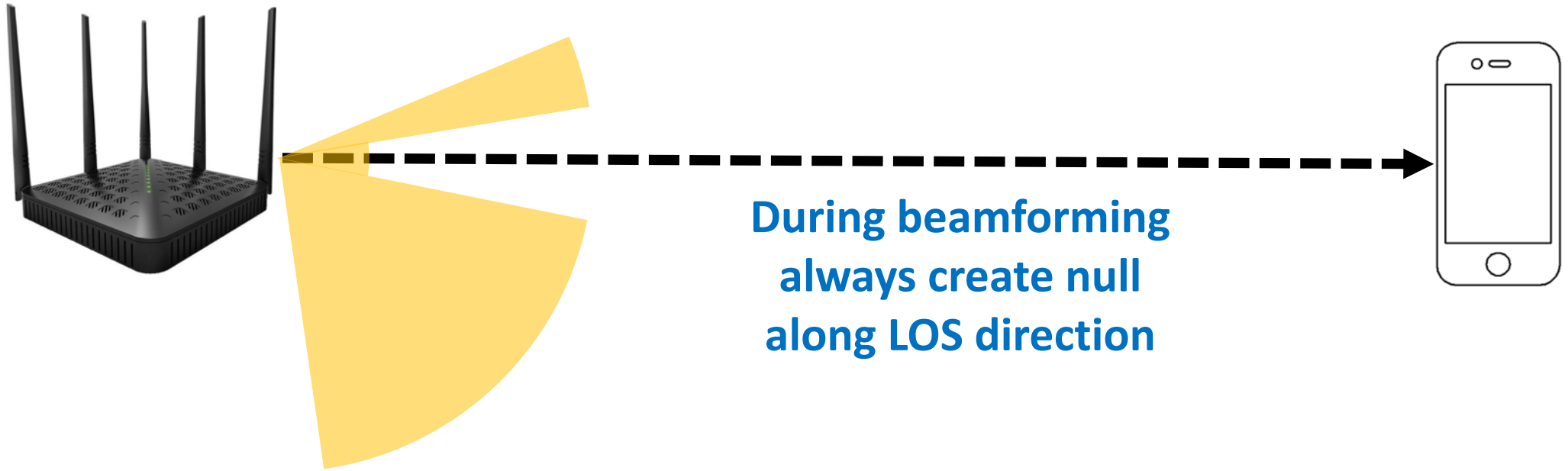


Robust Touch Detection

- WiFi receiver monitors the **change** at each notch position
- Constant false alarm rate detection

$$F(x) = 1 - \exp(-\frac{x^2}{4\rho^2})$$

$$P_f(V_{th}) = \exp(-\frac{V_{th}^2}{4\rho^2})$$

- Improving detection robustness
  - Multiple redundant resonators with different notch frequencies
  - Multiple sets of CSI

Implementation

- WARP software defined radios
- Linux PCs with CSI-Tool

Key Evaluation Results

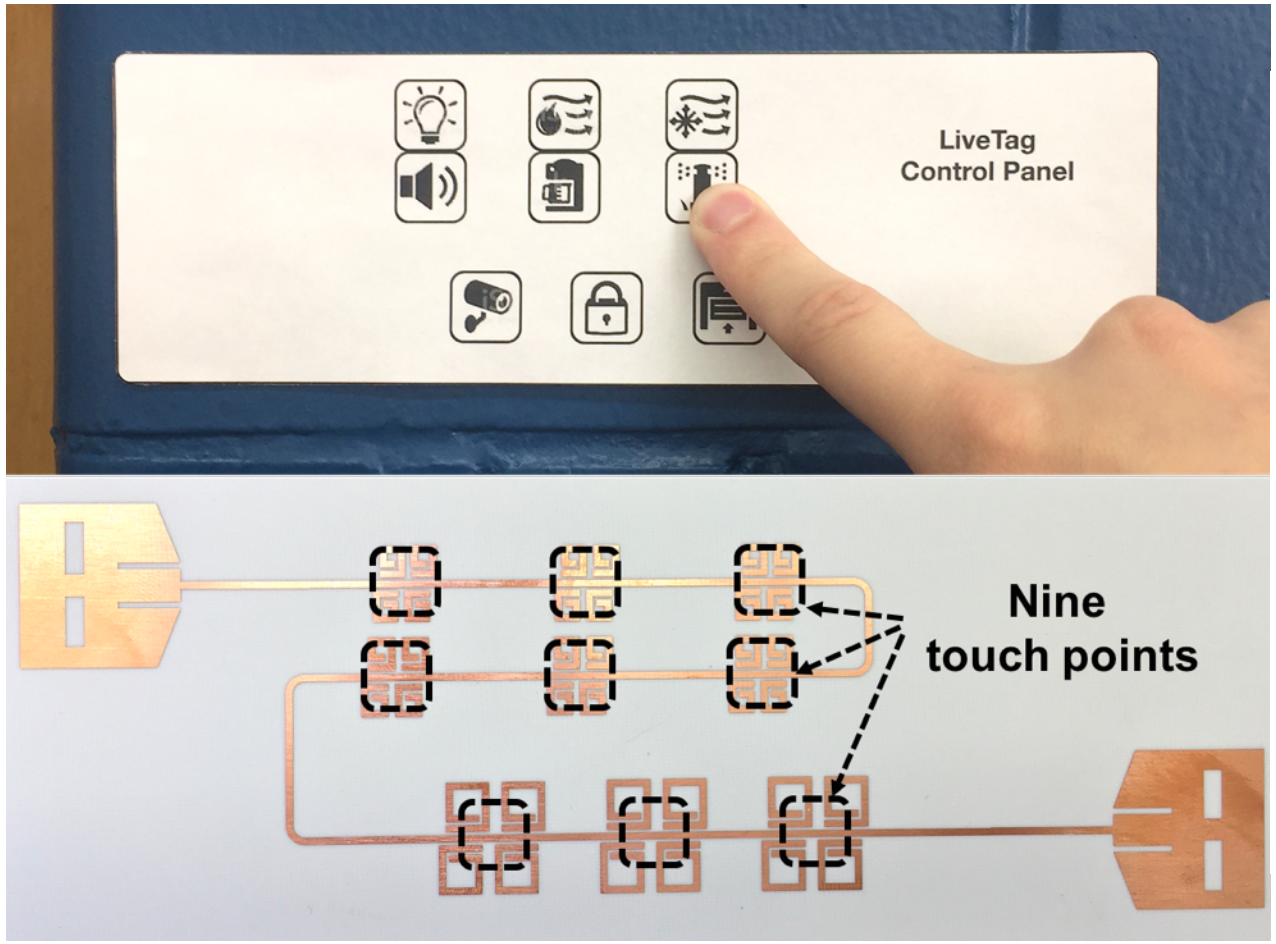
- **Detection Accuracy**

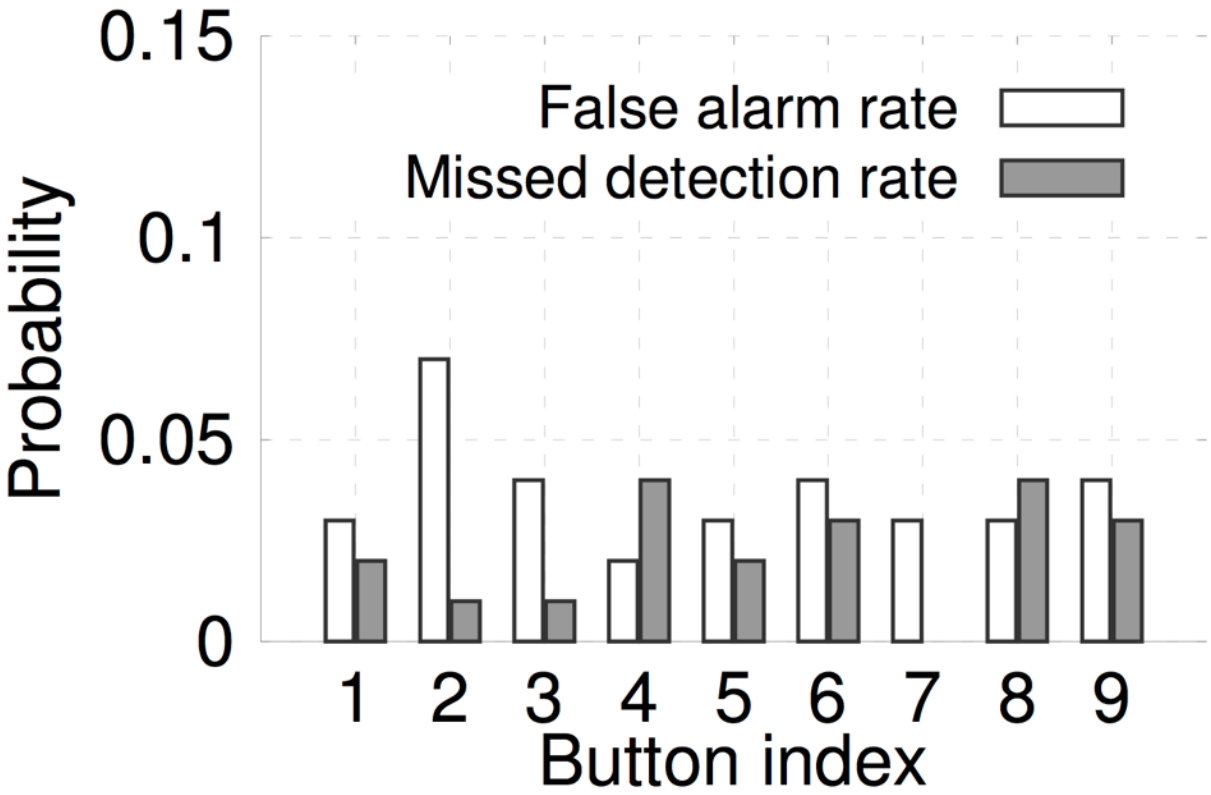
	Tag Detection	Touch Detection
Accuracy	**> 95%**	**> 95%**

- **Detection Range**

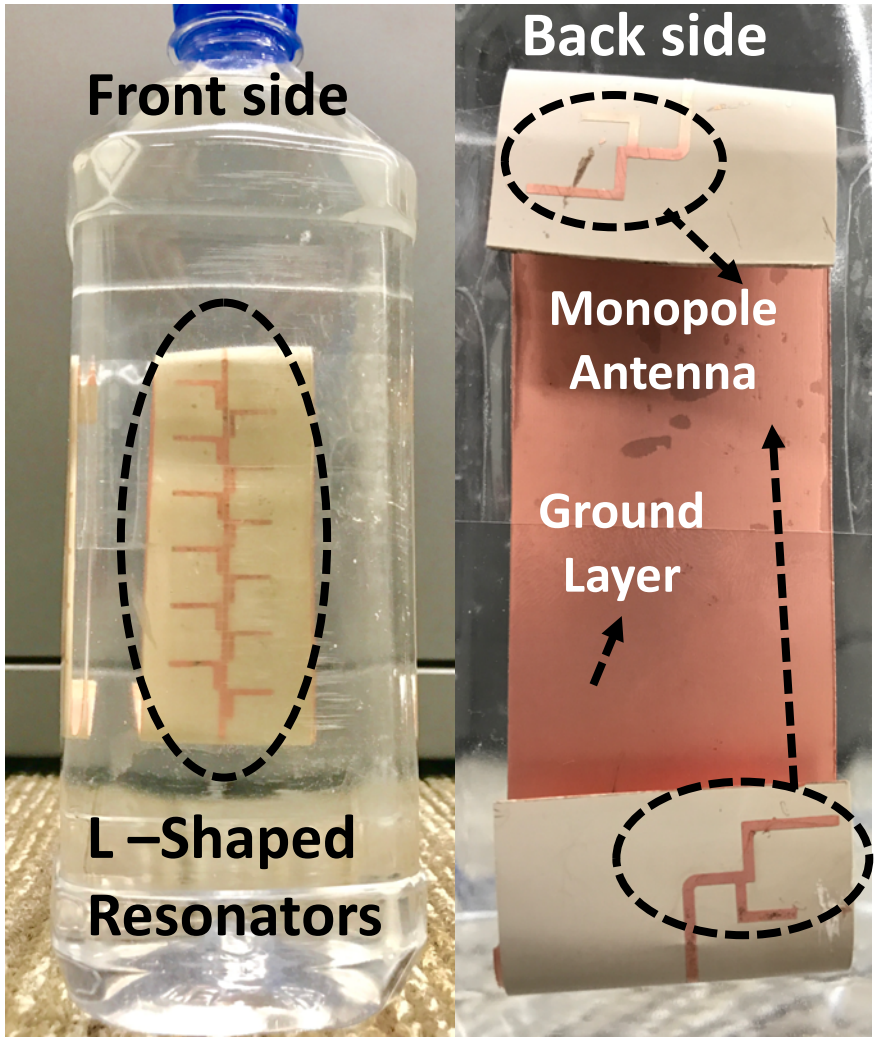
	Tx-to-Tag	Tag-to-Rx
Range	**4-5 m**	**0.4-0.5 m**

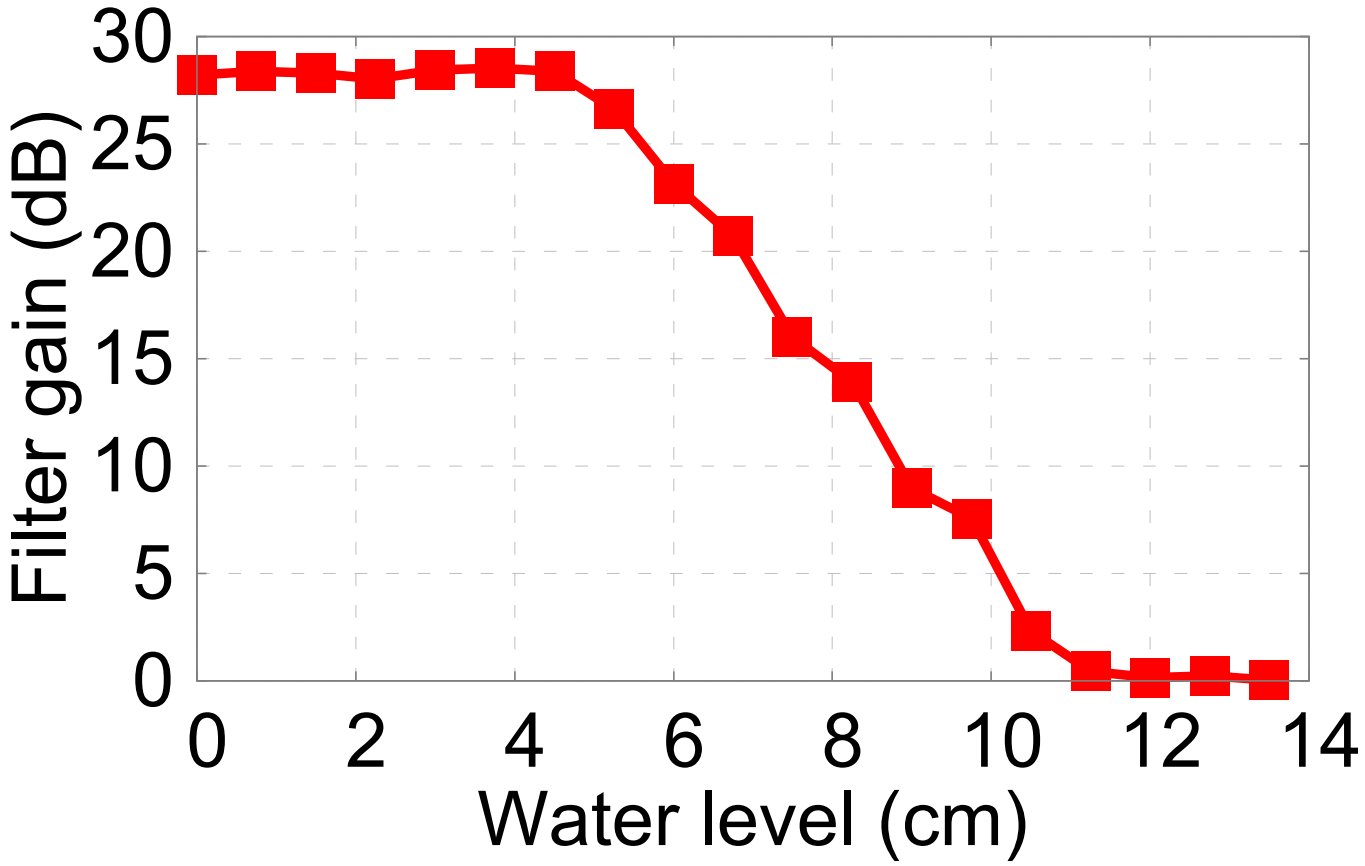
Control Panel for Smart Home





Water Level Detector





Summary

- **Bringing remote touch sensing to passive objects**
- **Passive, chipless WiFi tag**
- **Future Work**
  - Tag manufacture
  - Extending detection range

Questions?

Thank you