MAS.S66
Computational Wireless Sensing

Lecture 4:

Wireless Sensing of Vitals & Backscatter Communication

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Ubiquitous Health & Comfort Monitoring

Can smart homes monitor and adapt to our breathing and heart rates?

Applications?

Personal Health

Baby Sleep

Elderly Health

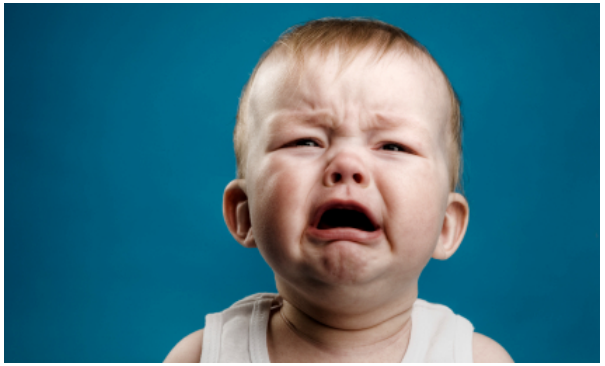
Adapt Lighting and Music to Mood

But: today's technologies for monitoring vital signs are cumbersome

Breath Monitoring

Heart Rate Monitoring

Not suitable for elderly & babies



Can we monitor breathing and heart rate from a distance?

Vital-Radio

- Technology that monitors breathing and heart rate remotely with 97% accuracy
- Can monitor multiple users simultaneously
- Operates through walls and can cover multiple rooms

Idea: Use wireless reflections off the human body

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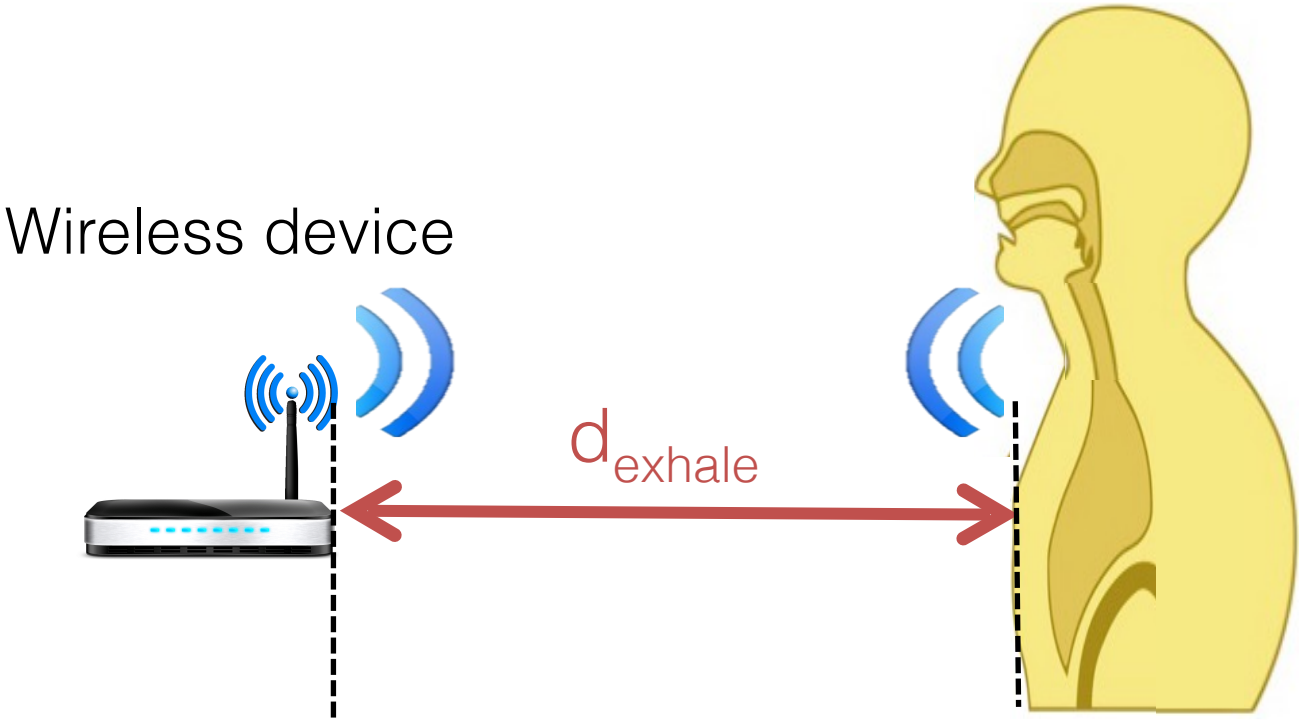
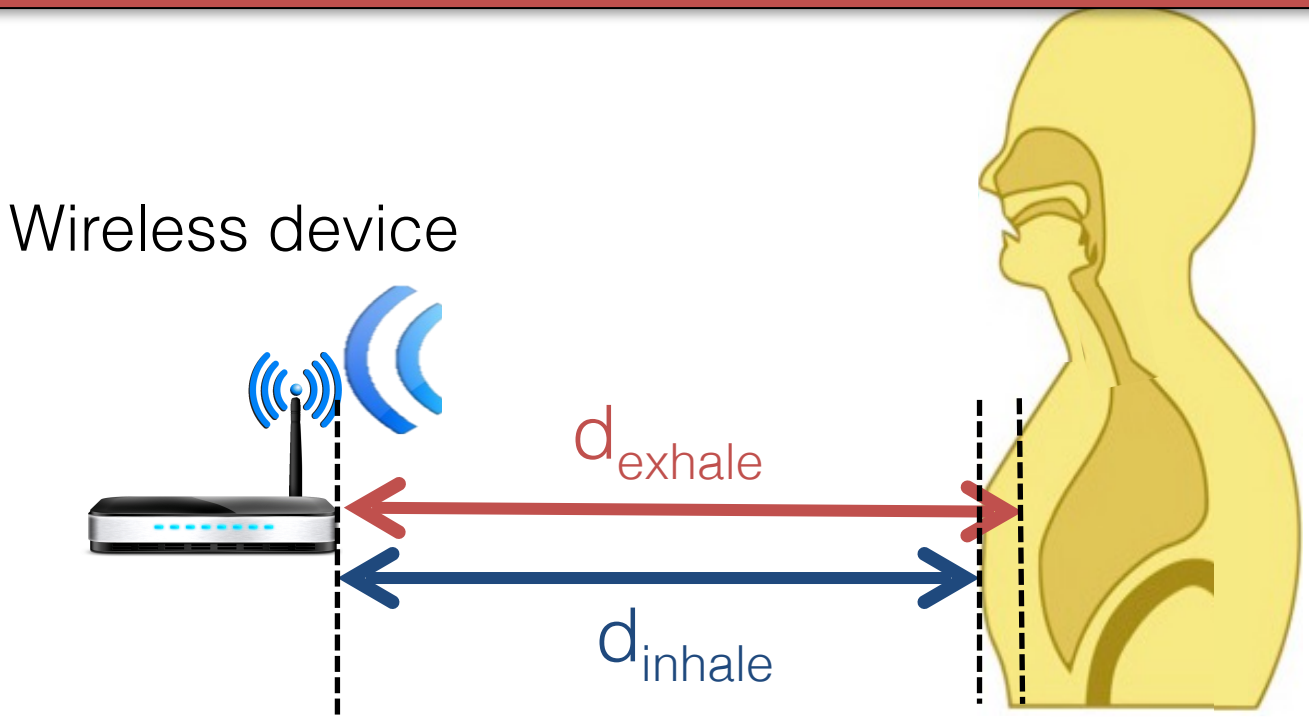
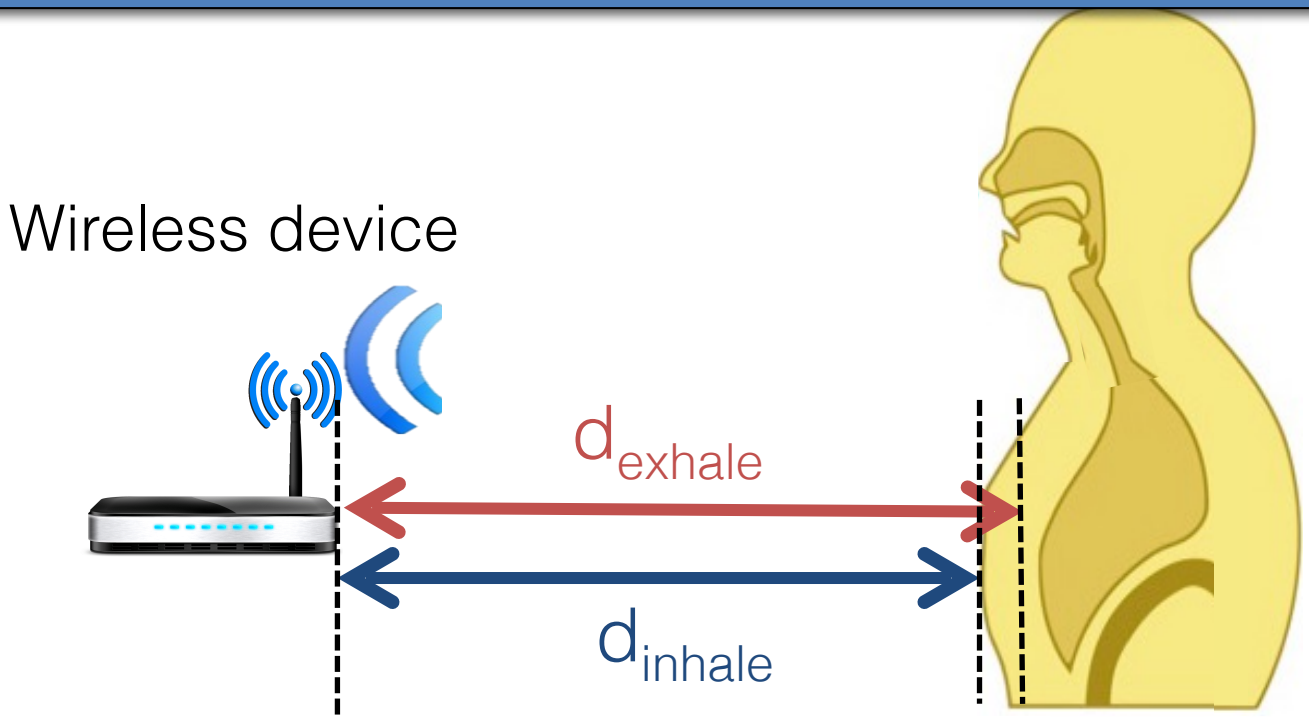


Problem: Localization accuracy is only 12cm and cannot capture vital signs



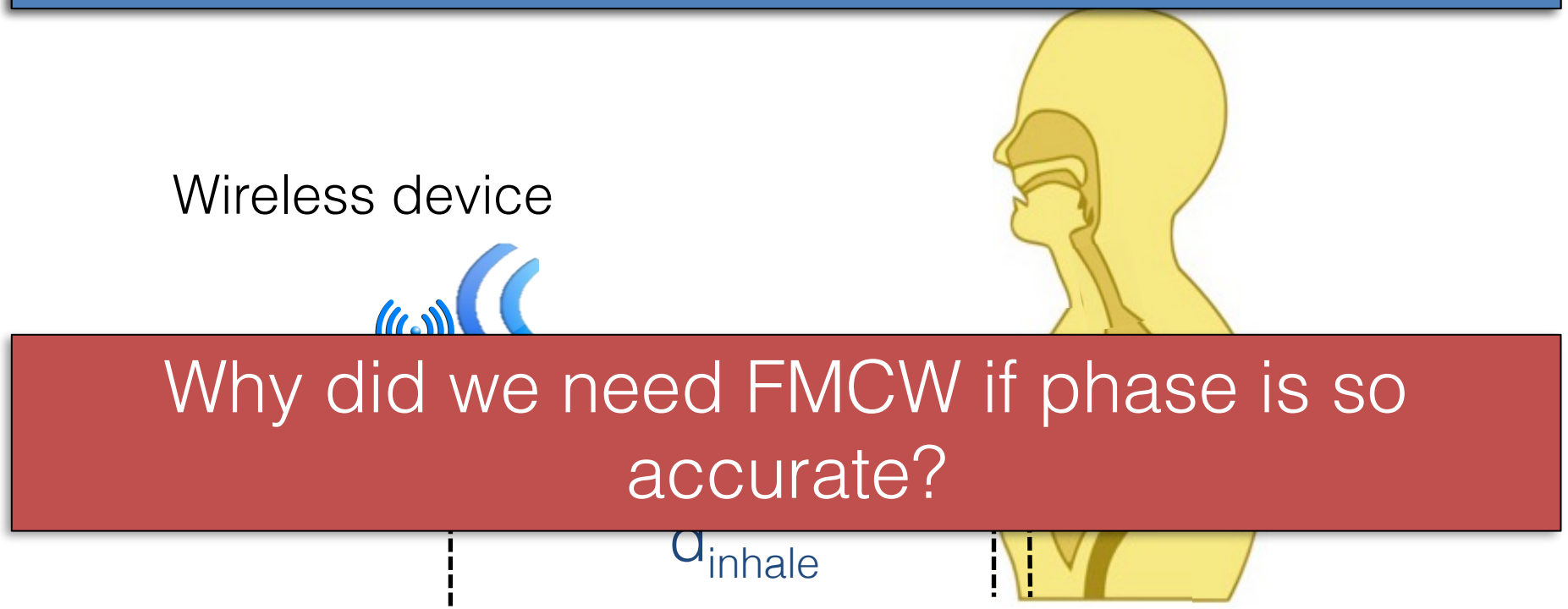
Why? How did we compute the resolution?

Solution: Use the phase of the wireless reflection



Why does phase allow us to get the distance at higher granularity?

Solution: Use the phase of the wireless reflection



Why did we need FMCW if phase is so accurate?

Wireless wave has a phase: $\Phi = 2\pi \frac{\text{distance}}{\text{wavelength}}$

- Chest Motion changes distance
- Heartbeats also change distance

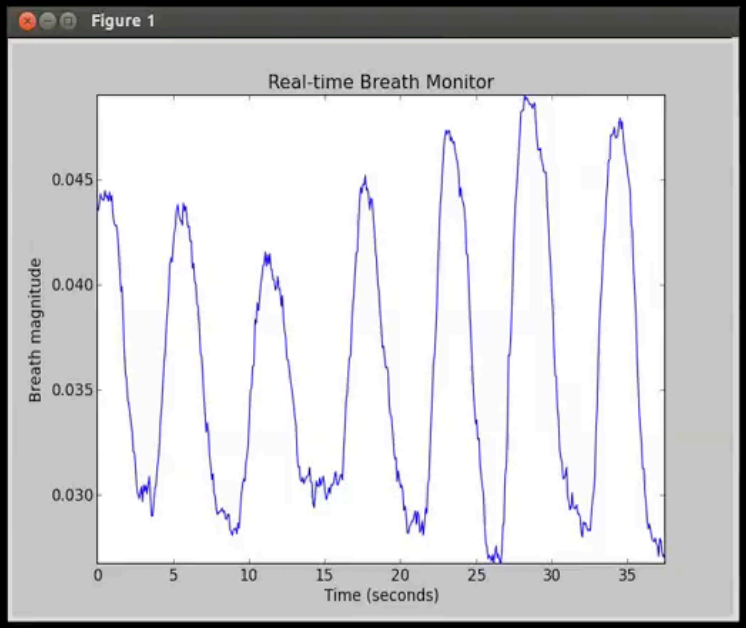
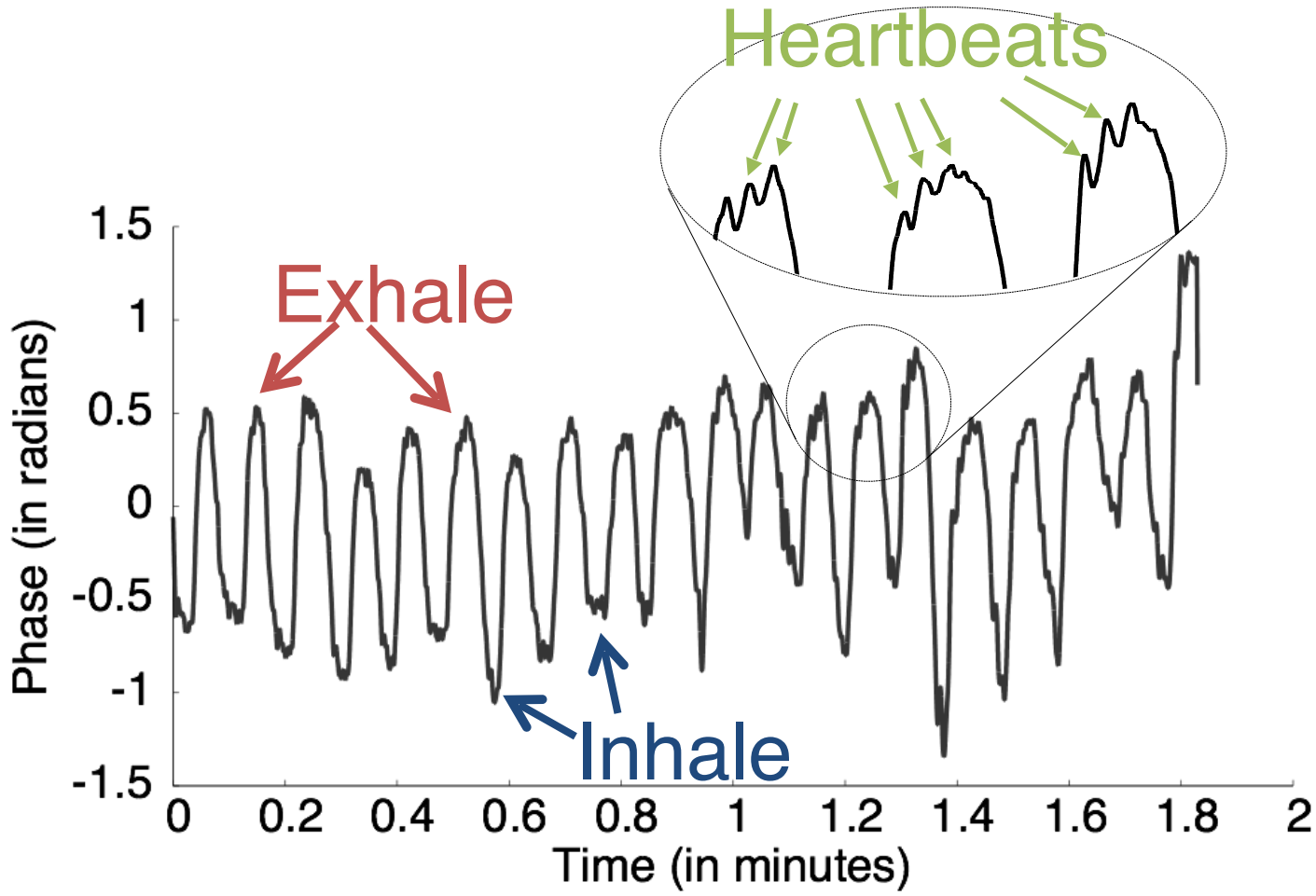


Figure 1
Real-time Breath Monitor
Breath magnitude
0.045
0.040
0.035
0.030
0
5
10
15
20
25
30
35
Time (seconds)

Let’s zoom in on these signals



How do we get from here to extracting breathing rate and heart rate?

What happens when a person moves his limb?

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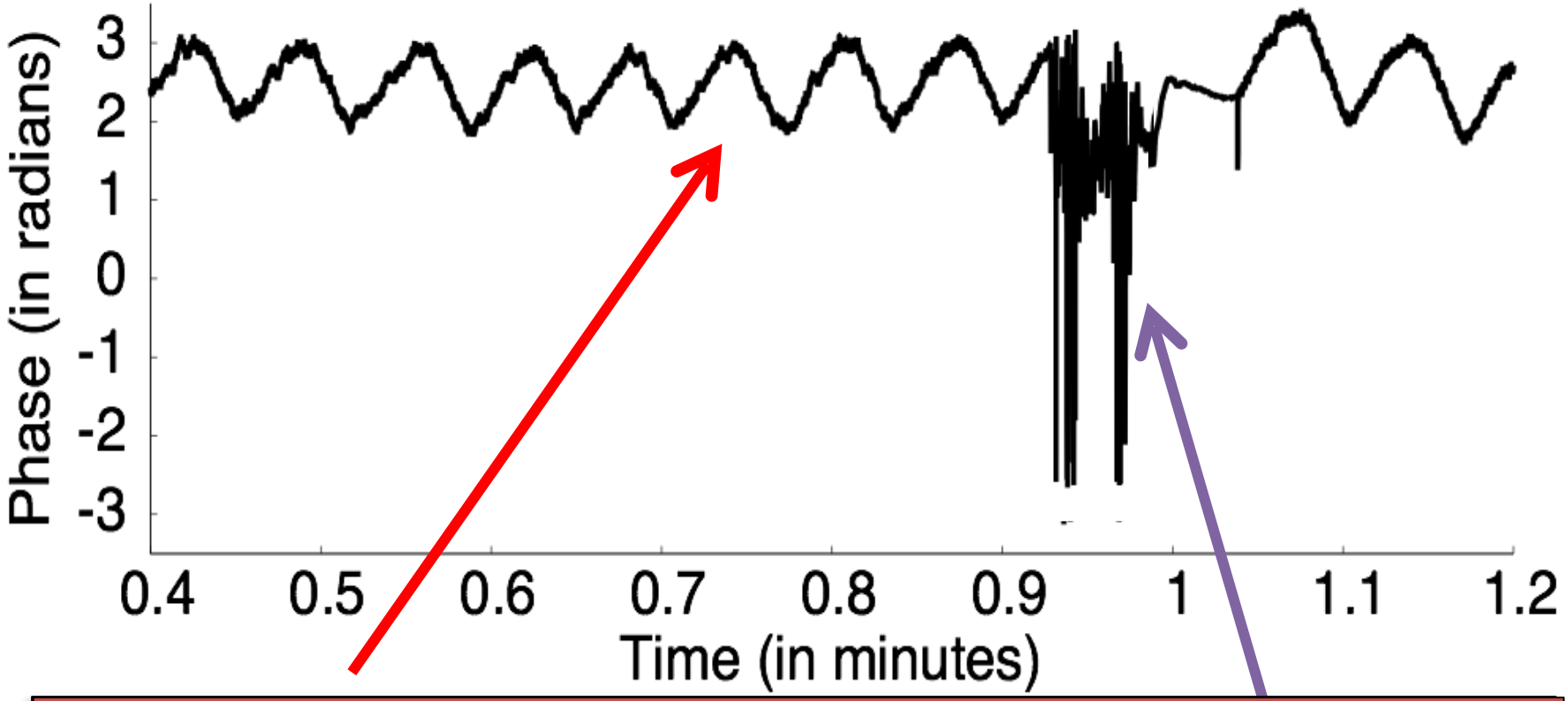
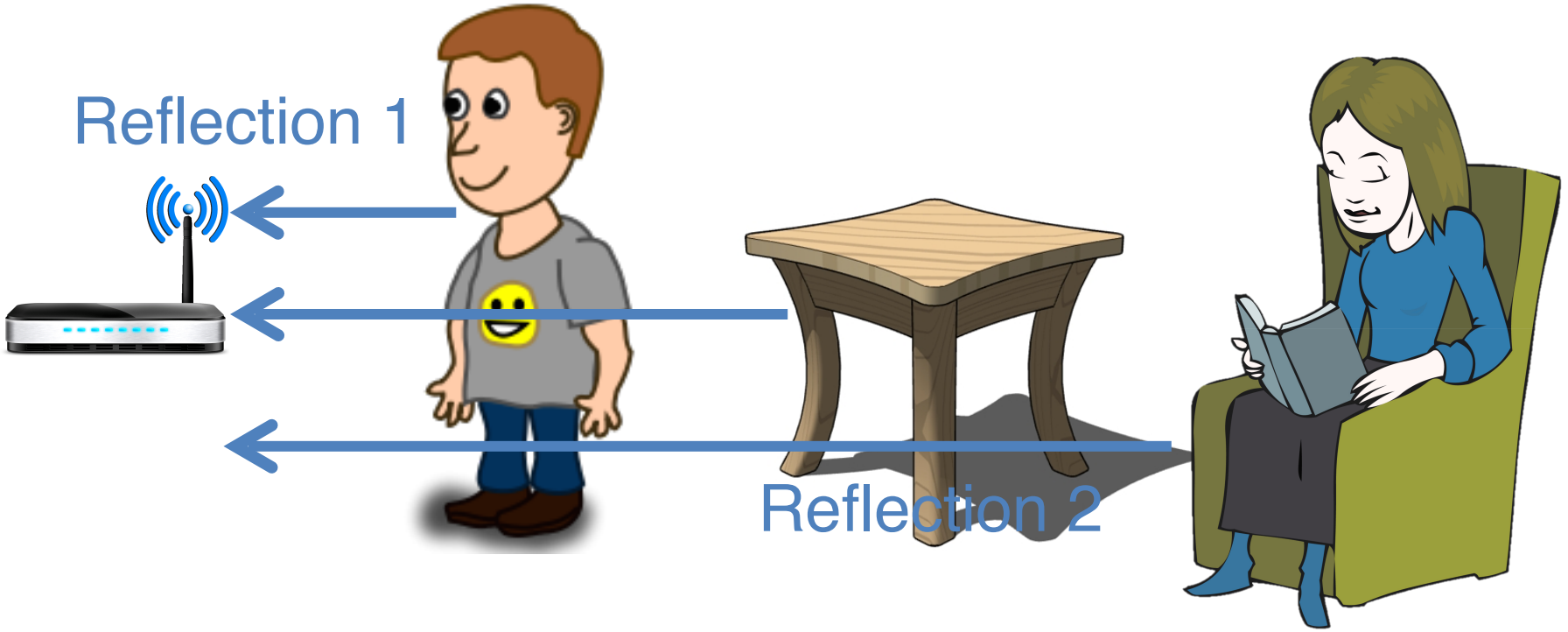


Band-pass filter the cleaned signals to extract breathing and heart rate

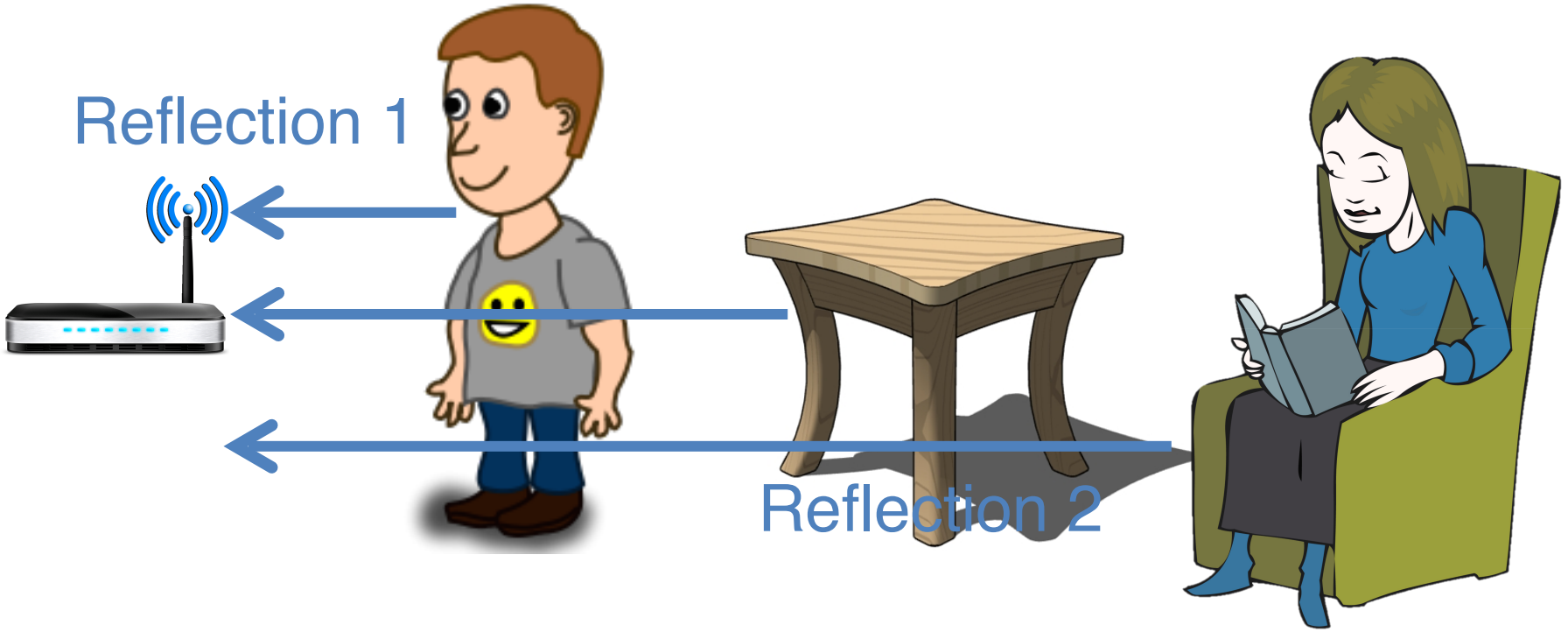
What happens with multiple users in the environment?

Reflections from different objects collide

Problem: Phase becomes meaningless!



Solution: Use WiTrack as a filter to isolate reflections from different positions



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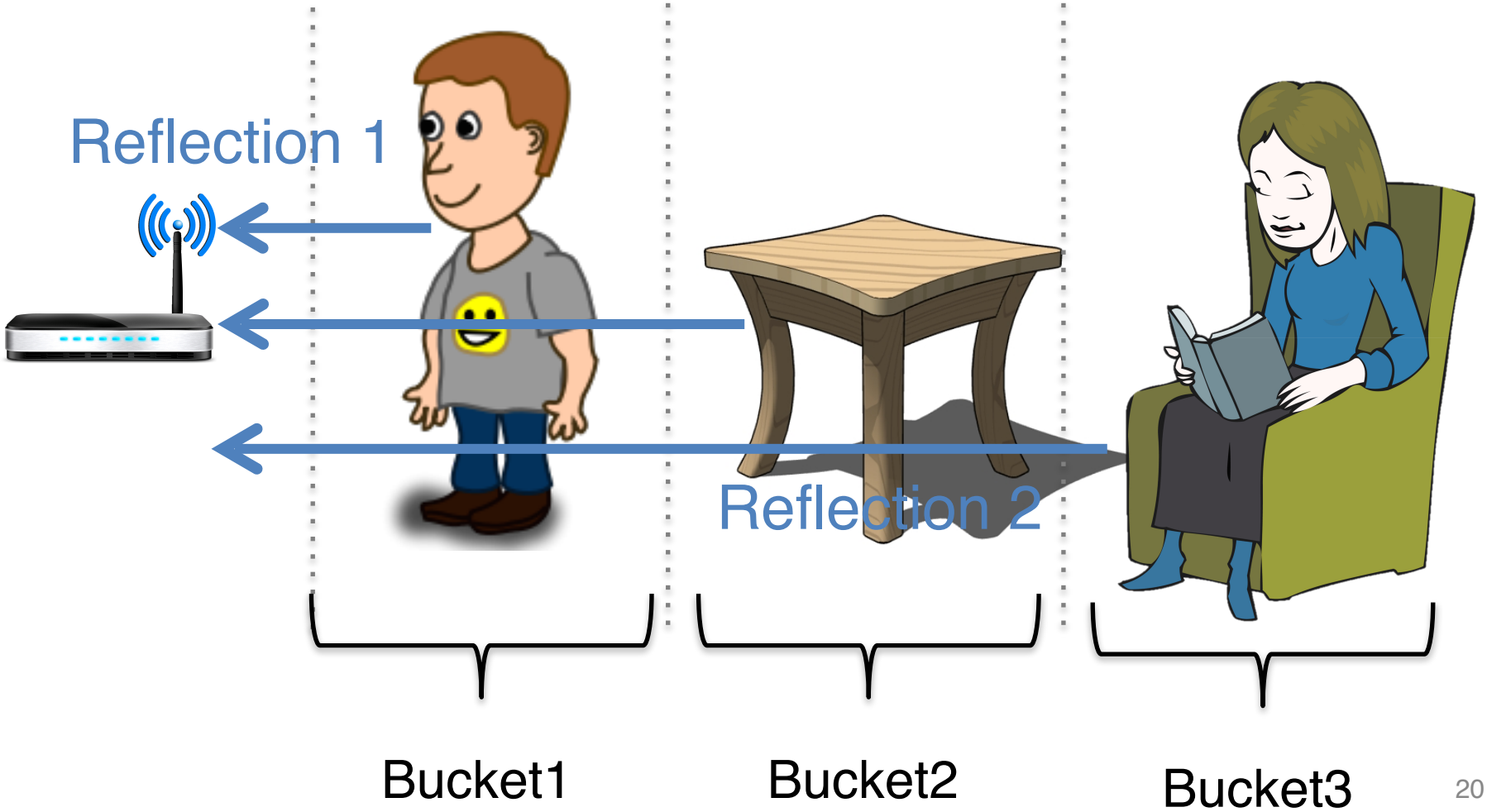

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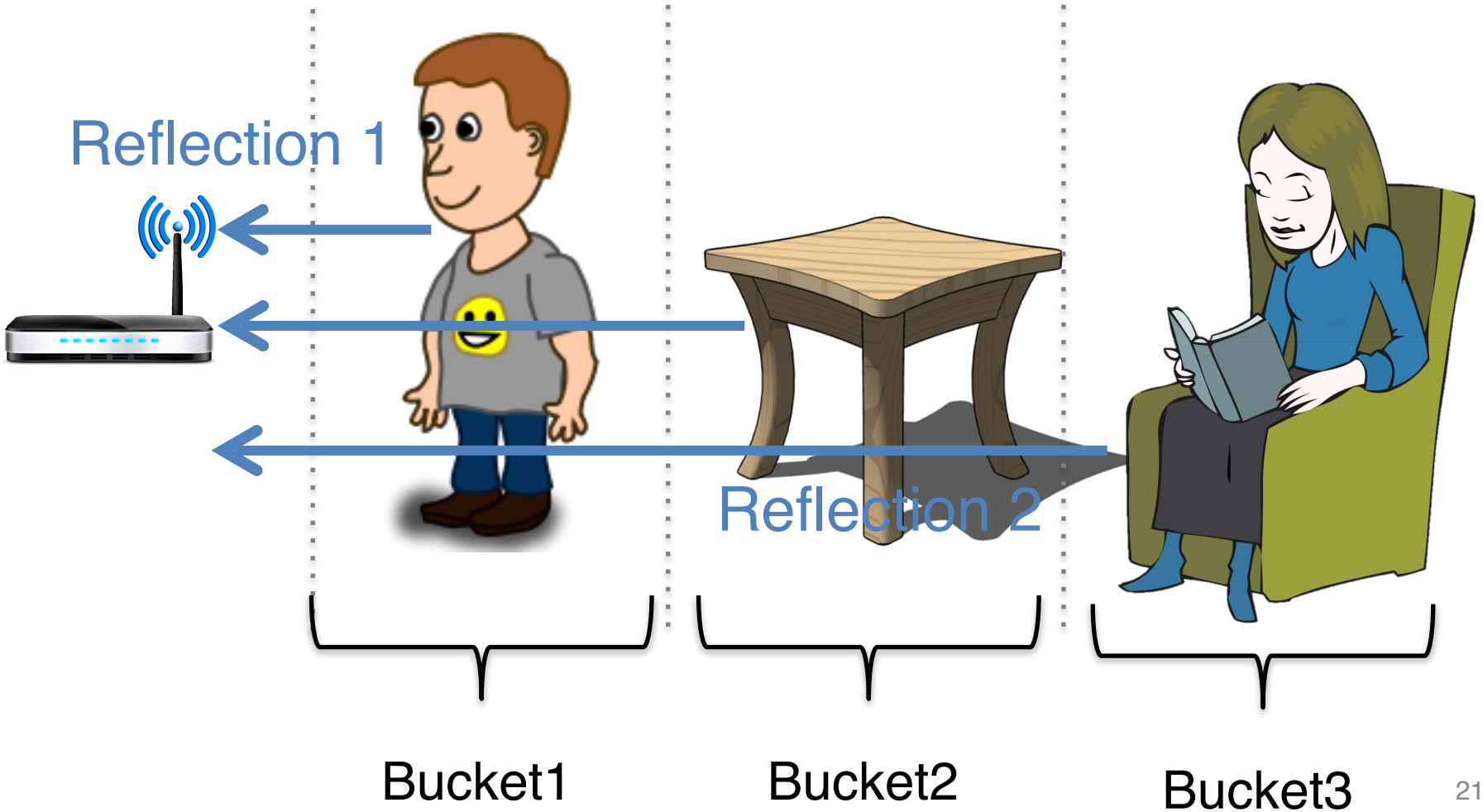


Recall Formulation with FMCW

- Output of FFT with reflectors
- Looked at the amplitude only
- Now will also look at phase

How do we deal with multipath?

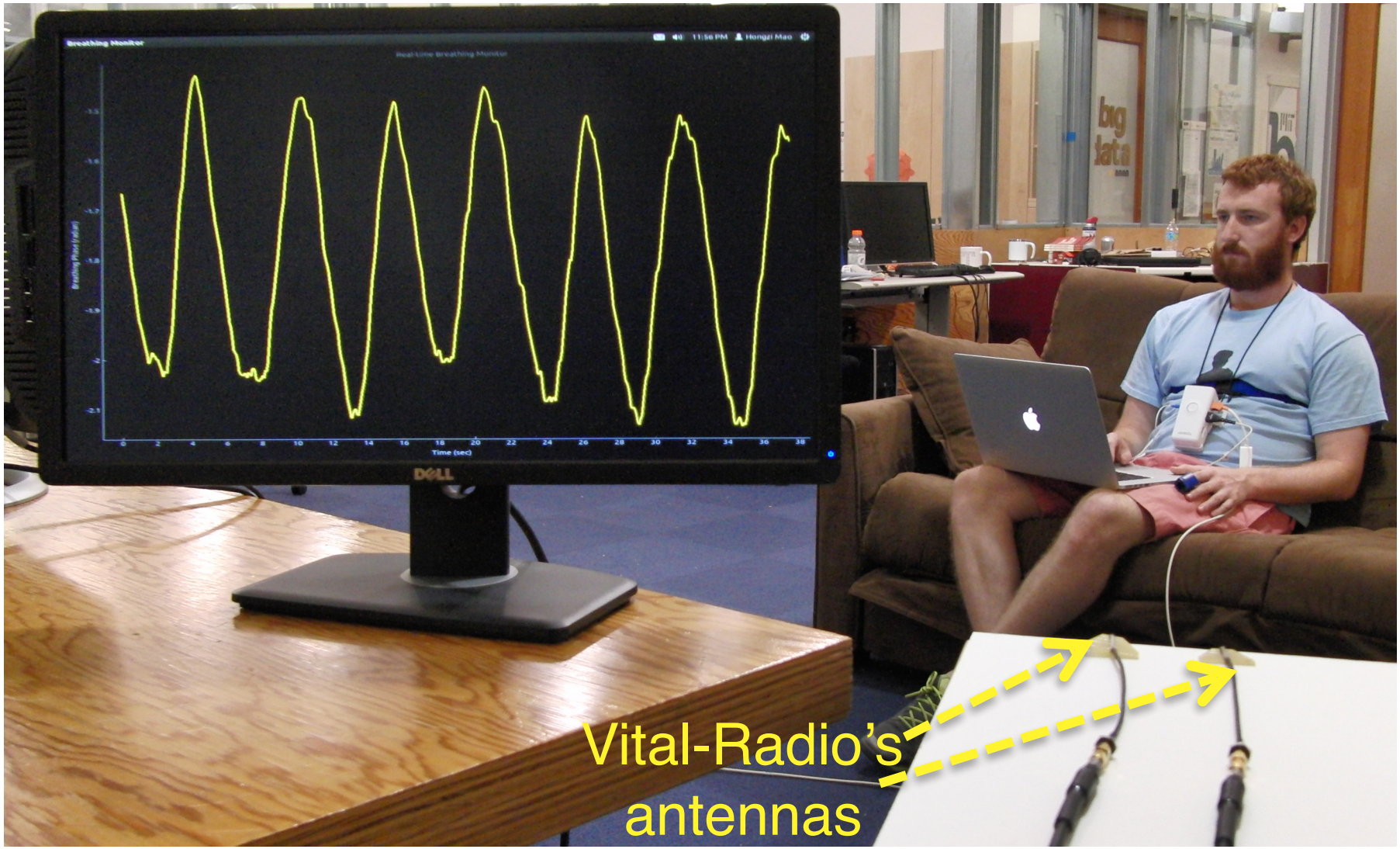
Putting It Together

Step 1: Transmit a wireless signal and capture its reflections

Step 2: Isolate reflections from different objects based on their positions

Step 3: Zoom in on each object's reflection to obtain phase variations due to vital signs

Vital-Radio Evaluation



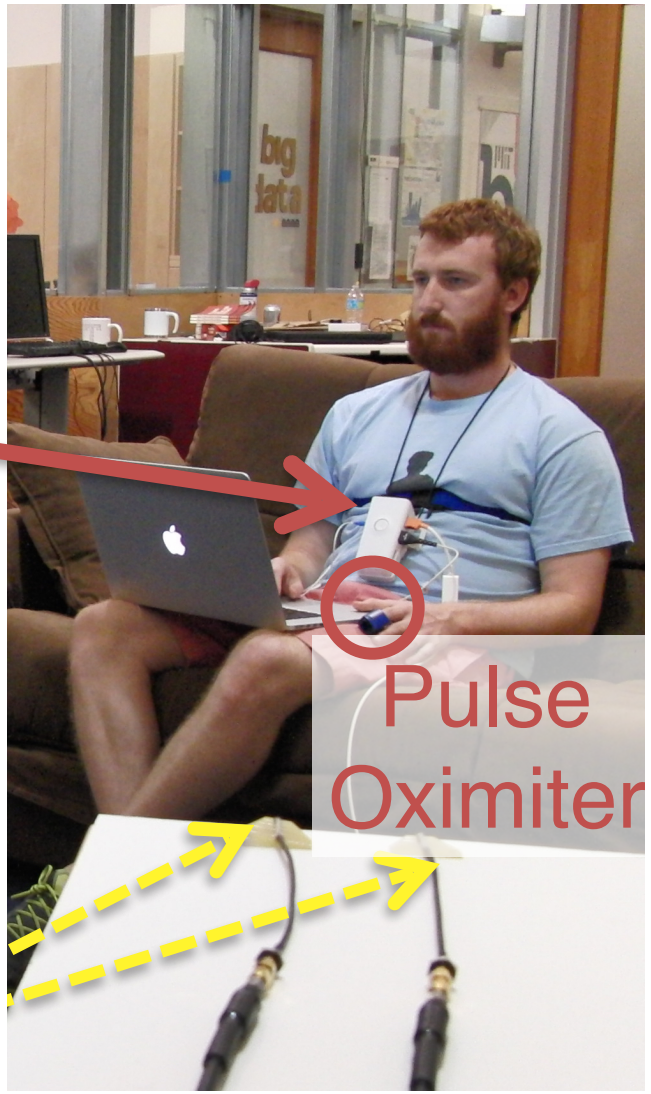
Vital-Radio Evaluation

Baseline:

- FDA-approved breathing and heart rate monitor

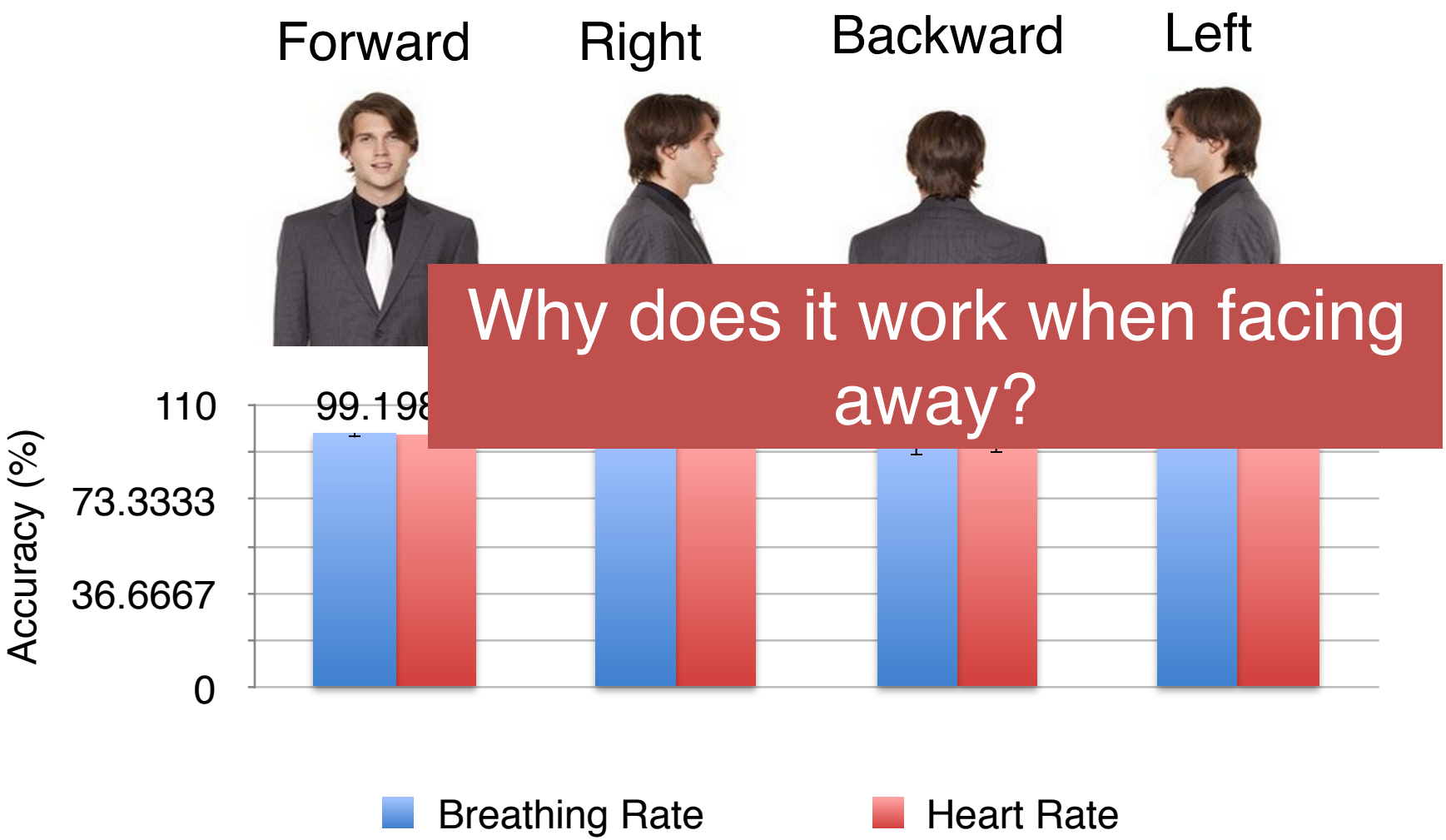
Experiments:

- 200 experiments
- 14 participants
- 1 million measurements



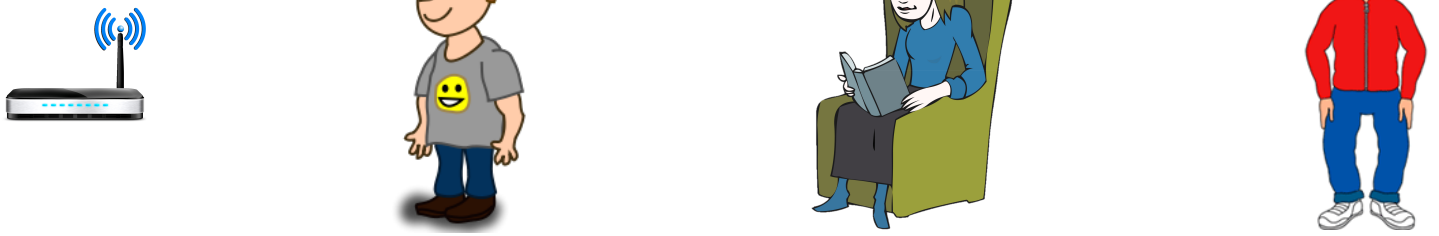
Accuracy vs. Orientation

User is 4m from device, with different orientations



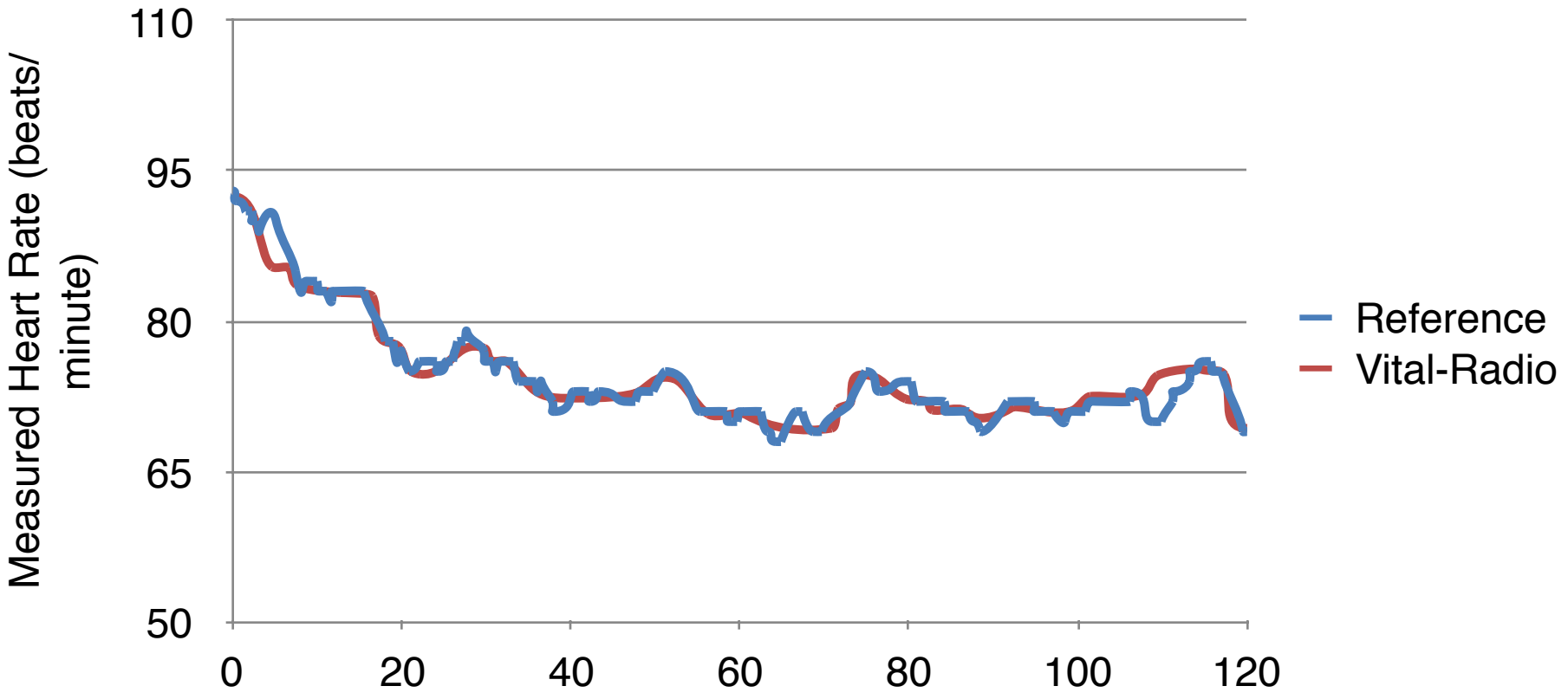
Accuracy for Multi-User Scenario

Multiple users sit at different distances



Accuracy for Tracking Heart Rate

Measure user's heart rate after exercising

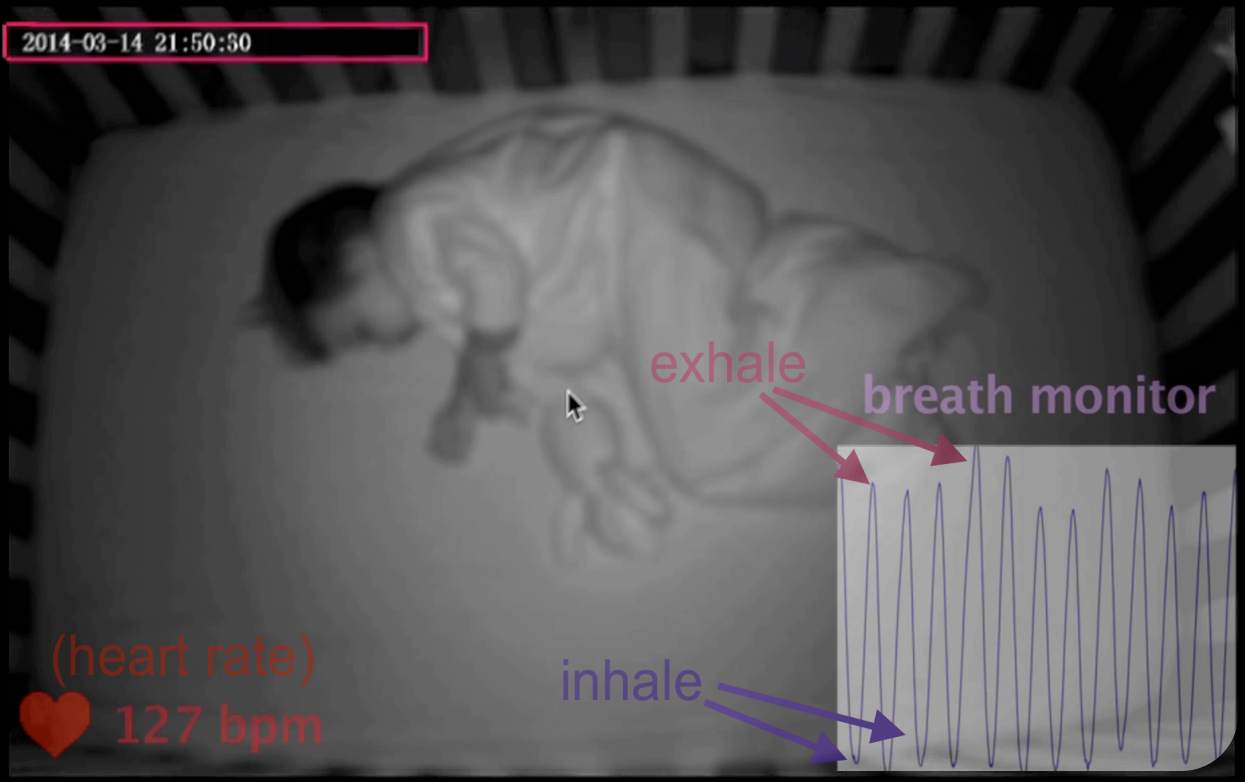


Vital-Radio accurately tracks changes in vital signs

Vital-Radio Limitations

- Minimum separation between users: 1-2m
- Monitoring range: 8m
- Collects measurements when users are quasi-static

Baby Monitoring

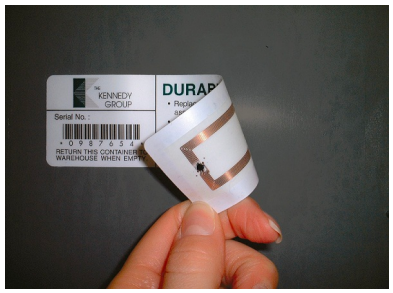


Works for multiple people and through walls

Rest of This Lecture

- Introduction to RFIDs
- WISP design and backscatter communication (Ian)
- RFID localization (Saad)

RFID (Radio Frequency IDentification)



Access Control

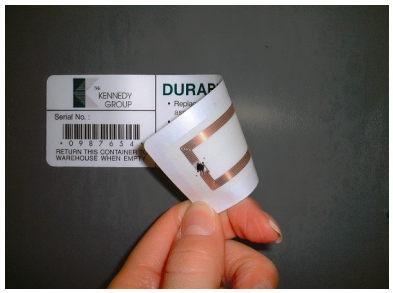
Inventory control

Security Sensitive Applications

Tracking & Localization

Long-Range Payment Systems

RFID (Radio Frequency IDentification)



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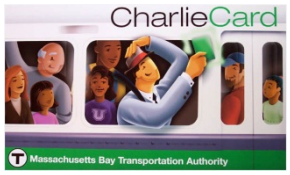


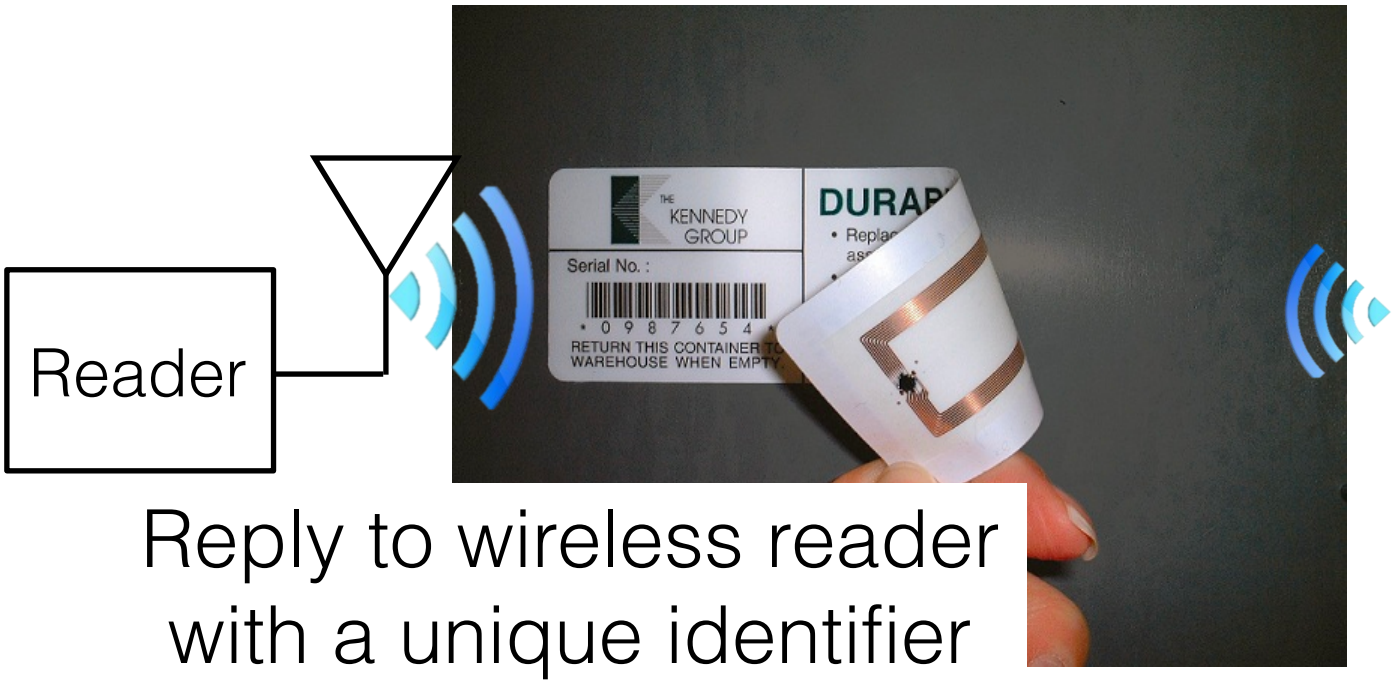
Inventory control

Largest and fastest growing market of networked devices by unit sale: 5 billion sold in 2016 alone

Long-Range Payment Systems

Basic Principle of Operation

RFID: cheap battery-free stickers



Reply to wireless reader with a unique identifier

History of RFIDs

- WWII: Aircraft IFF Transponder
  - Identify Friend or Foe, Transmitter-Responder

- 1945: “The Thing” or “The Great Seal Bug”
  - “Gift” given by the Soviets to American ambassador

- 1980s: development of E-Toll transponders

- 2004: Auto-ID lab at MIT led to the birth of modern battery-free RFIDs
  - Goal: supply chain chain optimization
  - Paper: “Towards the 5 cent tag”

Types of RFIDs

Frequency Range

UHF (~900MHz)

HF (13.56MHz)

LF (120-150kHz)

long range (few m)

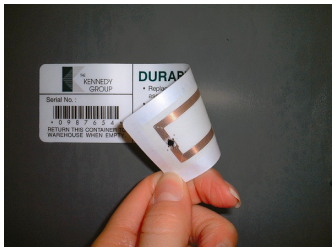
short range (few cm)

Range of Operation

"need to tap"

Power consumption

Where do these fall?



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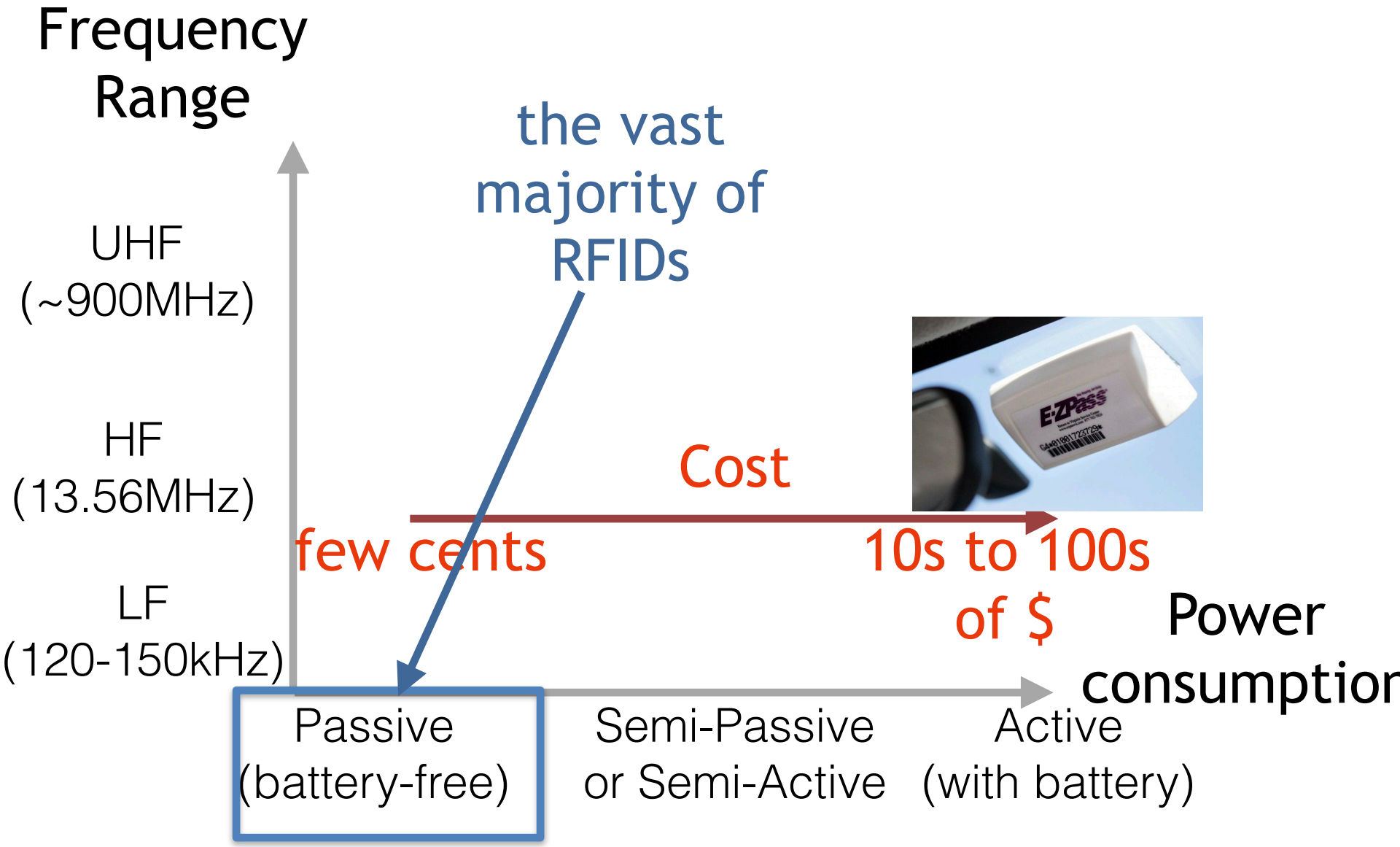


Other less common versions: 2.4GHz, UWB (3-10GHz), etc.

How does an RFID power up?

Harvests Energy from Reader's Signal

<u>Inductive Coupling</u>

LF
(120-150kHz)

HF
(13.56MHz)

Magnetic
(Near Field)

Coil

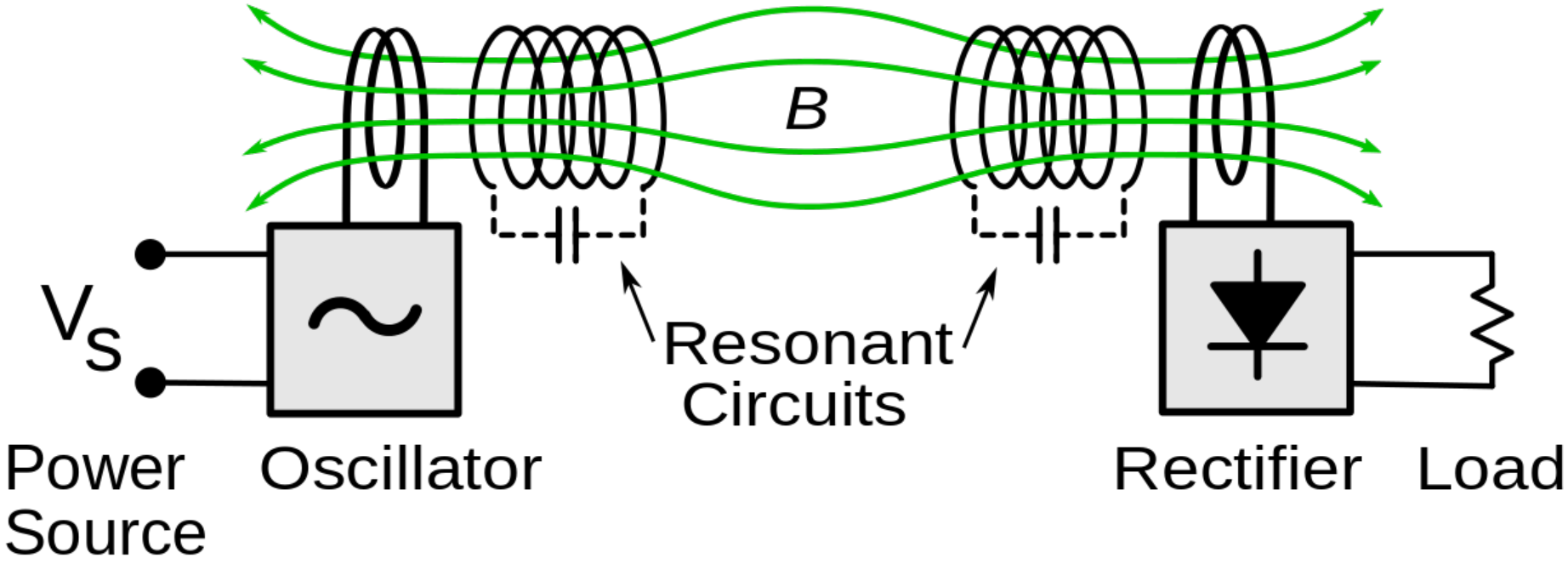
<u>Backscatter</u>

UHF
(~900MHz)

Electromagnetic
(Far Field)

Antenna

Inductive Coupling



Mutual inductance?

Impedance switching?