CIS 3990

Mobile and IoT Computing

https://penn-waves-lab.github.io/cis3990-24spring

Lecture 4: Device-Free Localization

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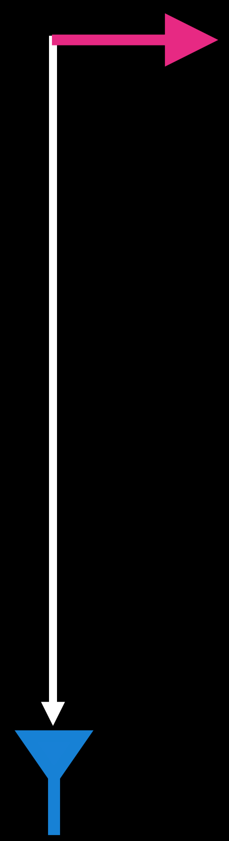
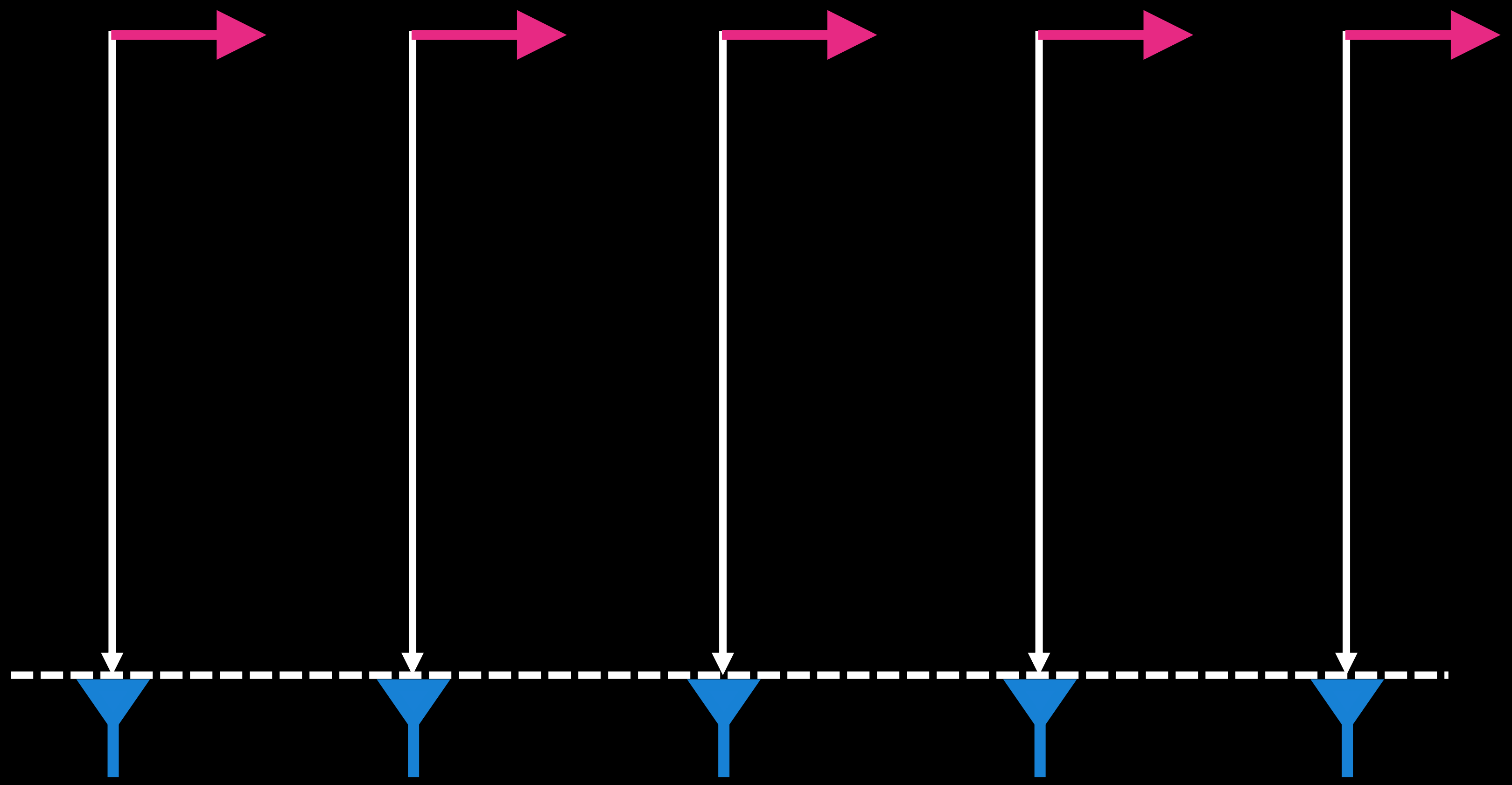
Recap: Angle-of-Arrival



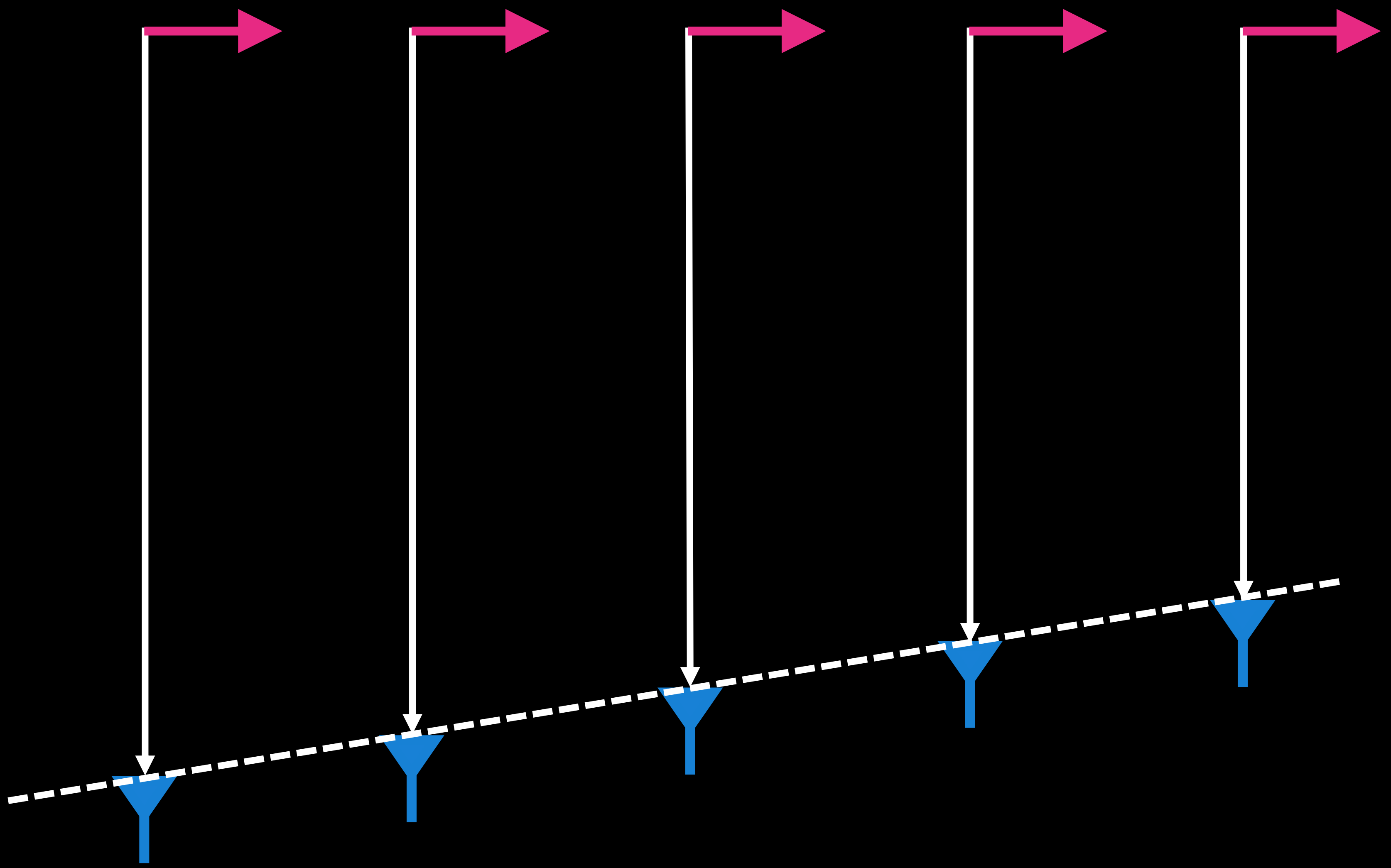
Recap: Angle-of-Arrival

$\theta = 90°$



Recap: Angle-of-Arrival

$\theta = 75°$

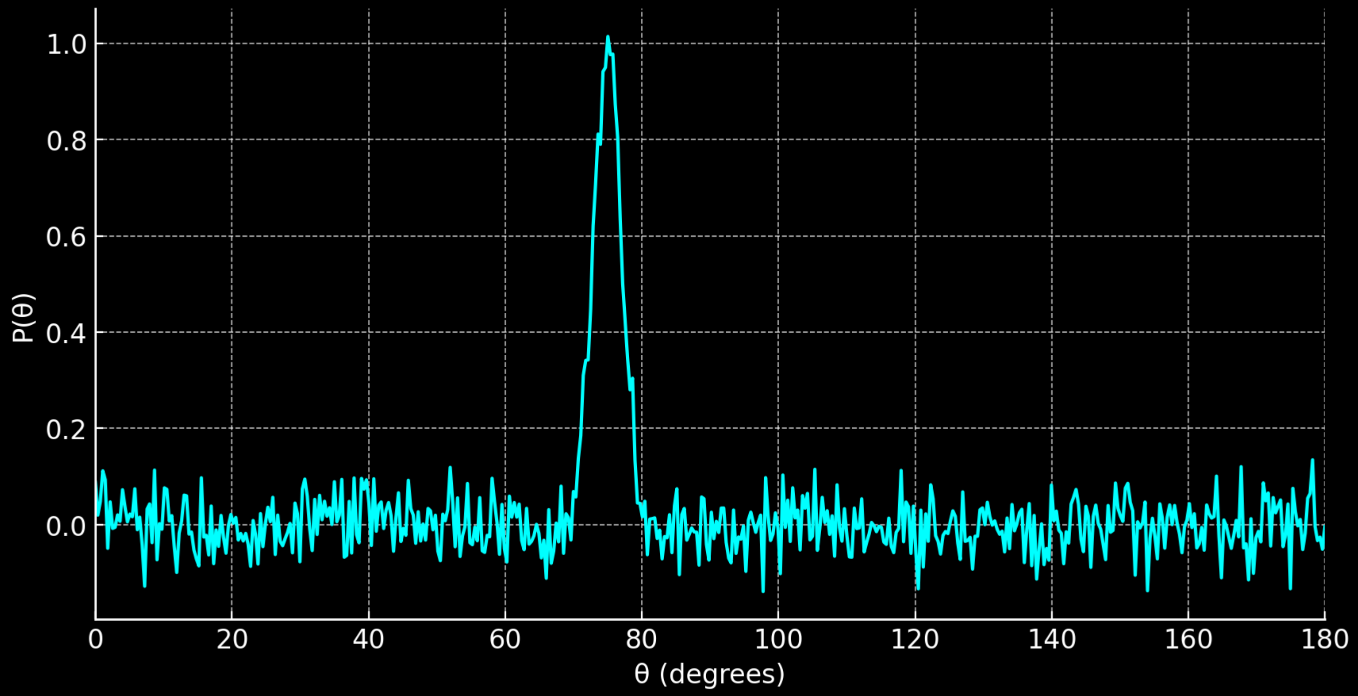


- **Combine constructively with the right delays**
- **Combine deconstructivity without or with the incorrect delays**

θ = 75°

Multipath profile (delay-and-sum): $$P(\theta) = || \sum_{k=1}^{N} h_i \exp(-j2\pi \frac{ks\cos(\theta)}{\lambda})||^2$$

Delay & Sum



Wireless Localization / Positioning

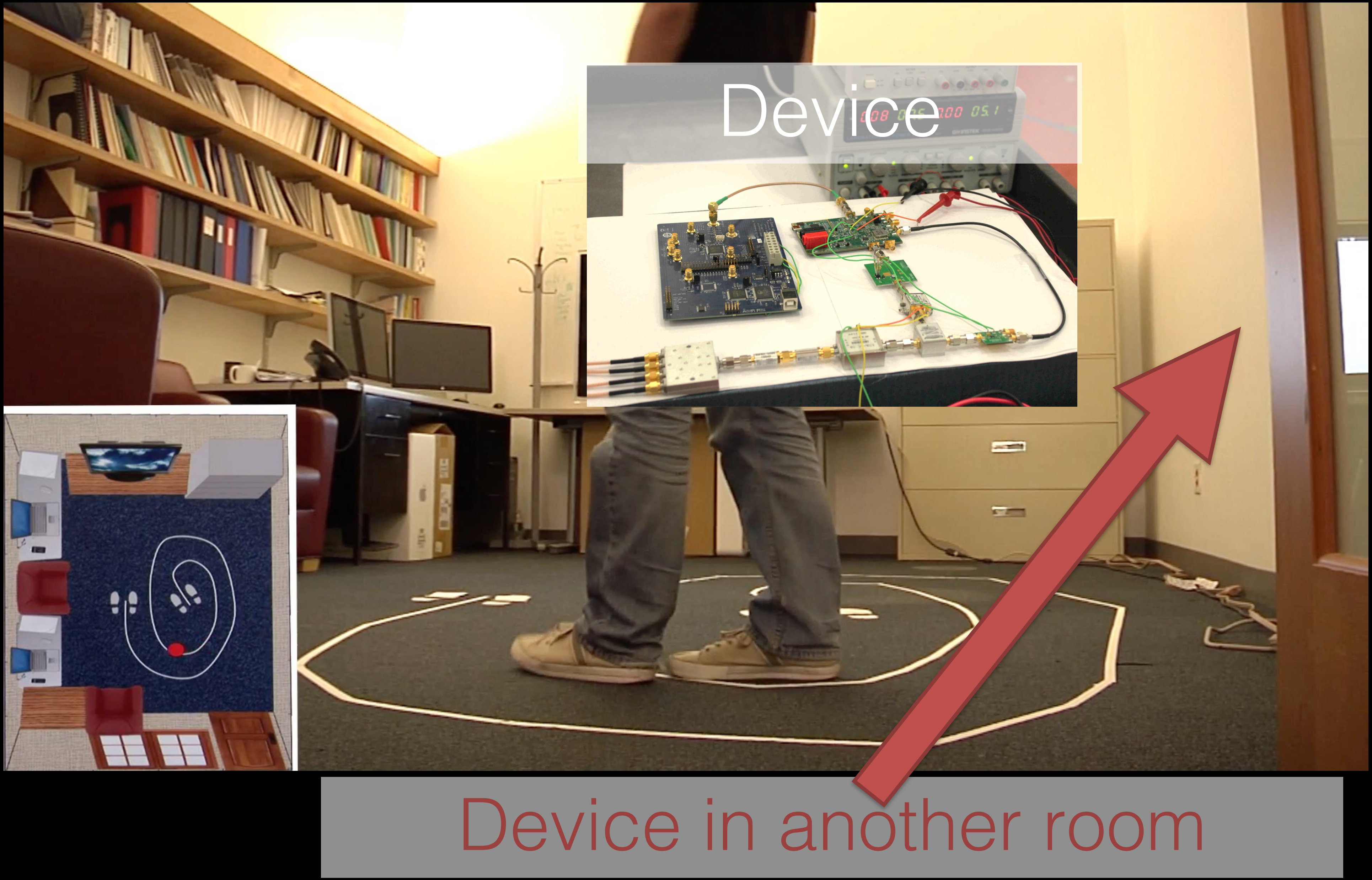
Past Lectures:

Device-based Localization

This Lecture:

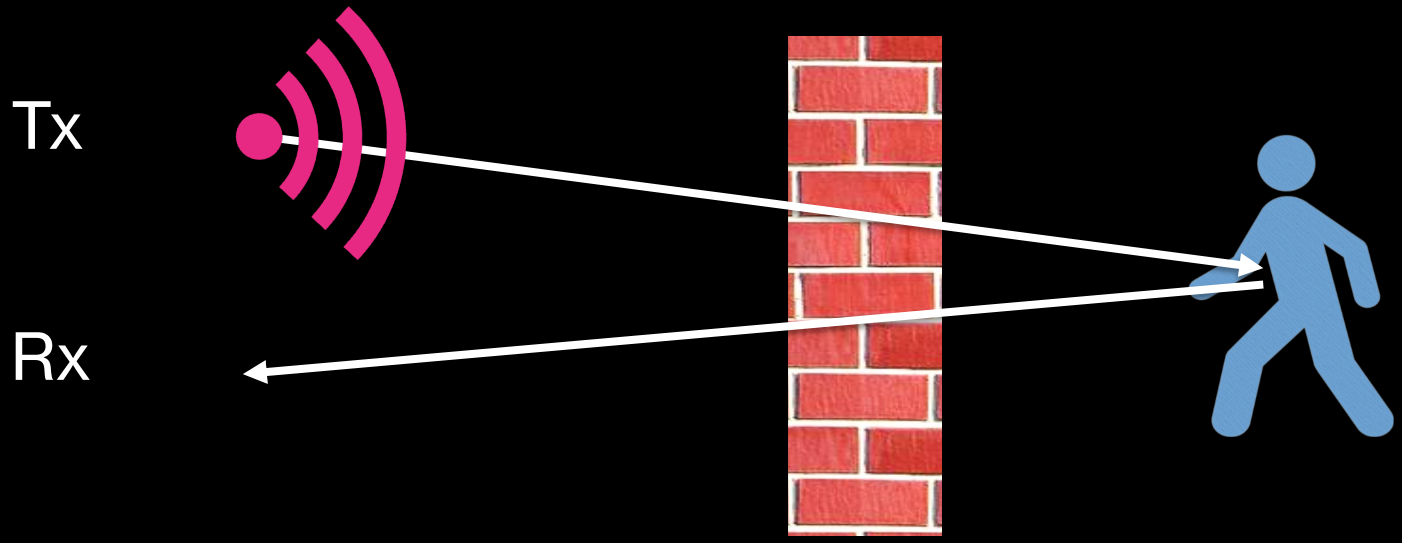
Device-free Localization

Device-Free Localization (WiTrack, 2014)



Applications

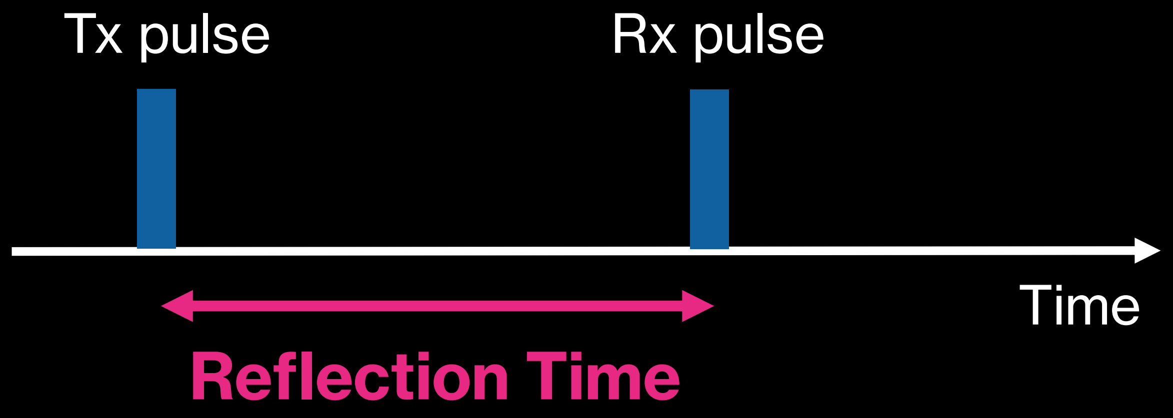
Measuring Distances



Round-Trip Distance = $\boxed{\text{Reflection time}}$ x Speed of light

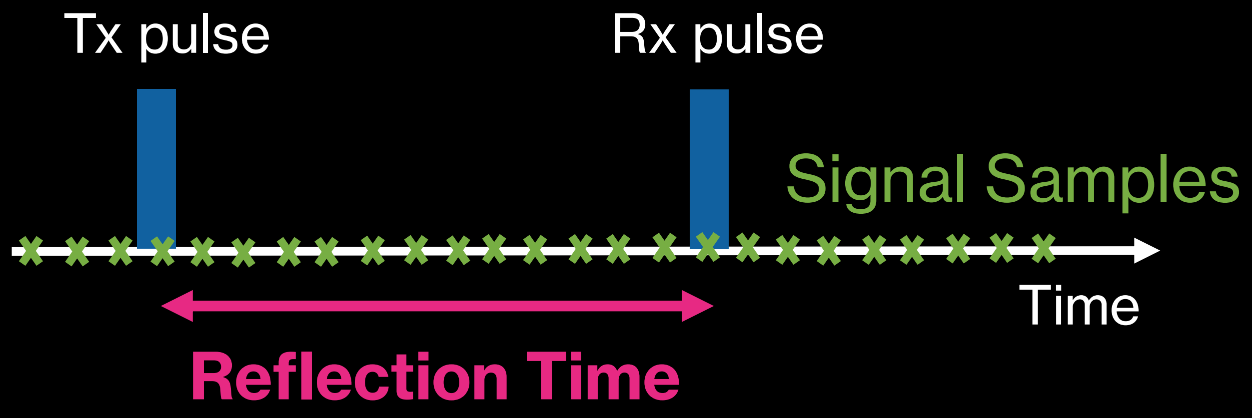
Measuring Reflection Time

Option 1: Transmit short pulse and listen for echo



Measuring Reflection Time

Option 1: Transmit short pulse and listen for echo



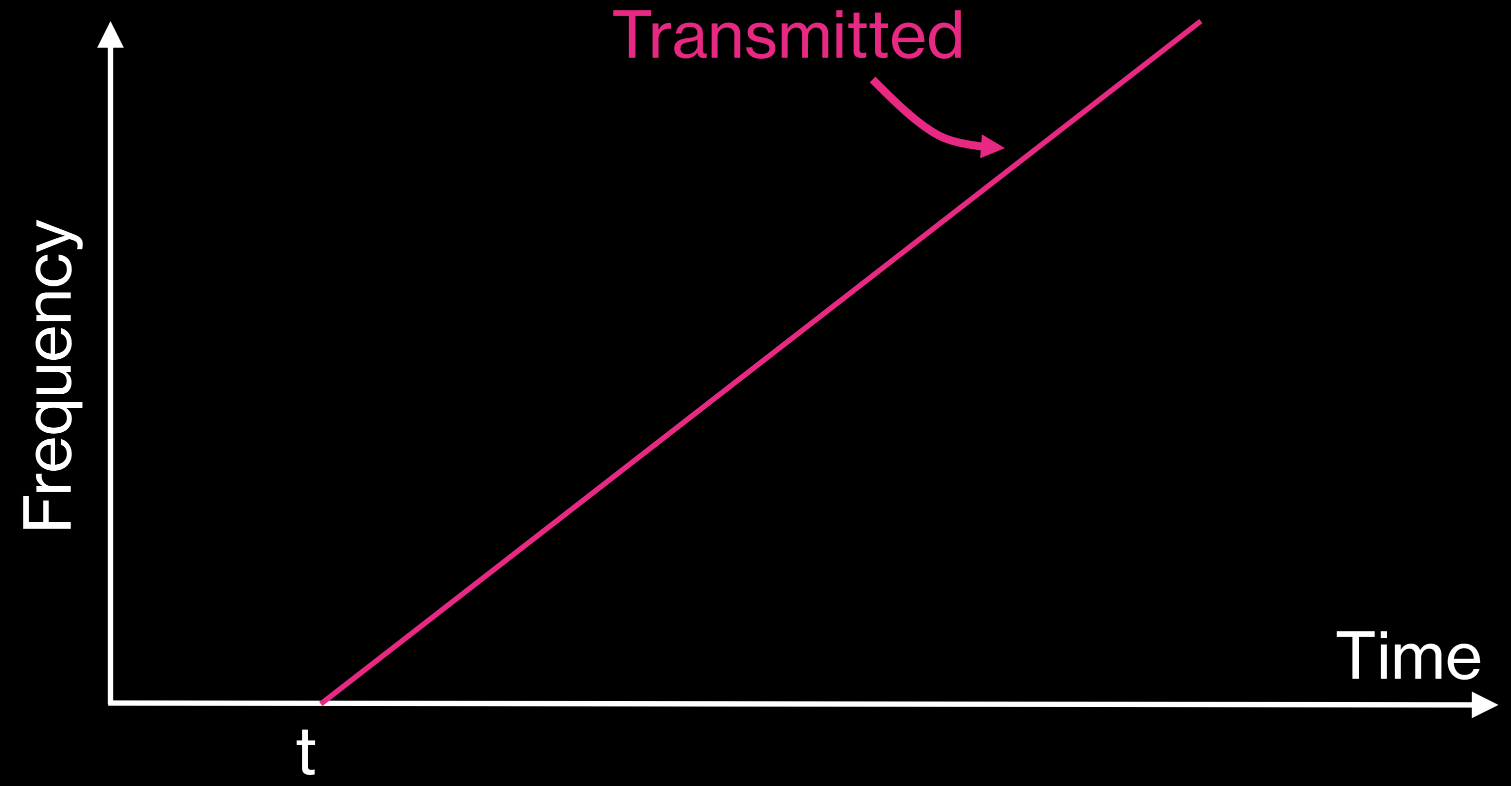
Capturing the pulse needs sub-nanosecond sampling!

Distance = Reflection time x Speed of light

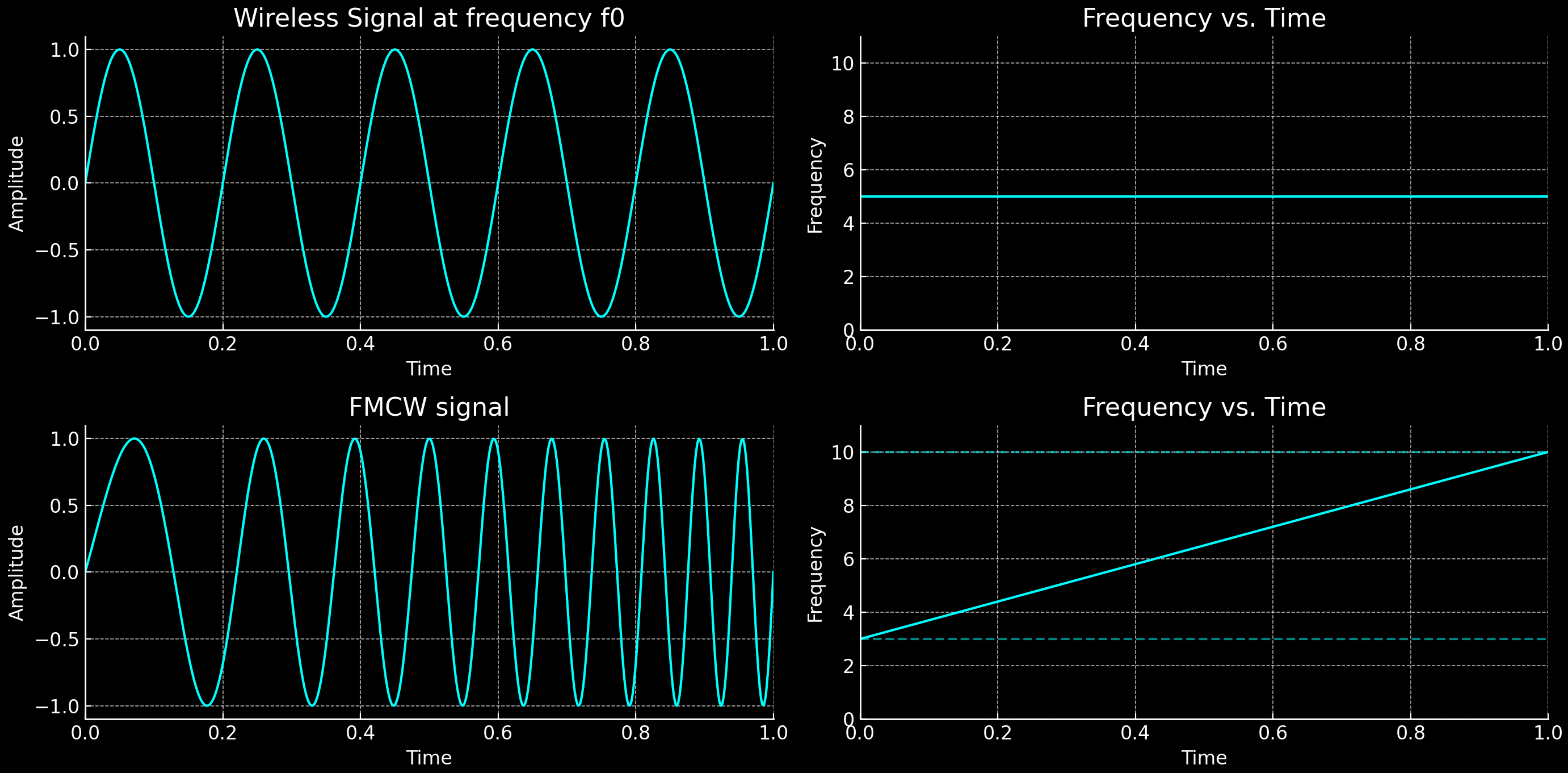
"smallest distance resolution" = "smallest time" x Speed of light

10 cm ➔ 0.3 ns

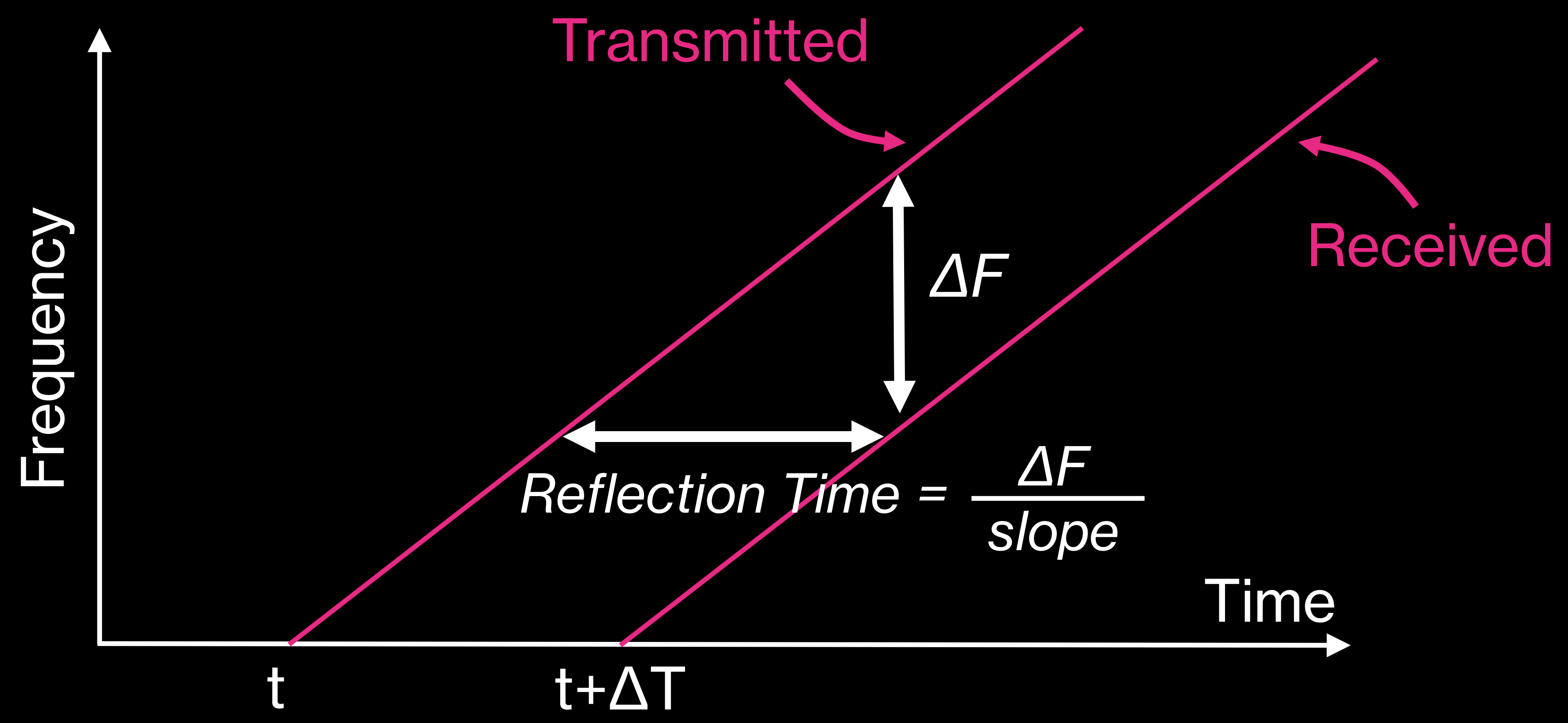
FMCW: Measure time by measuring frequency



How does it look in time domain?
(and in comparison to single frequency)


Wireless Signal at frequency f0
Amplitude
Time
Frequency vs. Time
Frequency
Time
FMCW signal
Amplitude
Time
Frequency vs. Time
Frequency
Time
1.0
0.5
0.0
−0.5
−1.0
0.0
0.2
0.4
0.6
0.8
1.0
10
8
6
4
2
0

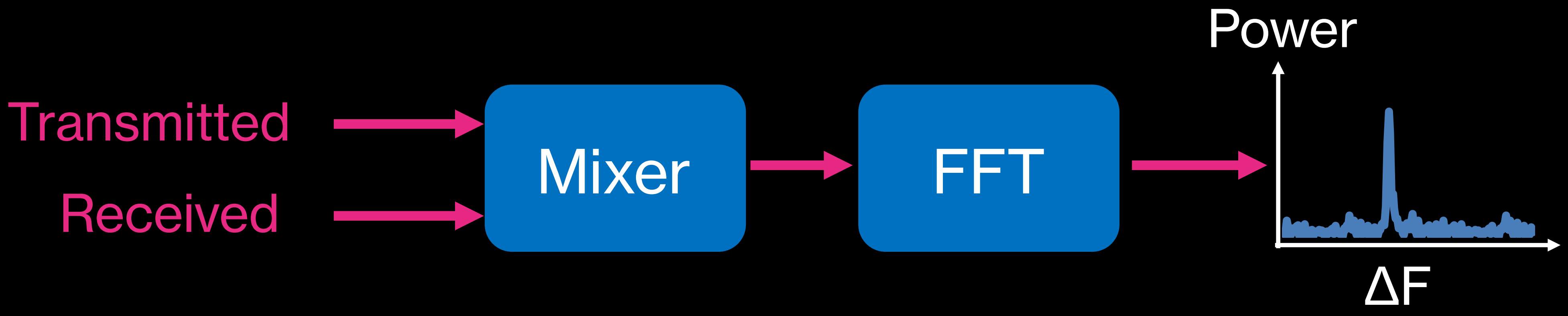
FMCW: Measure time by measuring frequency



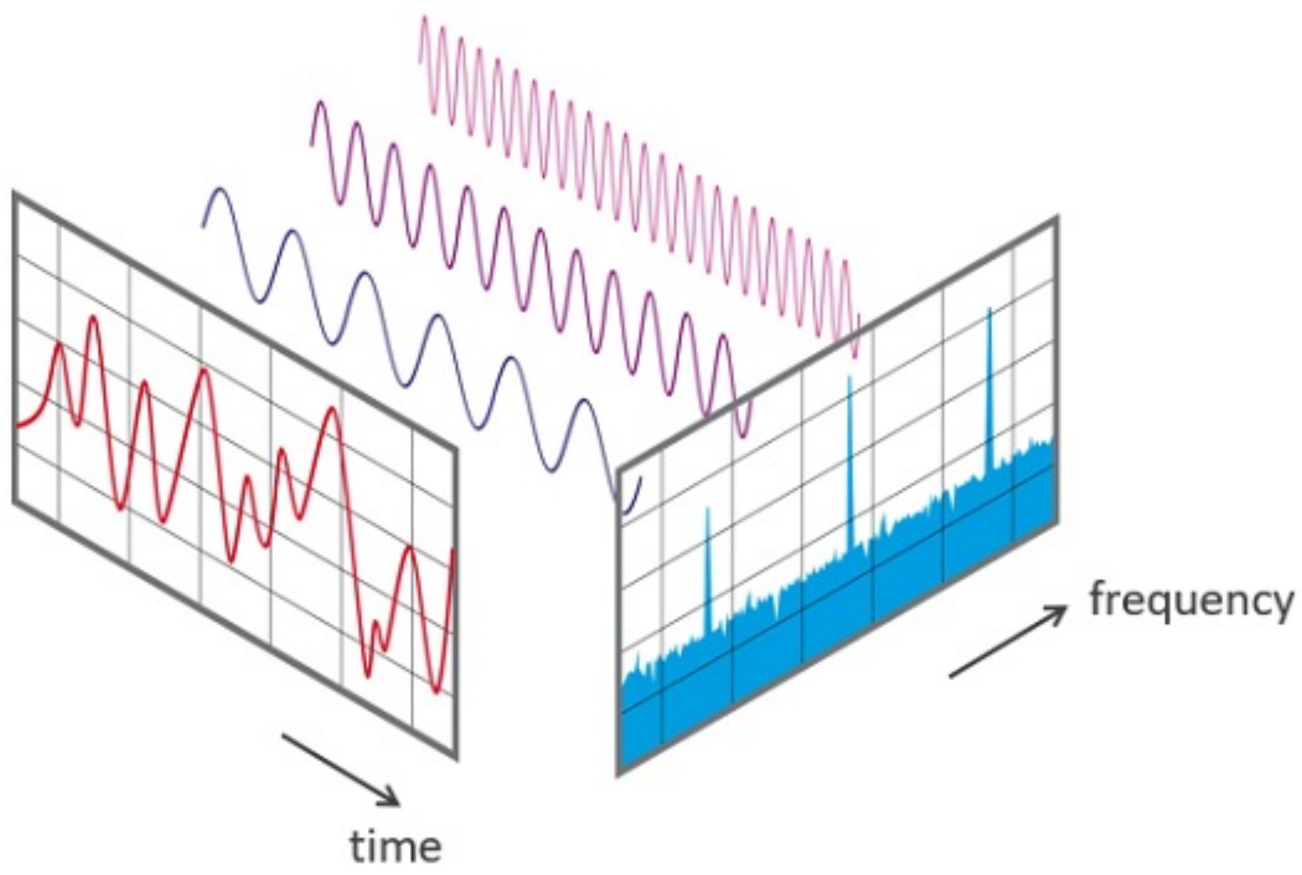
How do we measure *ΔF*?

Measuring ΔF

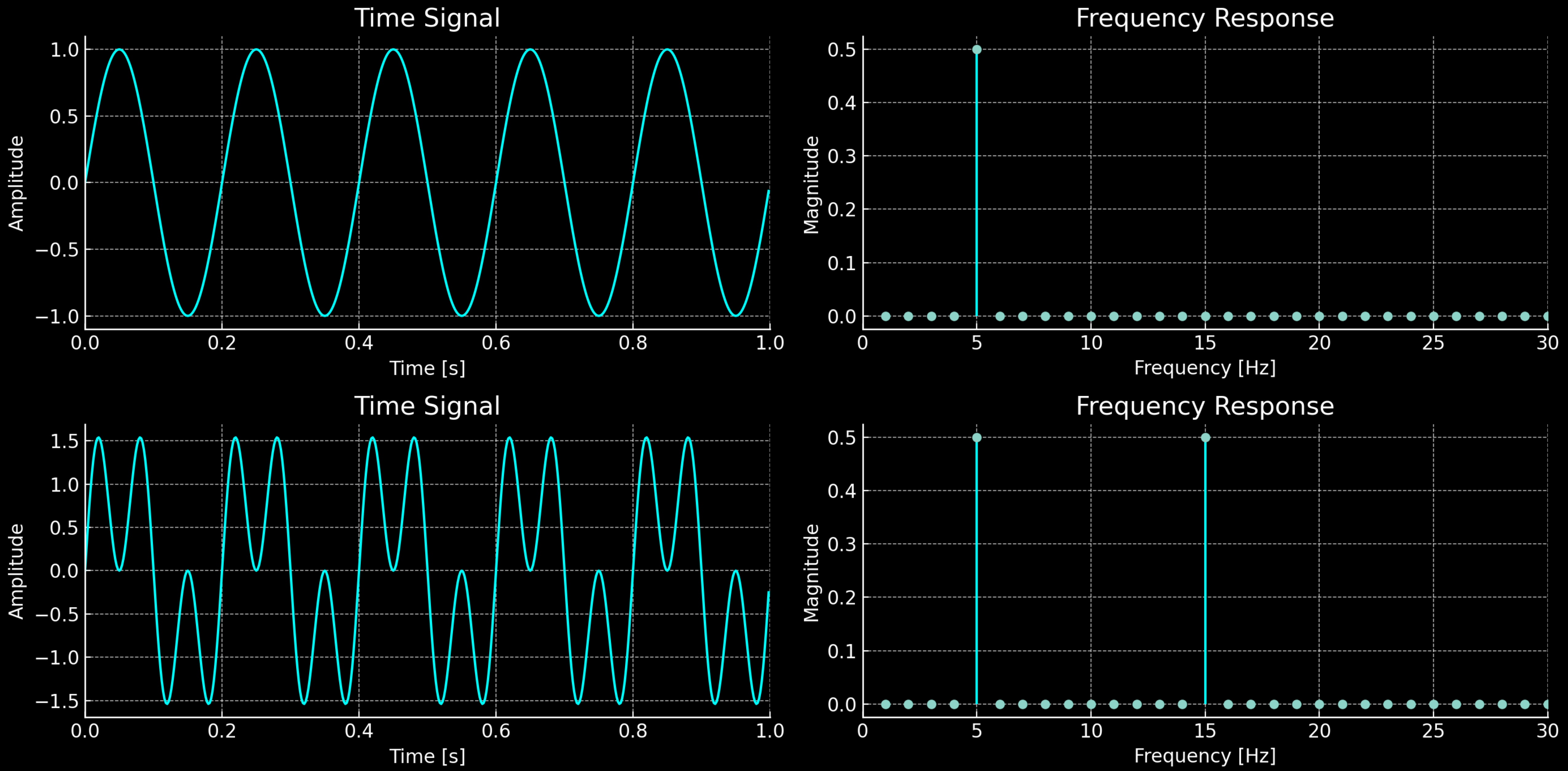
- Subtracting frequencies is easy (e.g., removing carrier in WiFi)
- Done using a mixer (low-power; cheap)



Let's talk about FFT

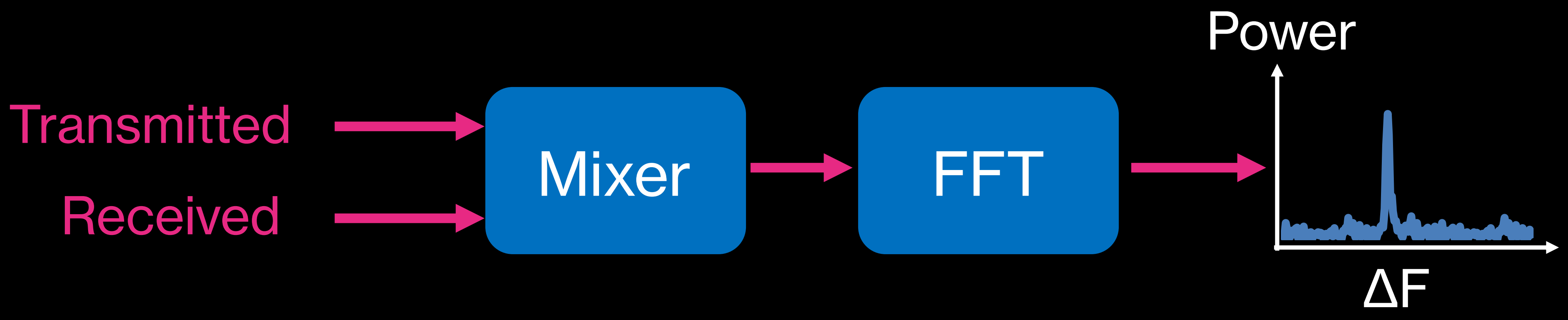


Basics of Fourier Transform


Time Signal
Amplitude
Time [s]
Frequency Response
Magnitude
Frequency [Hz]
Time Signal
Amplitude
Time [s]
Frequency Response
Magnitude
Frequency [Hz]

Measuring ΔF

- Subtracting frequencies is easy (e.g., removing carrier in WiFi)
- Done using a mixer (low-power; cheap)



ΔF ➔ Reflection Time ➔ Distance (Round-trip)

FMCW

FMCW Transmitted Signal:

slope

Frequency is linear in time; hence phase is quadratic

$$x(t) = e^{j2\pi\left(\frac{k}{2}(t^2 + f_0 t)\right)}$$

FMCW Received Signal:

$$y(t) = \sum_i A_i e^{j2\pi\left(\frac{k}{2}((t-\tau_i)^2 + f_0(t-\tau_i))\right)}$$

Reflections linearly combine over the wireless medium

reflector i

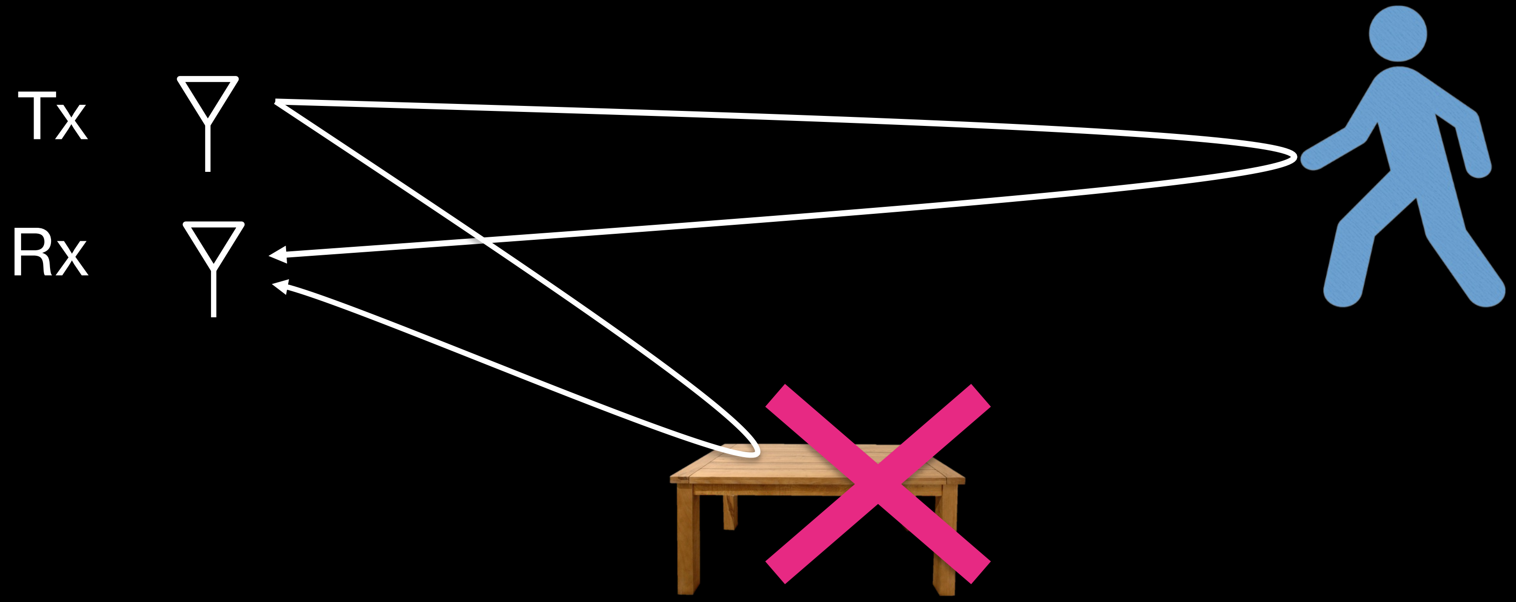
delay τ_i

FMCW after down-conversion:

$$y_b(t) = \sum_i A_i e^{j2\pi(k\tau_i t + f_0\tau_i)}$$

frequency $k\,\tau_i$

Dealing with Multi-path

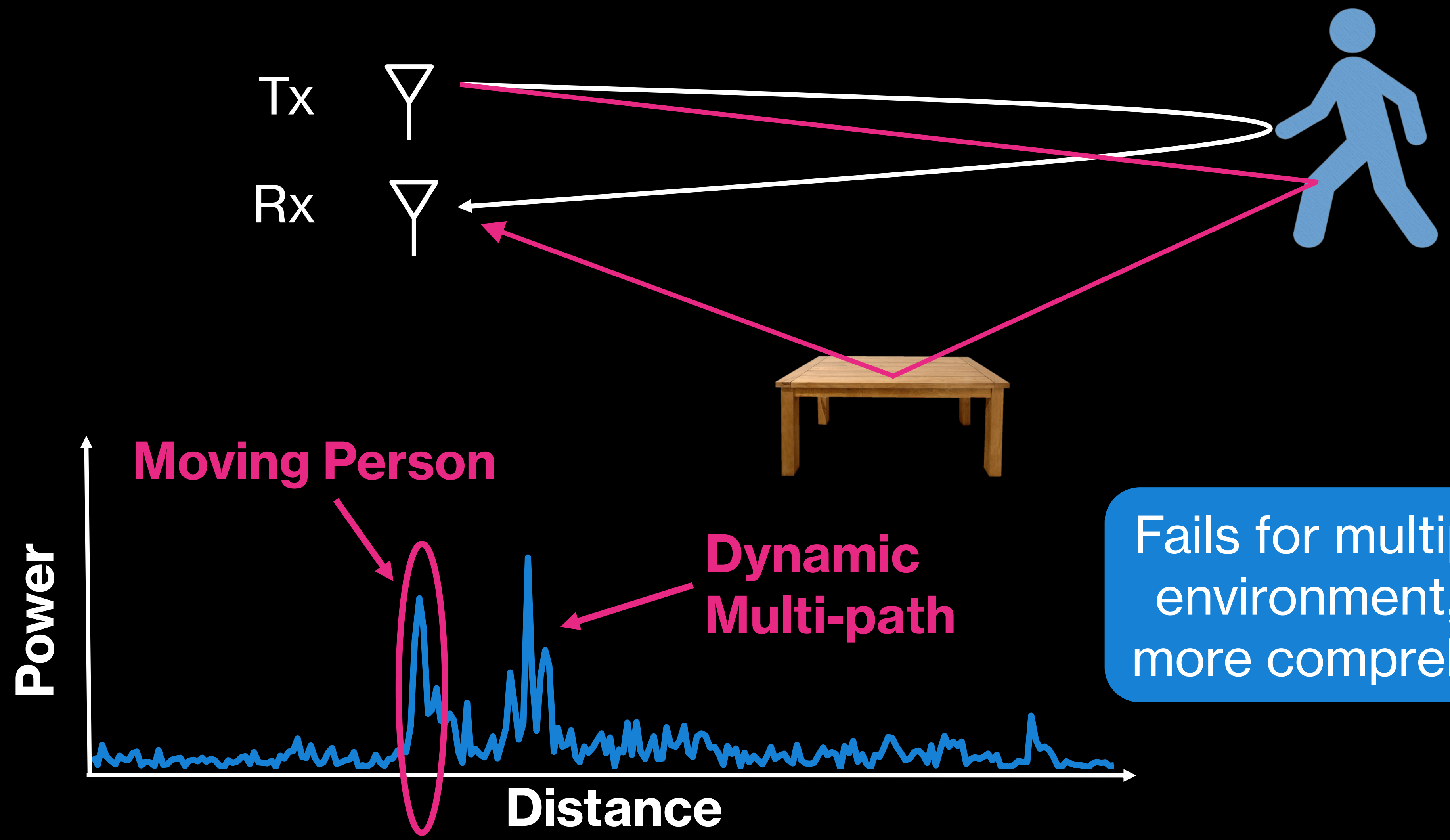


Direct furniture reflection:

eliminated by subtracting consecutive measurements

Needs User to Move!

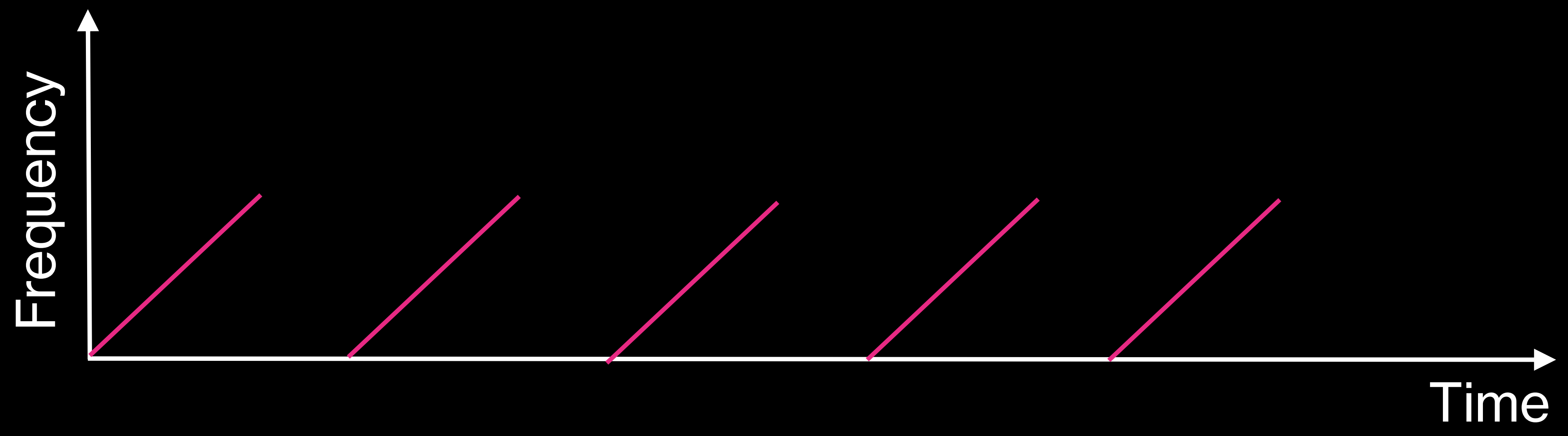
Dynamic Multi-path



Fails for multiple people in the environment, and we need a more comprehensive solution!

From Location to Tracking

- Send FMCW chirps respectively
- Estimate distance or location for chirp i
- Keep track of location over chirp index i (slow time)



Objectives of This Module

Learn the fundamentals, applications, and implications of localization, motion tracking, and sensing

1. What are some motivating applications of localization and location-based services?
2. What are the unifying principles of positioning?
3. How do wireless positioning like GPS, Wi-Fi positioning, and Bluetooth ranging work?
4. What is wireless sensing?
5. How do visual positioning and tracking systems work?

iOS Lab 0 is out

- Topic: Get familiar with Xcode IDE and develop an OpenWeather API
- Due: Mon Feb 5th, 11:59 pm
- You will need MacBook + iPhone/iPad.
- We can help if you don't have one. Please coordinate with our TA.

Next Lecture

- Time: Mon Feb 5th
- Topic: Visual localization and tracking