MAS.S62:

Ocean IoT

Technologies, Industries, Sustainability

Lecturer

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TA

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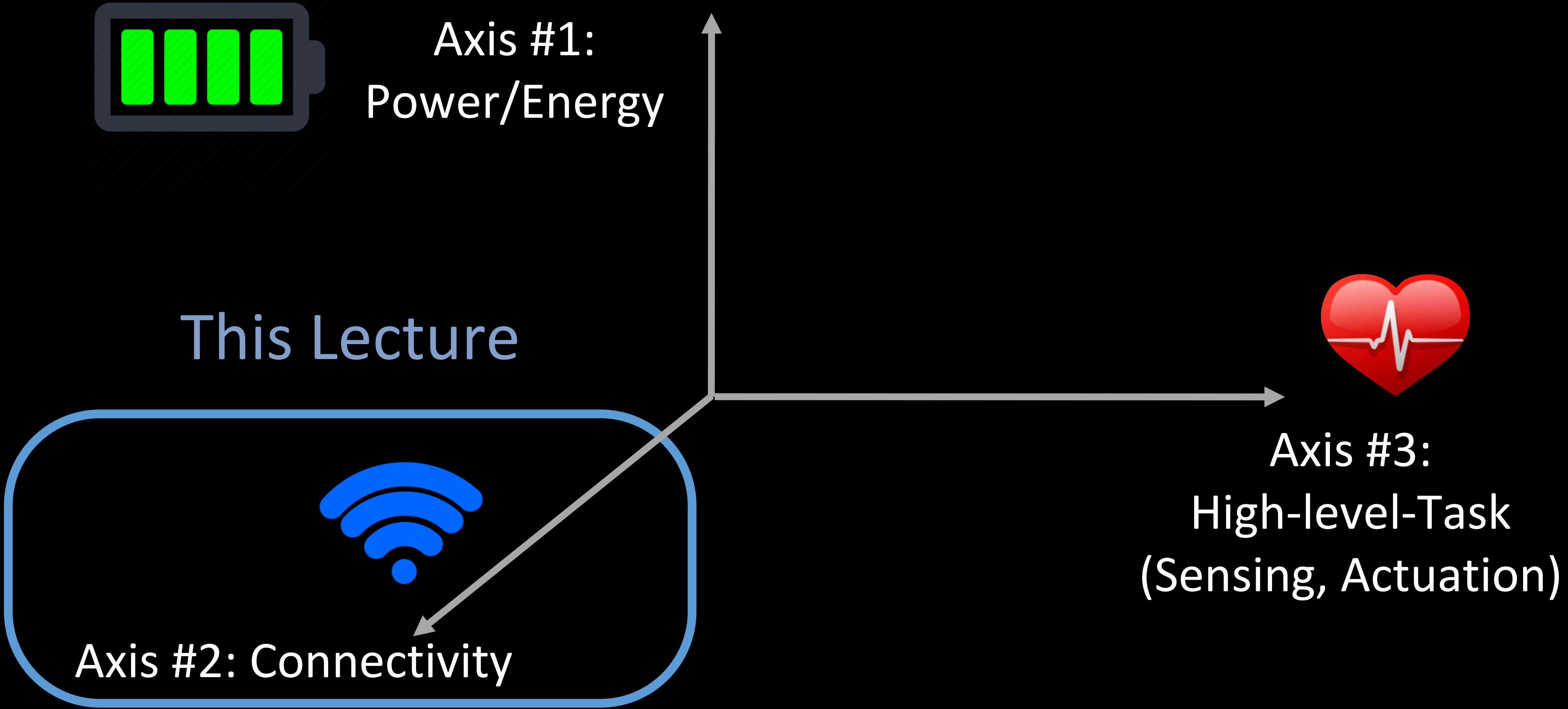
Website

http://www.mit.edu/~fadel/courses/MAS.S62/index.html

Main Components of (Ocean) IoT Systems



Objectives of Today's Lecture

Learn the **fundamentals** of communications and emerging technologies for underwater-to-air comms

1. What are the existing approaches for underwater-to-air communications?
2. What are new approaches for enabling such communications?
   - Acoustic-RF translation, Laser/optical
3. What are the fundamentals of end-to-end wireless communications?
   - The physical, mathematical, engineering, and design fundamentals
   - Why are these systems designed the way they are

How can we send sensed information from underwater to outside the ocean?

Underwater-to-Air Comm Applications

Submarine-Airplane Communication

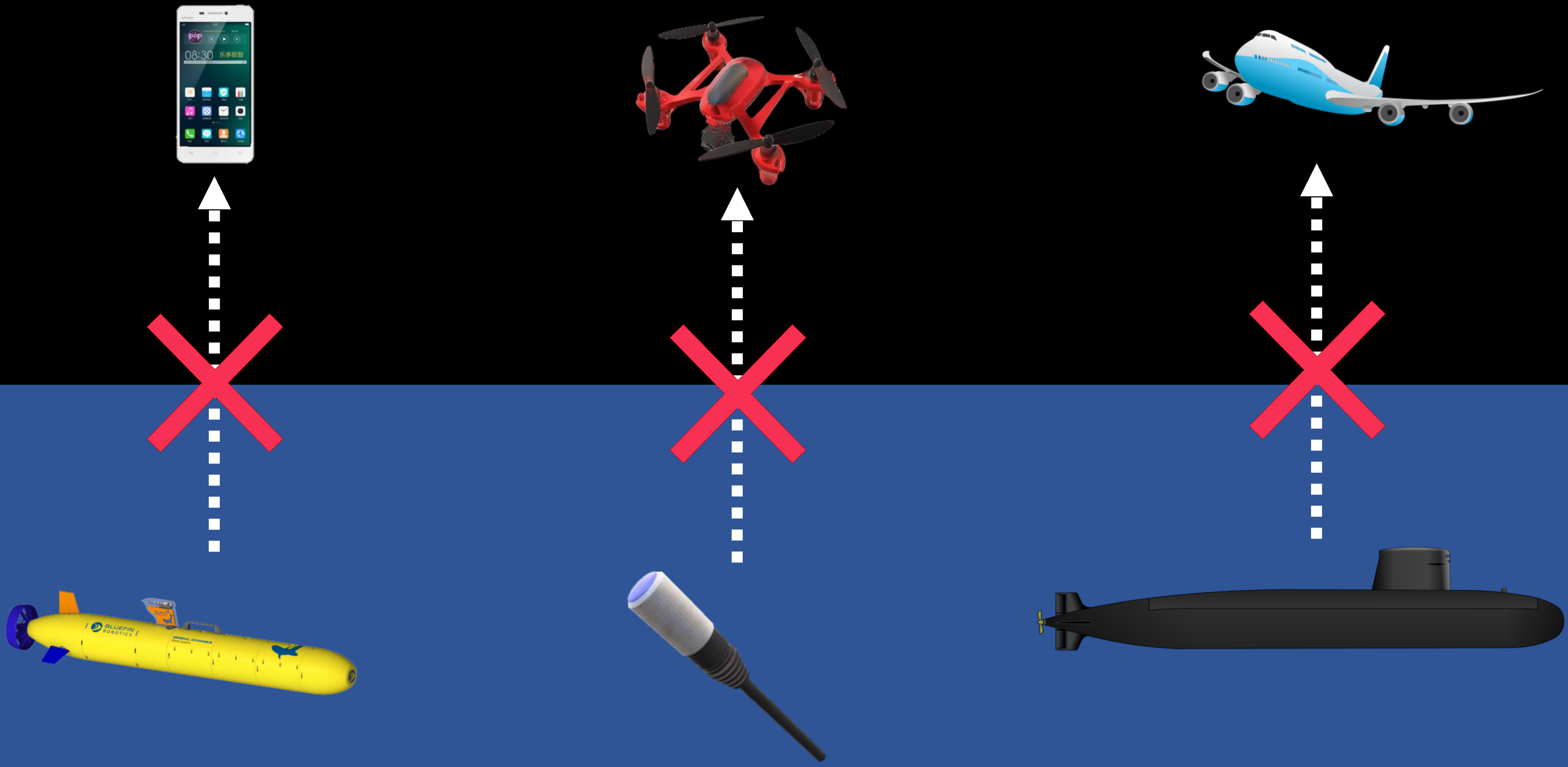
Finding Missing Airplanes

Ocean Scientific Exploration

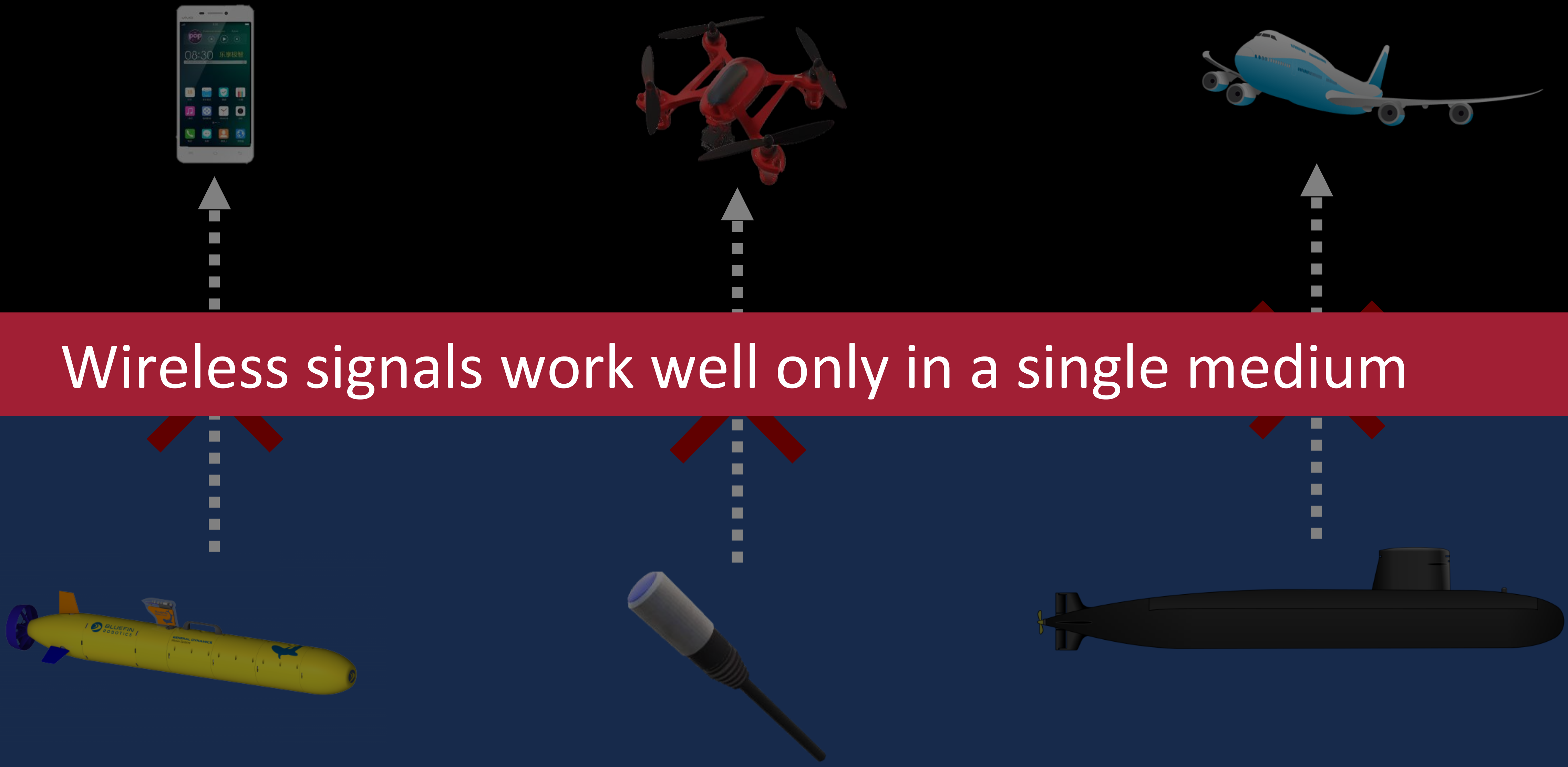
Underwater-to-Air Comm Applications

Why is it difficult?

Direct Underwater-Air Communication is Infeasible

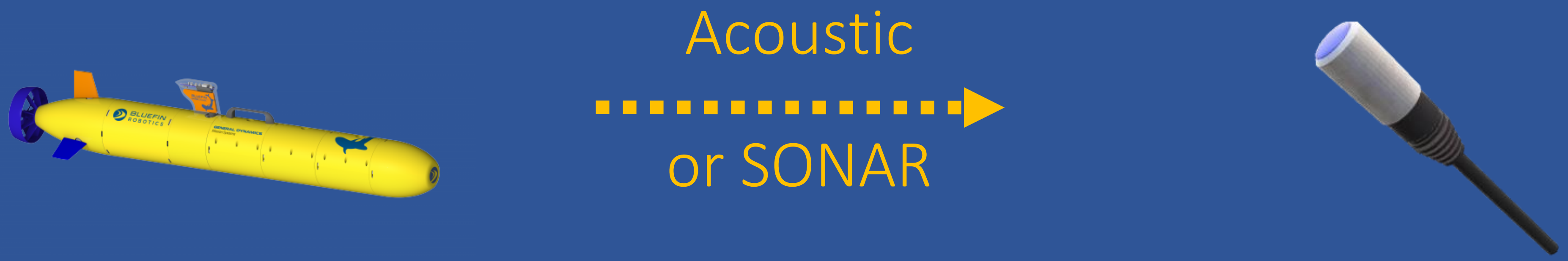


Direct Underwater-Air Communication is Infeasible



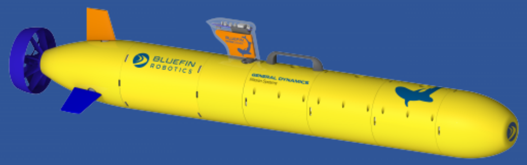
Wireless signals work well only in a single medium

Wireless Signals Work Well Only in a Single Medium



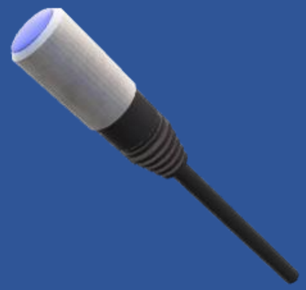
Wireless Signals Work Well Only in a Single Medium

Radio

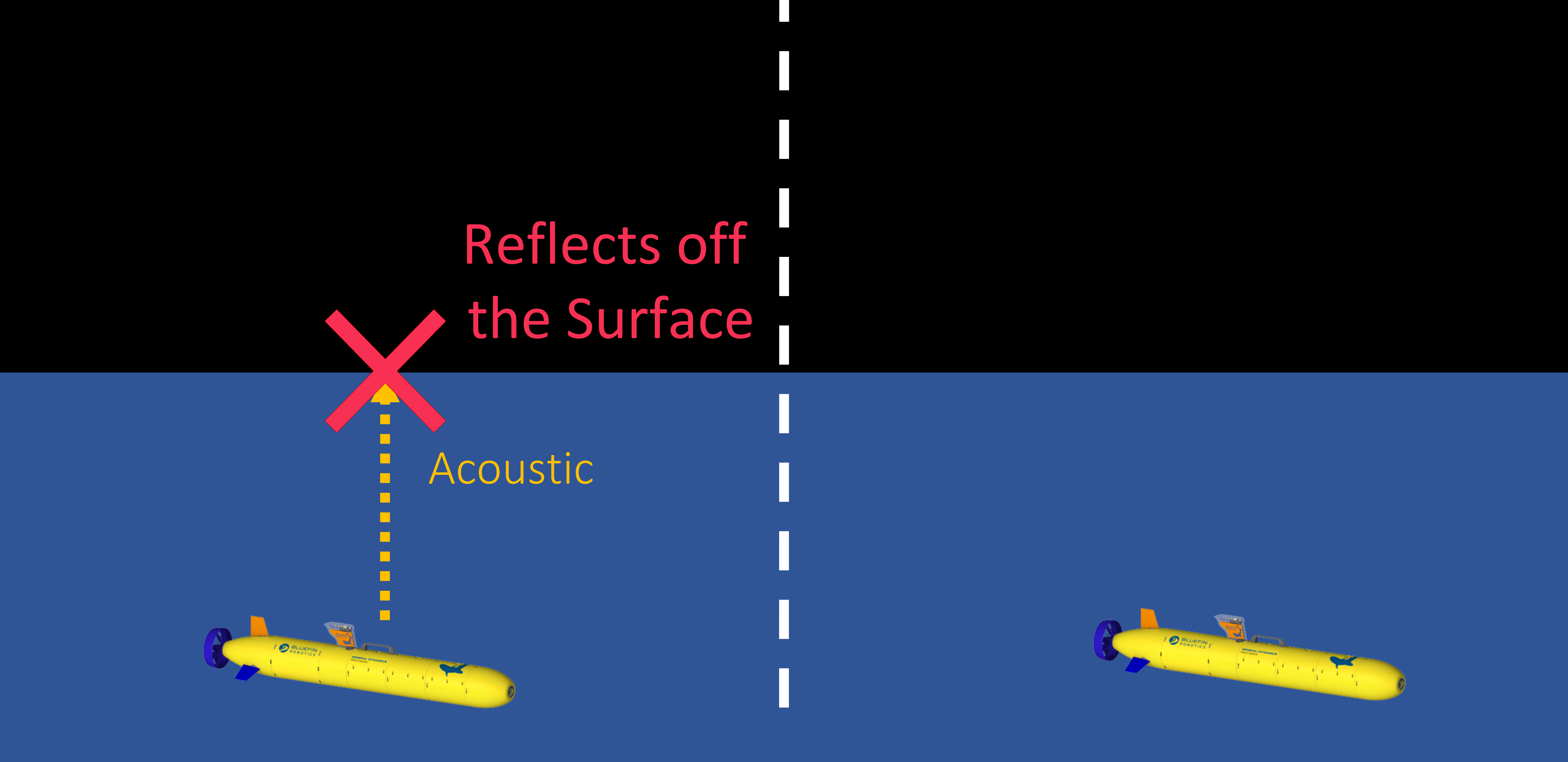


Acoustic

or SONAR

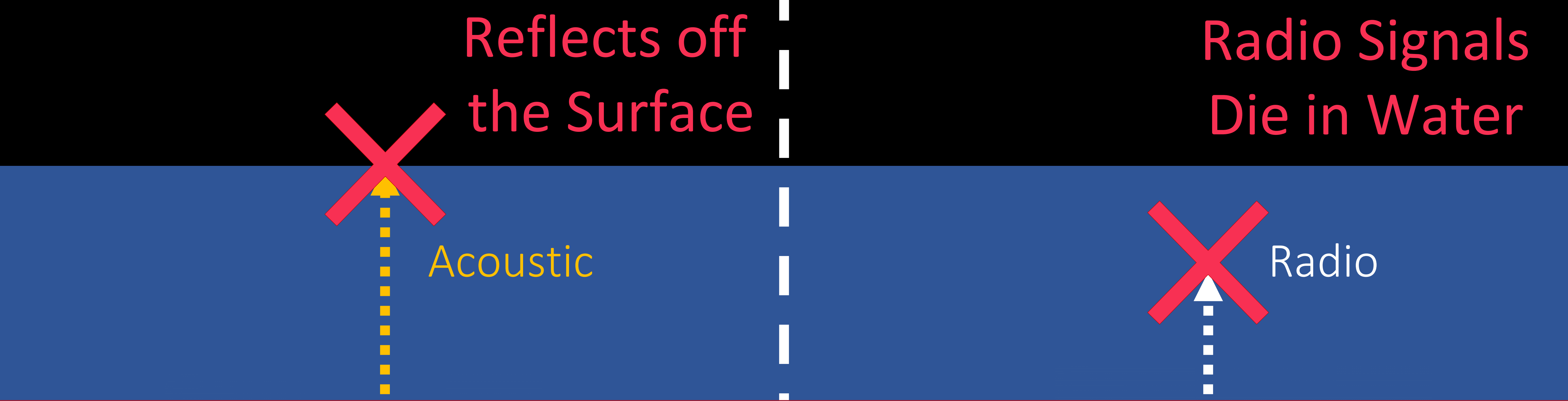


Use Acoustic signals?



Use Acoustic signals?

Use Radio Signals?

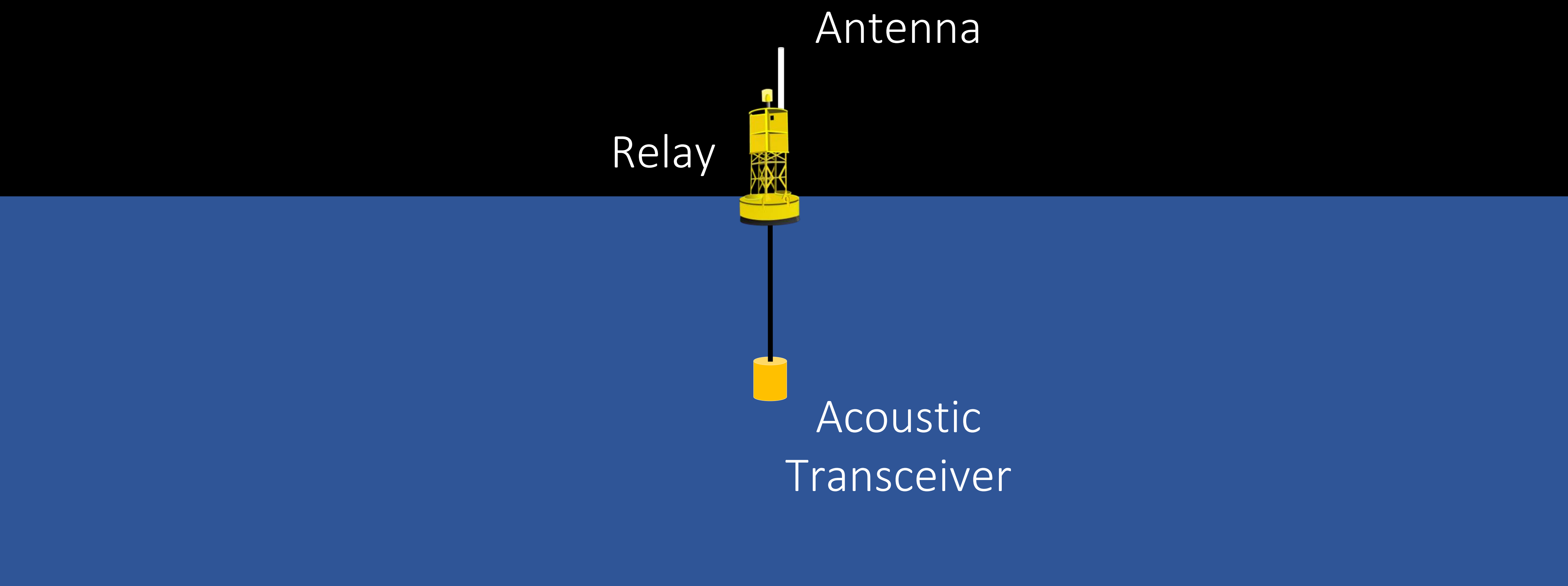


Work-arounds like relays, sunobouys, or surfacing are not cost-efficient or scalable

What are today's approaches for solving this problem?

Approach #1: Relay Nodes

[OCEANS’07, ICC’11, ICC’14, Sensors’14]



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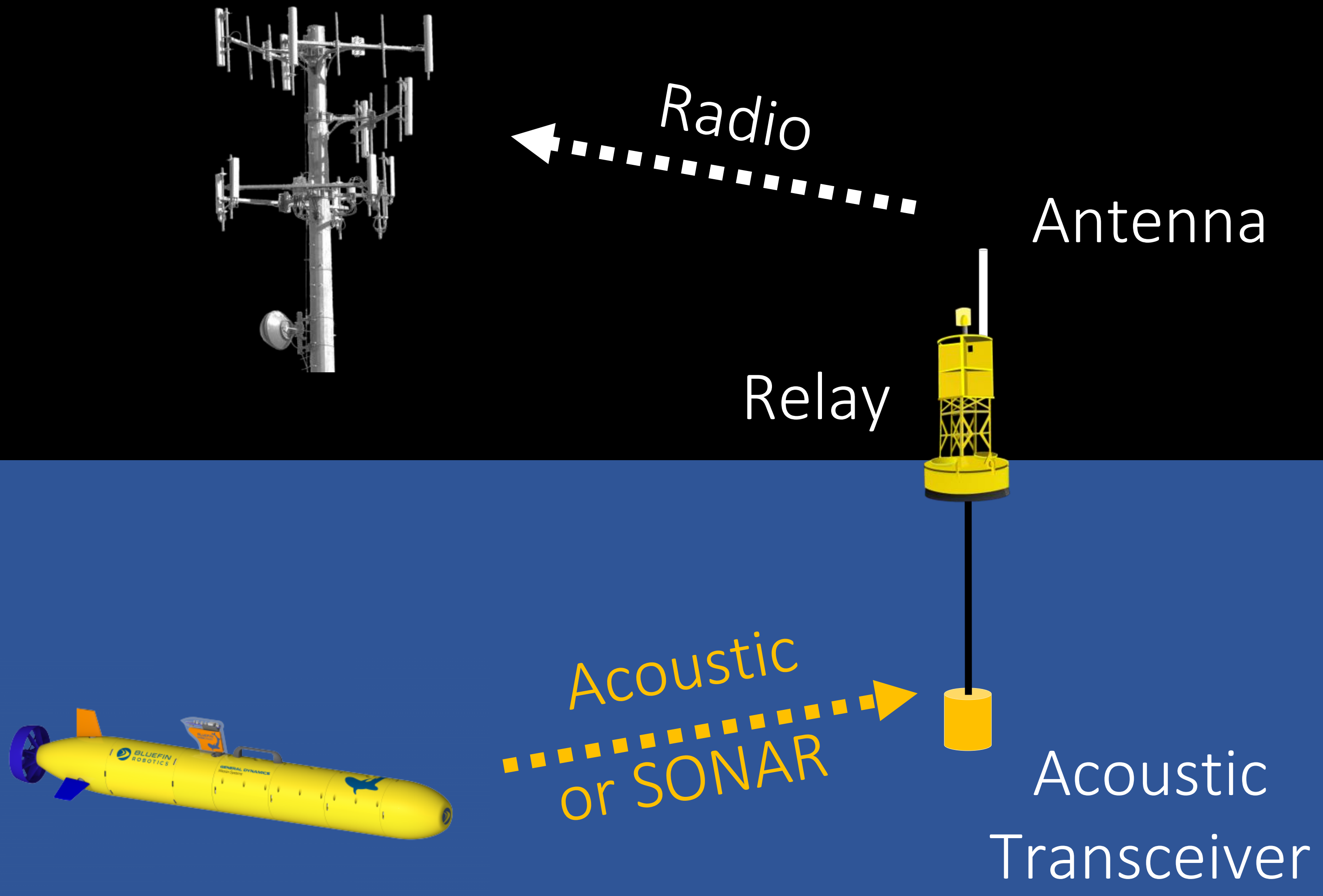
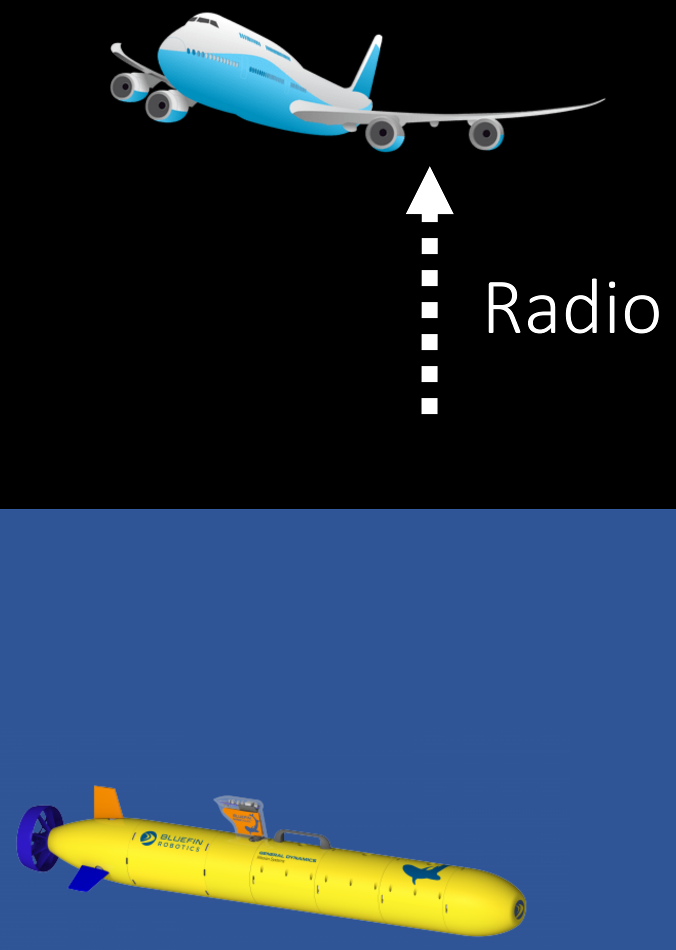


Approach #2: Surfacing

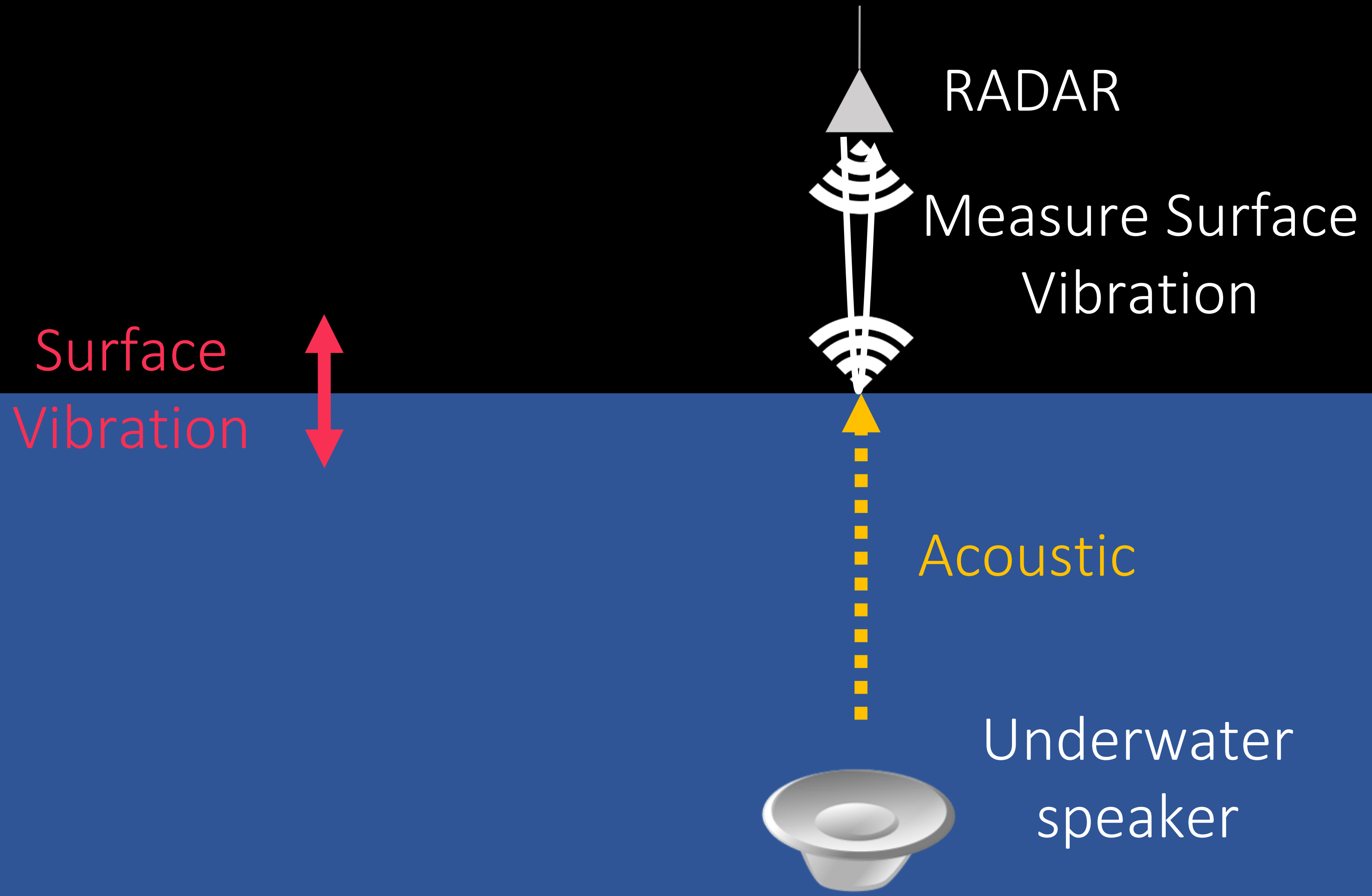
[ICRA'06, MOBICOM'07, OCEANS'10, ICRA'12]



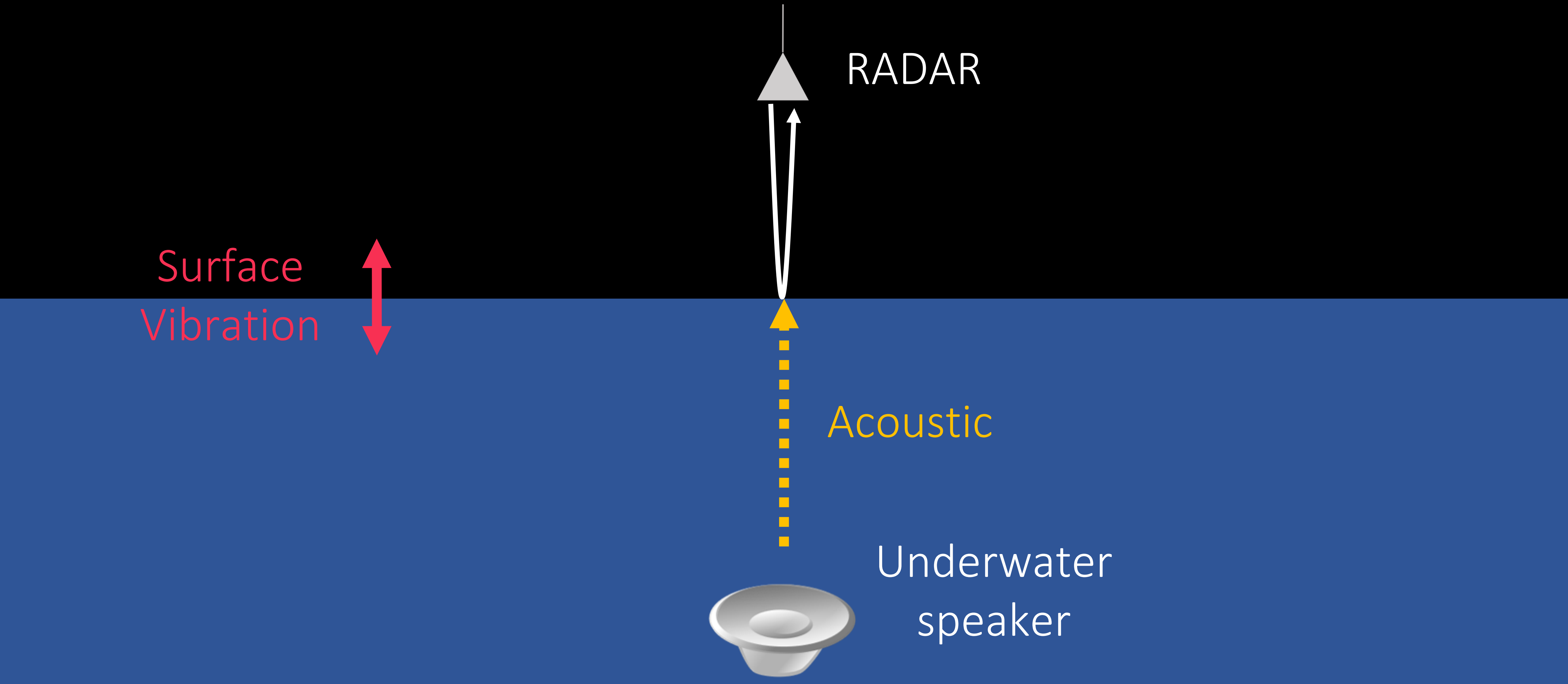
Technology that Enables Compact Sensors to Wirelessly Communicate Across the Water-Air Boundary

How does it work?

Technology that Enables Compact Sensors to Wirelessly Communicate Across the Water-Air Boundary



Translational Acoustic RF Communication (TARF)



Translational Acoustic RF Communication

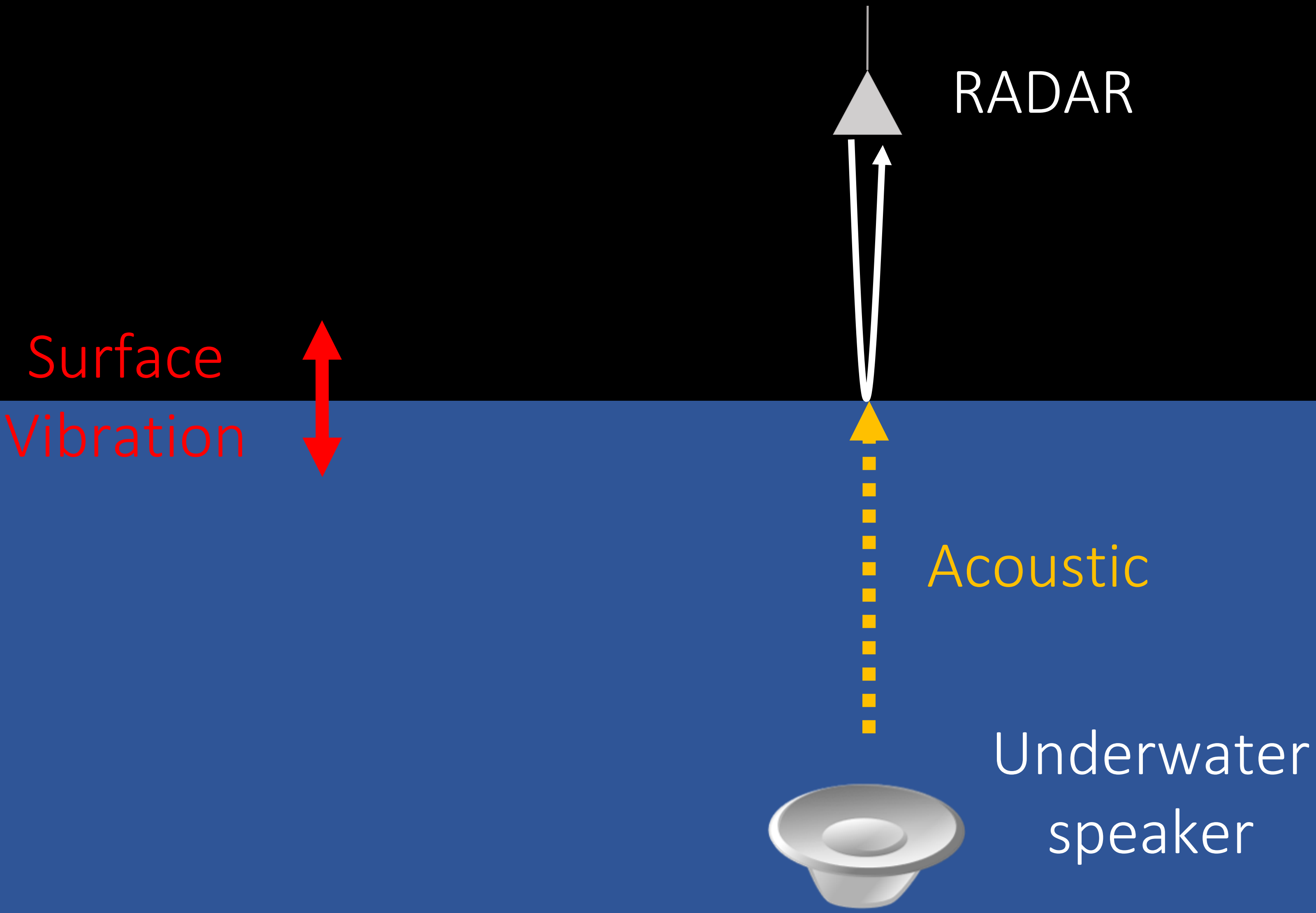
First technology that enables wireless communication across water-air interface

Theoretically achieves the best of both RF and acoustic signals in their respective media

Deals with practical challenges of communicating across water-air interface including natural surface waves

Implemented and tested in practical environments

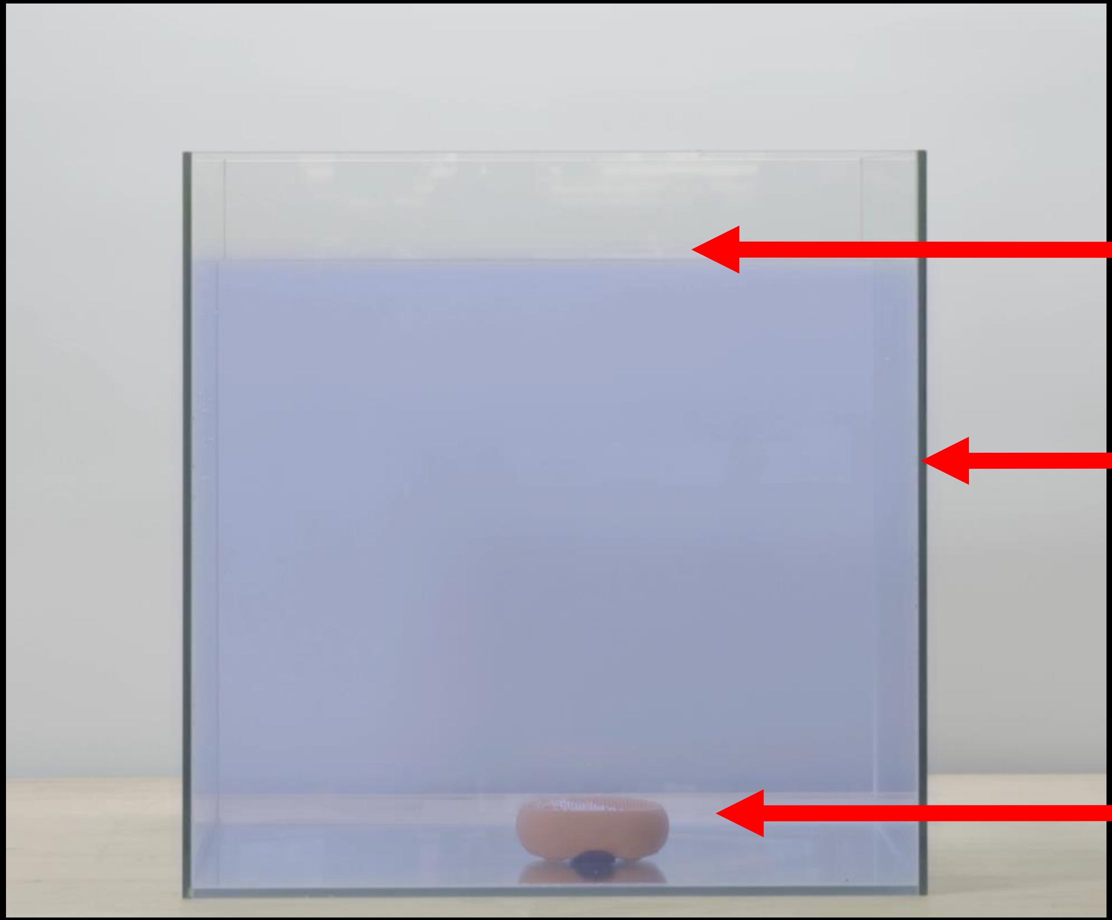
Key Idea



Can We Sense the Surface Vibration Caused by the Transmitted Underwater Acoustic Signal?

Recording the Surface Vibration

Experiment: Transmit Acoustic Signals at 100Hz



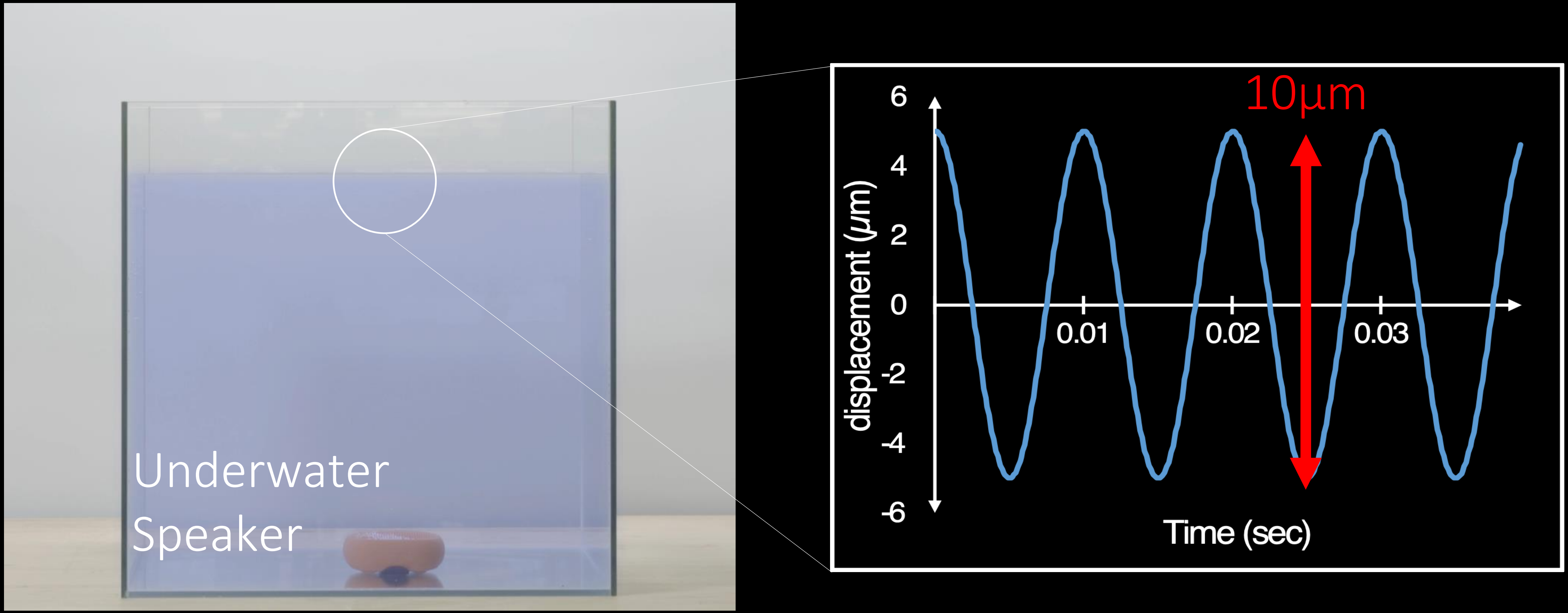
Water Surface

Water Tank

Underwater Speaker

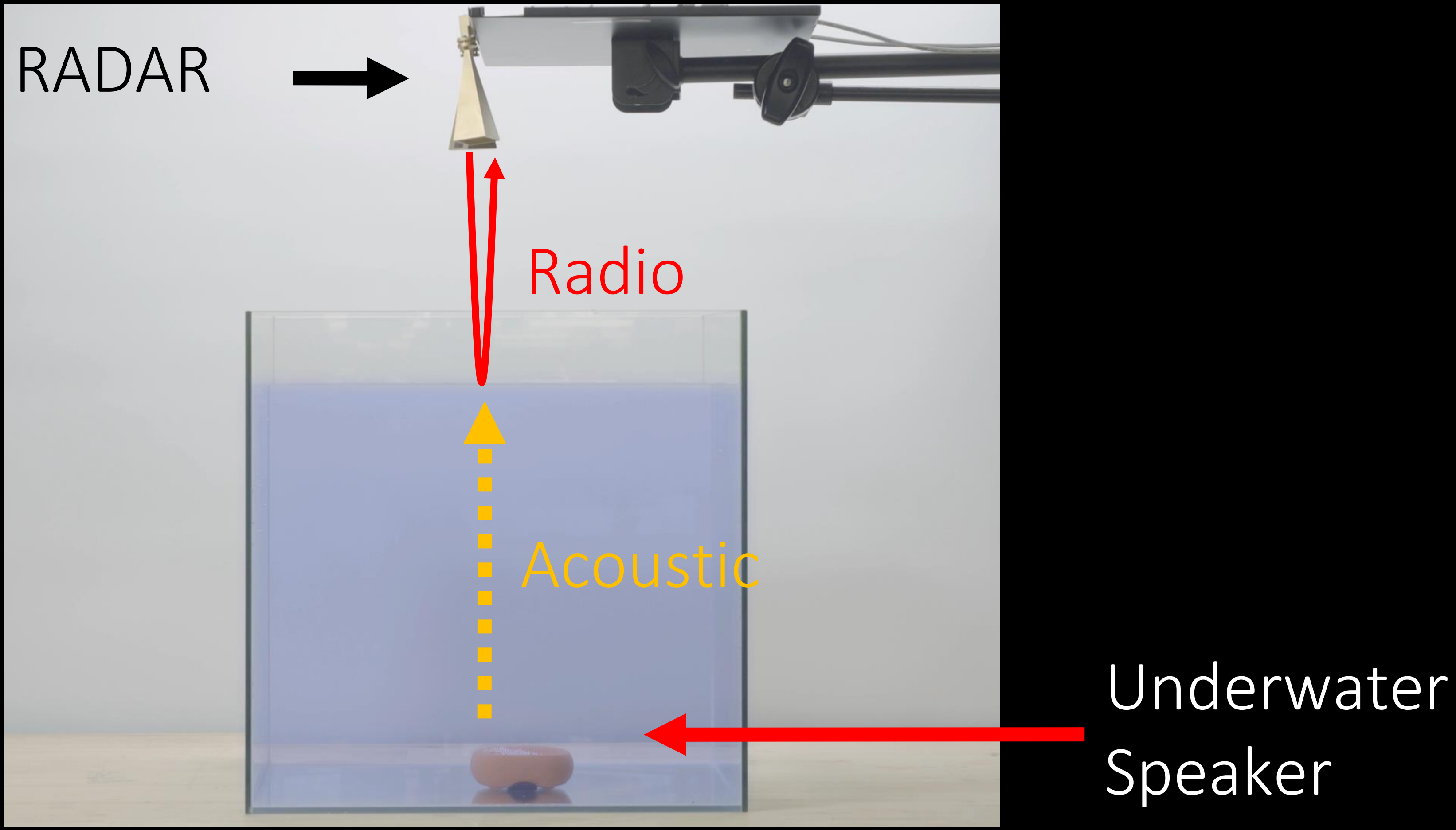
Recording the Surface Vibration

Experiment: Transmit Acoustic Signals at 100Hz



How Can We Sense Microscale Vibration?

Idea: Use RADAR to measure the surface vibration



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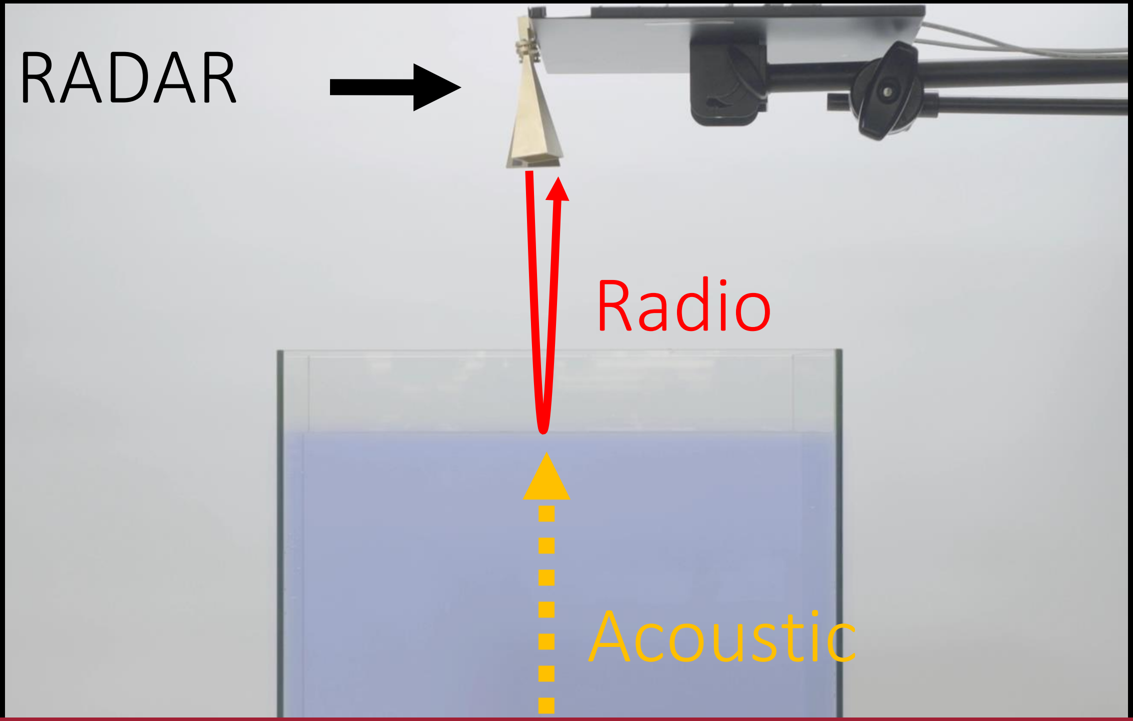
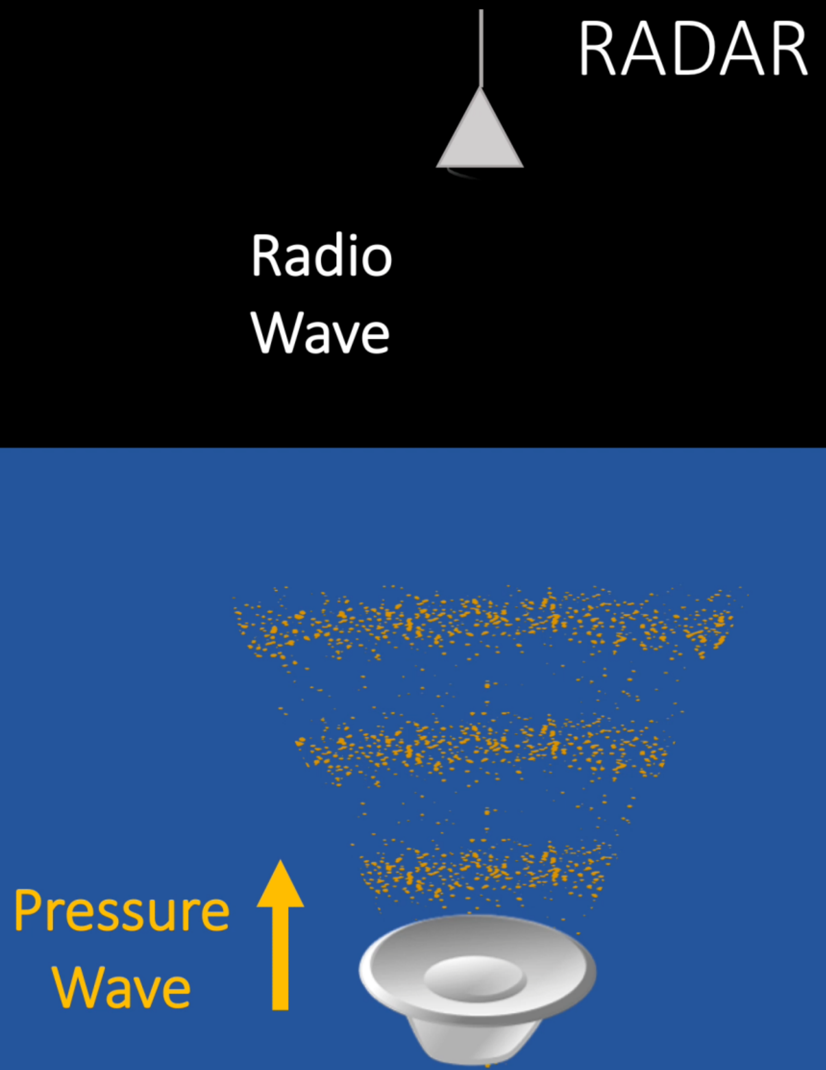


Problem: Measuring micrometer vibrations requires 100s of THz of bandwidth → Impractical & Costly

Solution: Measure Changes in Displacement Using the Phase of Millimeter-Wave RADAR



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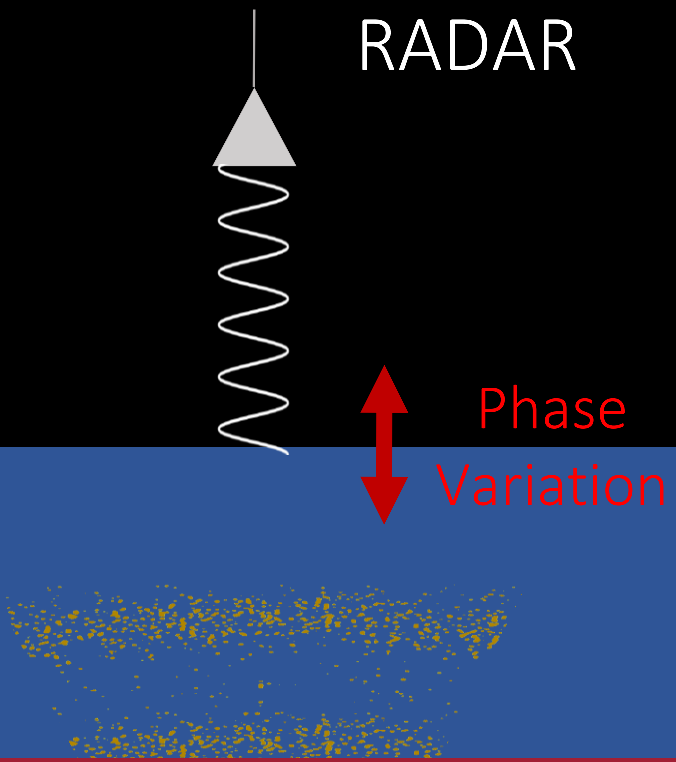


10μm

$$Phase = 360 \times \frac{displacement}{wavelength}$$

5mm

Phase Variation = 0.72degrees

The phase of the milimeter-wave RADAR encodes transmitted information from underwater

Natural Surface Waves Mask the Signal

On Calm Days, Ocean Surface Ripples (Capillary Waves)
Have 2cm Peak-to-Peak Amplitude

1,000 Times Larger than Surface Vibration
Caused by the Acoustic Signal (µm)

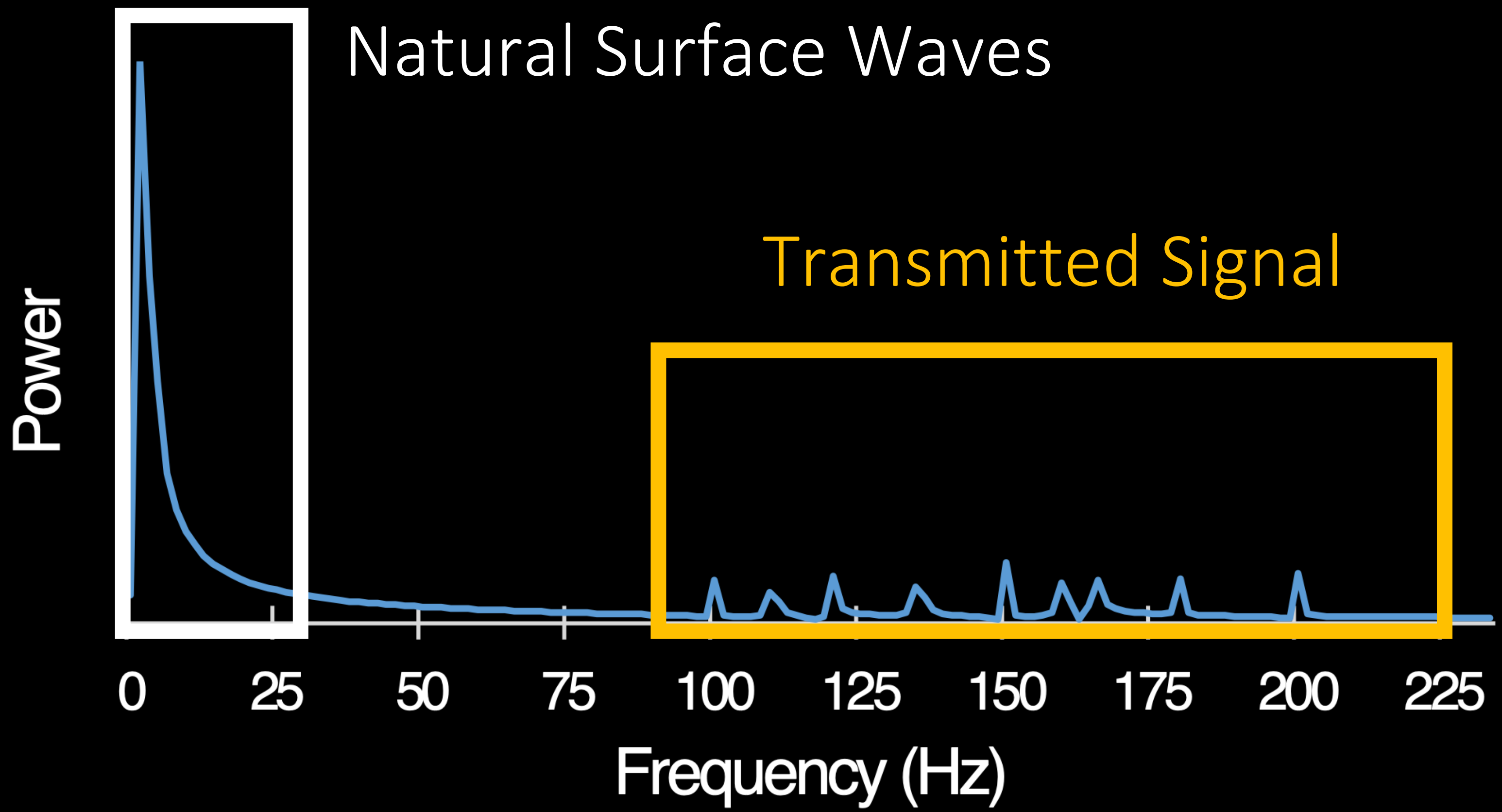
Natural Surface Waves Can Be Treated as Structured Interference and Filtered Out

Frequency

Naturally occurring waves (e.g., ocean waves) are relatively slow → 1 – 2Hz

Acoustic signals are transmitted at higher frequencies → 100 – 200Hz

Natural Surface Waves Can Be Treated as Structured Interference and Filtered Out



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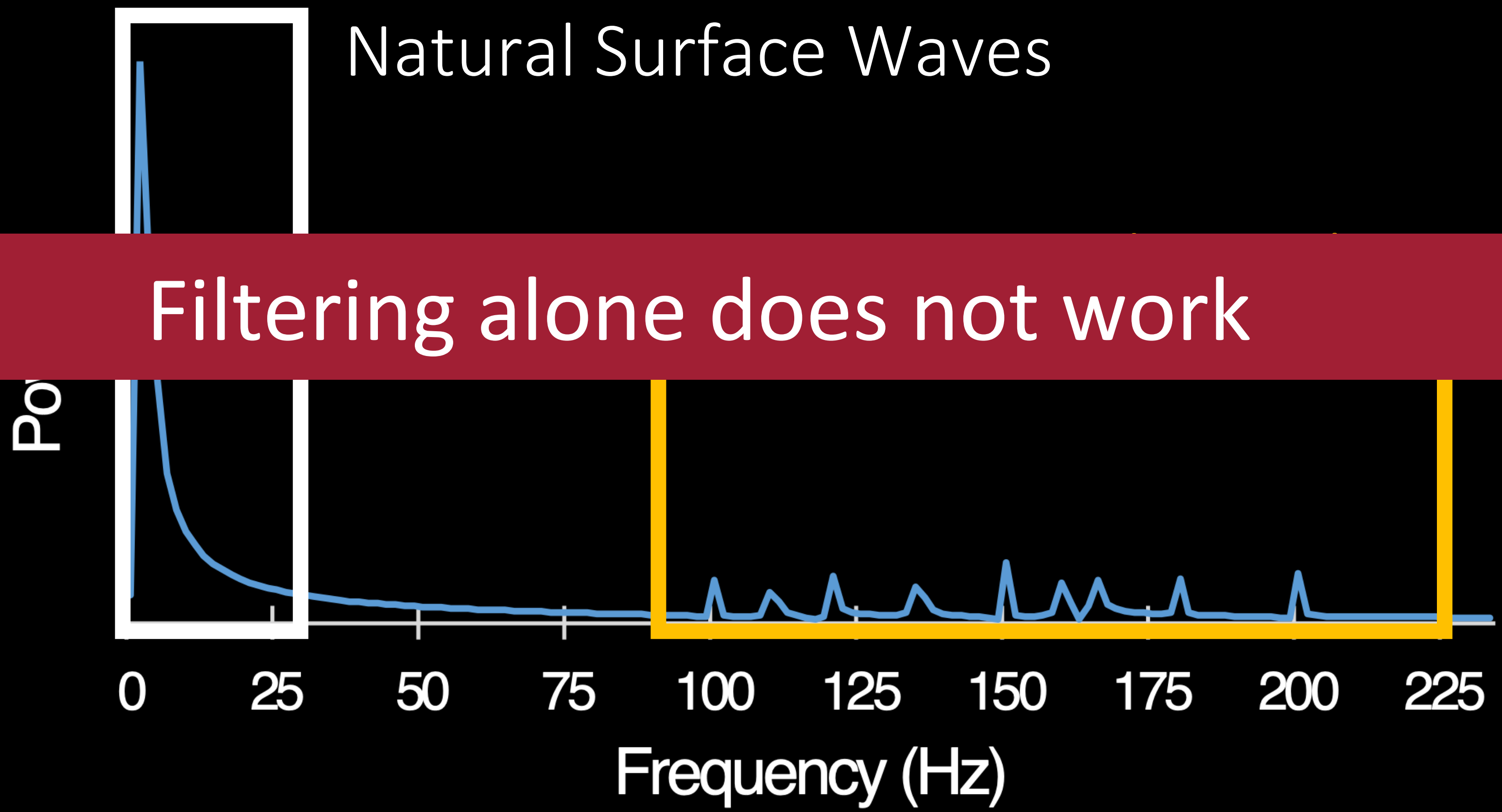

Filtering alone does not work

Dealing with Waves

$$Angle = 360 \times \frac{displacement}{wavelength}$$

Dealing with Waves

$$Angle = 360 \times \frac{displacement}{wavelength} \quad mod\ 360$$

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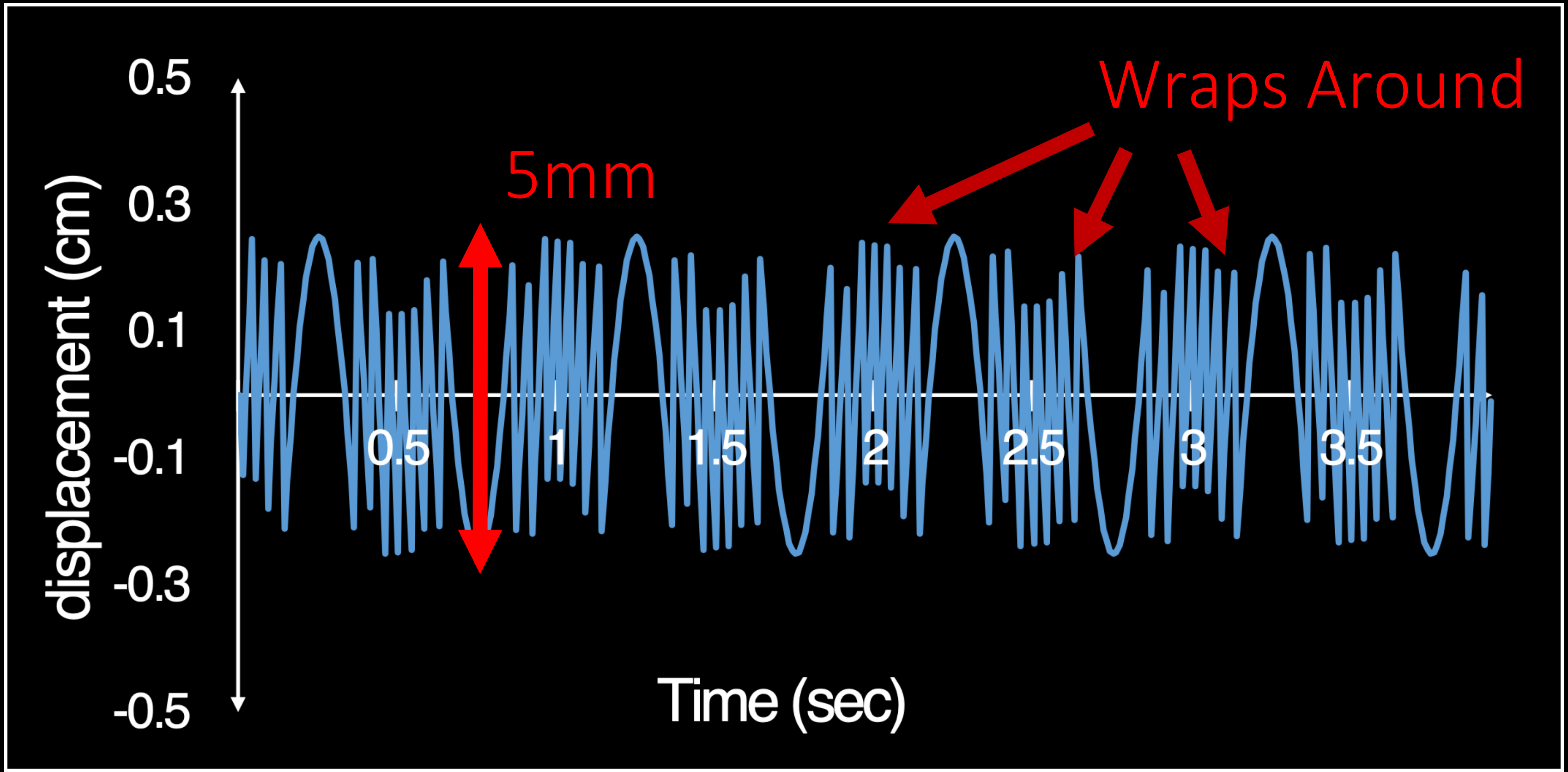
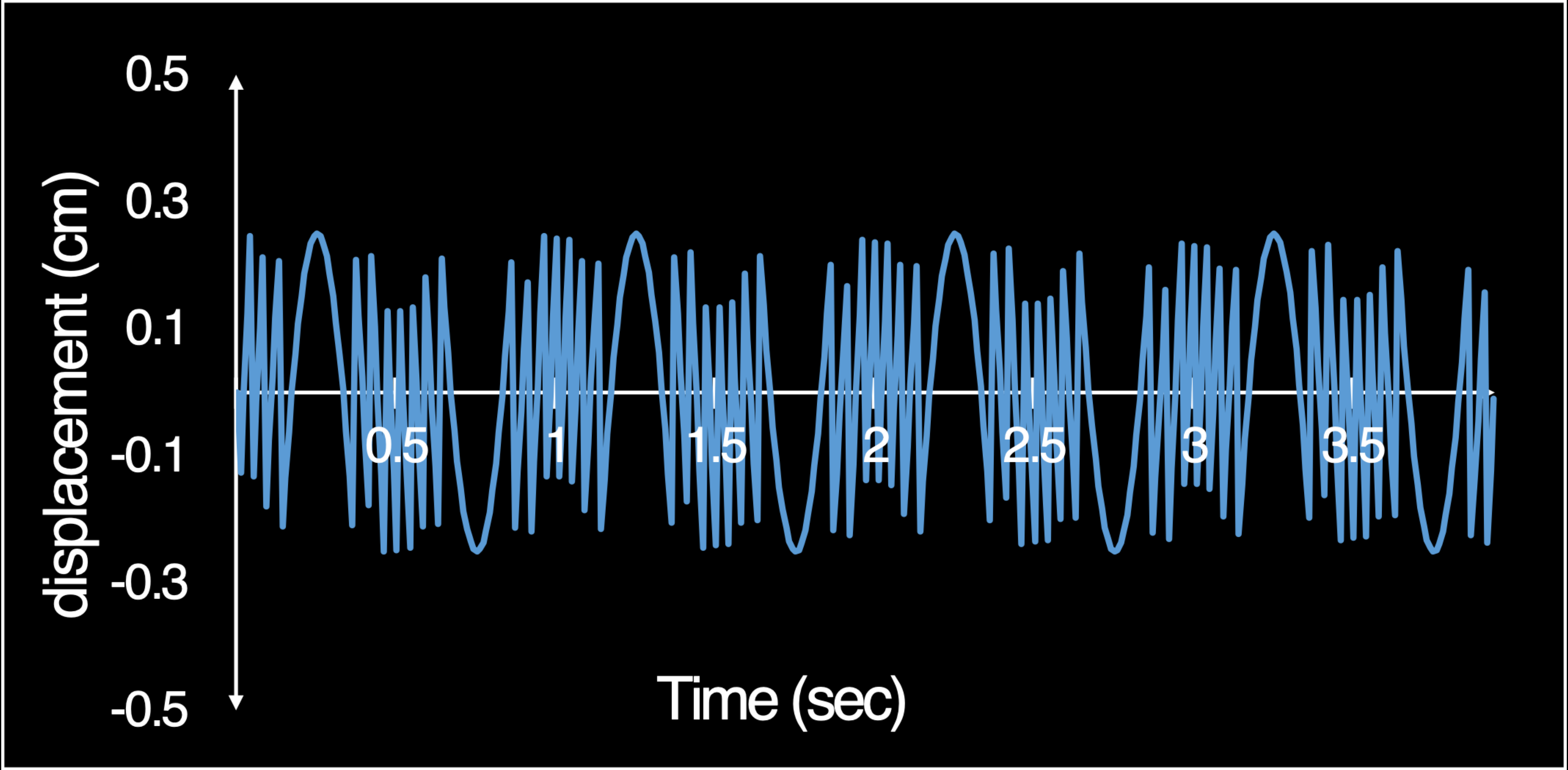


Dealing with Waves



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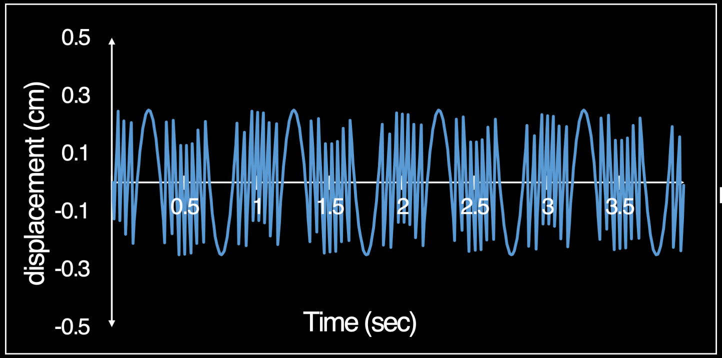
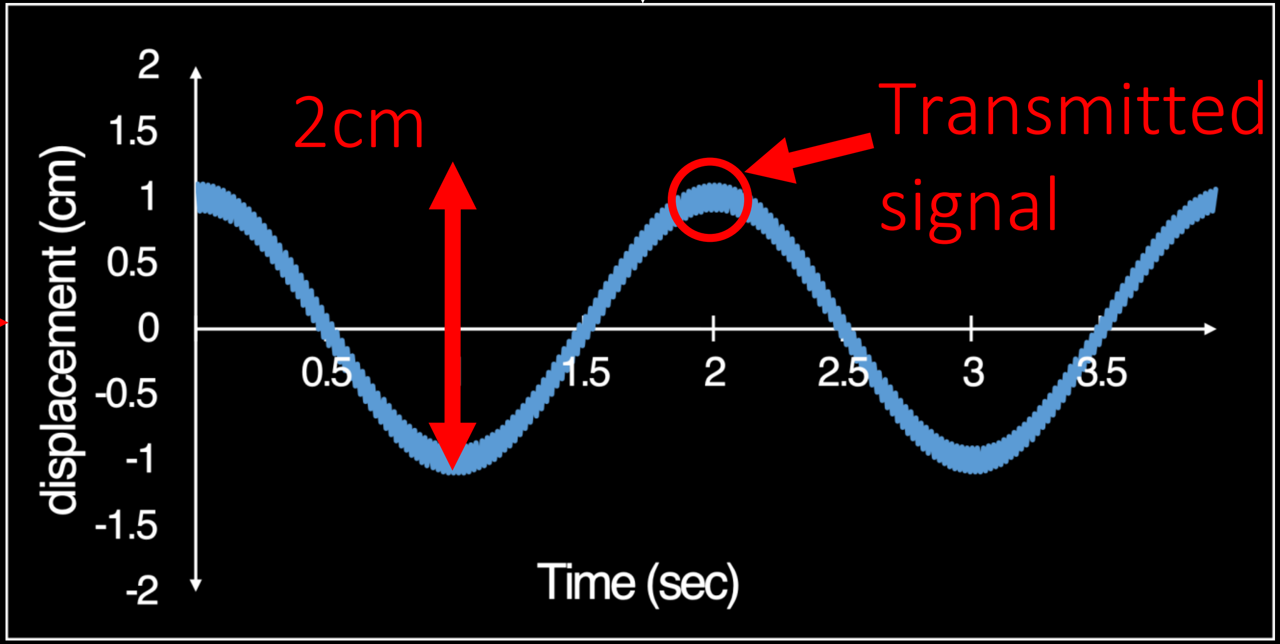
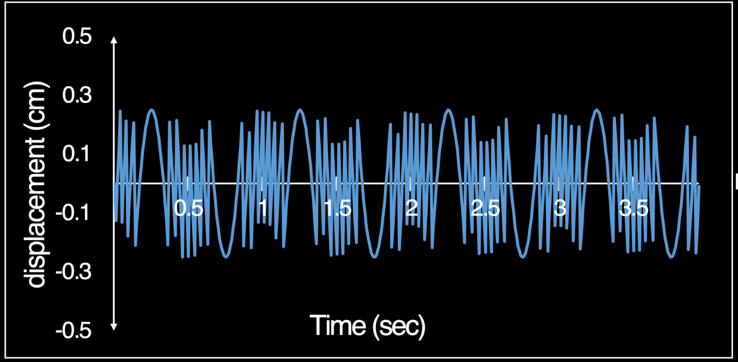


Track & Unwrap

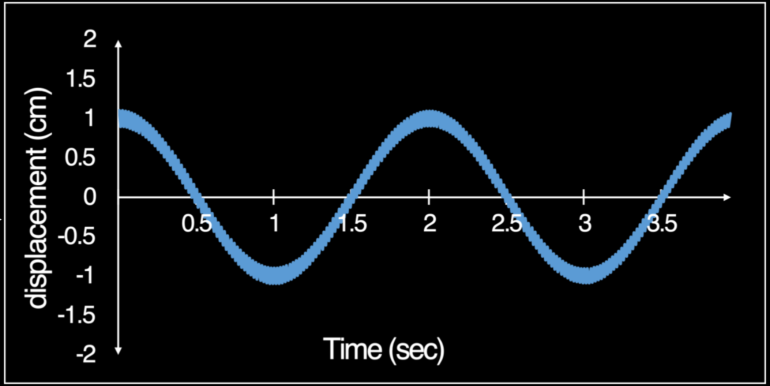
Trend is Water Surface Wave



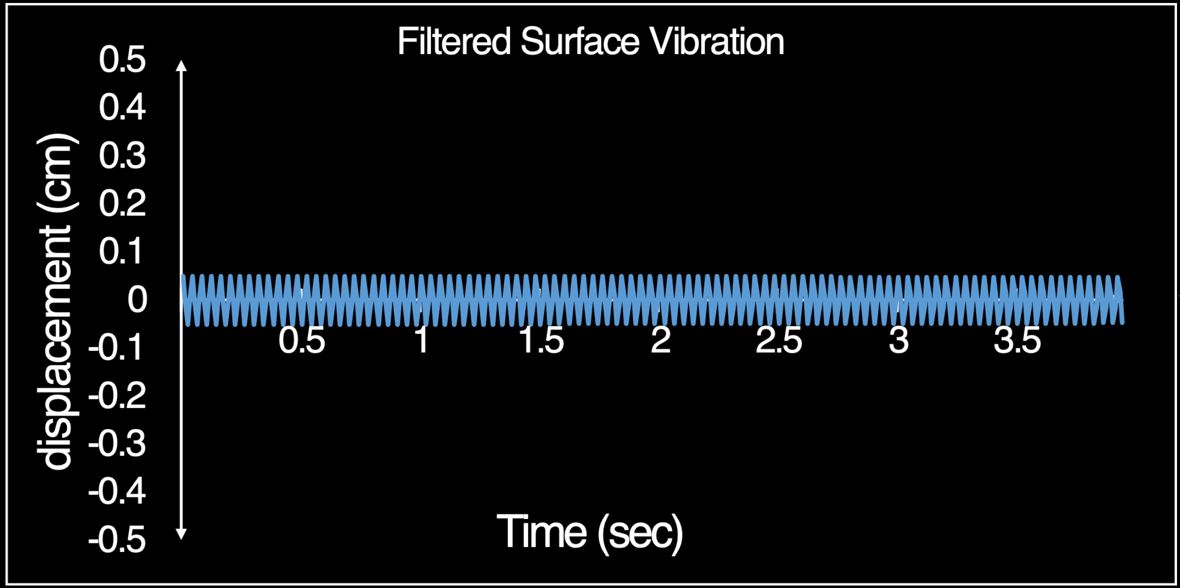
Dealing with Waves



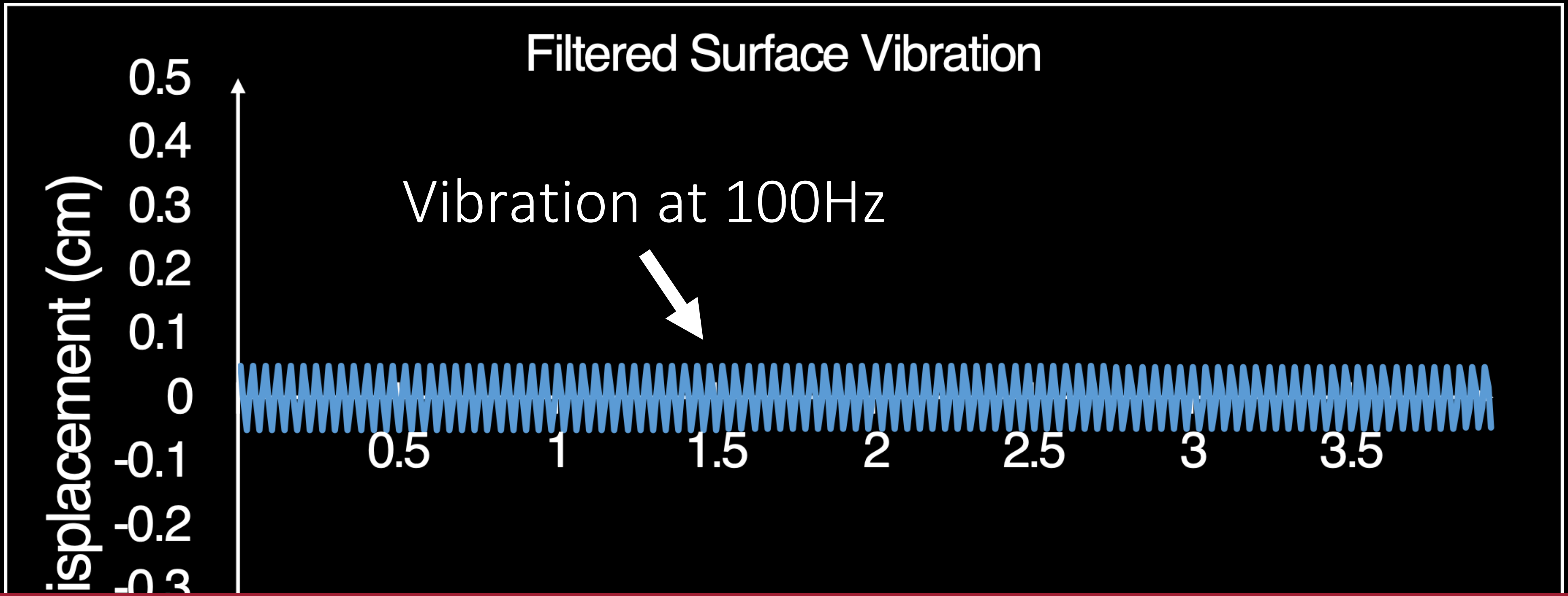
Track & Unwrap



Filter

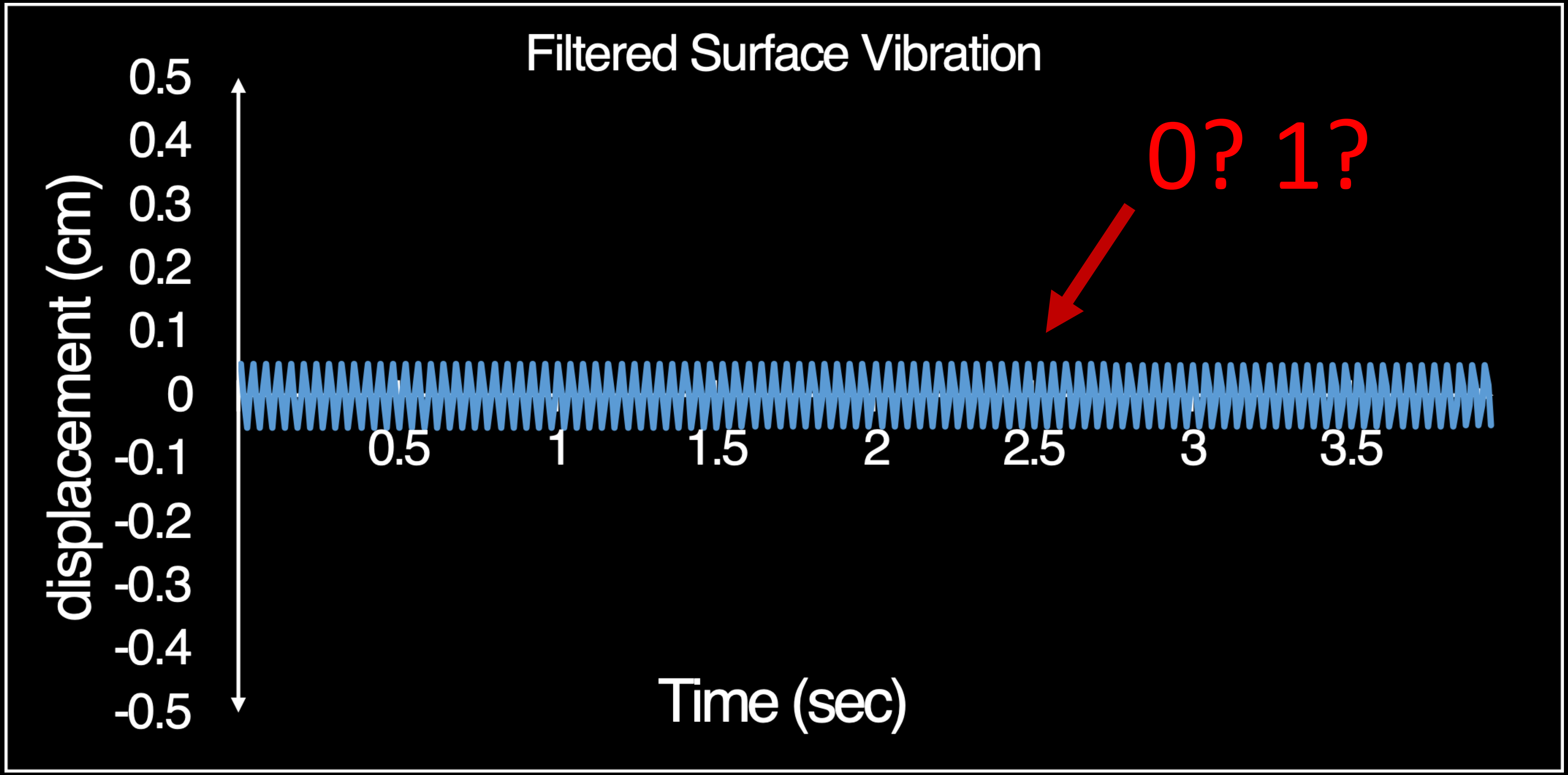


Dealing with Waves



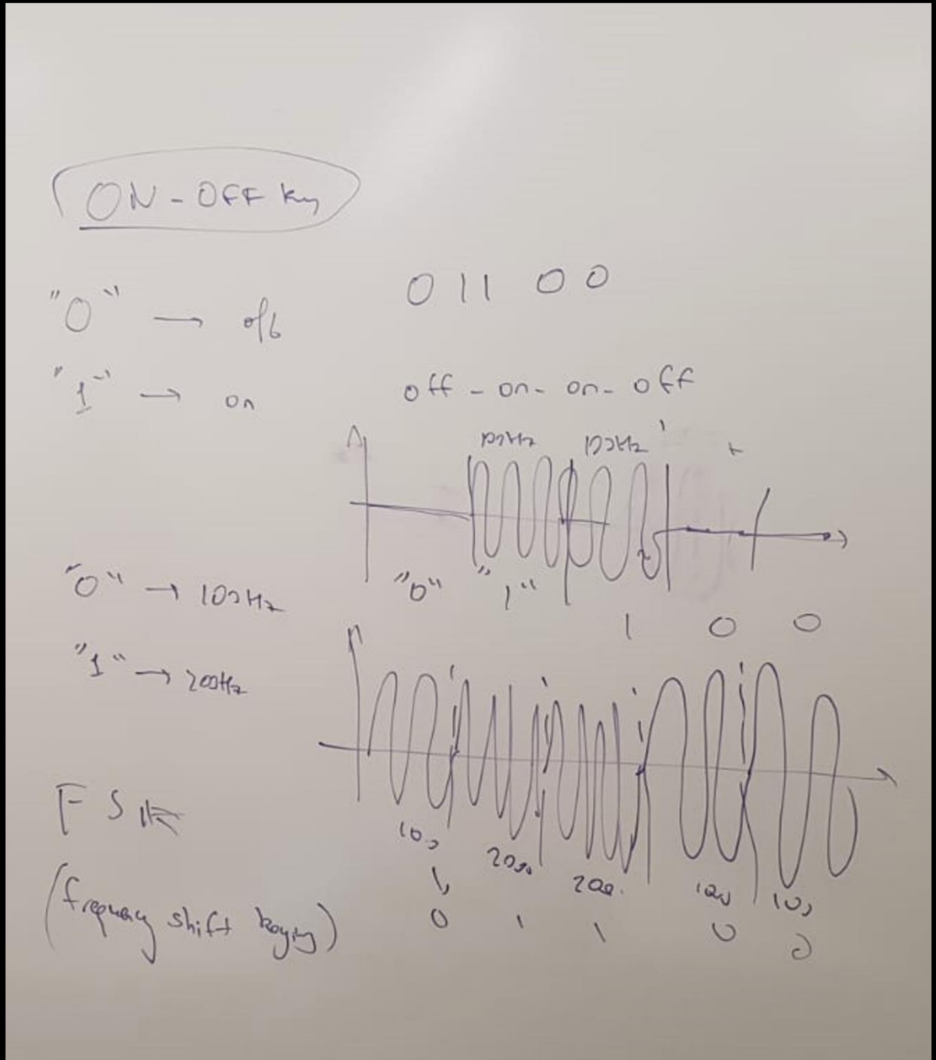
By treating natural surface waves as structured interference, we are able to track and eliminate their impact on our signal

How Can We Decode?

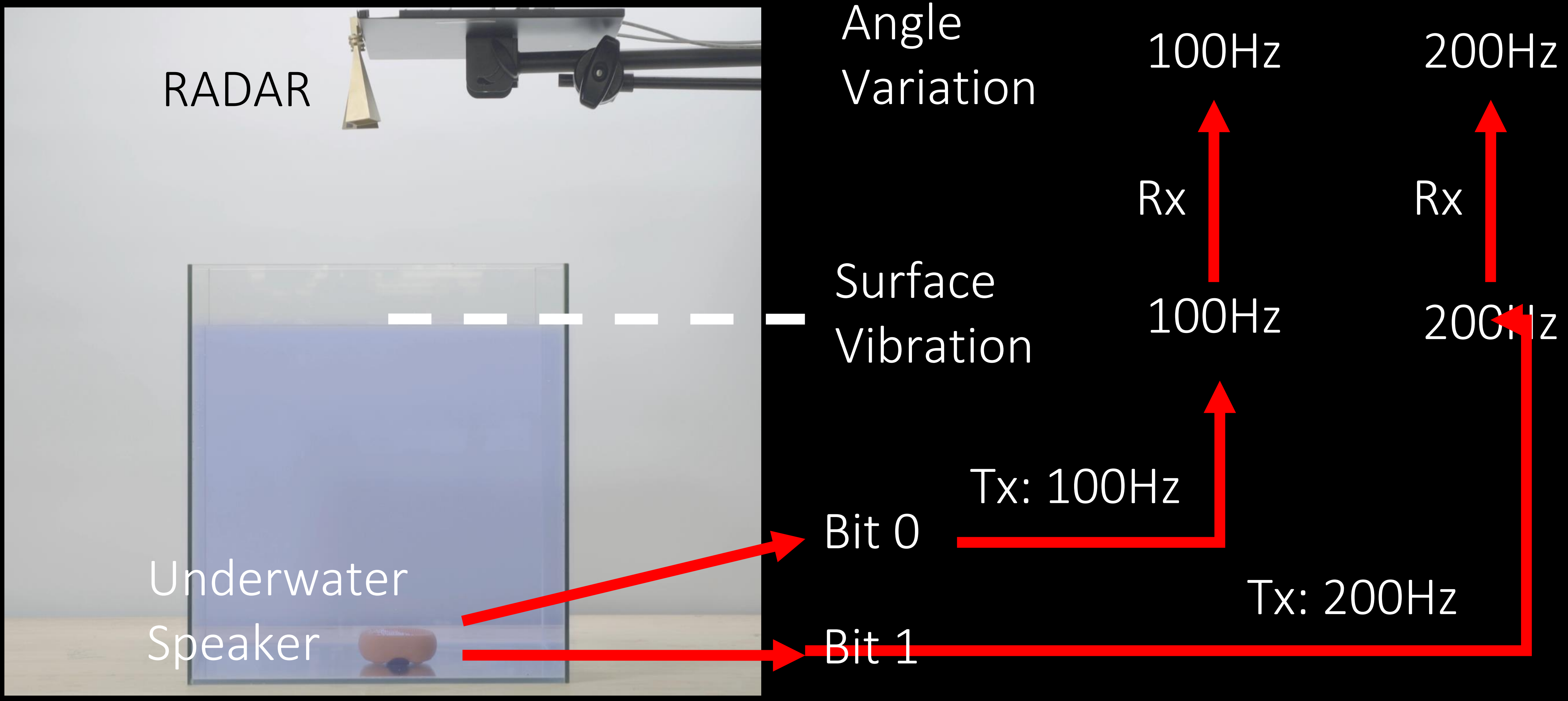


Simple Modulation schemes

ON-OFF keying, FM0/Manchester, FSK



Decoding Information



Standard Modulation Schemes?

The wireless channel

Mathematics & Physical Interpretation

Upconversion & Downconversion

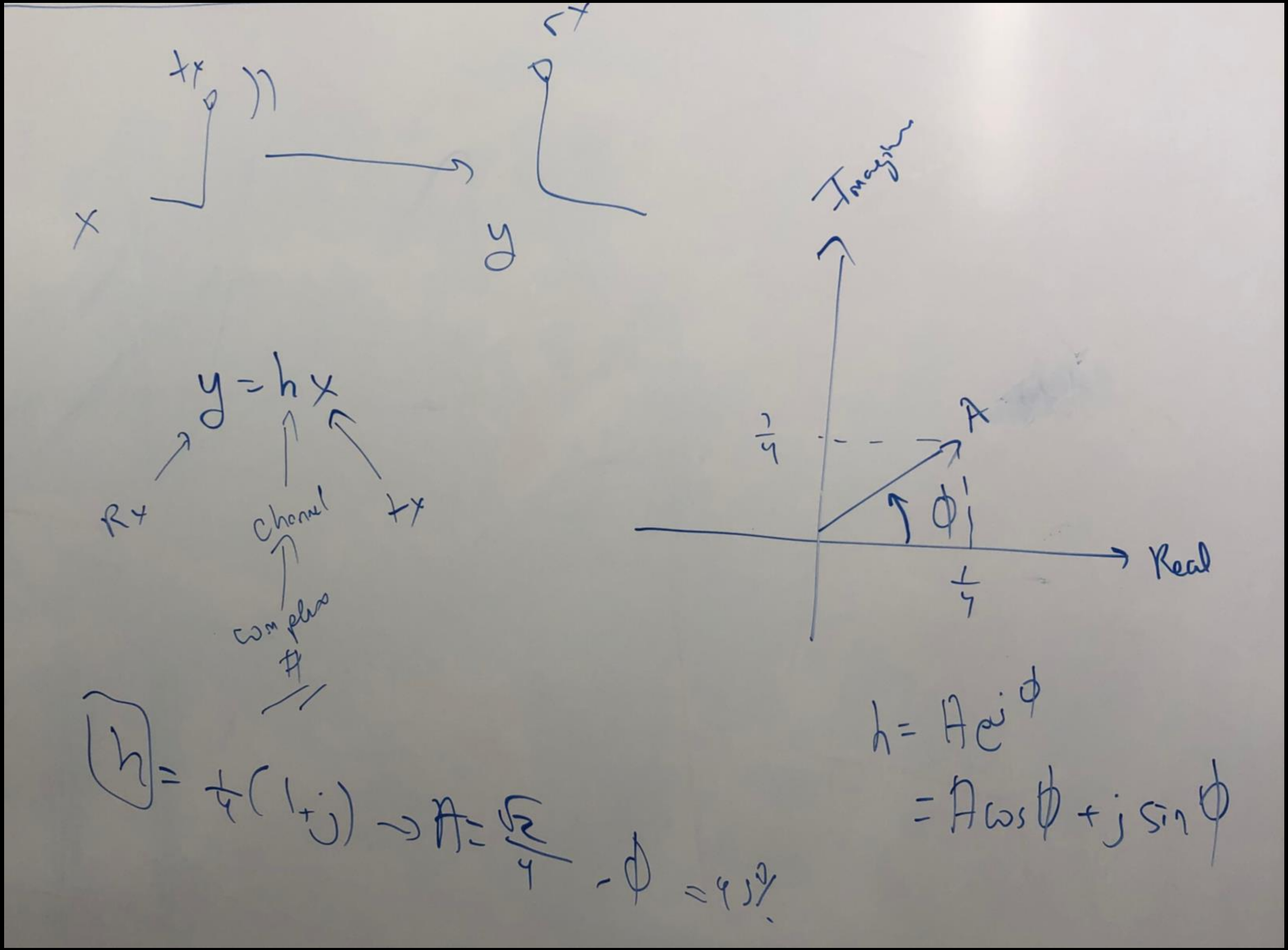
Modulation & Demodulation

The Wireless Channel (Math)

Complex number, I/Q plane, example

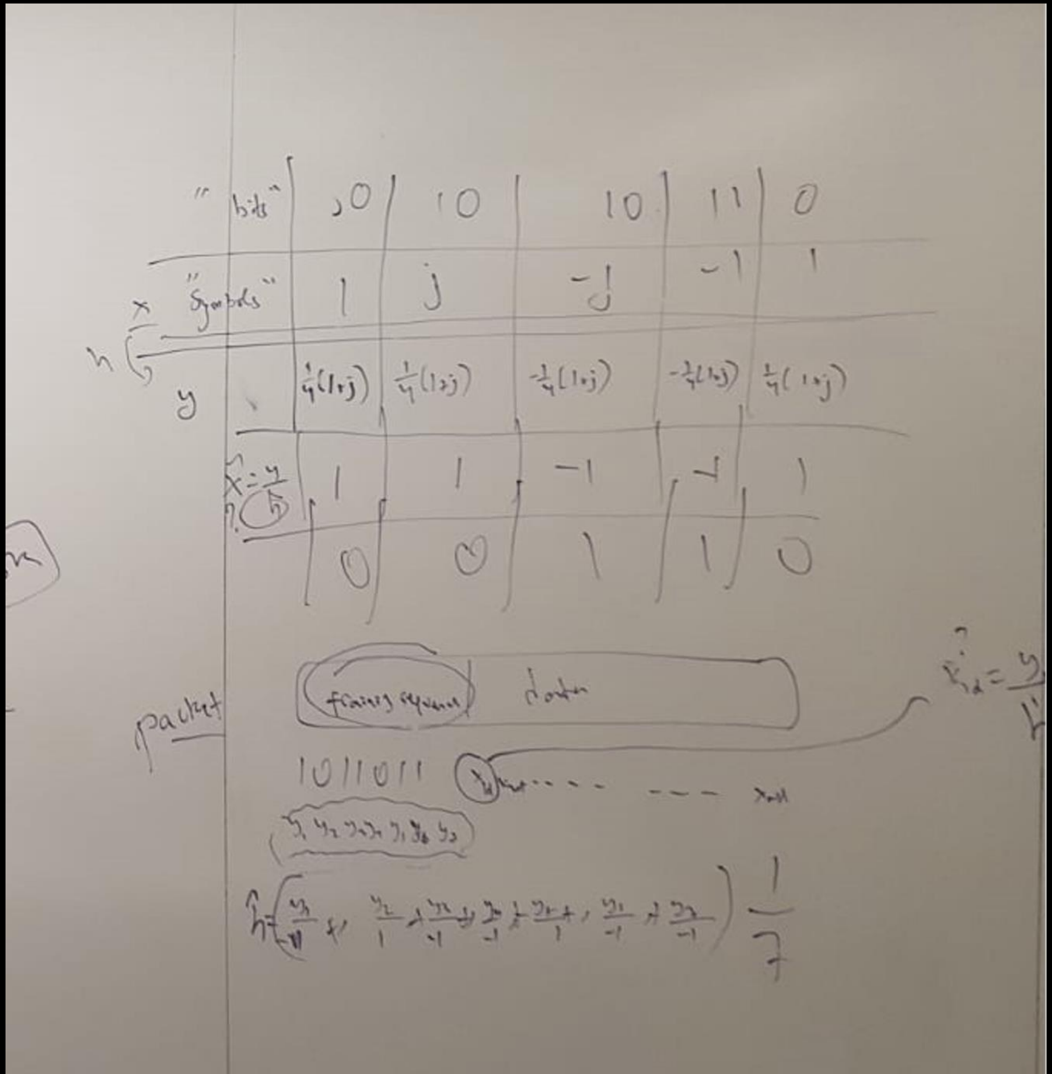
The Wireless Channel (Math)

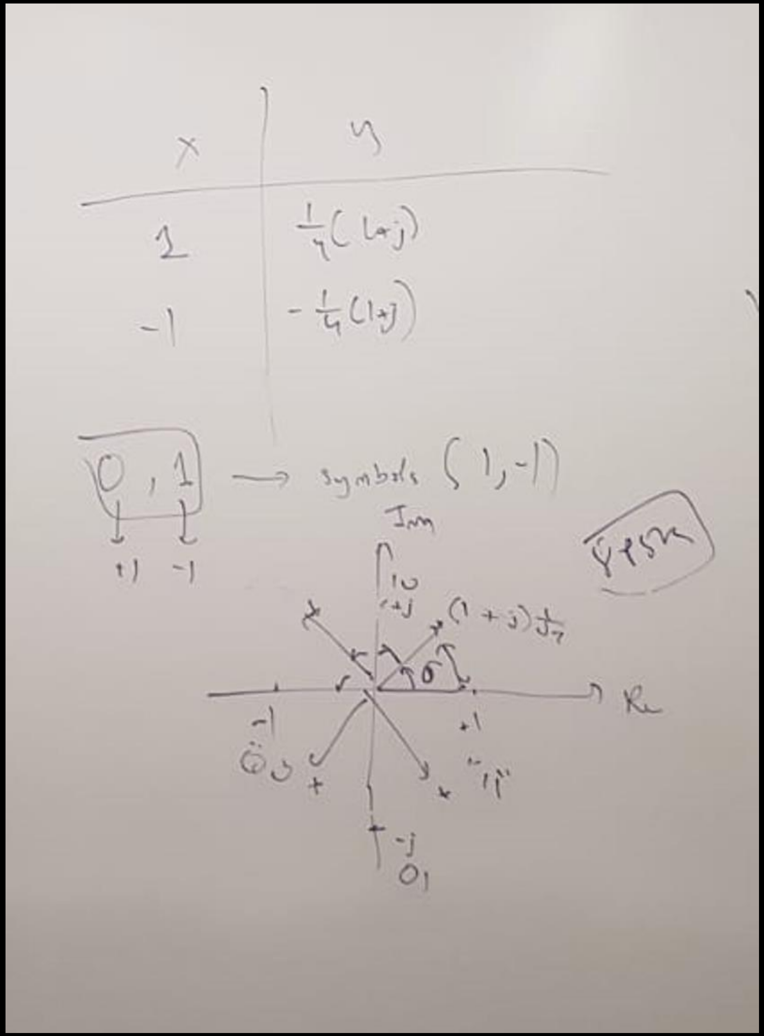
Complex number



Encoding & Decoding

Symbols (+/-1) Example, Preambles, Channel Estimation, Length of Preamble





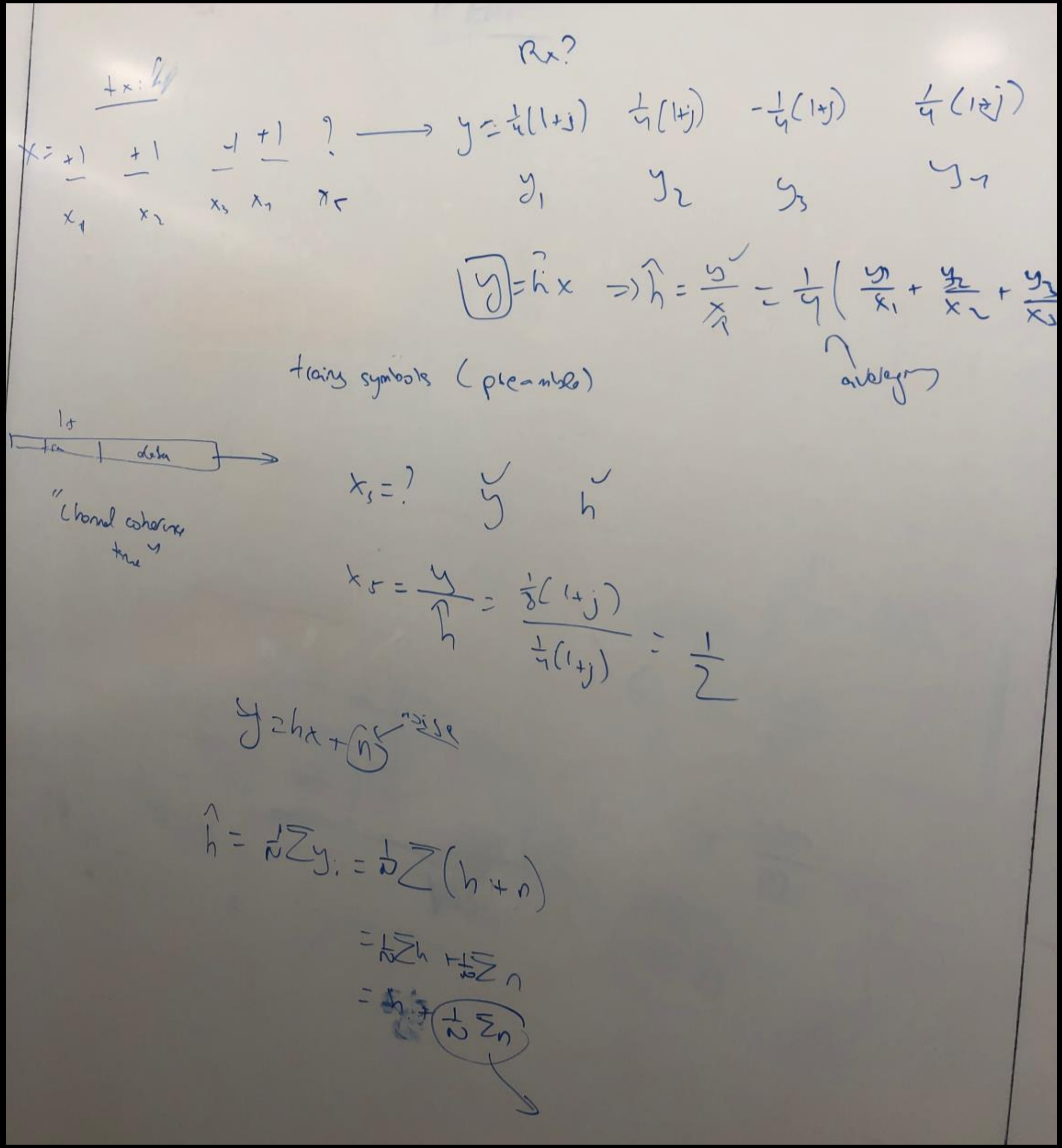
Encoding & Decoding

Example channel: x->y?

How can I know what was transmitted?

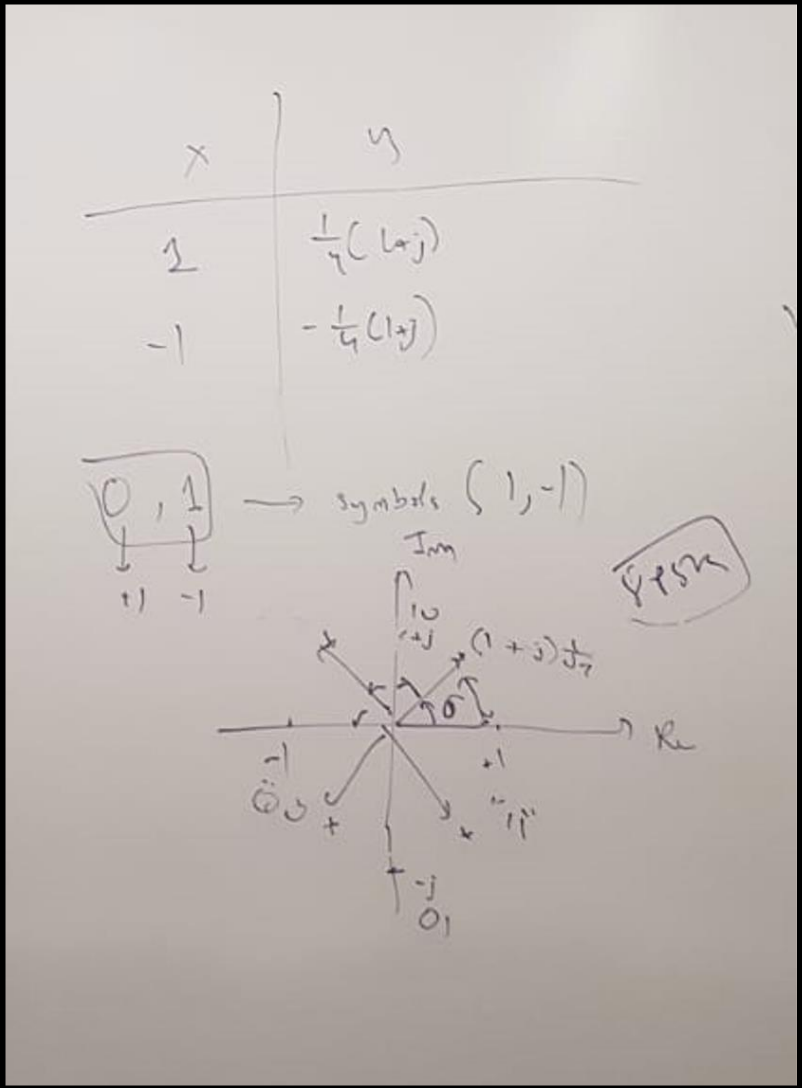
- preamble, training sequence
- channel estimation

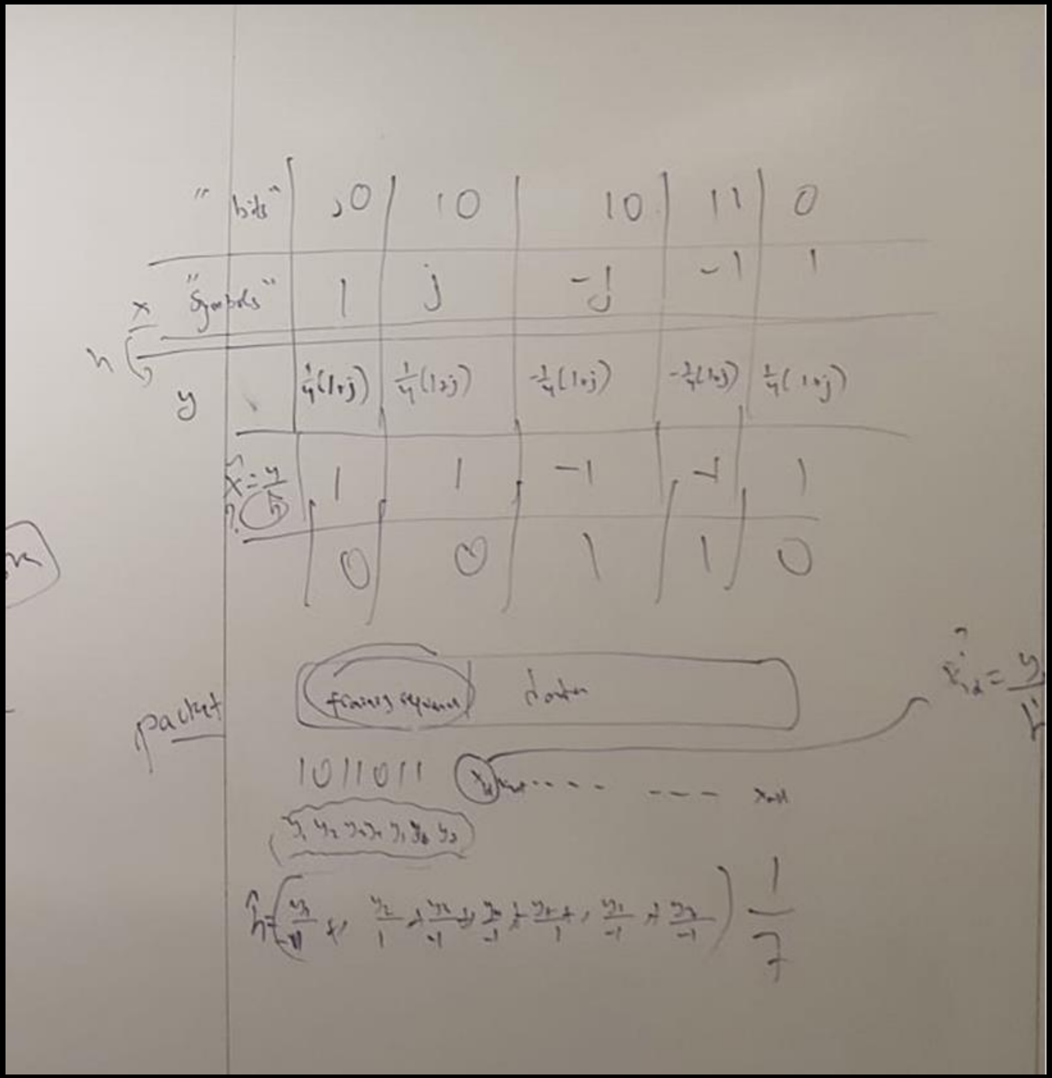
Pros and cons of long vs short preamble?
How long should it be?



Modulation Schemes

Bits -> Complex numbers, Preambles, BPSK/QAM, benefits





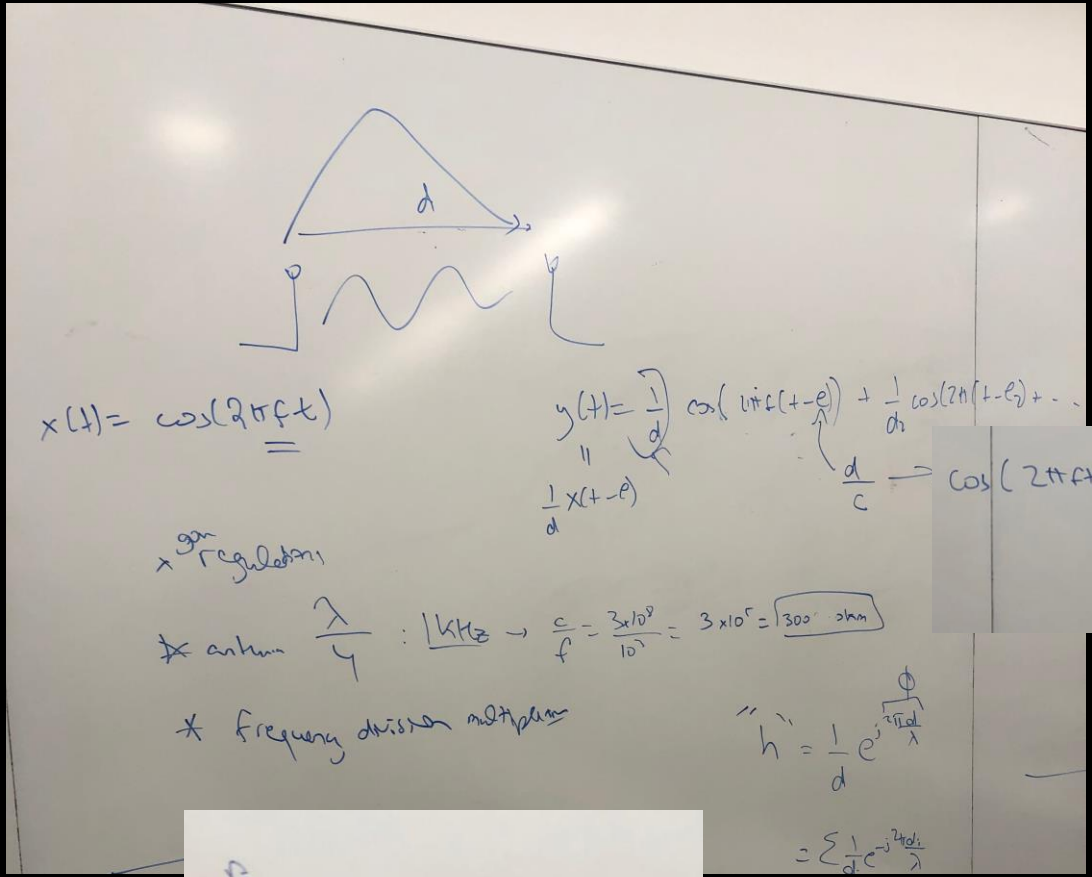
The Wireless Channel (Physics)

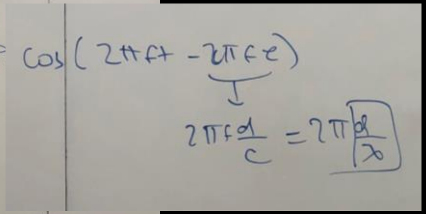
Cosine (at frequency), 1 path, what happens over the medium (and why), why not baseband

The Wireless Channel (Physics)

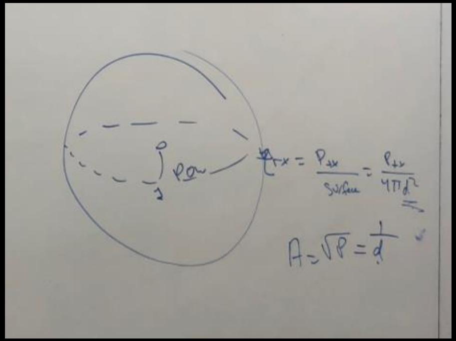
Attenuation and delay

focus on 1 path

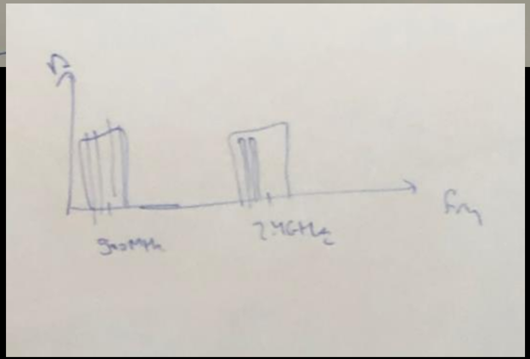


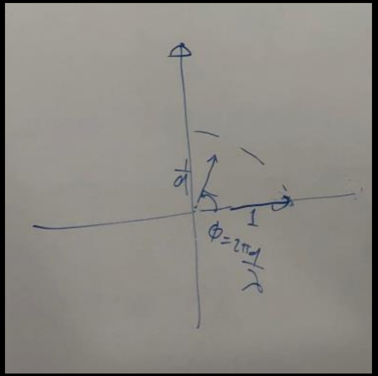


Why is attenuation 1/d?



Why can’t transmit directly over the air (without cos)? 3 reasons



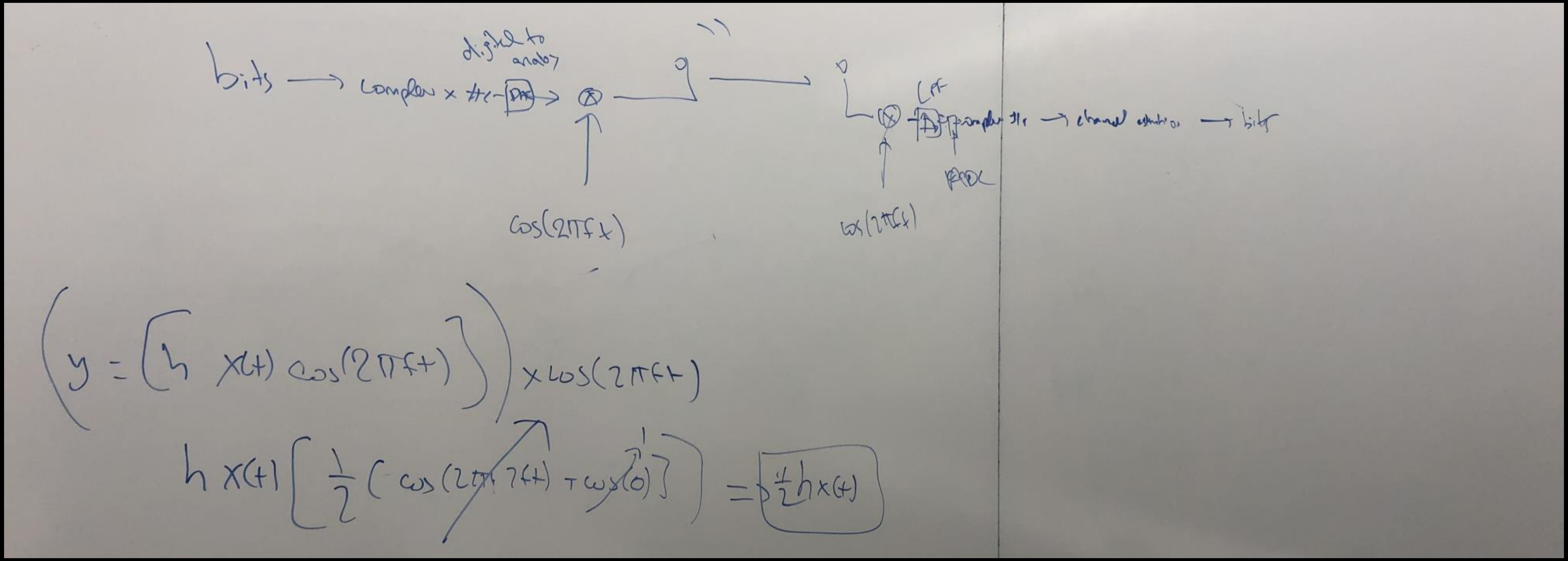


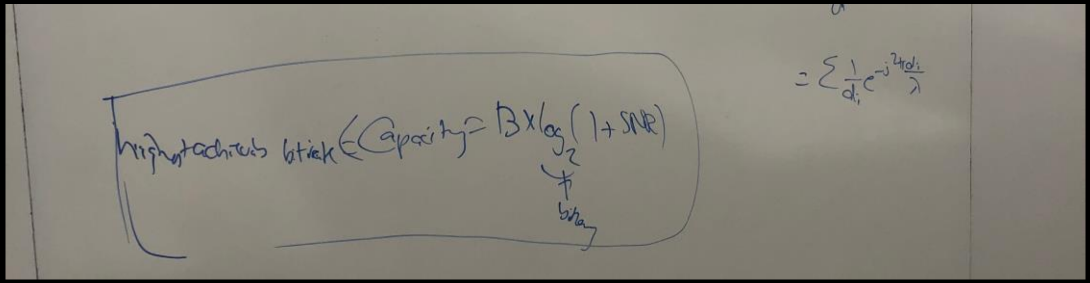
illustration

Downconversion

How do we recover upon receiving?

Downconversion



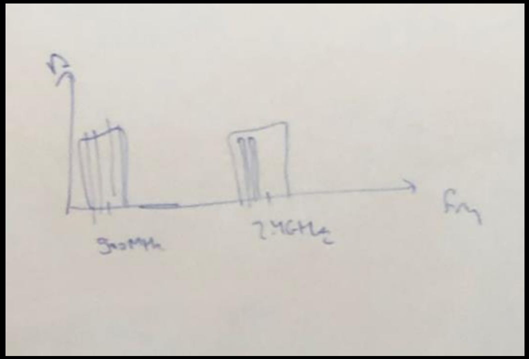


Extensions

Can Tx more frequencies (see later), highest rate

Extensions

Can transmit over more frequencies (scope outside this class)



What determines how much information I can get across?

Bandwidth, SNR

$$R<C = B*\log(1+SNR)$$

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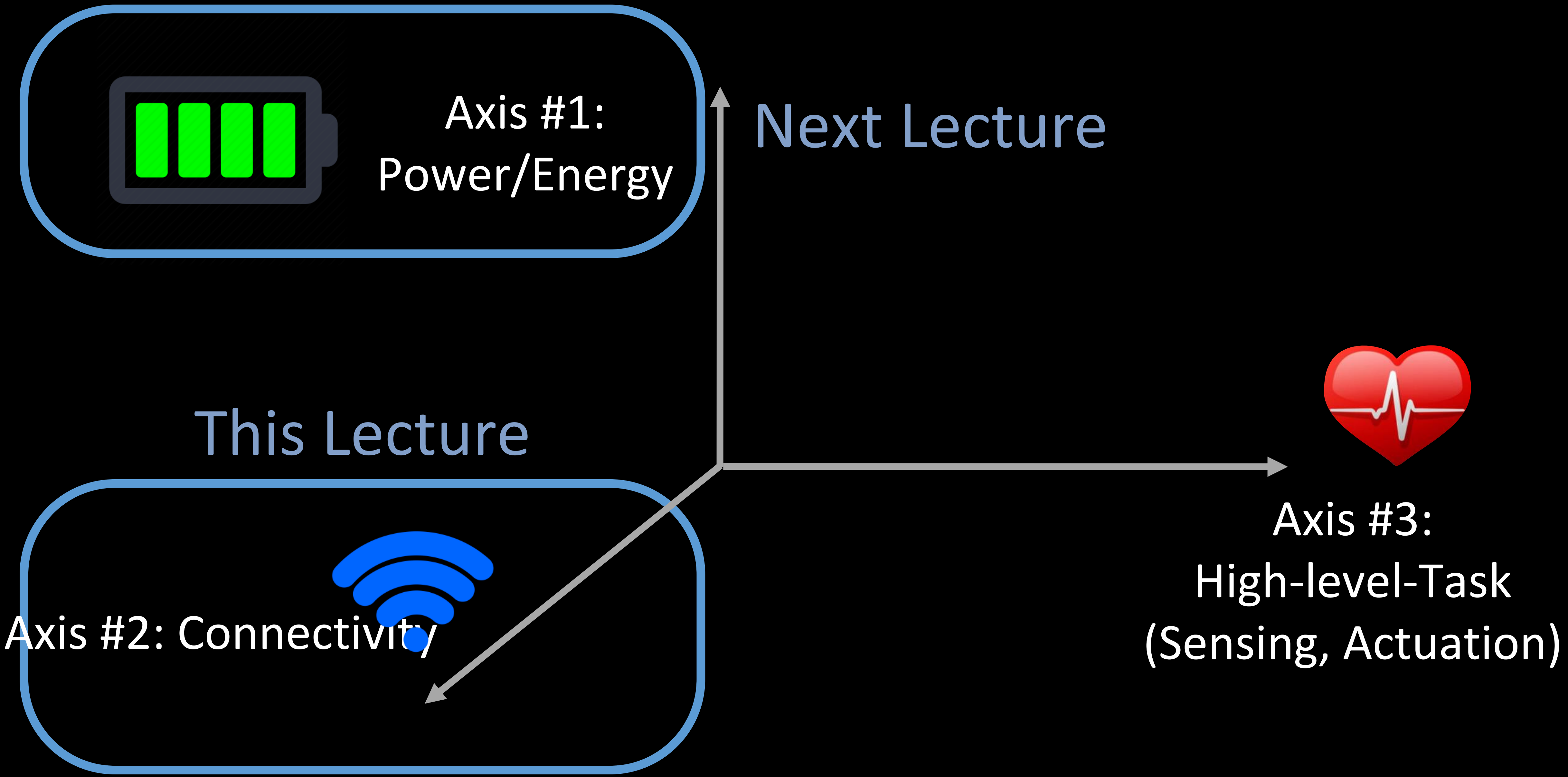
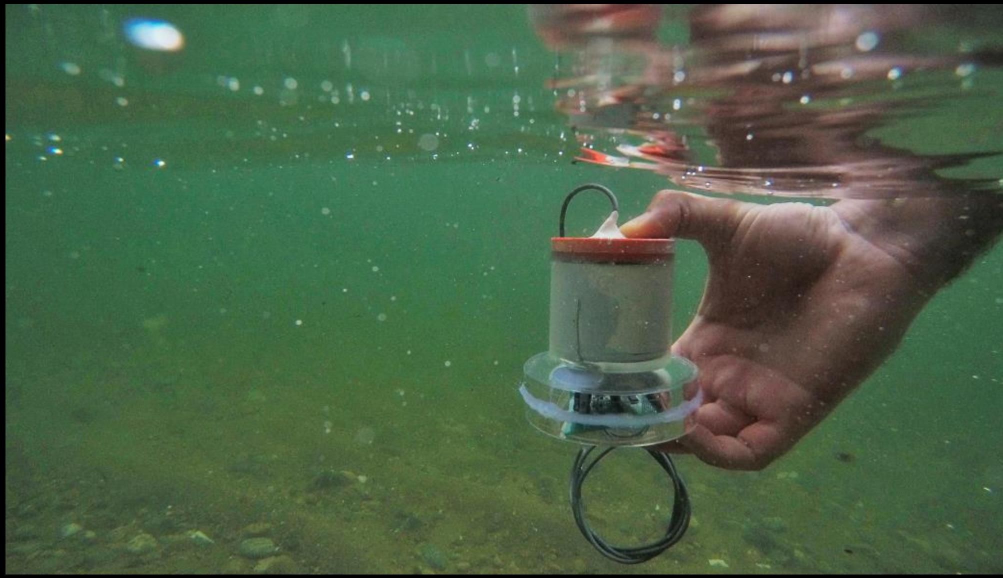
Main Components of (Ocean) IoT Systems



Next Class (Power: Backscatter, Energy Harvesting)

1) Required (Reviews)

- Underwater Backscatter, SIGCOMM ’19
- Ultrasonic Power, TMC ’20



2) Optional Readings

- UWB Backscatter
- RFID WISP Platform