MAS.S62:

Ocean IoT

Technologies, Industries, Sustainability

Lecturer

Fadel Adib fadel@mit.edu

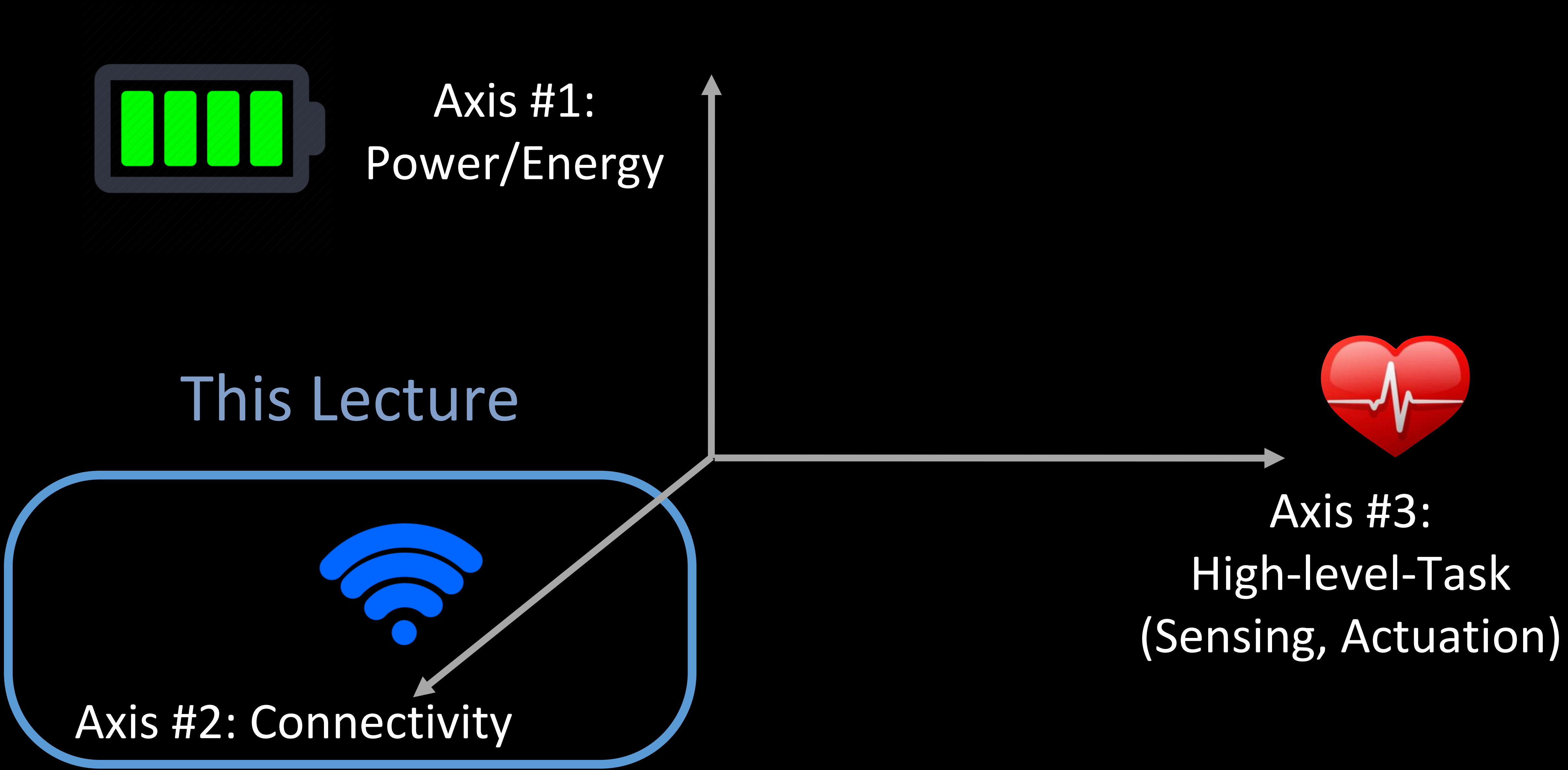
TA

Sayed Saad Afzal afzals@mit.edu

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

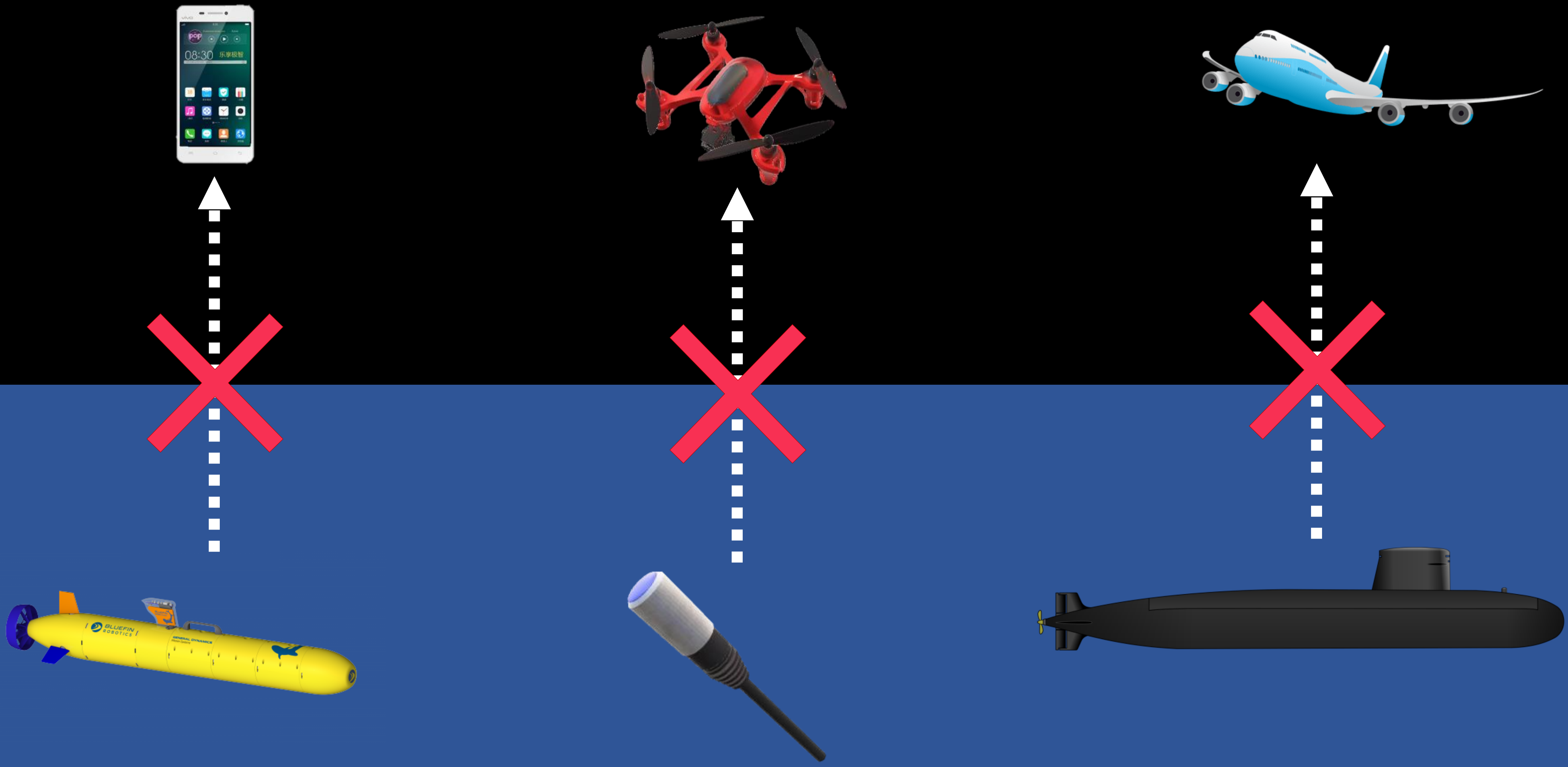
Finding Missing Airplanes

Ocean Scientific Exploration

Underwater-to-Air Comm Applications

Why is it difficult?

Direct Underwater-Air Communication is Infeasible



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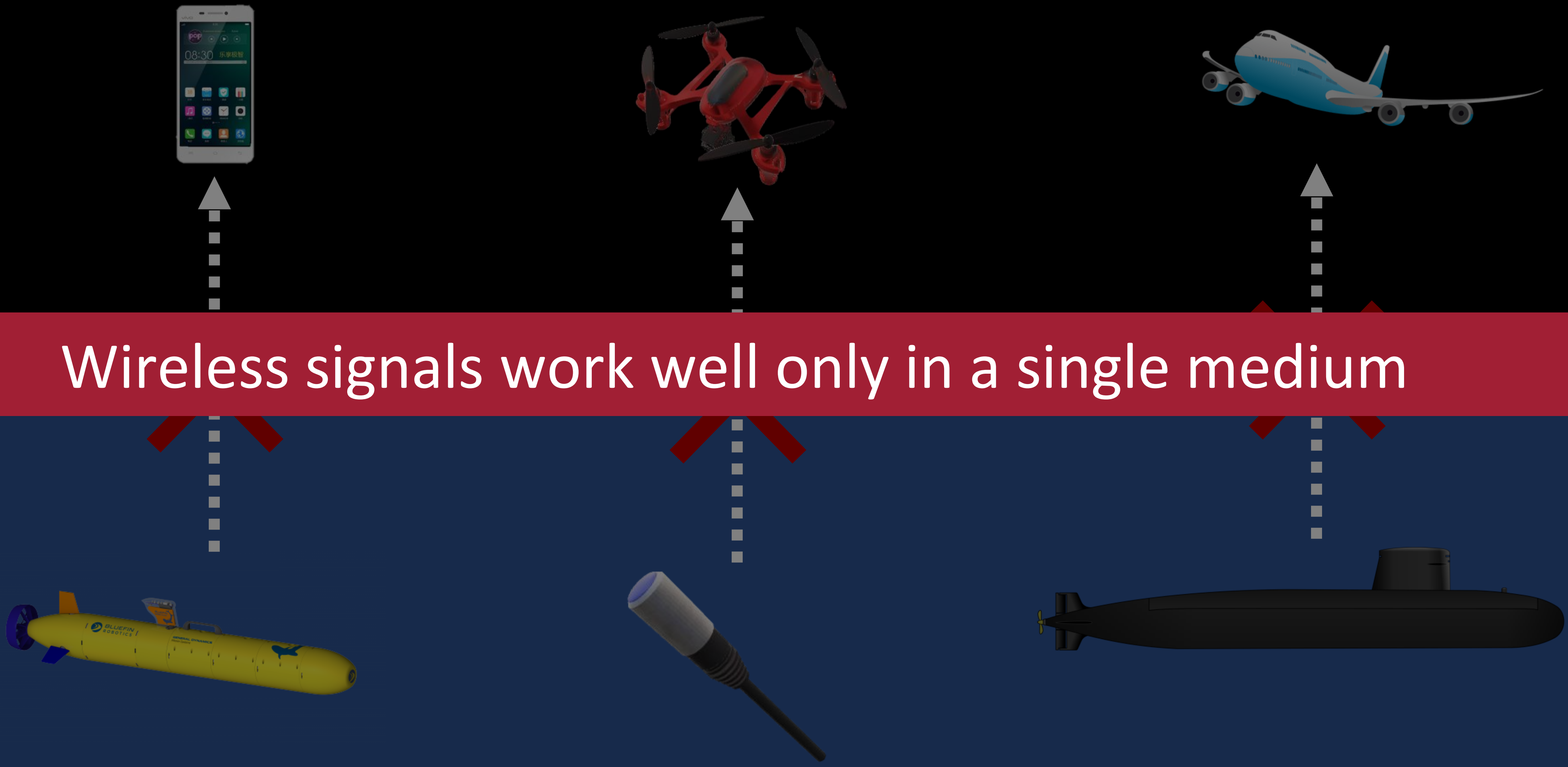
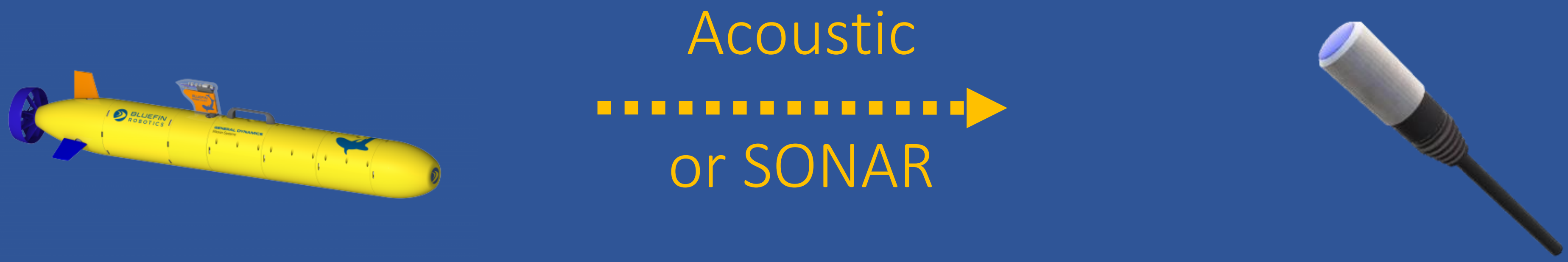


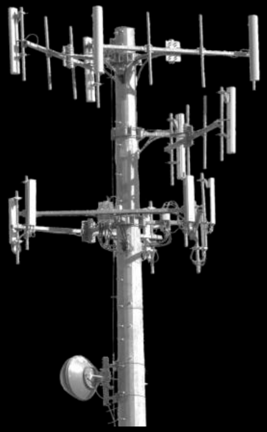
Wireless signals work well only in a single medium

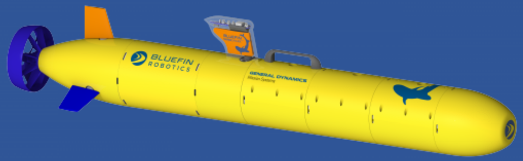
Wireless Signals Work Well Only in a Single Medium



Wireless Signals Work Well Only in a Single Medium

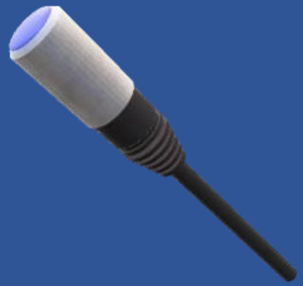
Radio



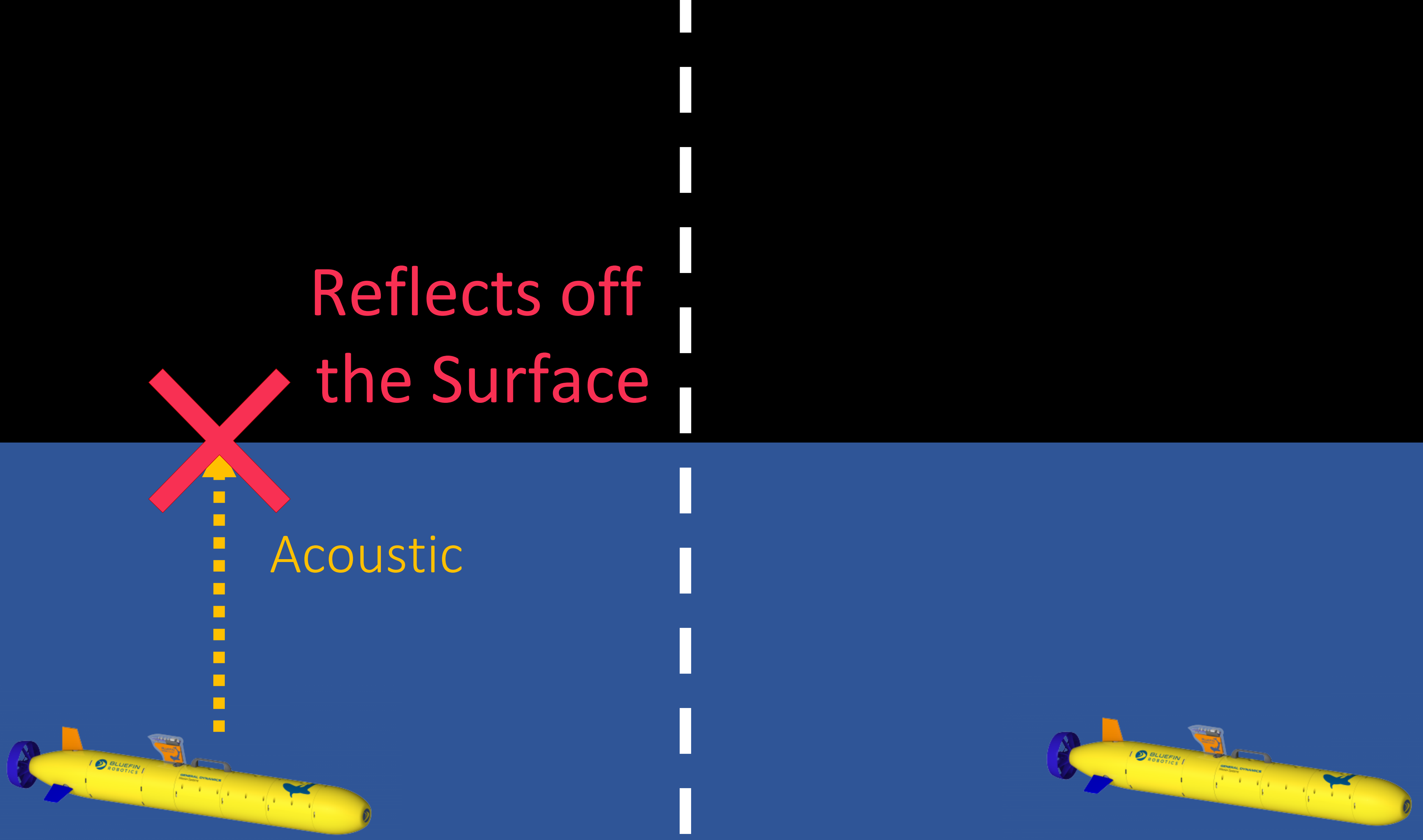


Acoustic

or SONAR



Use Acoustic signals?

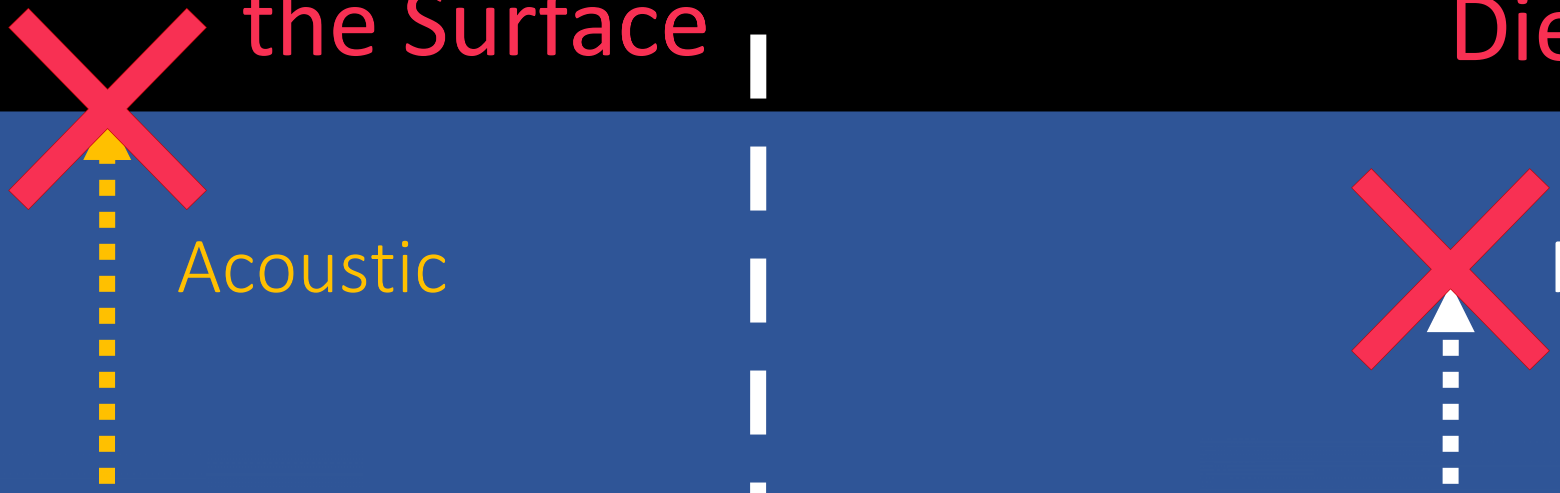


Use Acoustic signals?

Use Radio Signals?

Reflects off the Surface

Radio Signals Die in Water

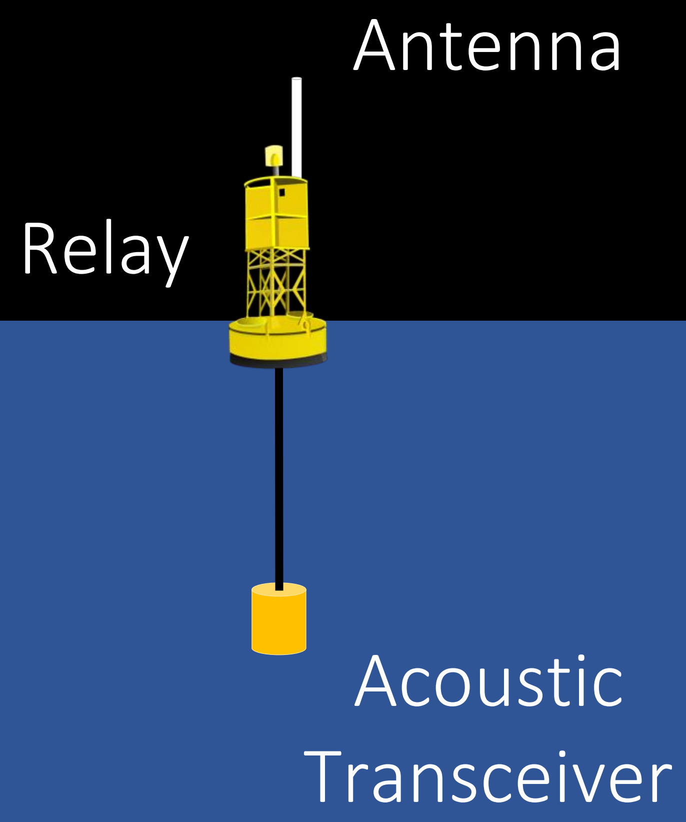


Work-arounds like relays, sunobouys, or surfacing are not cost-efficient or scalable

What are today’s approaches for solving this problem?

Approach #1: Relay Nodes

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



Approach #1: Relay Nodes

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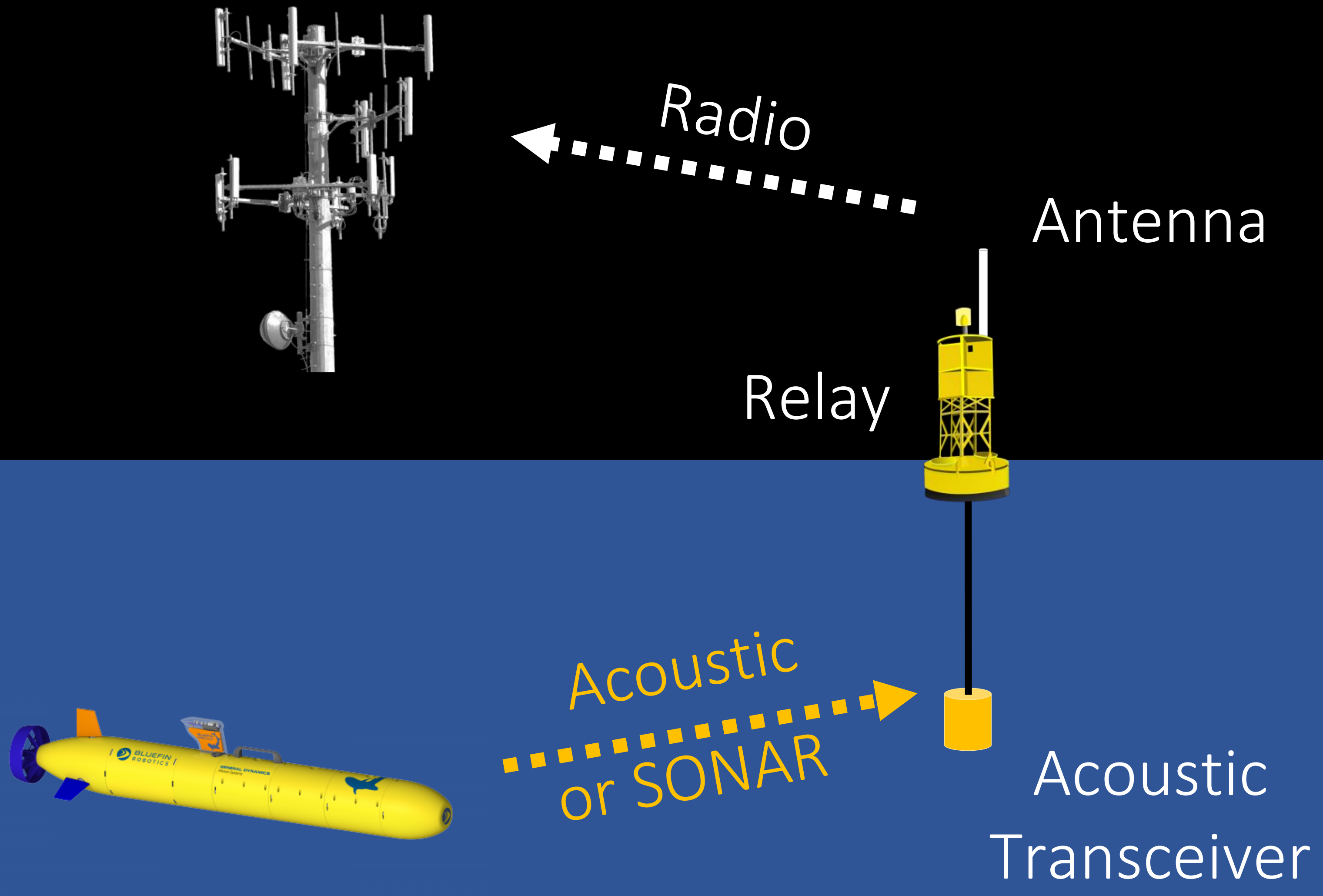
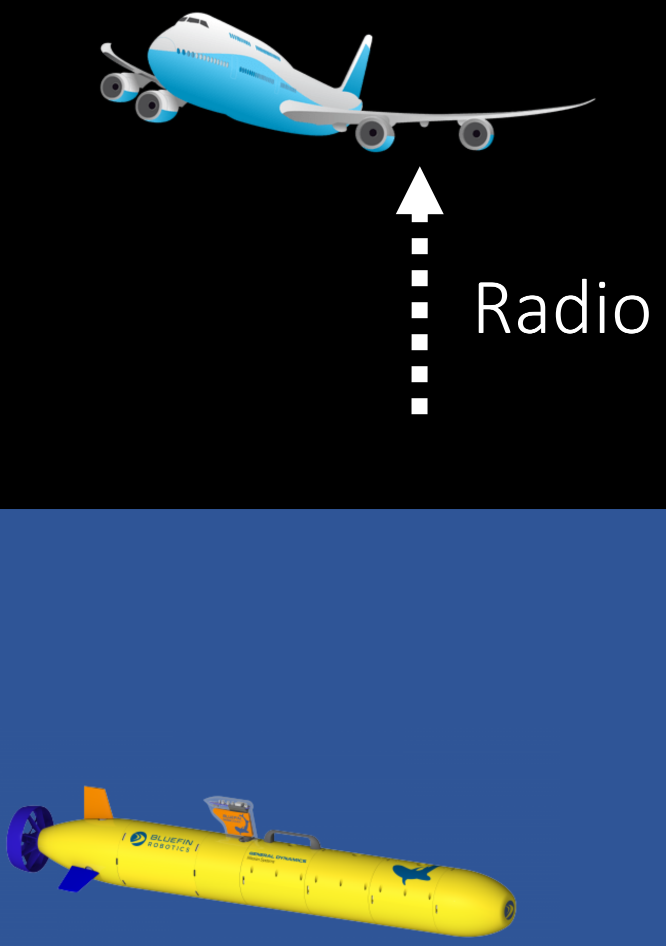


Approach #2: Surfacing

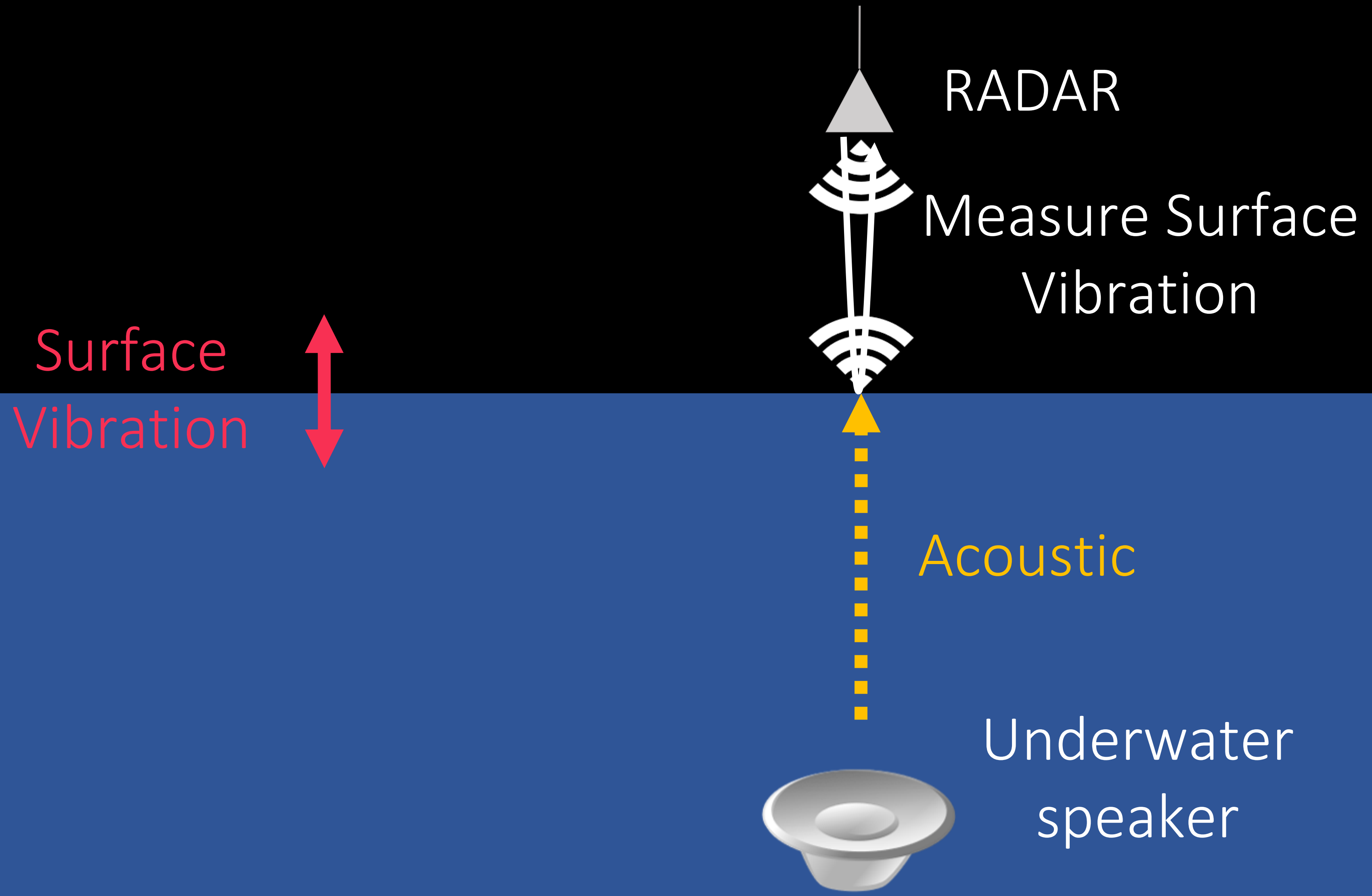
[ICRA’06, MOBICOM’07, OCEANS’10, ICRA’12]



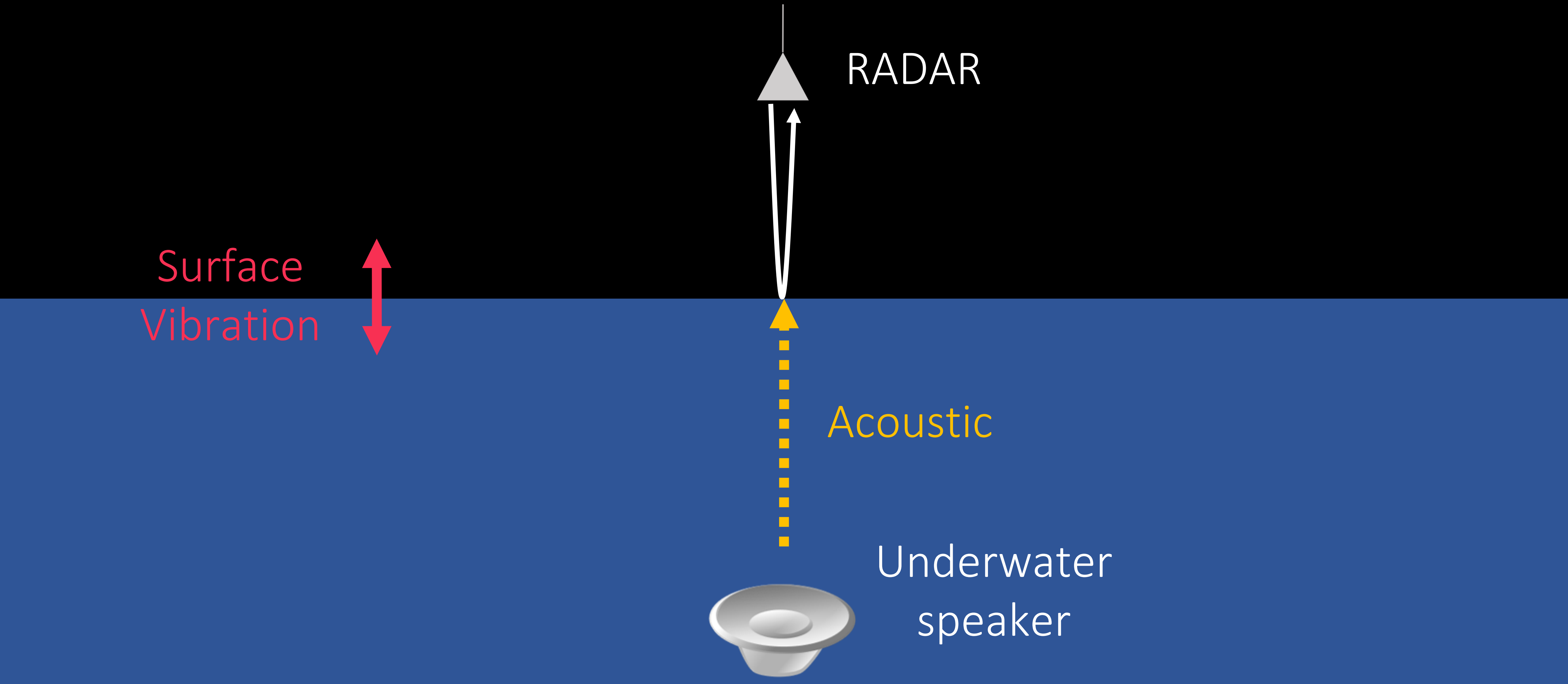
Technology that Enables Compact Sensors to Wirelessly Communicate Across the Water-Air Boundary

How does it work?

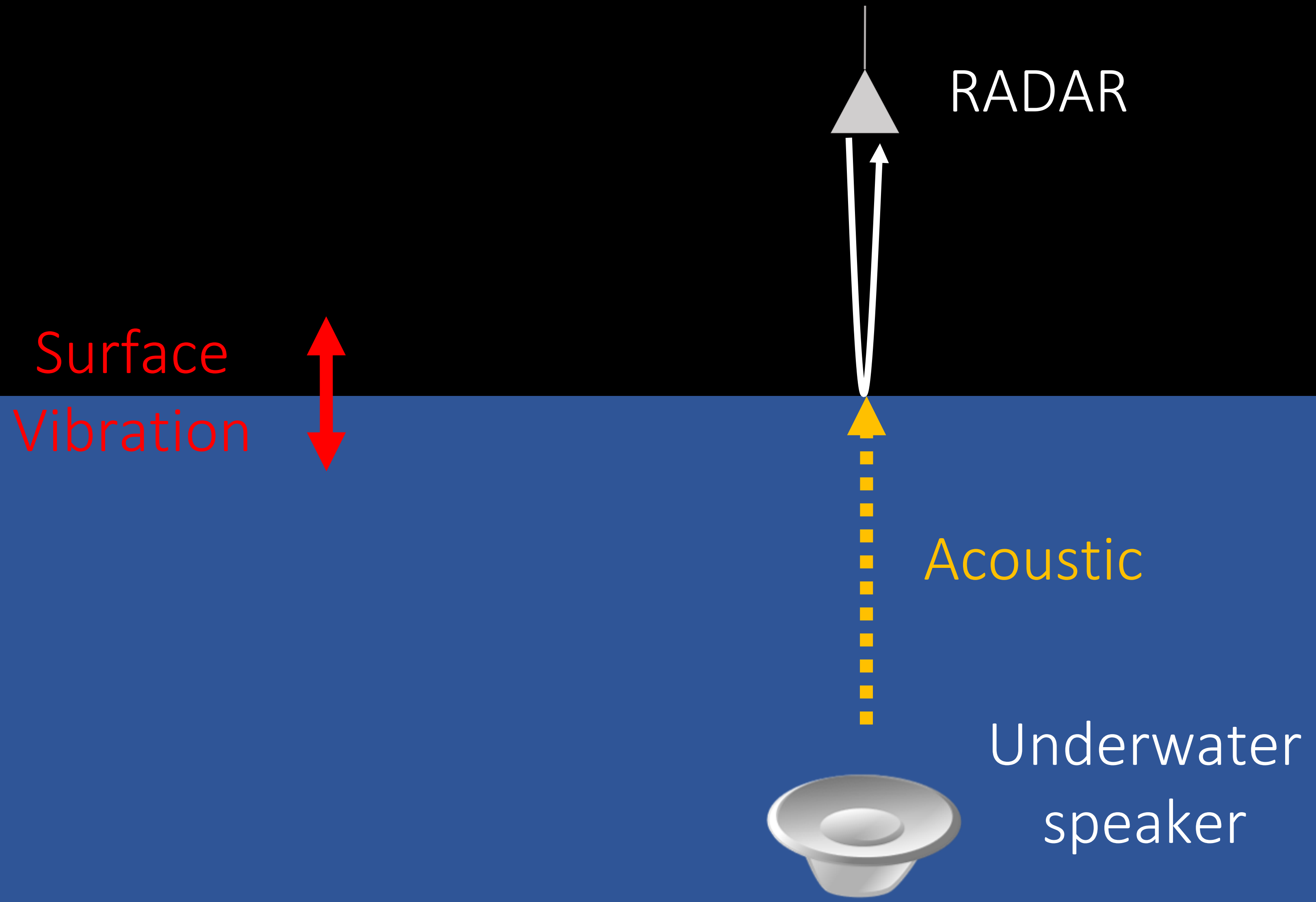
Technology that Enables Compact Sensors to Wirelessly Communicate Across the Water-Air Boundary



Translational Acoustic RF Communication (TARF)



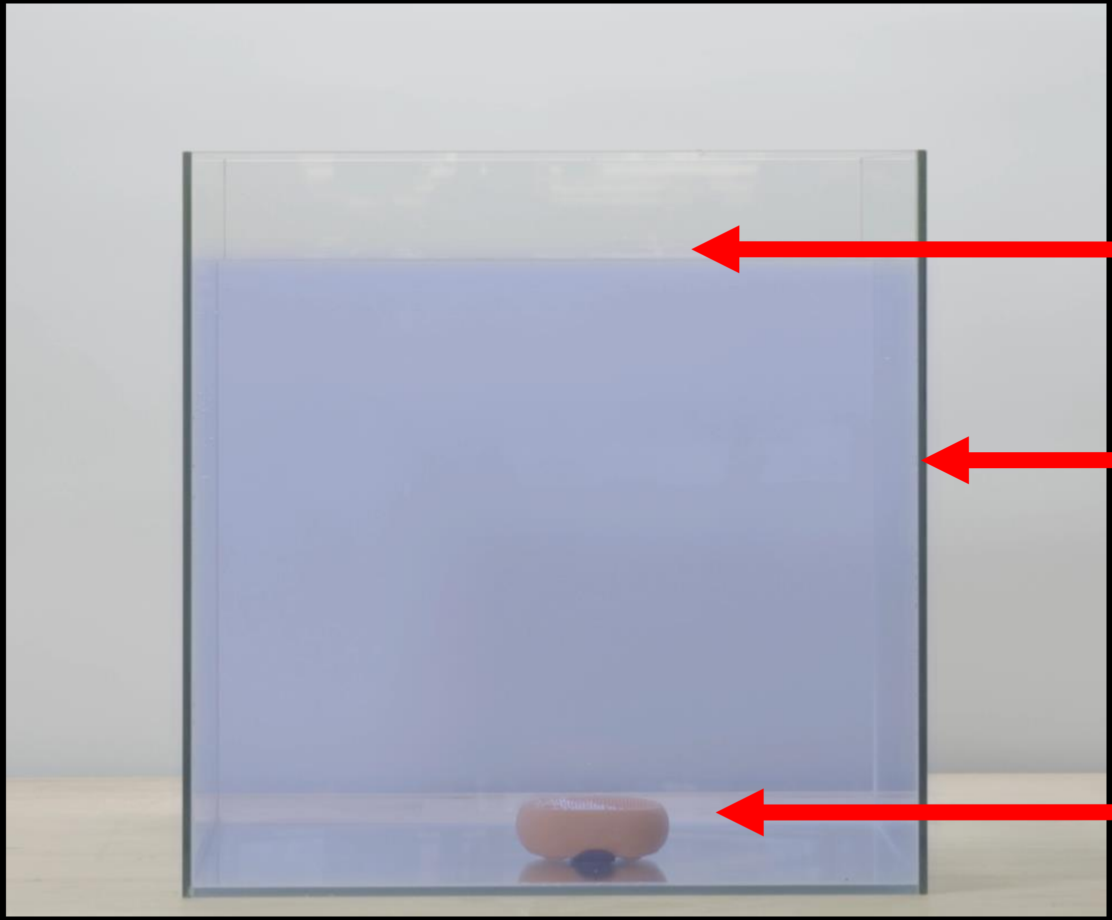
Key Idea



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

Recording the Surface Vibration

<u>Experiment:</u> Transmit Acoustic Signals at 100Hz



Recording the Surface Vibration

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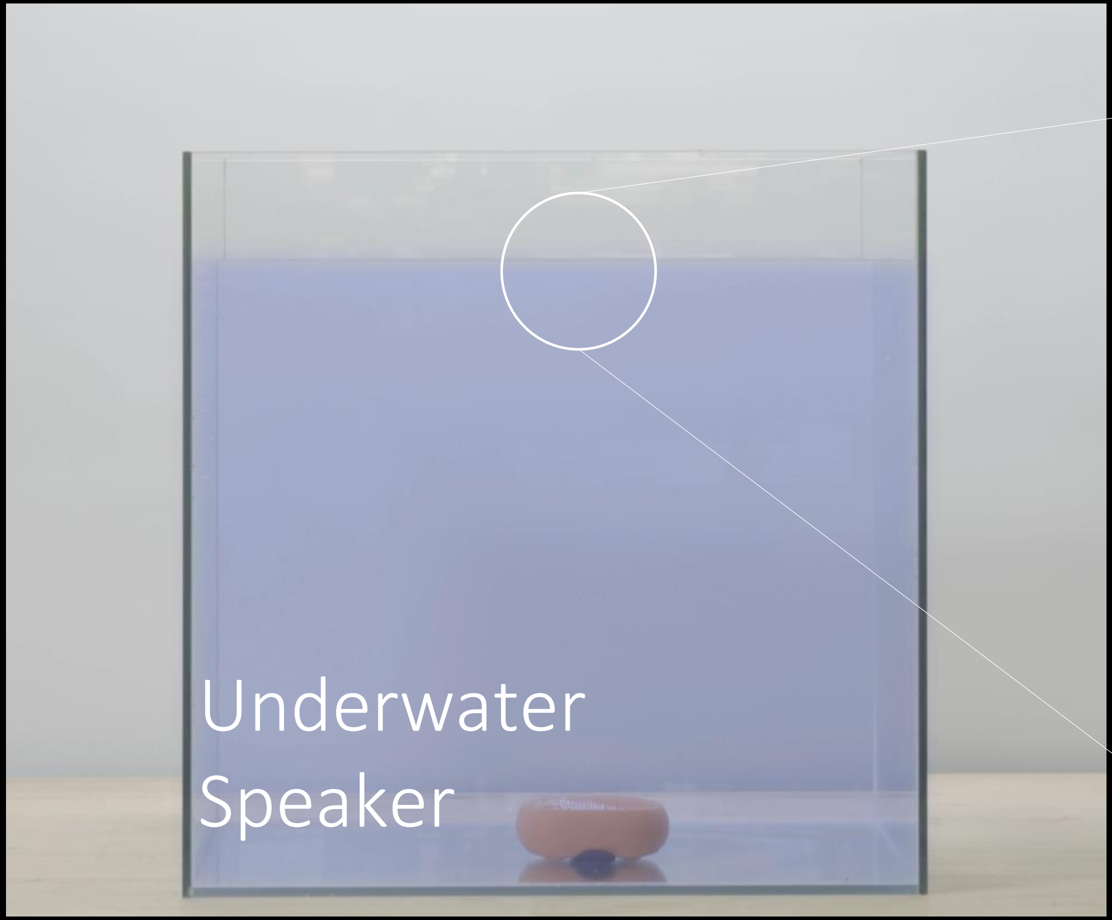
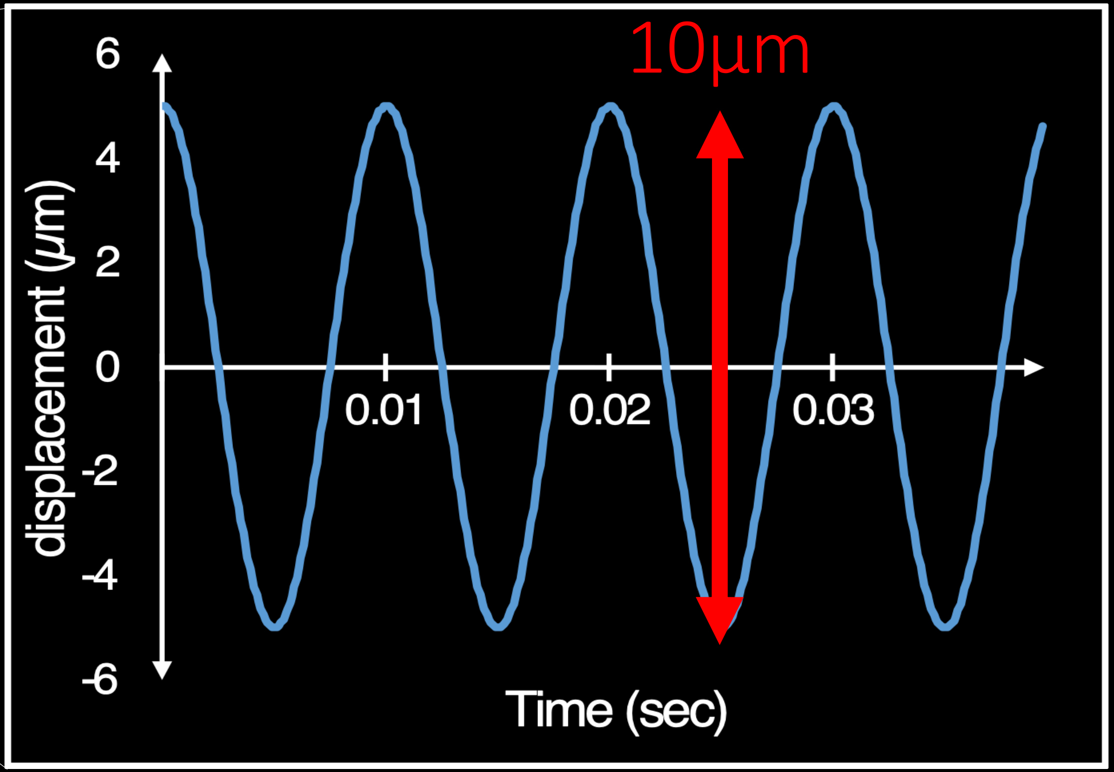
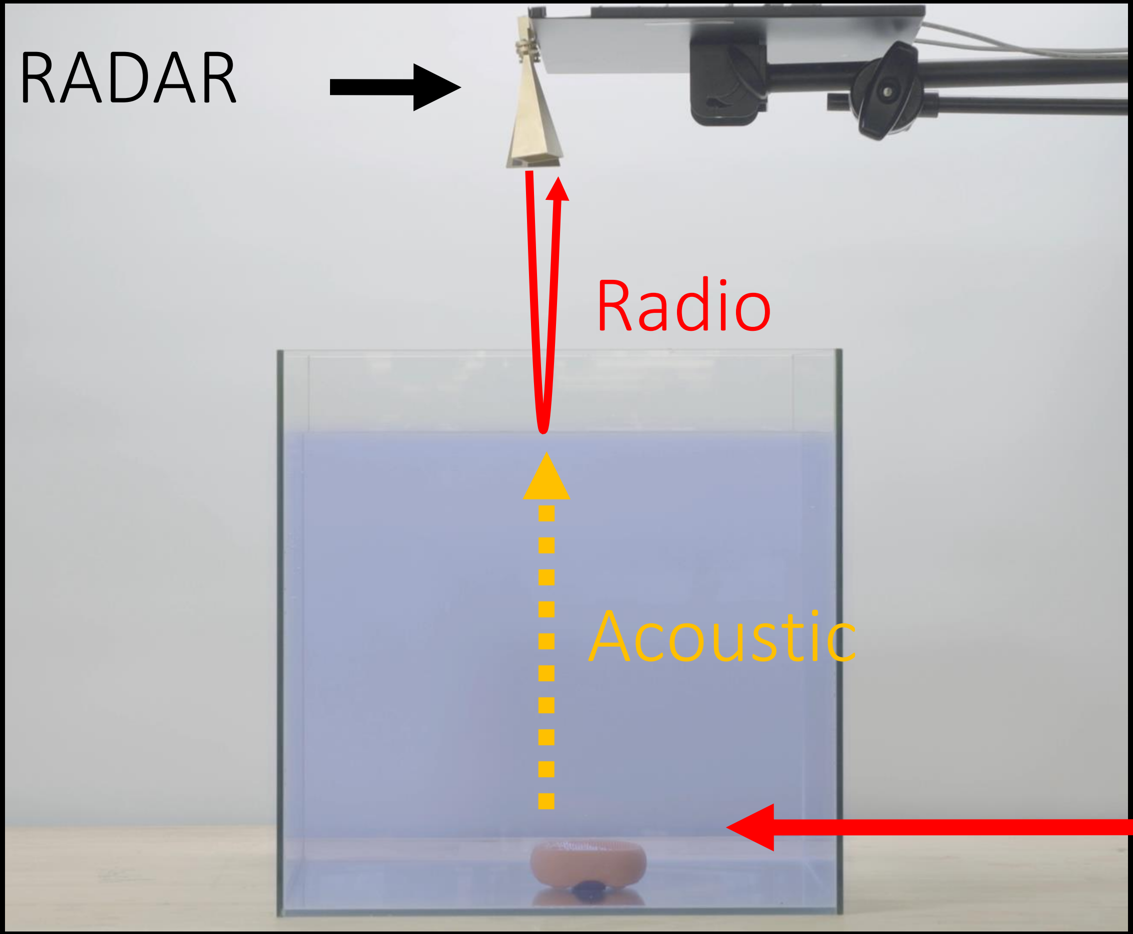




How Can We Sense Microscale Vibration?

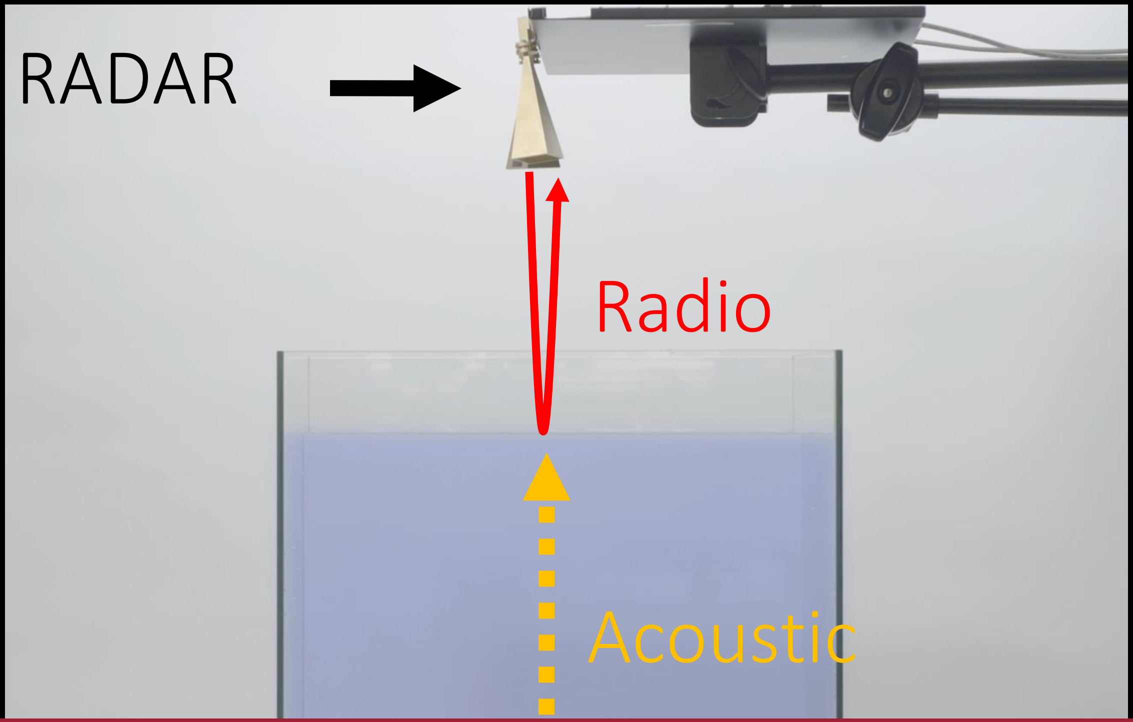
Idea: Use RADAR to measure the surface vibration



Underwater Speaker

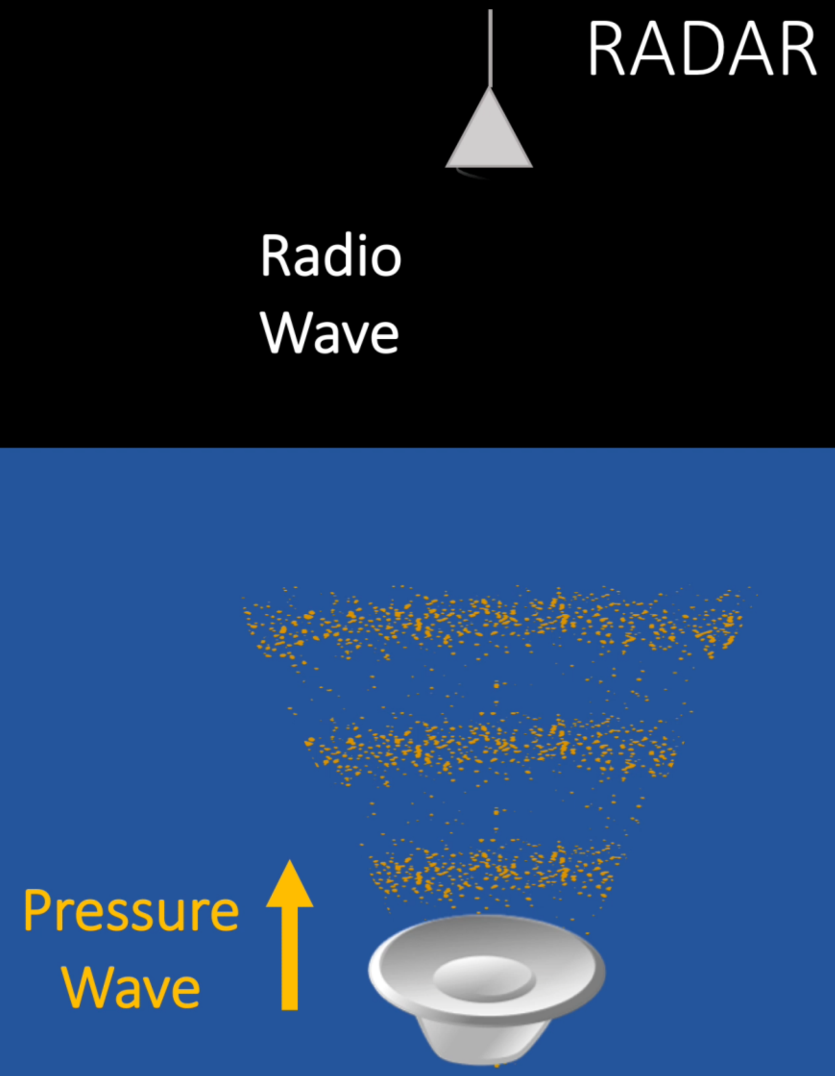
How Can We Sense Microscale Vibration?

Idea: Use RADAR to measure the surface vibration



<u>Problem:</u> 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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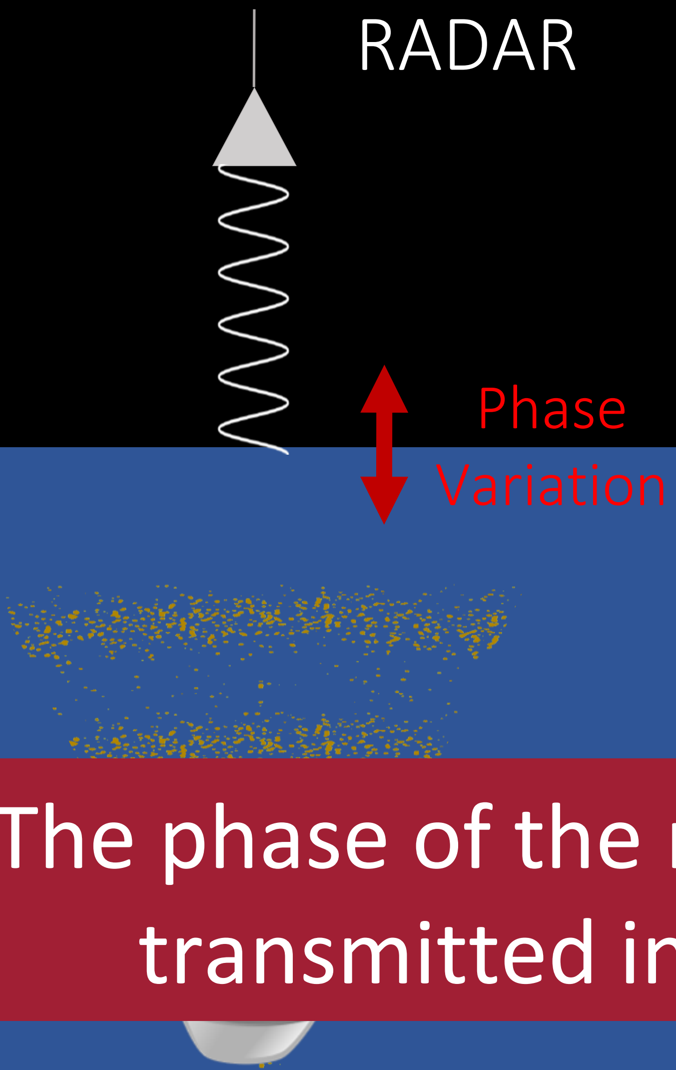


$$Phase = 360 \times \frac{displacement}{wavelength}$$

10µm

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

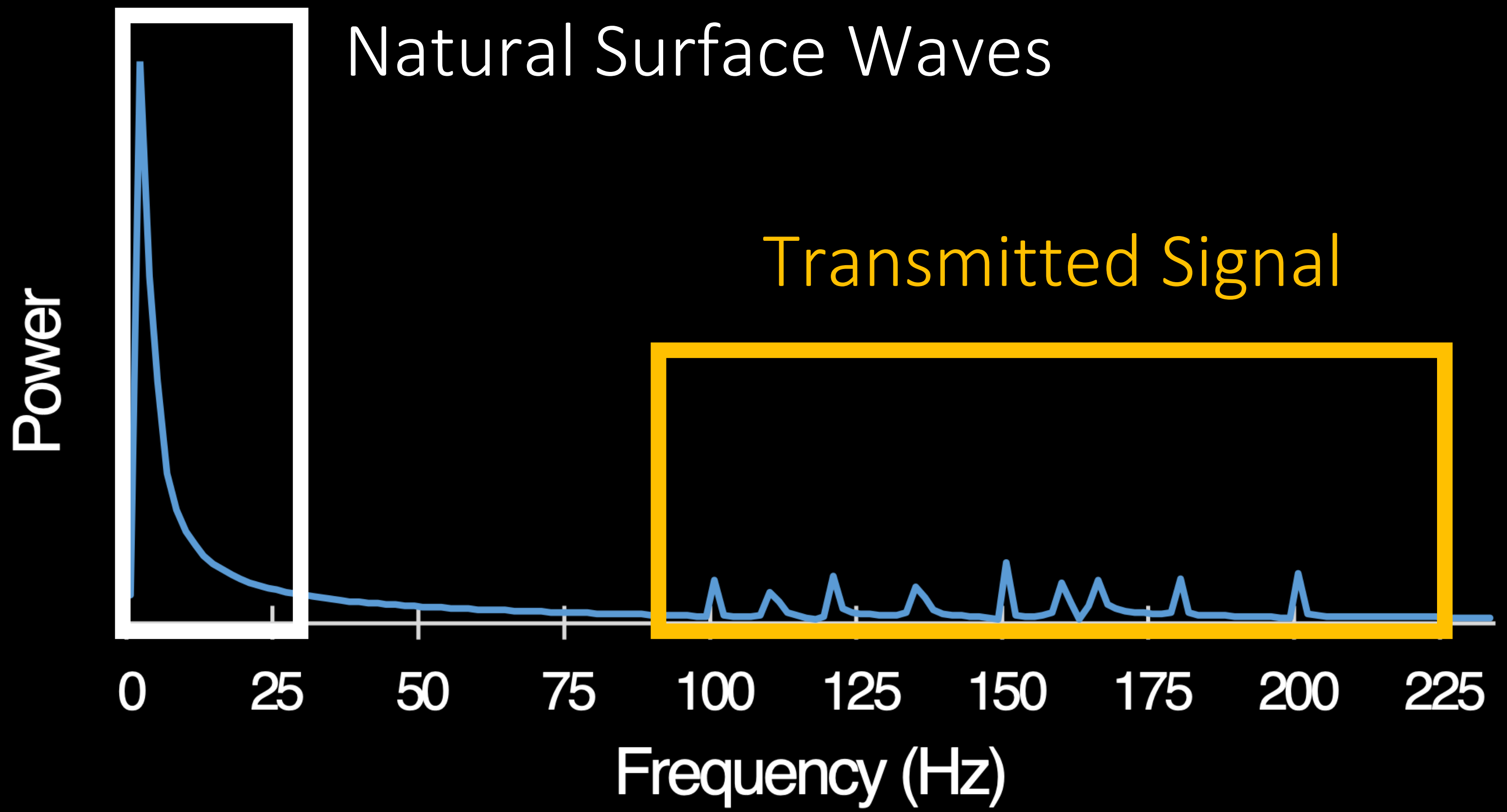
↓

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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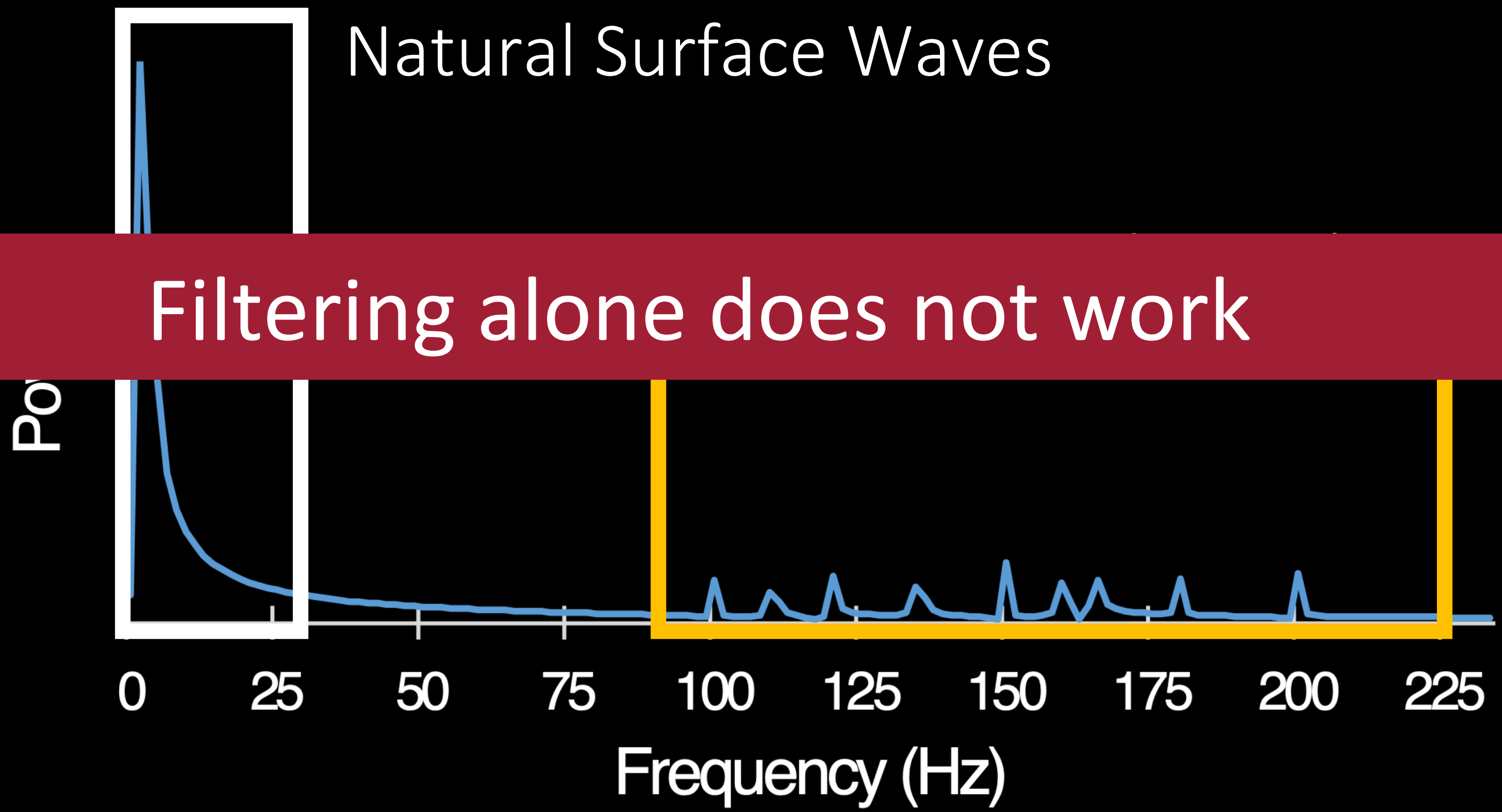

Filtering alone does not work

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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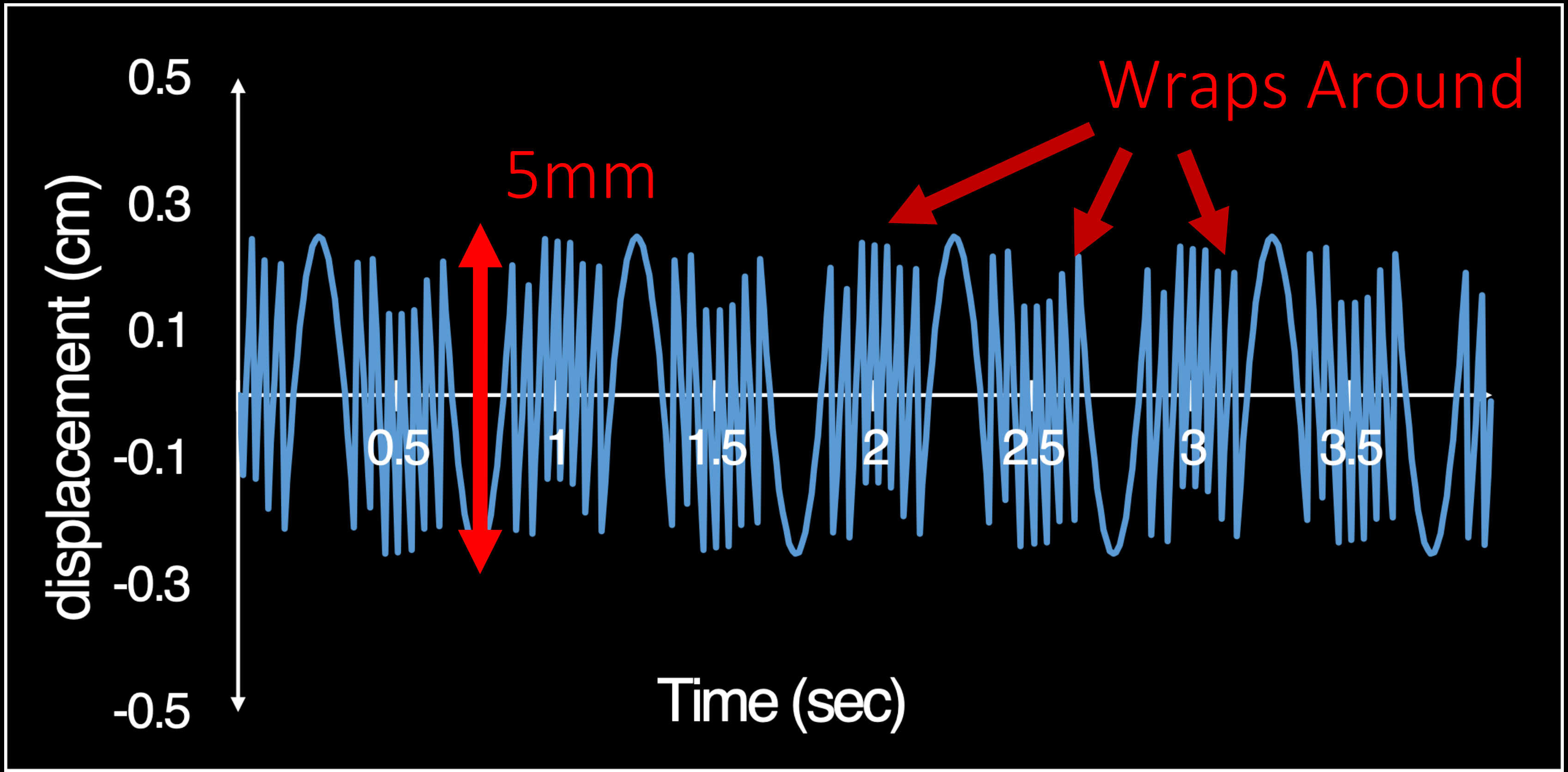
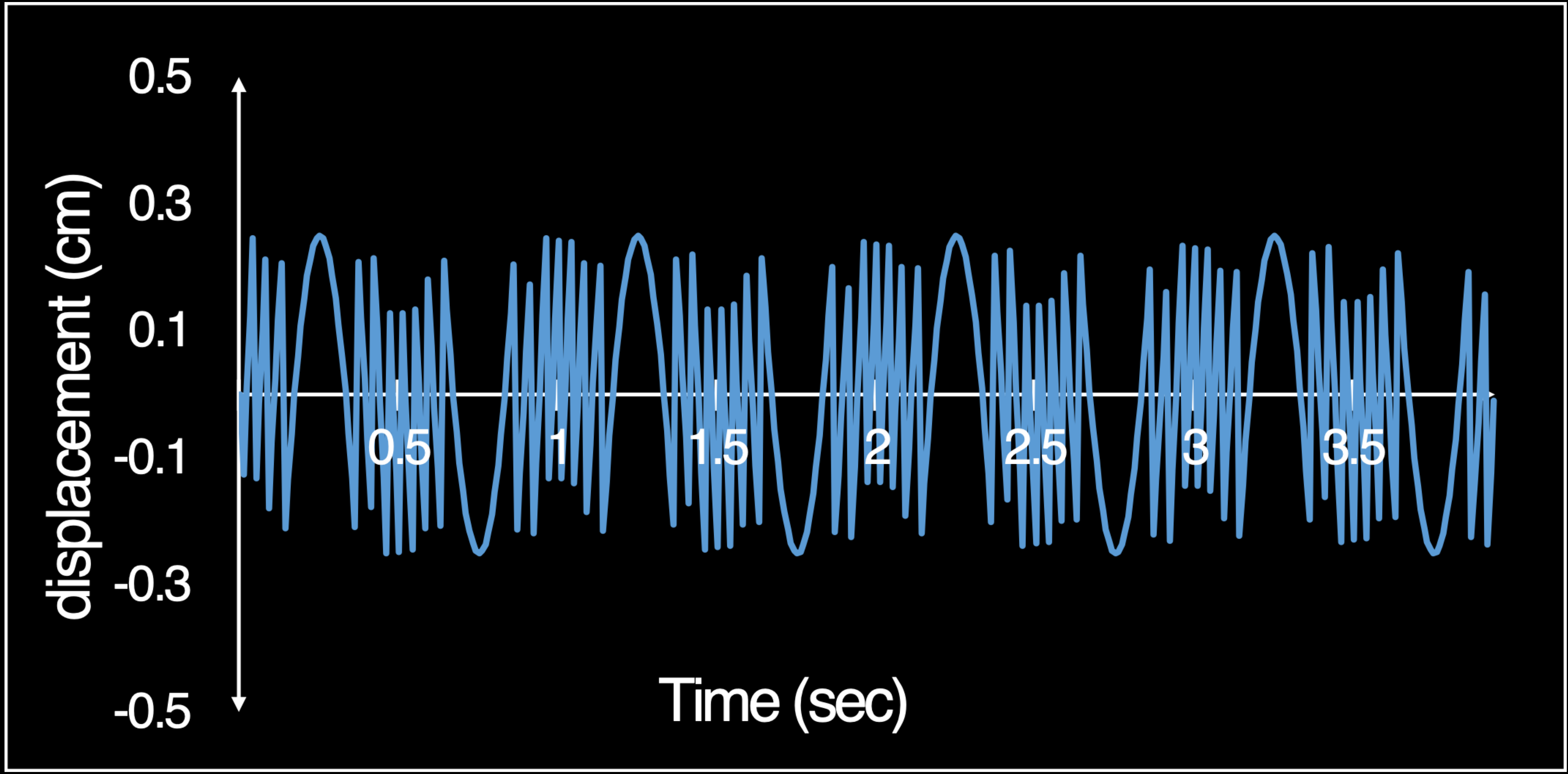
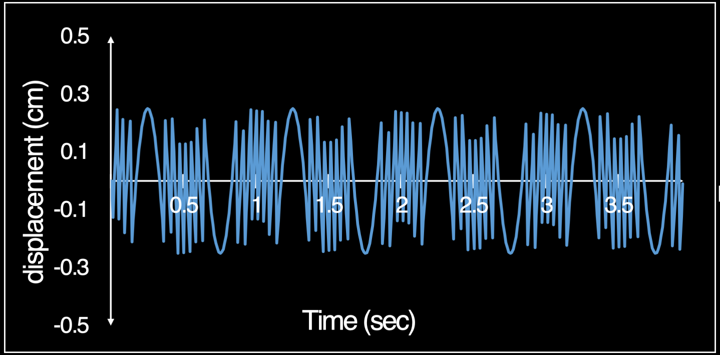


Dealing with Waves

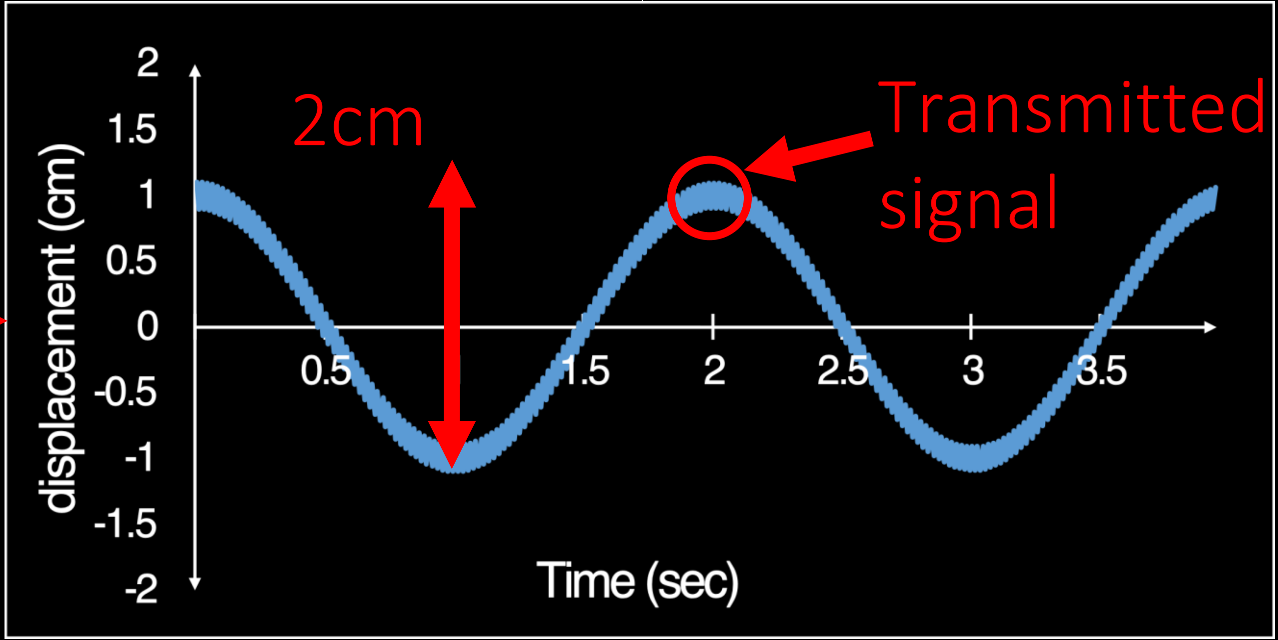


Dealing with Waves

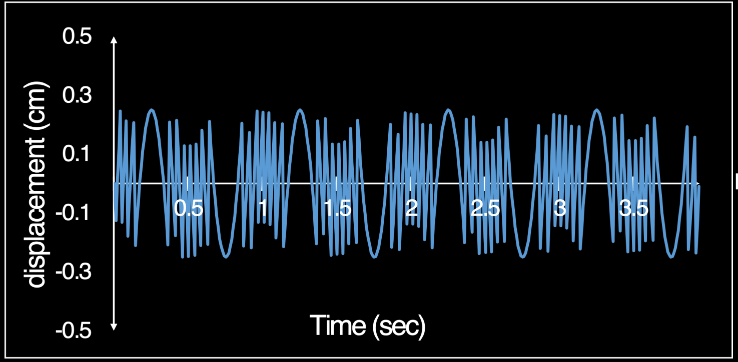


Track & Unwrap

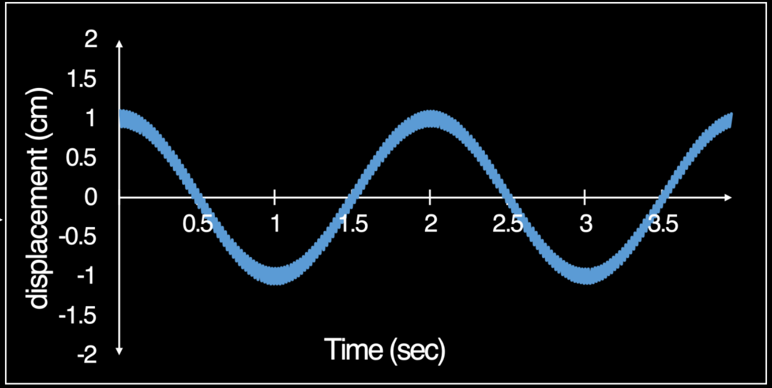
Trend is Water Surface Wave



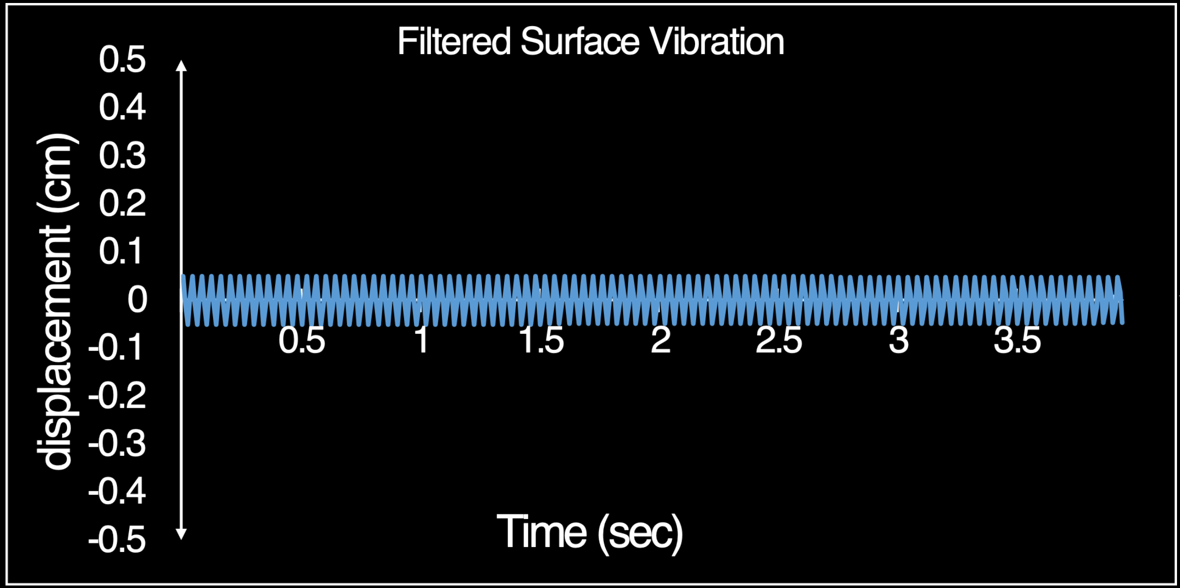
Dealing with Waves



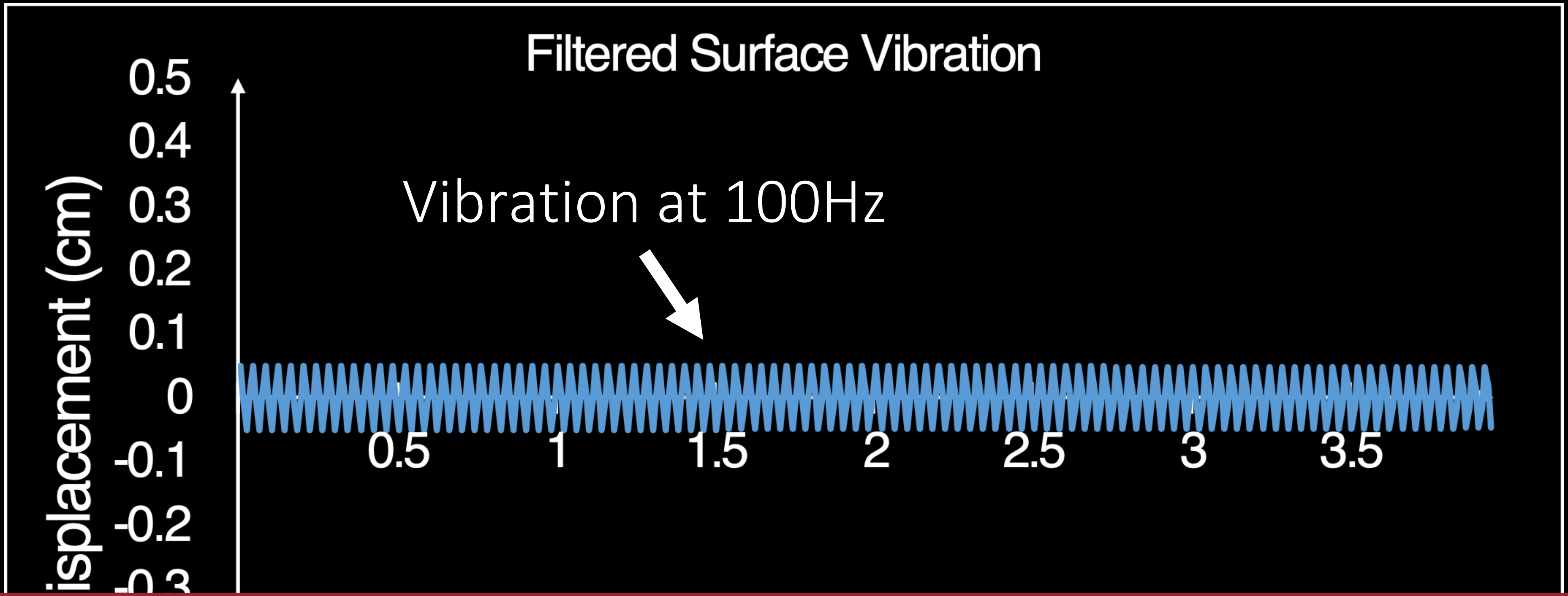
Track & Unwrap



Filter

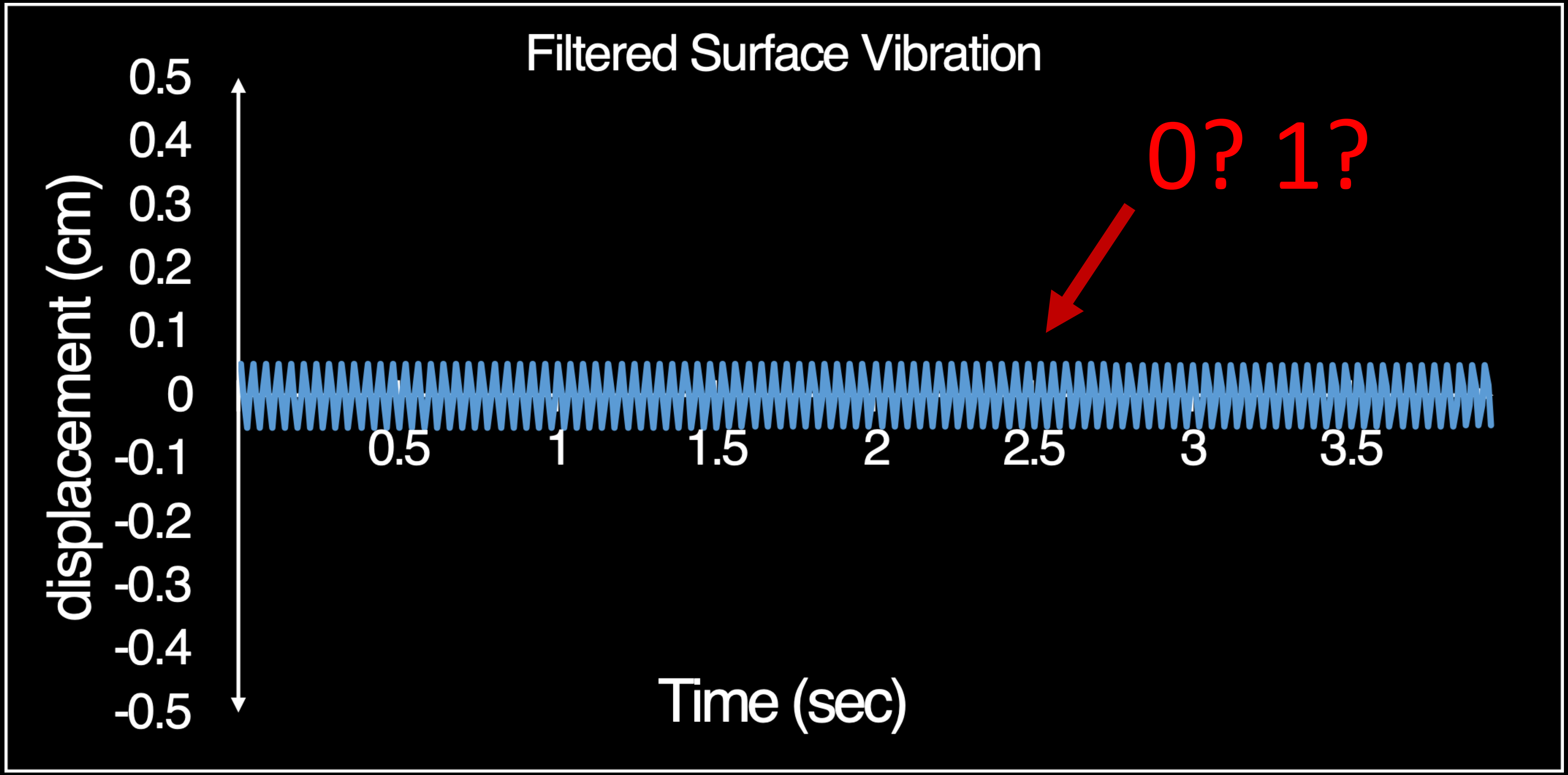


Dealing with Waves



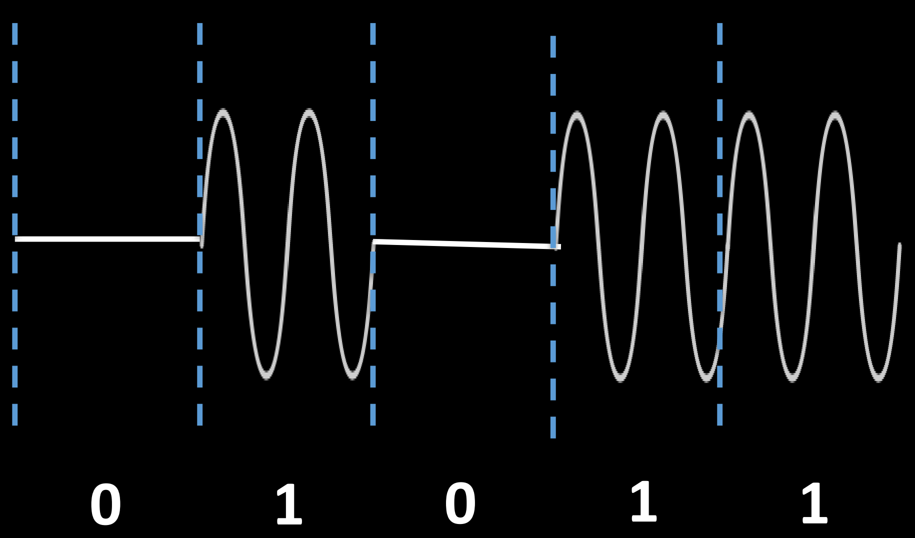
By treating natural surface waves as structured interference, we are able to track and eliminate their impact on our signal

How Can We Decode?

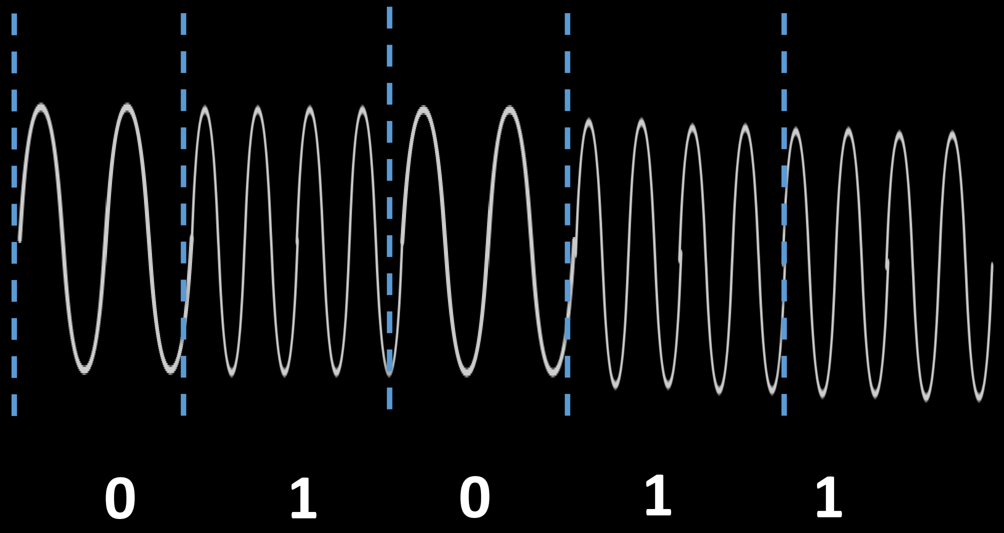


Simple Modulation schemes

ON-OFF keying, FM0/Manchester, FSK

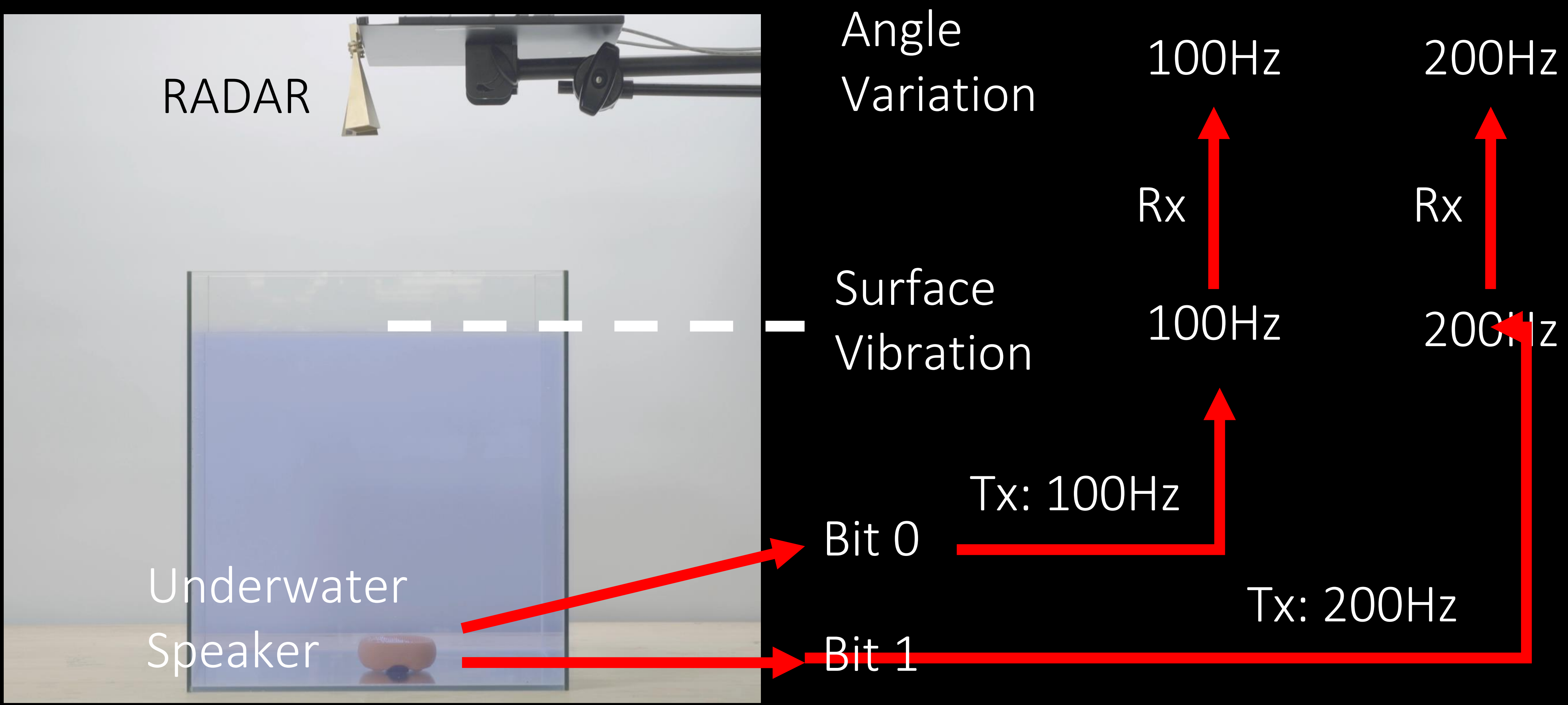


On – Off Keying



Frequency shift keying (FSK)

Decoding Information



Standard Modulation Schemes?

The wireless channel

Mathematics & Physical Interpretation

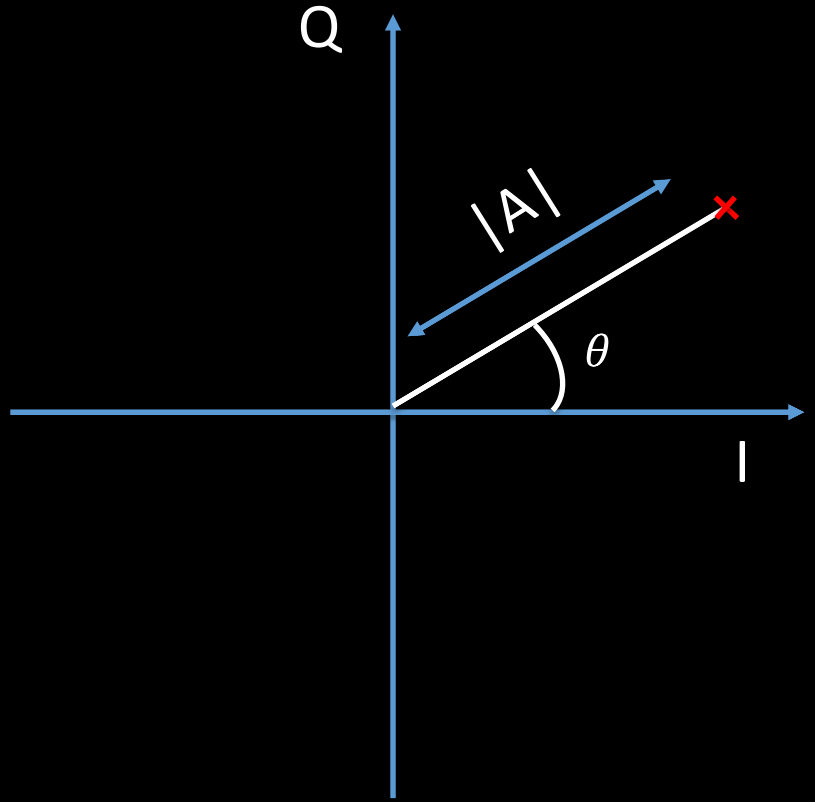
Upconversion & Downconversion

Modulation & Demodulation

The Wireless Channel (Math)

Complex number, I/Q plane, example

$$X = Ae^{j\theta}$$

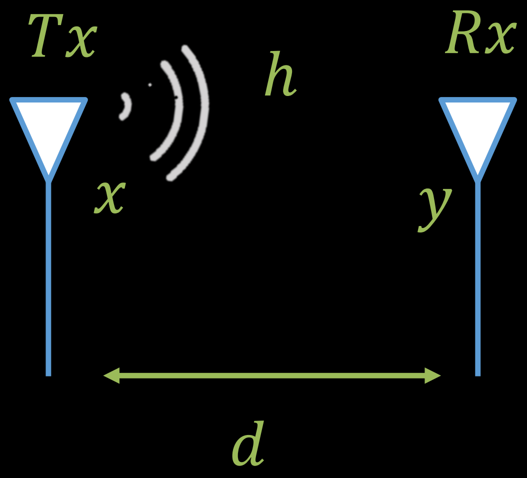


$$\theta = \frac{2\pi d}{\lambda} \qquad |A| = \frac{1}{d}$$

$$x = \cos(2\pi f t)$$

$$y = \frac{1}{d}\cos(2\pi f(t-\tau))$$

$$h = \frac{1}{d}e^{j\frac{2\pi d}{\lambda}}$$



Encoding & Decoding

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

Example channel: x->y? $h = \frac{1}{4} + \frac{1}{4}j$ $Bits = \{1,0\}$ $Symbols = \{-1,+1\}$

How can I know what was transmitted?

- preamble, training sequence
- channel estimation

$h = \frac{Y}{X_a}$ → Where Xa is known

Bits	0	1	1	0	0
Symbols = X	-1	+1	+1	-1	+1
Y = hX	$-\frac{1}{4}-\frac{1}{4}j$	$\frac{1}{4}+\frac{1}{4}j$	$\frac{1}{4}+\frac{1}{4}j$	$-\frac{1}{4}-\frac{1}{4}j$	$-\frac{1}{4}-\frac{1}{4}j$
Decoded Symbols = X’	-1	+1	+1	-1	+1
Decoded bits	0	1	1	0	0

Pros and cons of long vs short preamble?

How long should it be?

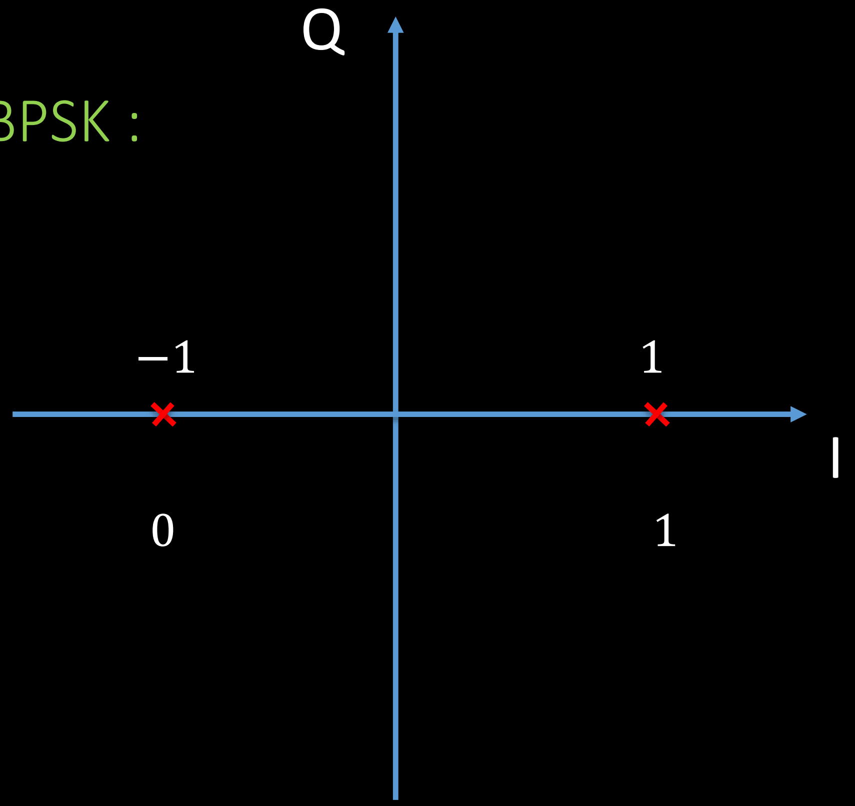
Pro: Can average out effect of noise

Con: channel can change if length of preamble > channel coherence time

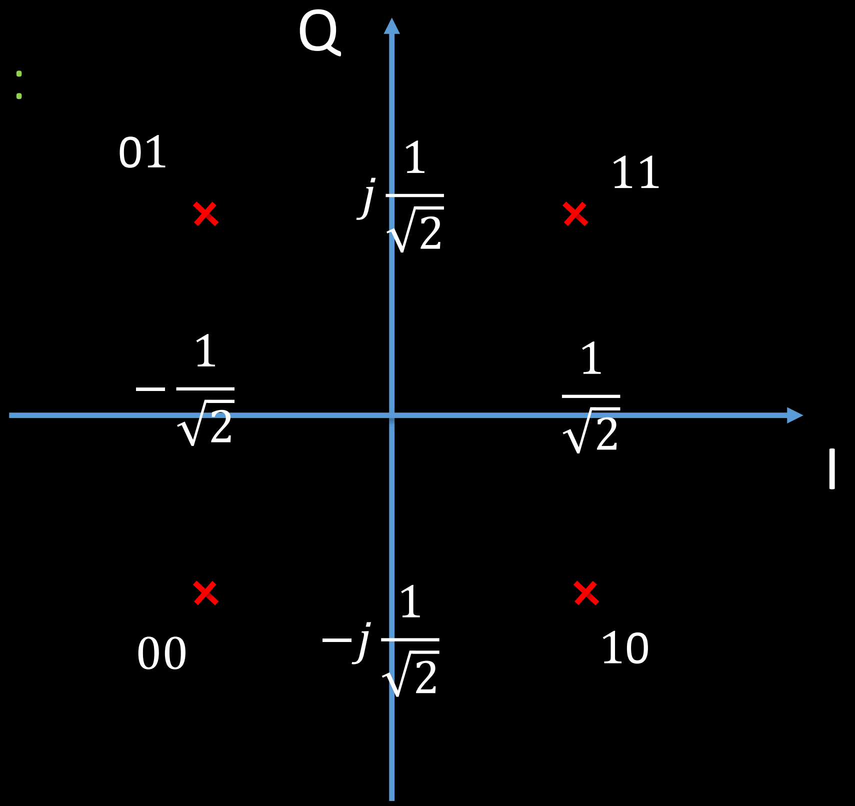
Modulation Schemes

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

BPSK :



QPSK :



BPSK is less susceptible to noise but it only sends 1 bit per symbol, on the other hand QPSK can pack more bits per symbol (2) but it is more susceptible to error due to noise (because the symbol locations get closer in the I-Q plane)

The Wireless Channel (Physics)

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

Q. Why do we use a cosine to communicate data(and not send bits directly)?

A. 1. To aid concurrent transmission and avoid interference from different stations
2. FCC regulations
3. Frequency division multiplexing

Q. Why do we use a large frequency for our carrier signal?

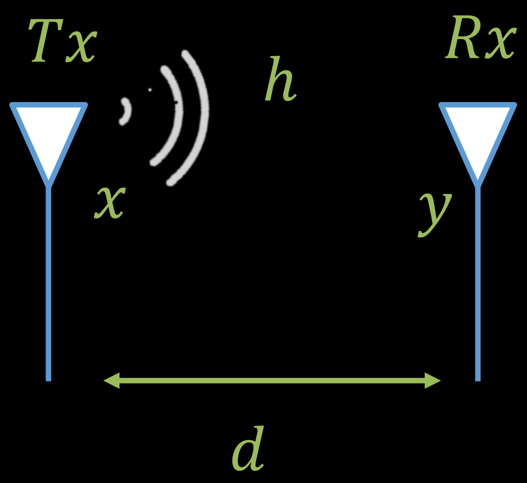
A. To limit the size of antenna at a smaller length (typically antenna size is $\lambda/4$)

Q. Why happens over medium (and why)?

A. Signal decays with 1/r where r is the distance between Rx and Tx. This happens because power is spread out in a sphere (surface area = $4\pi r^2$), since power $\propto$ signal^2 so the signal amplitude decays with 1/r

Downconversion

How do we recover upon receiving?



$x = \mathrm{d.}\cos(2\pi f t)$ → d = Data (bits)

$\mathrm{y} = h.x$ → $\mathrm{y} = \mathrm{h.d.}\cos(2\pi f t)$

$\mathrm{yd} = y * \cos(2\pi f t)$

$\mathrm{yd} = \mathrm{h.d.}\cos(0) + \mathrm{h.d.}\cos(4\pi f t)$ → yd = Downconverted y

$\mathrm{LPF}\{\mathrm{yd}\} = \mathrm{h.d}$ → LPF = low pass filter, you can obtain data now by normalizing by the channel h

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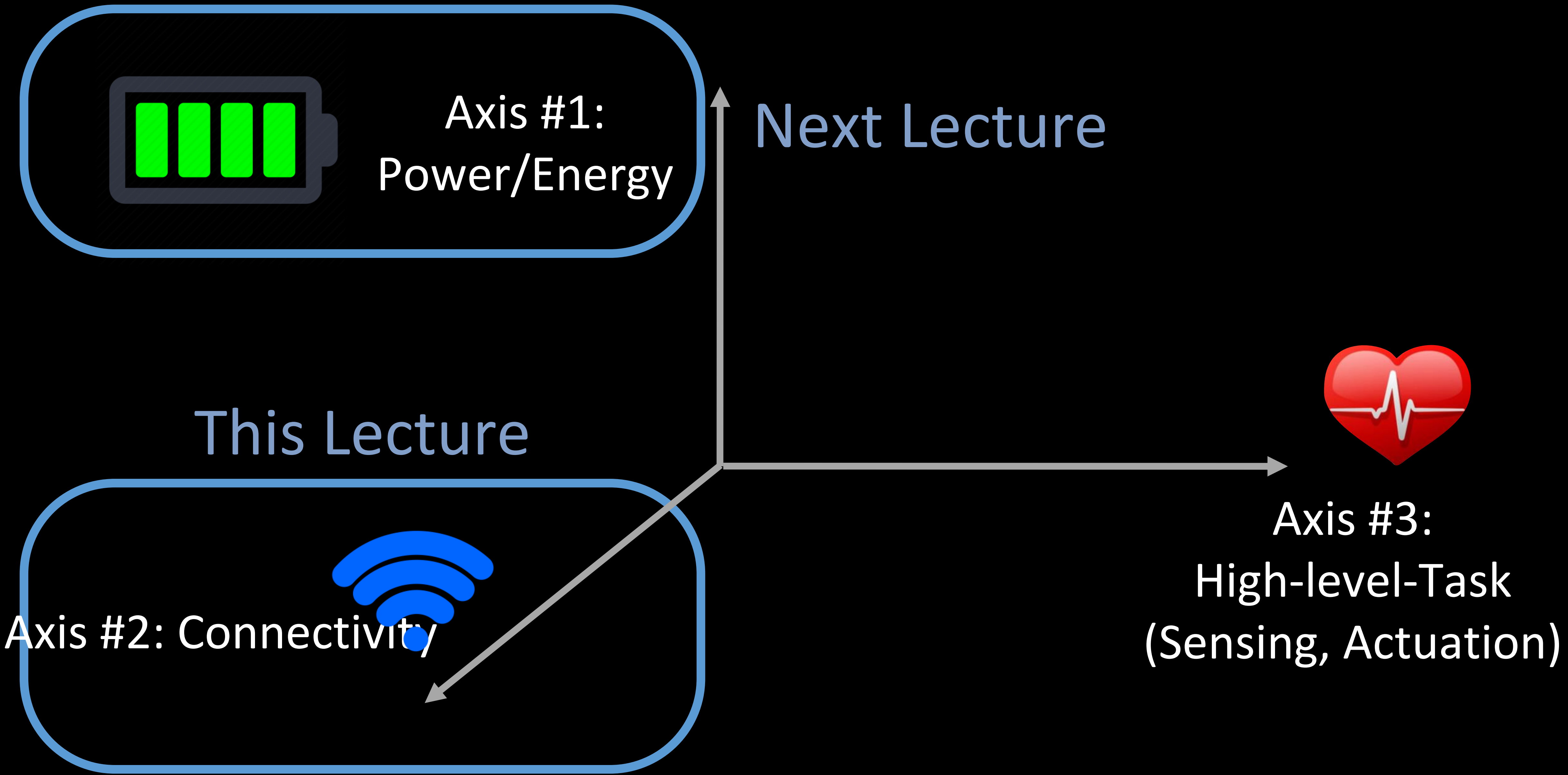
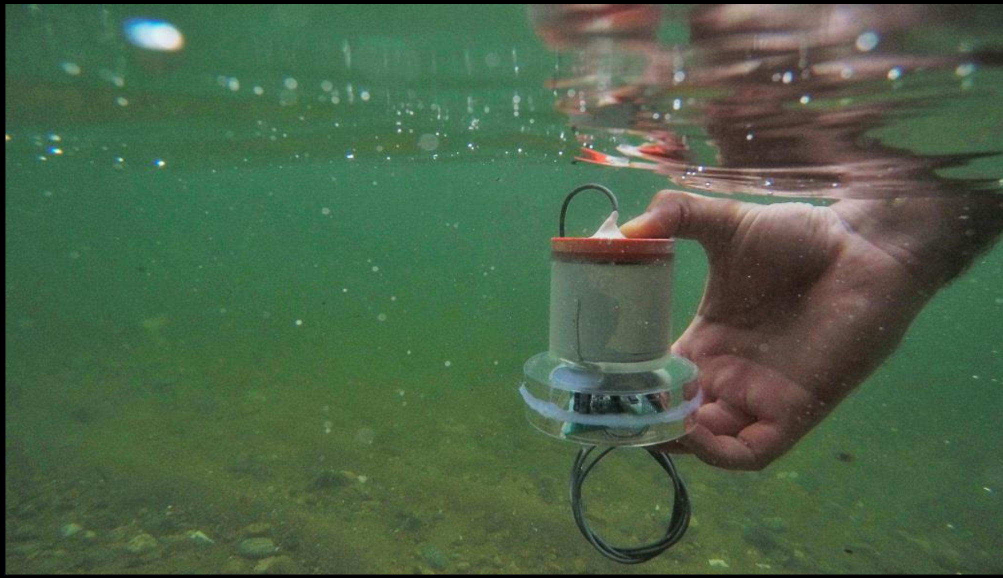
Main Components of (Ocean) IoT Systems



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