MAS.S66
Computational Wireless Sensing

Lecture 5 (part 3):
Underwater to Air Communication

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Underwater-to-Air Comm Applications

Submarine-Airplane Communication

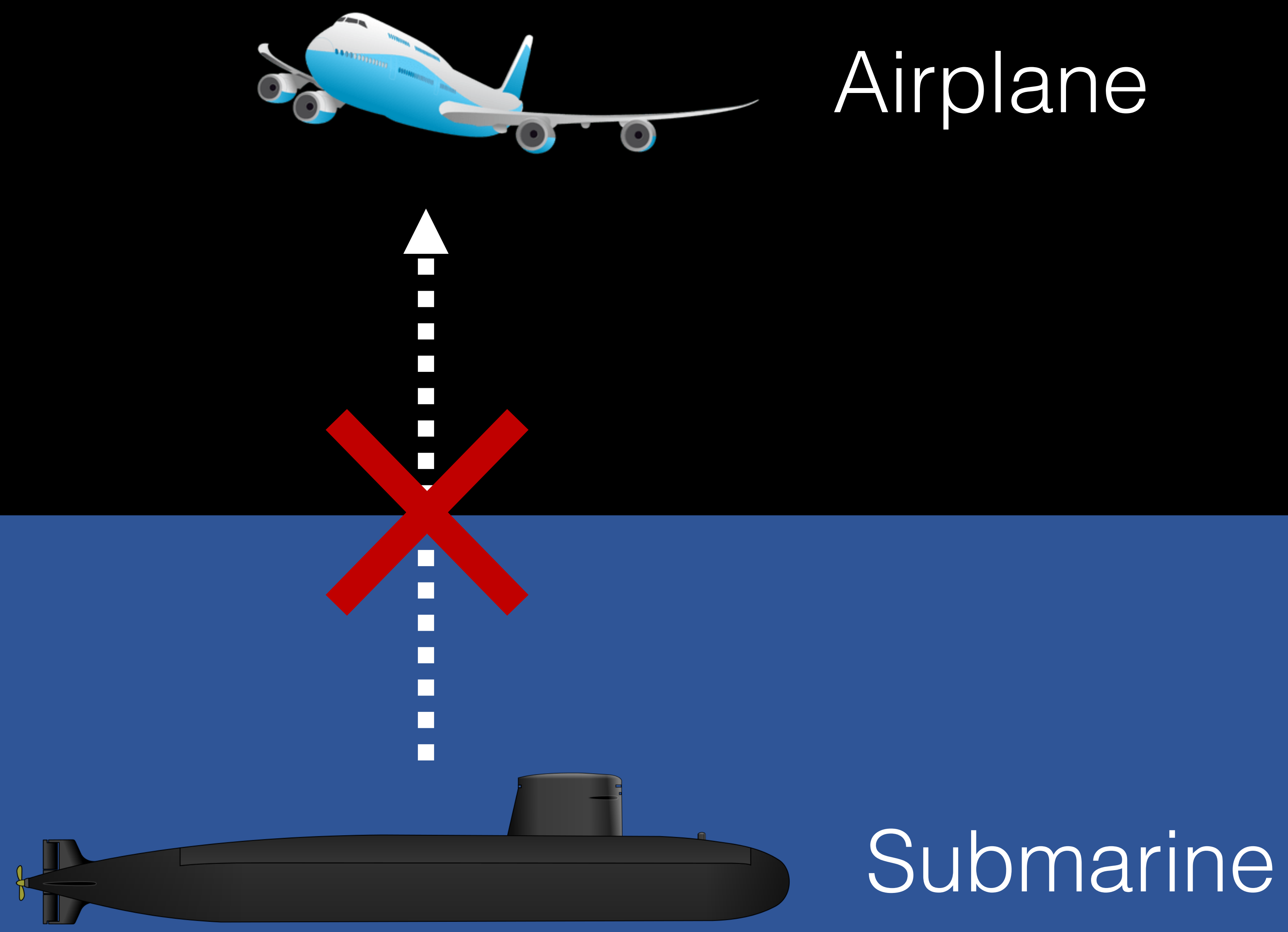
Finding Missing Airplanes

Ocean Scientific Exploration

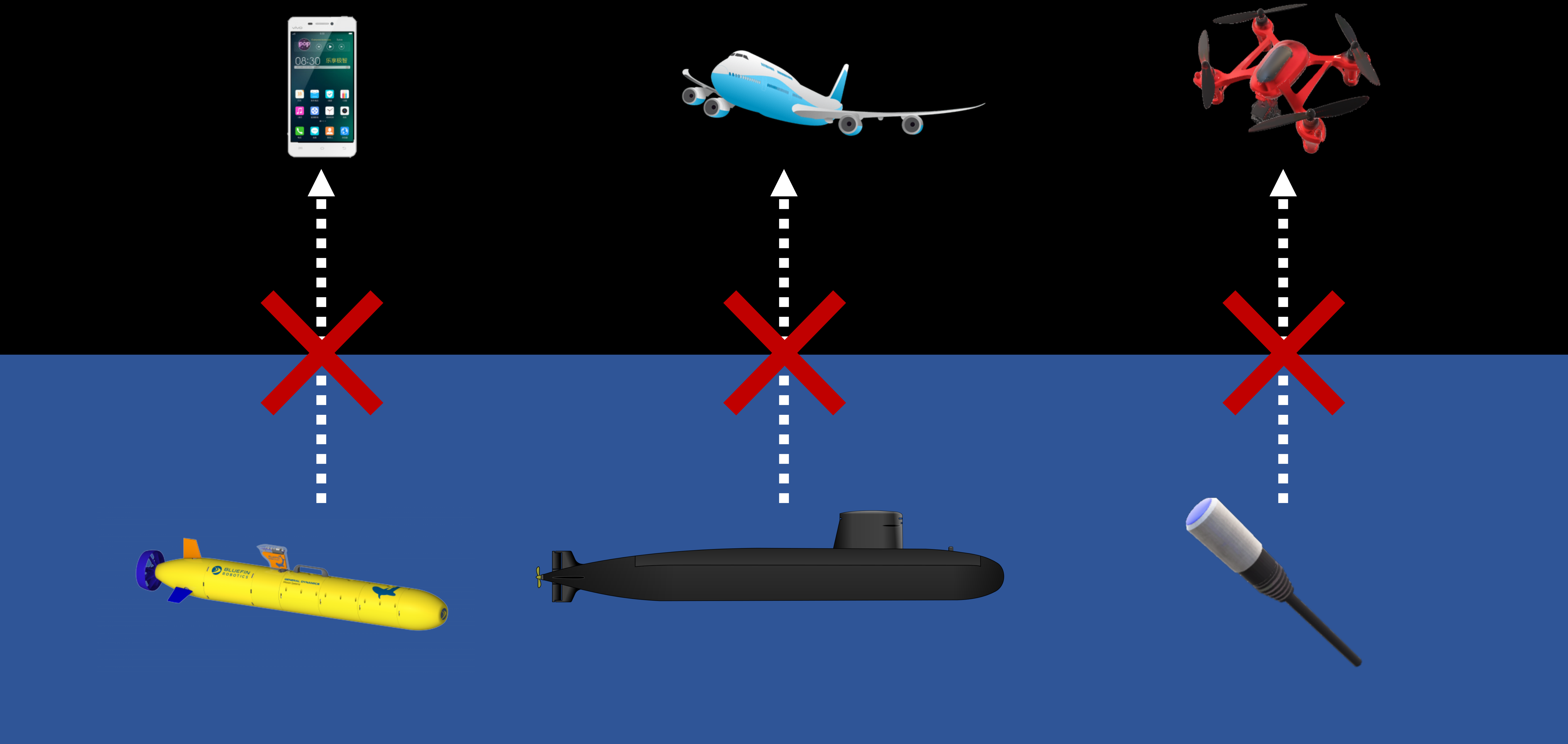
Underwater-to-Air Comm Applications

Why is it difficult?

Submarines Cannot Communicate with Airplanes



Direct Underwater-Air Communication is Infeasible



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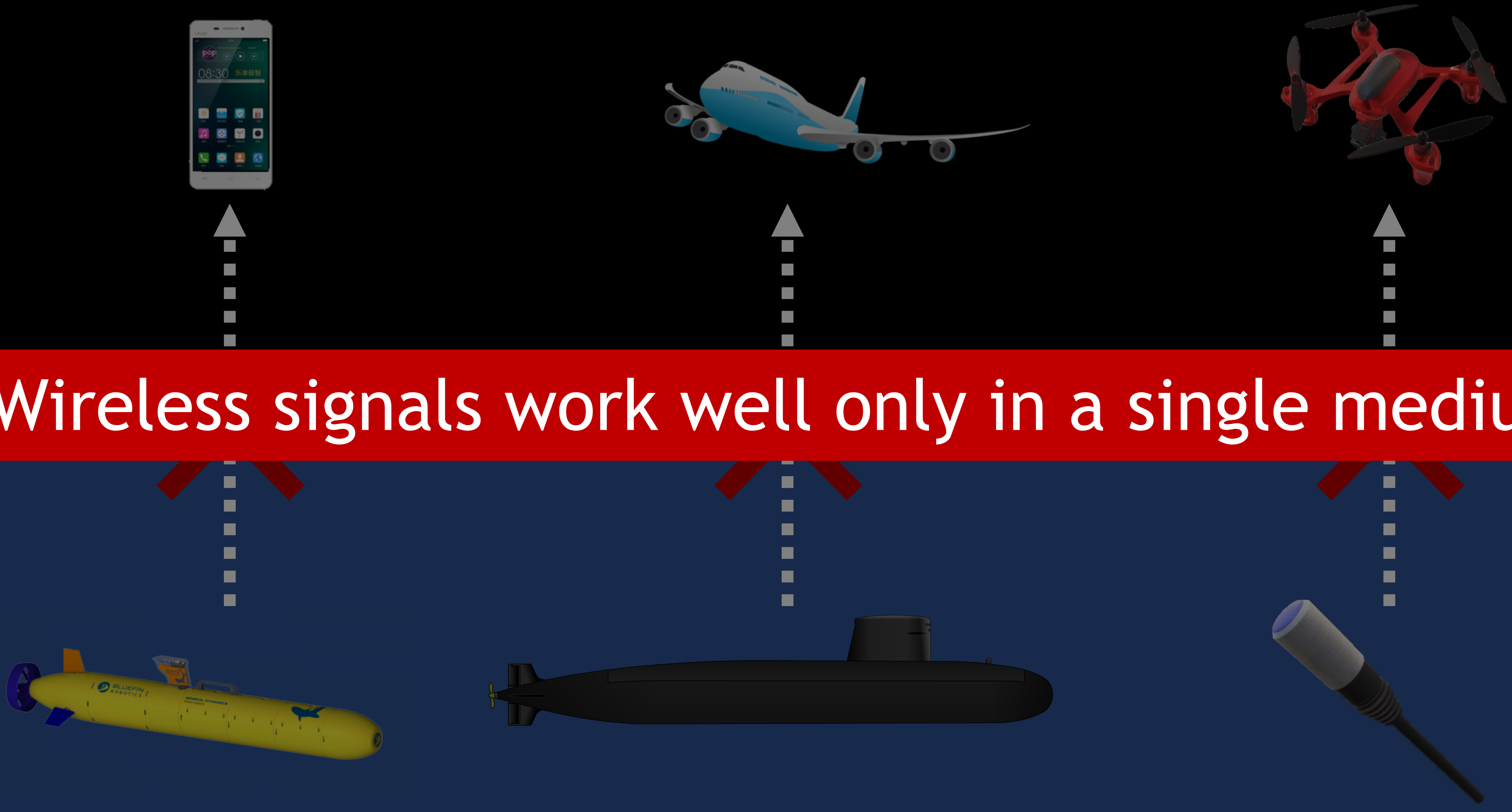
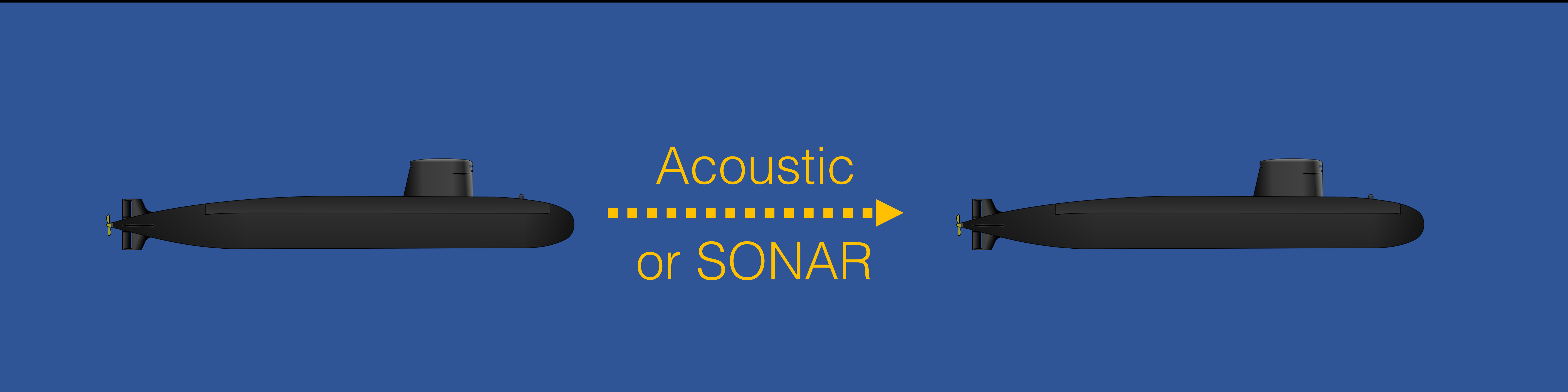


Wireless Signals Work Well Only in a Single Medium



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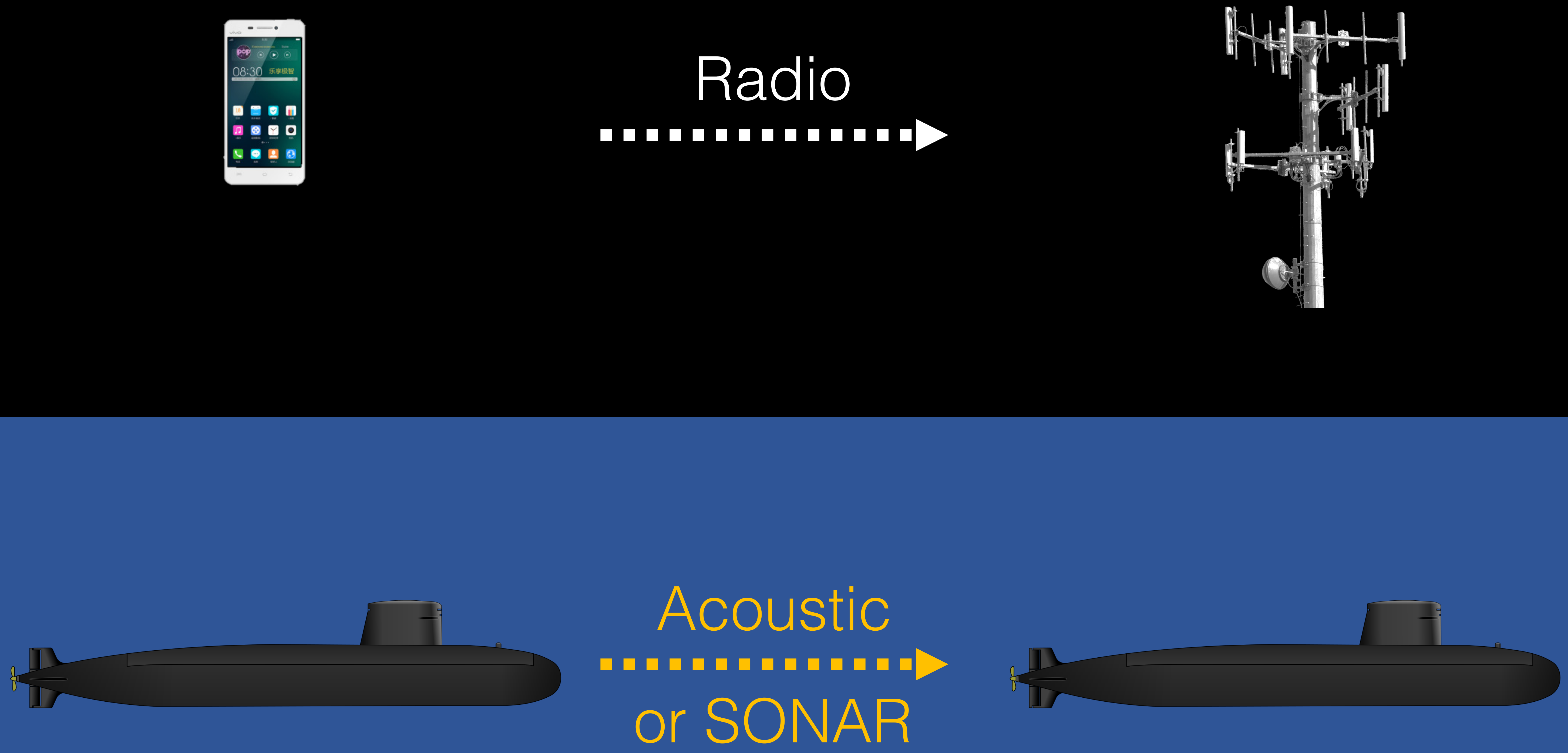
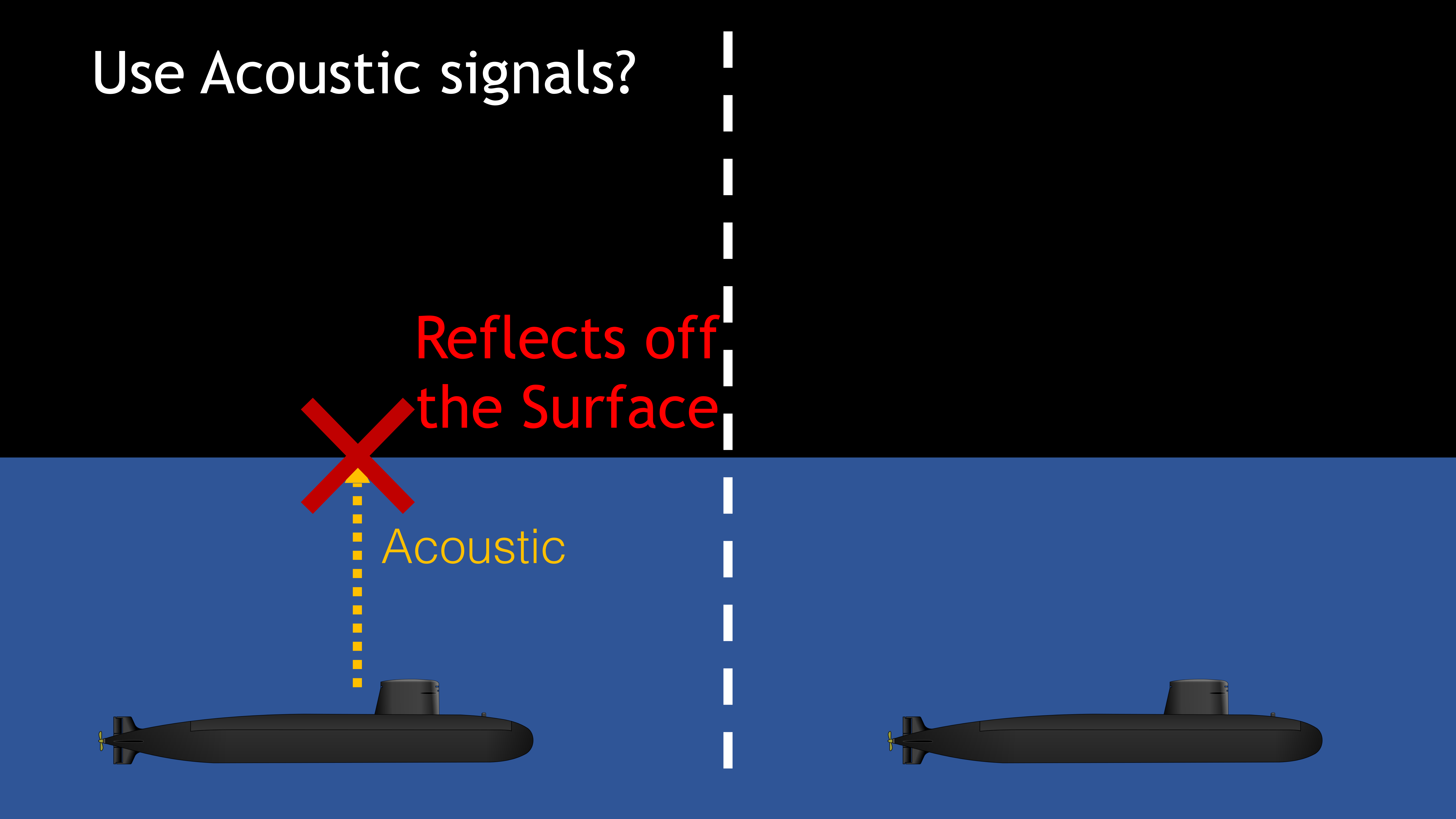
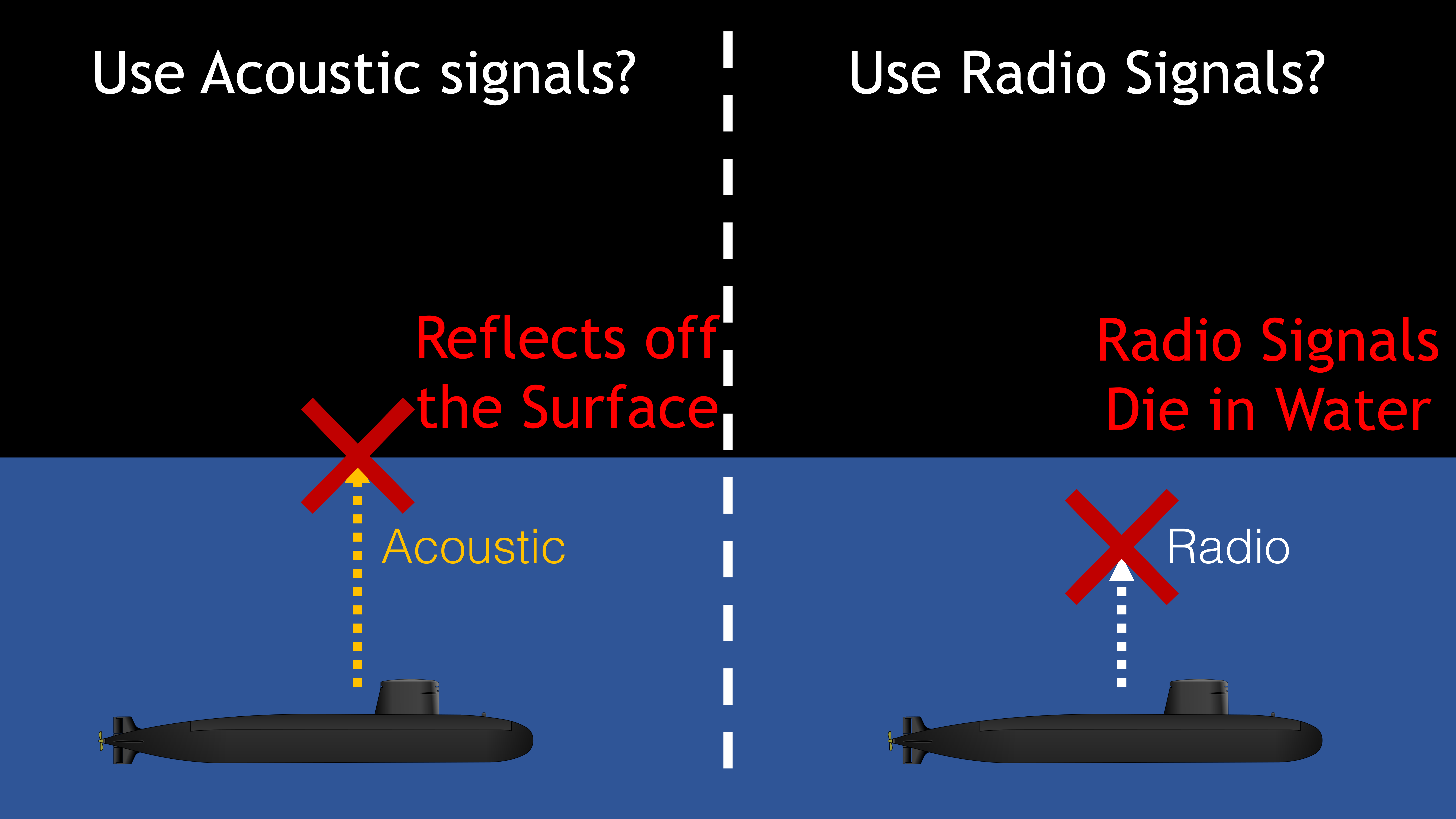


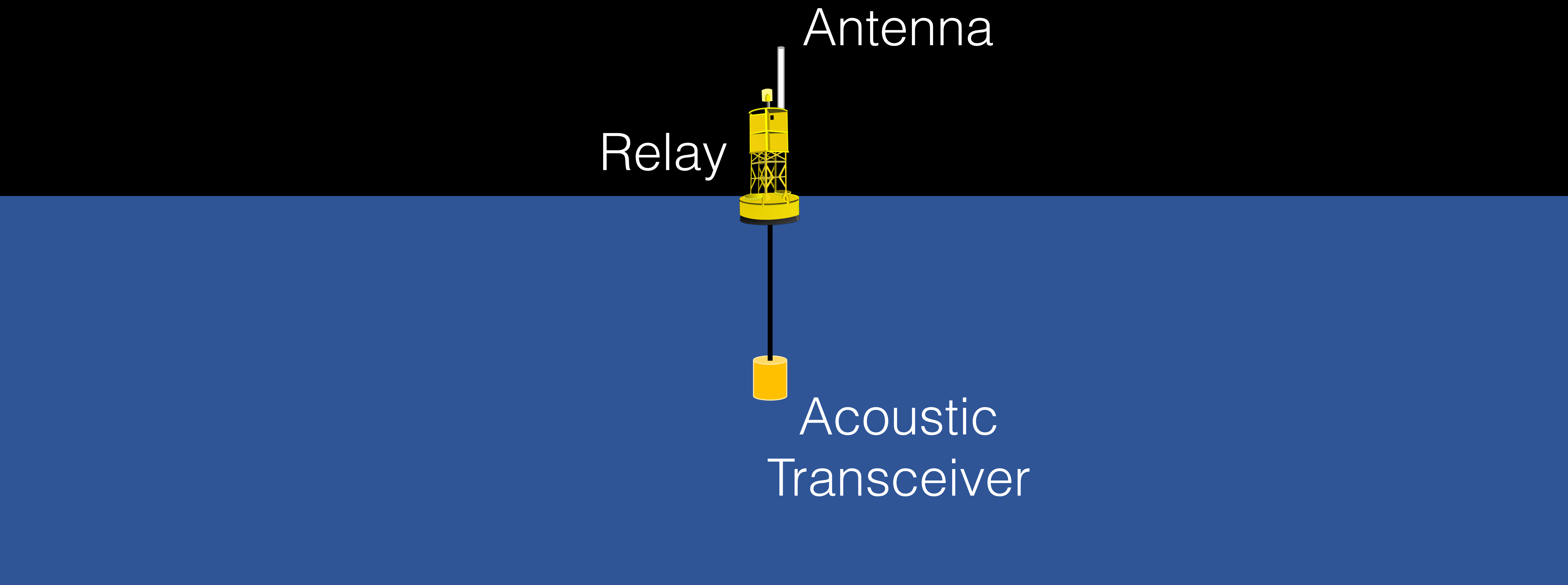

Use Acoustic signals?
Reflects off the Surface
Acoustic


Use Acoustic signals?
Use Radio Signals?
Reflects off the Surface
Radio Signals Die in Water
Acoustic
Radio

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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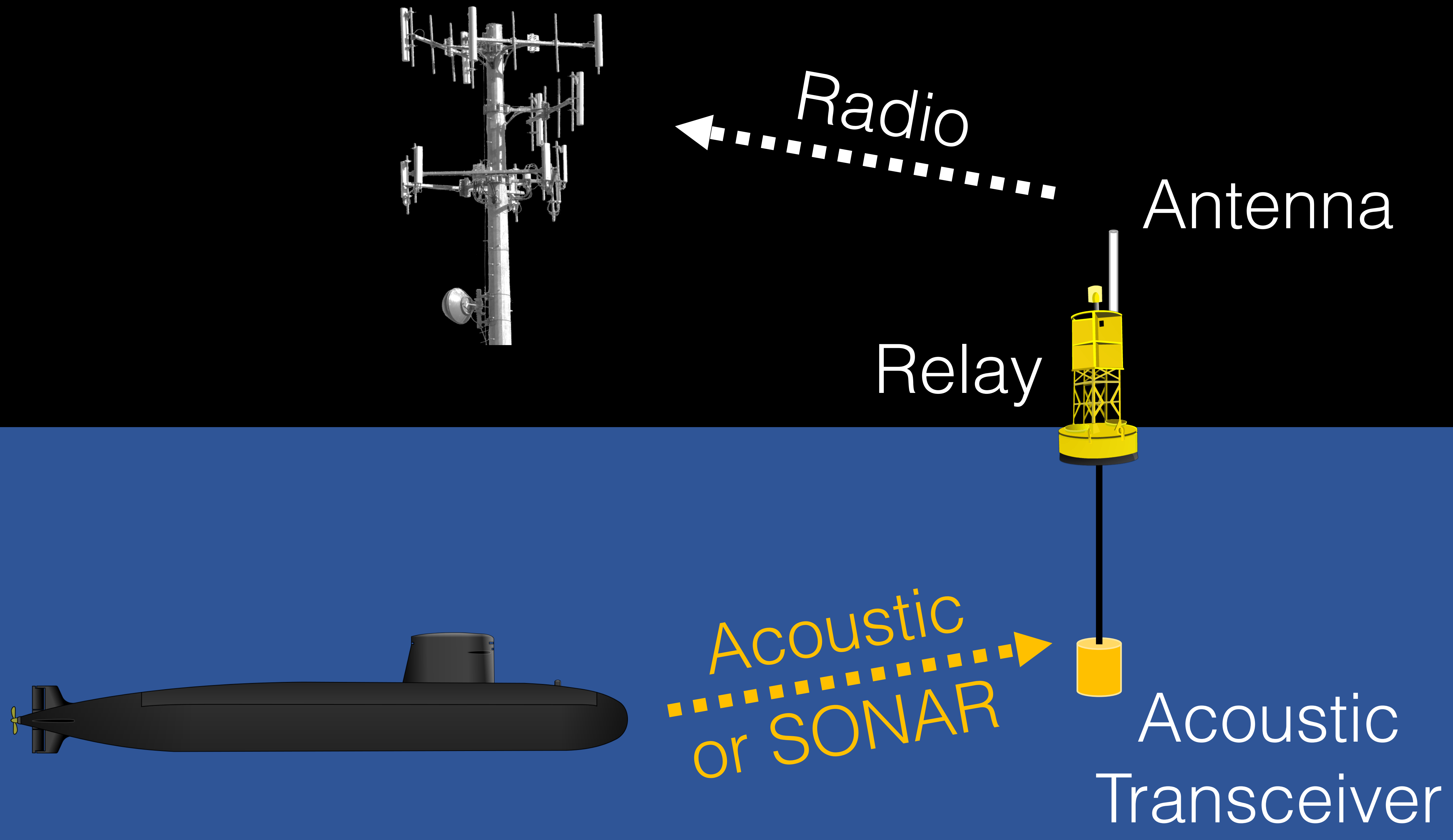
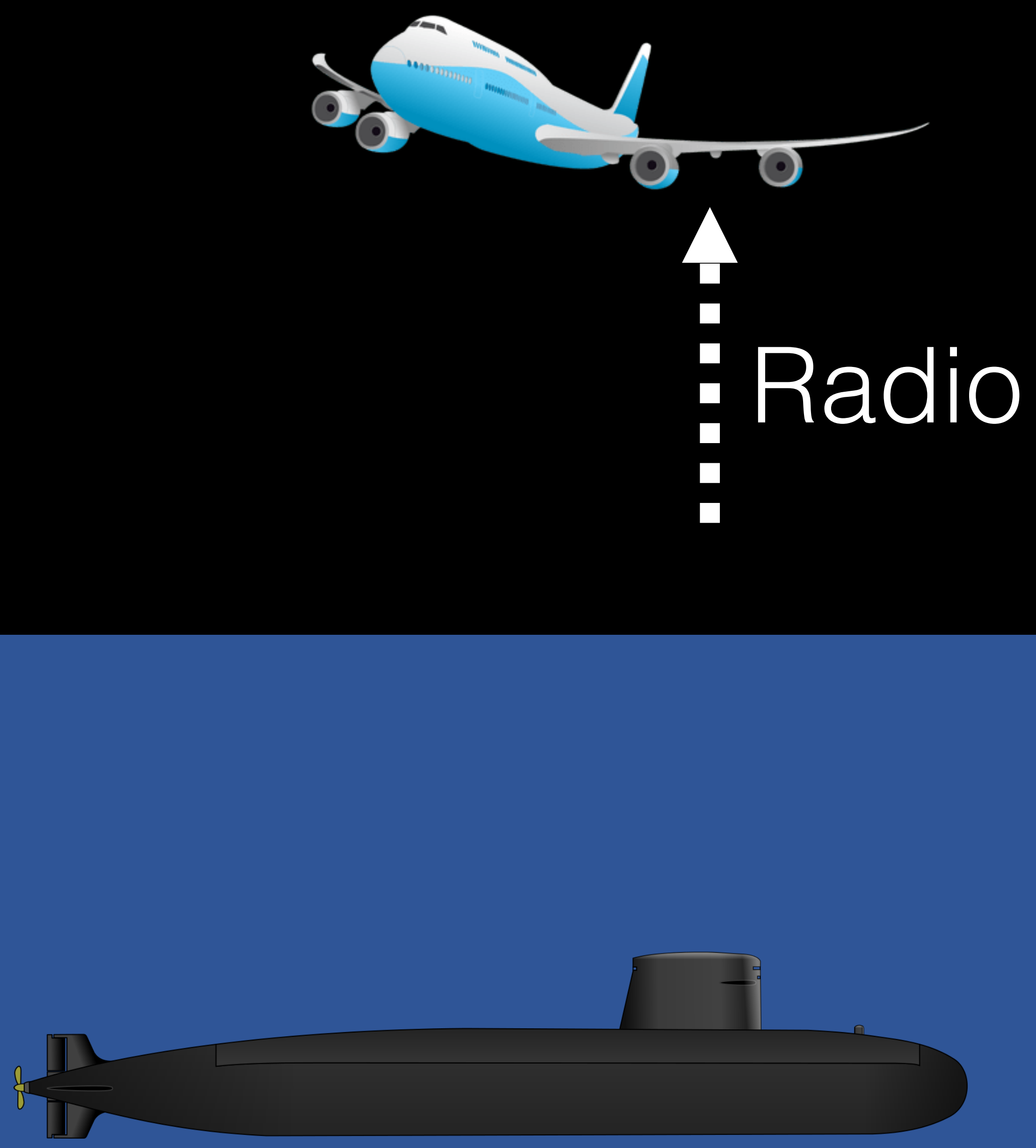


Approach #2: Surfacing

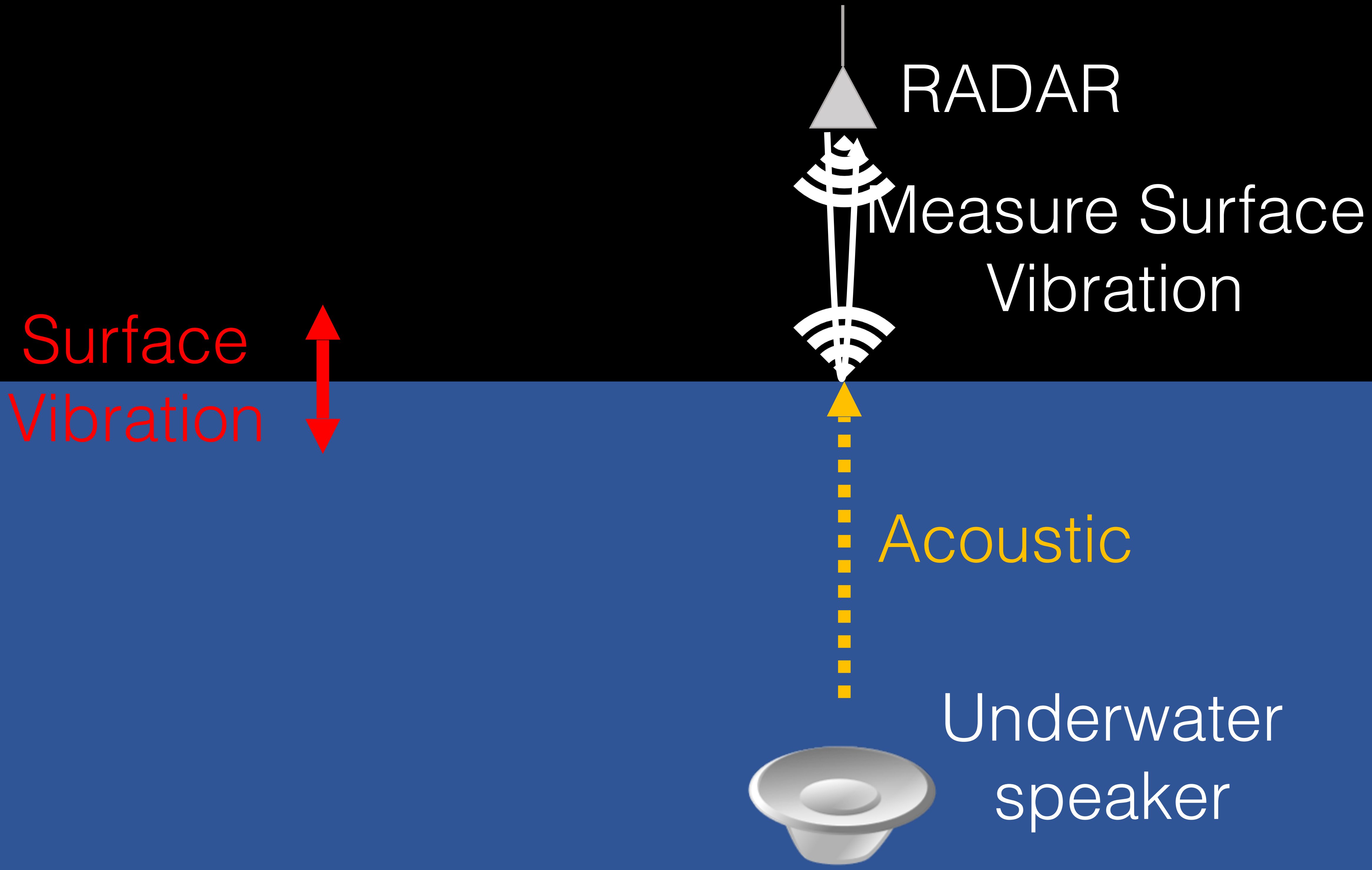
[ICRA'06, MOBICOM'07, OCEANS'10, ICRA'12]



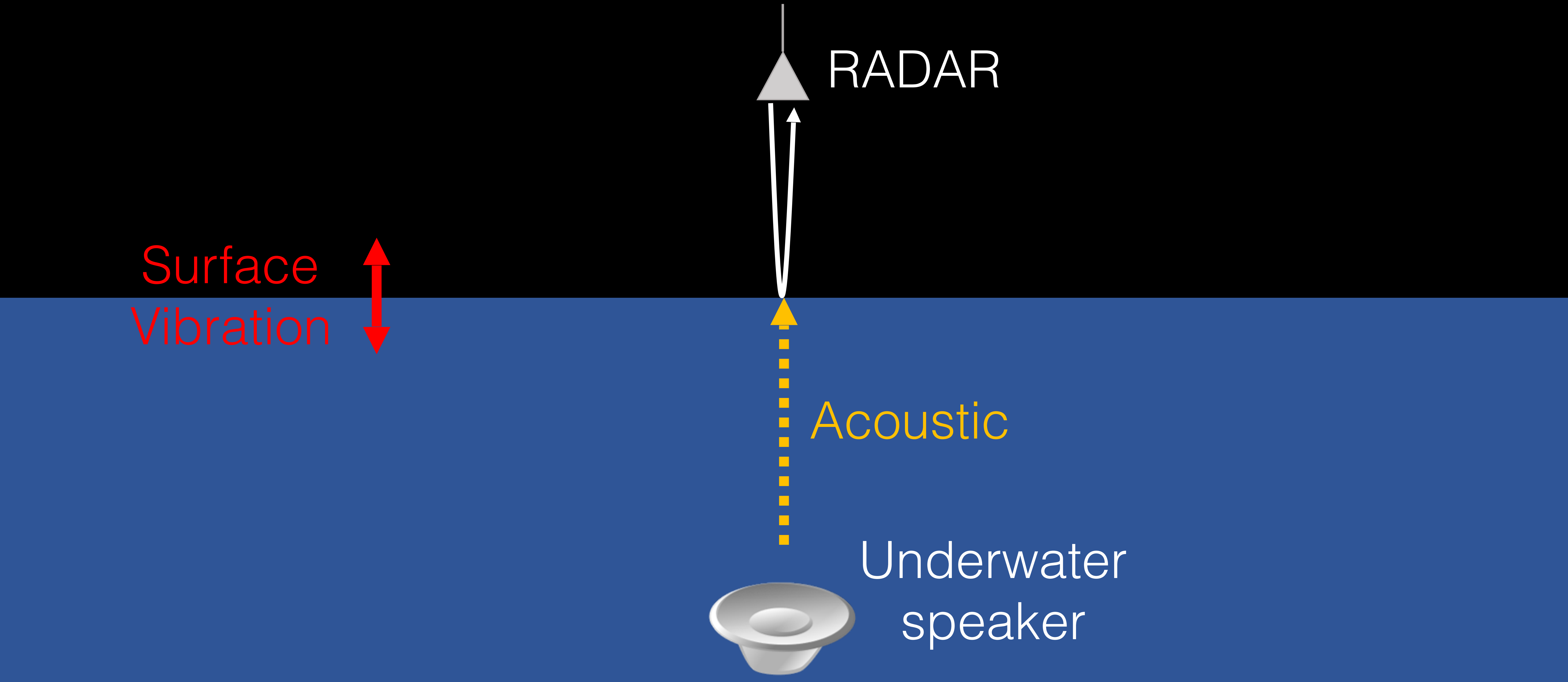
First Technology that Enables Wireless Communication Across the Water-Air Boundary

How does it work?

First Technology that Enables Wireless Communication Across the Water-Air Boundary



Translational Acoustic RF Communication (TARF)



Translational Acoustic RF Communication

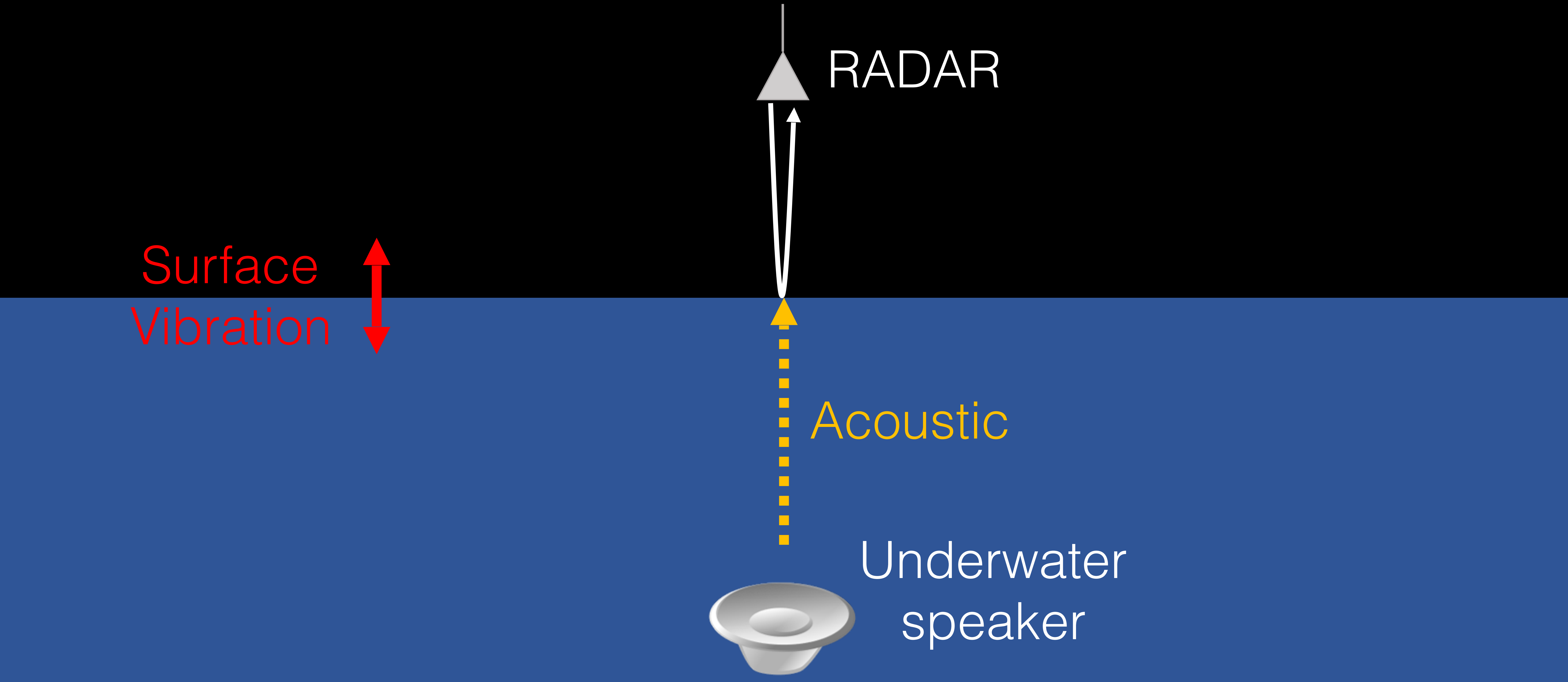
First technology that enables wireless communication across water-air interface

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

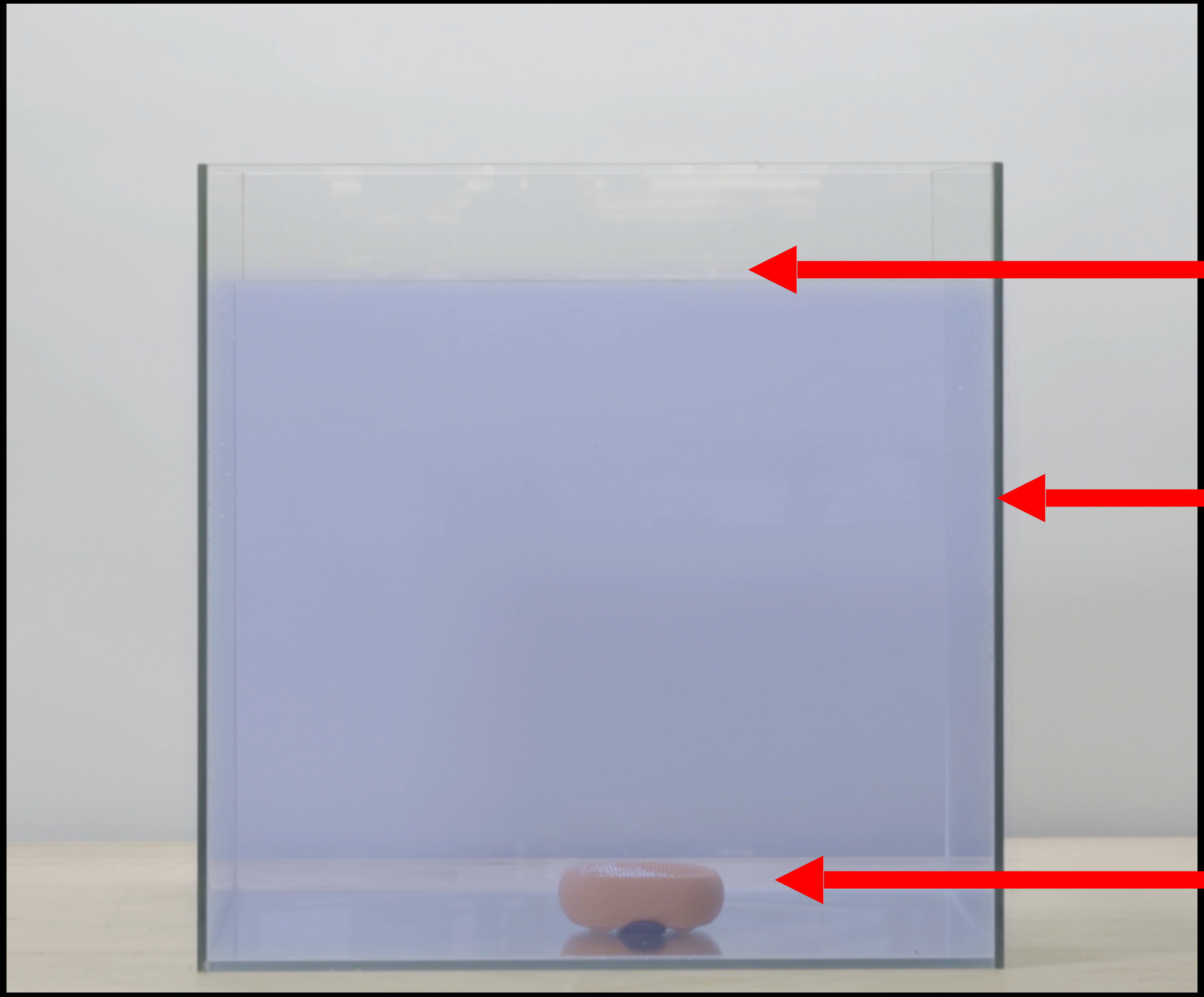
Key Idea



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

Recording the Surface Vibration

Experiment: Transmit Acoustic Signals at 100Hz



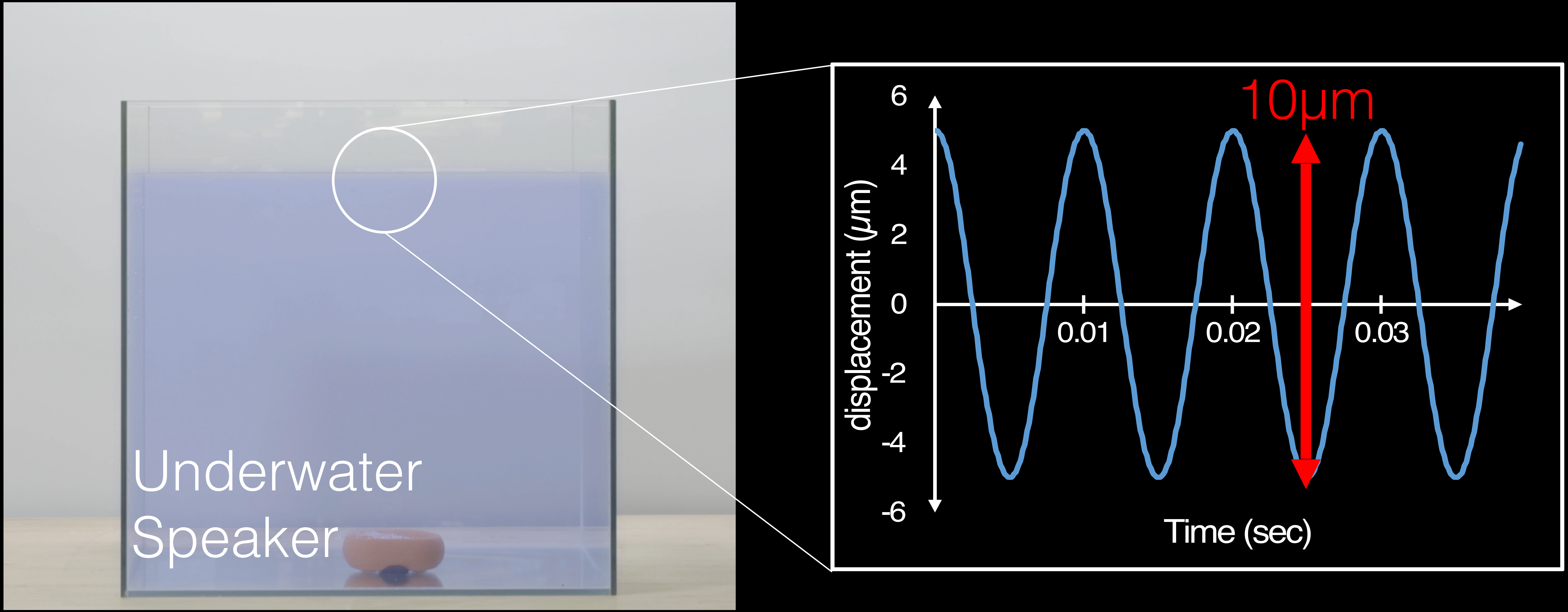
Water Surface

Water Tank

Underwater Speaker

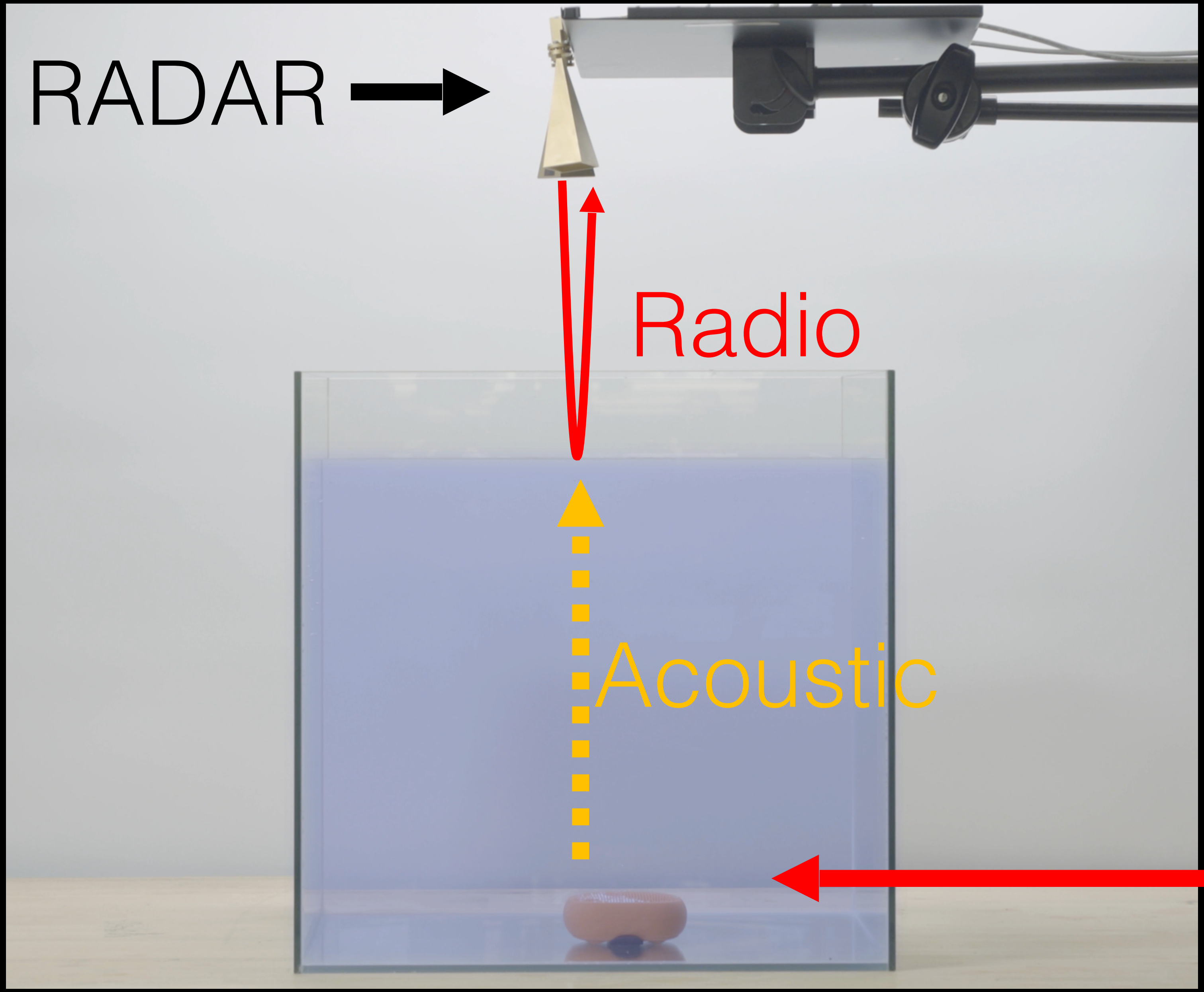
Recording the Surface Vibration

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



How Can We Sense Microscale Vibration?

Idea: Use RADAR to measure the surface vibration



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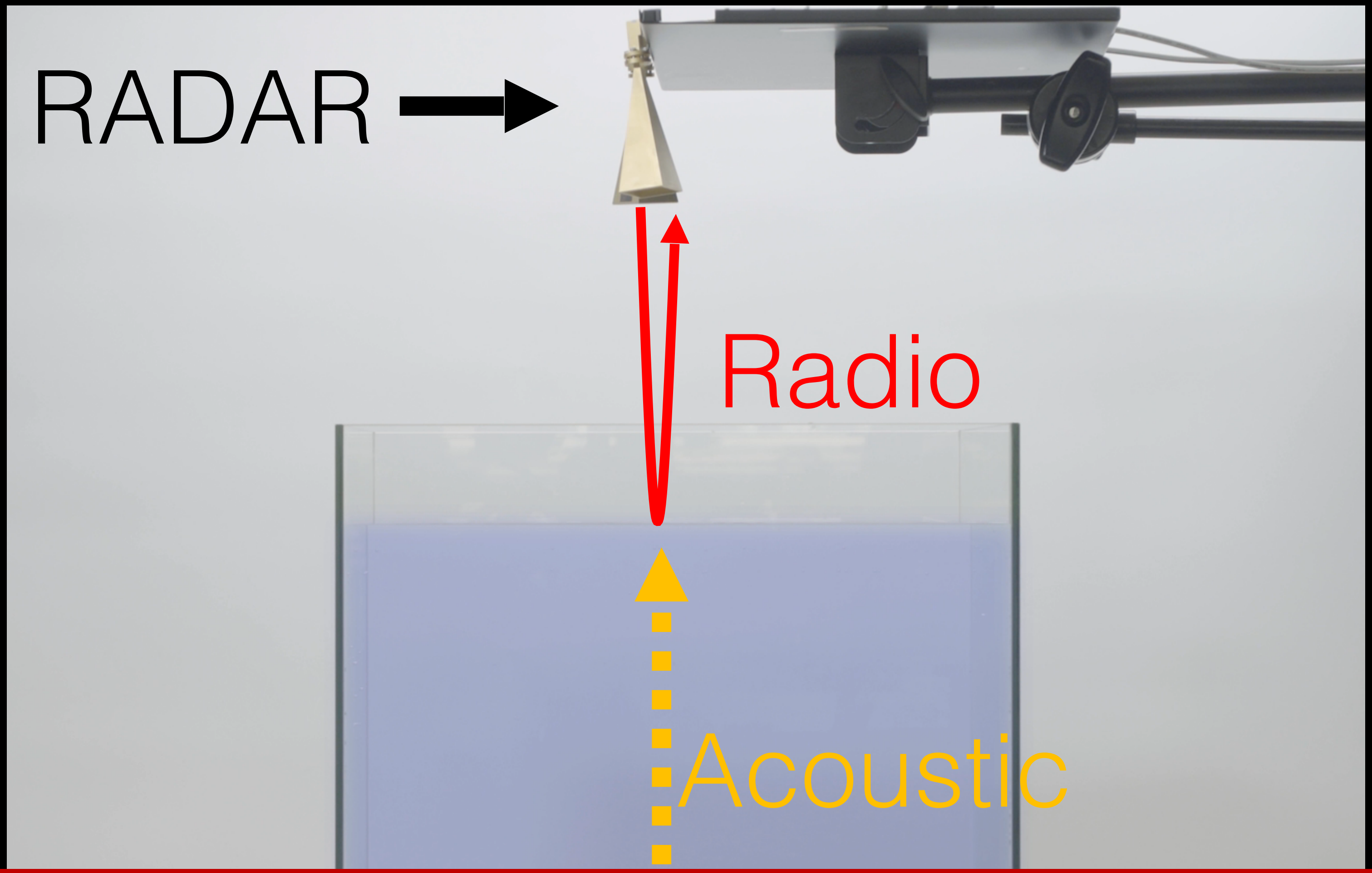
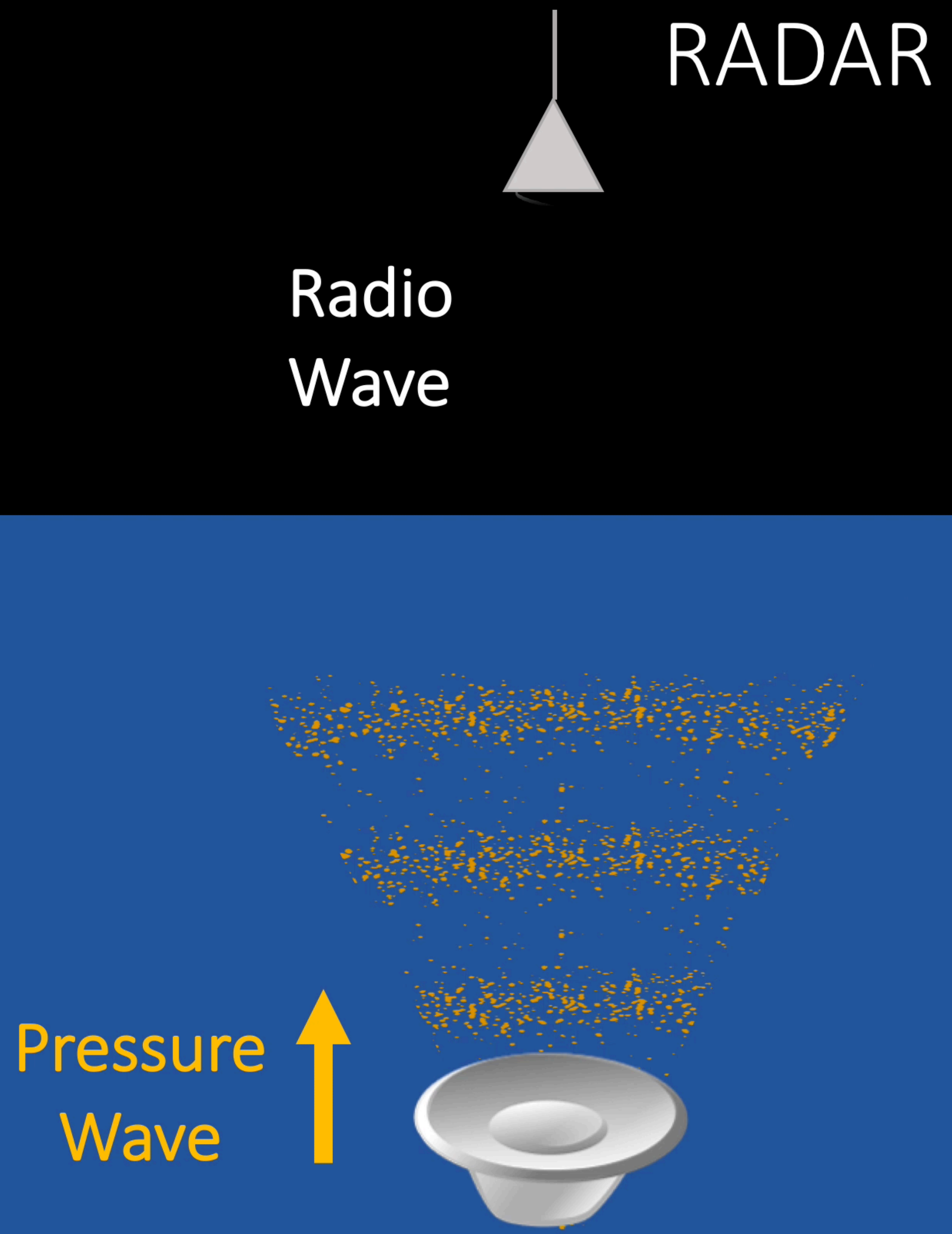


<u>Problem:</u> Measuring micrometer vibrations requires 100s of THz of bandwidth → Impractical & Costly

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



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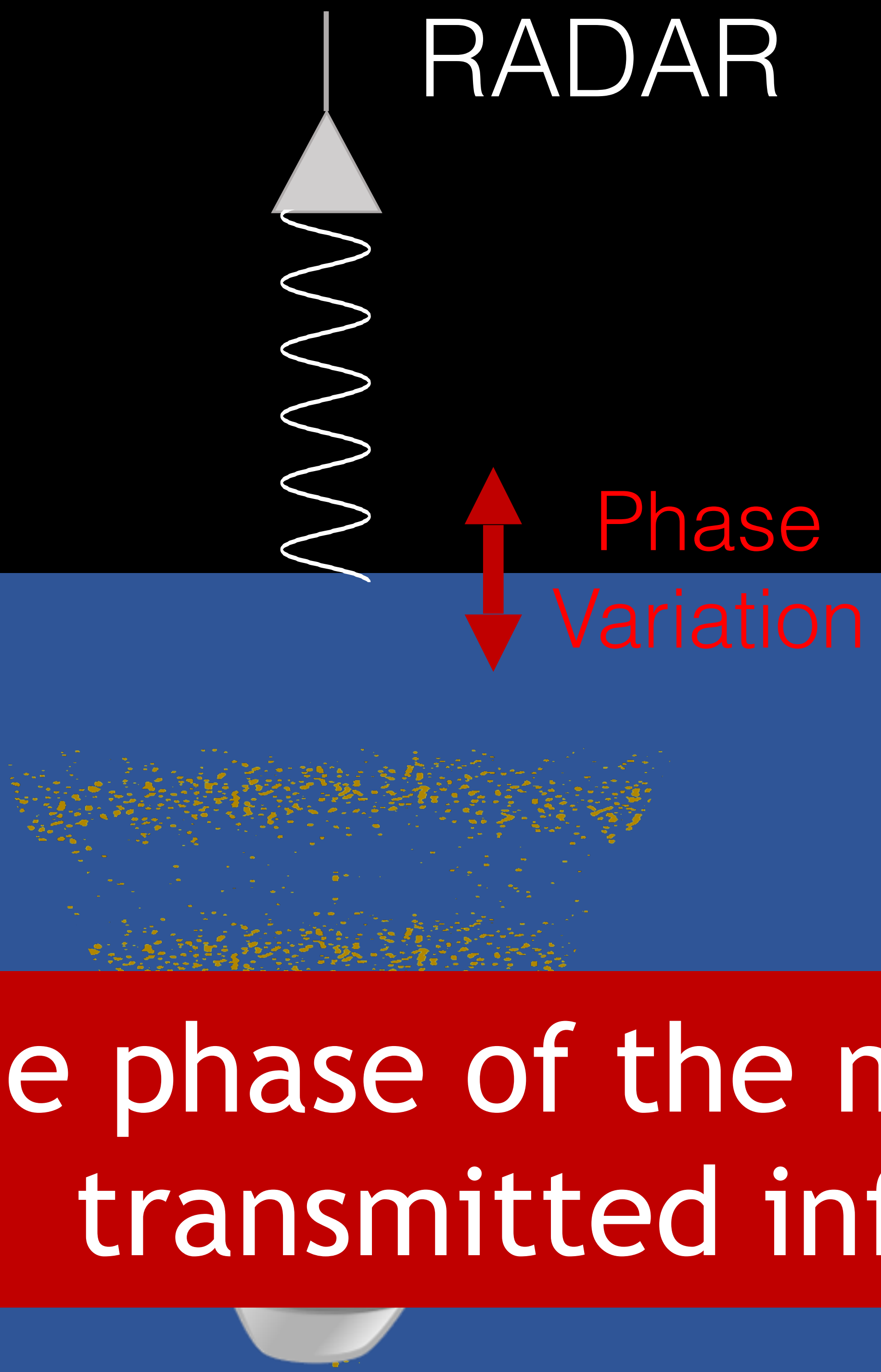


10μm

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

5mm

Phase Variation = 7.2degrees

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

Natural Surface Waves Mask the Signal

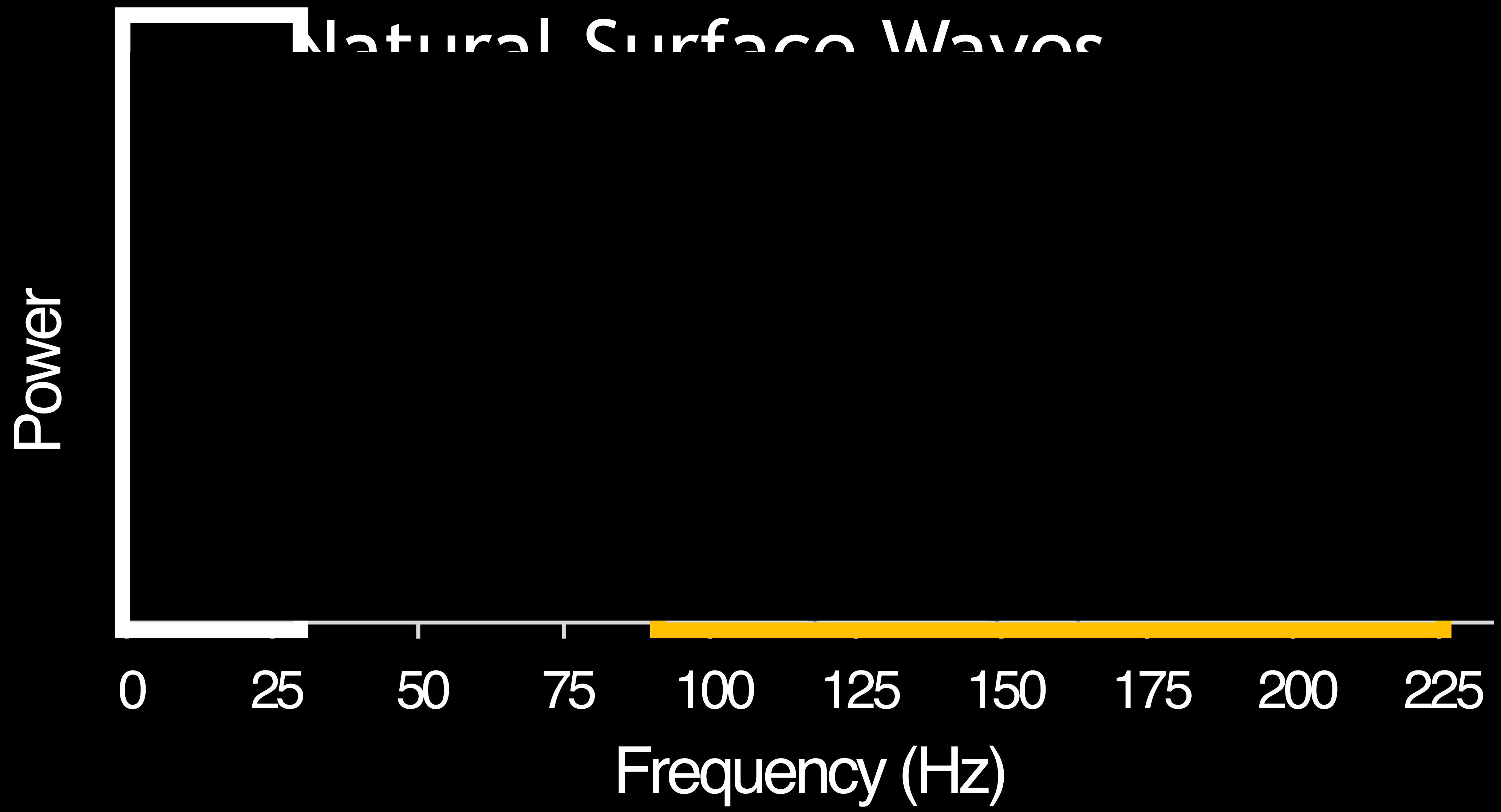
On Calm Days, Ocean Surface Ripples (Capillary Waves)
Have 2cm Peak-to-Peak Amplitude

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

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

		<u>Frequency</u>
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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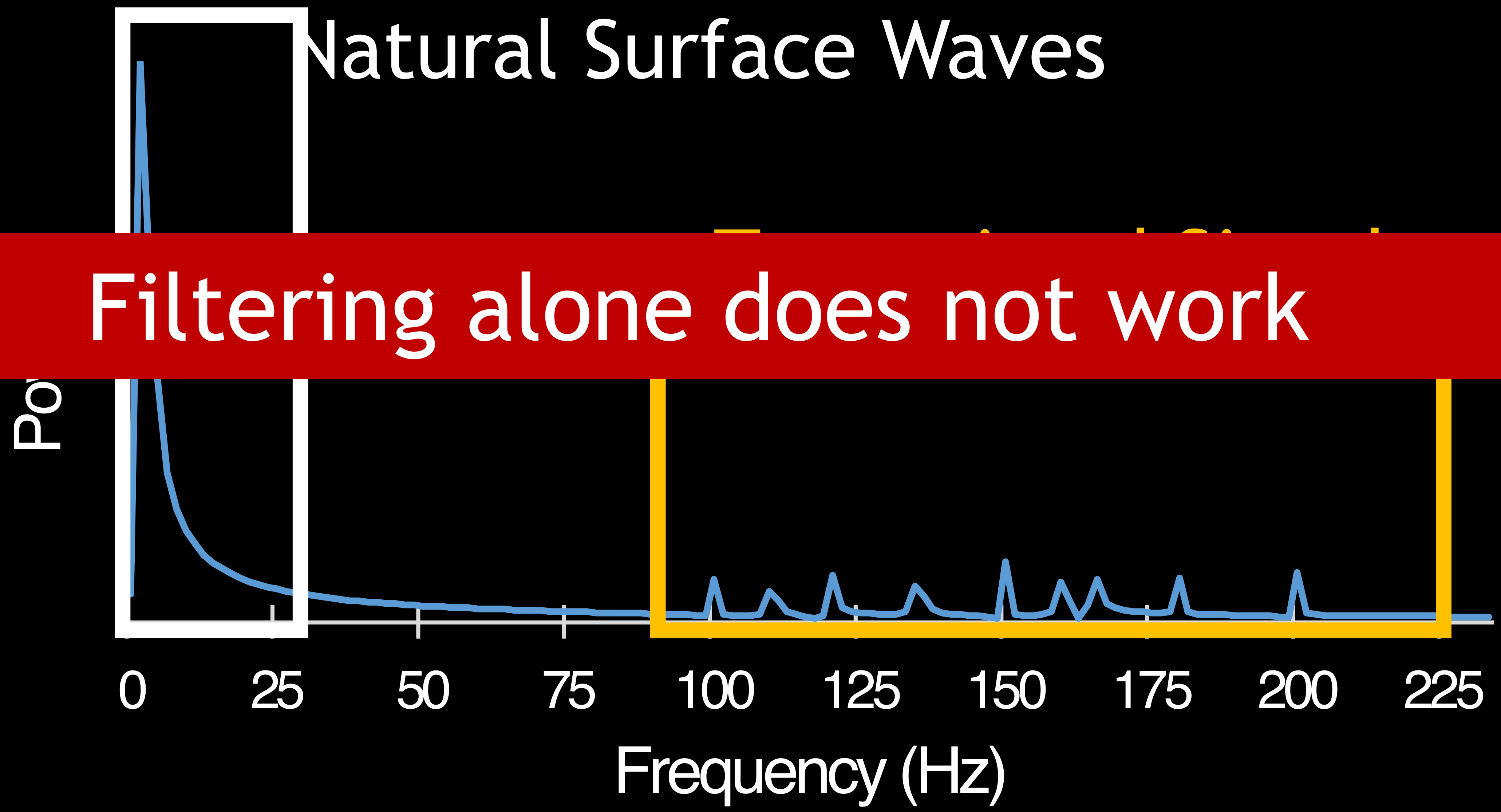


Filtering alone does not work

Dealing with Waves

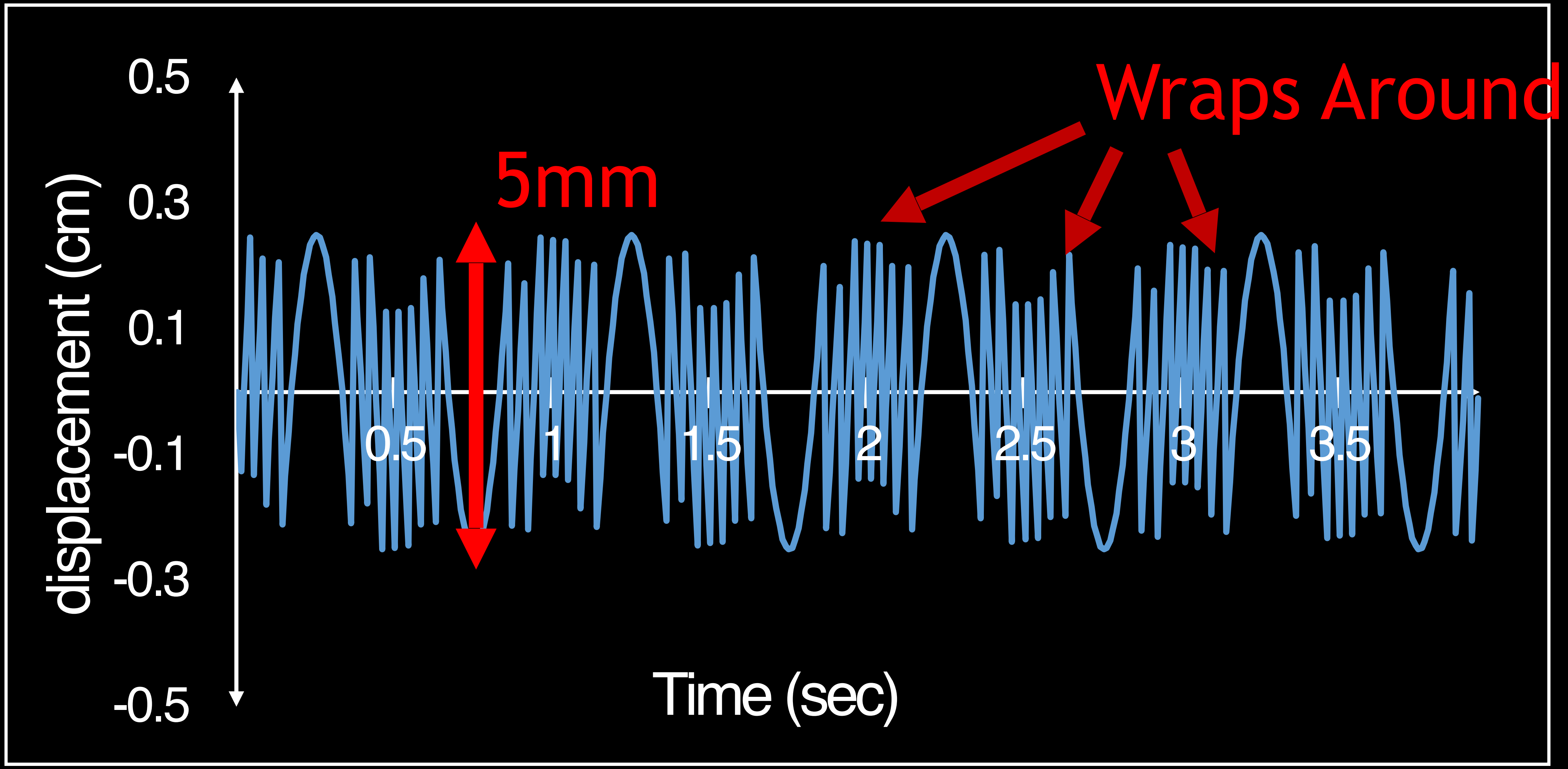
$$_{Angle} = 360 \times \frac{displacement}{wavelength}$$

Dealing with Waves

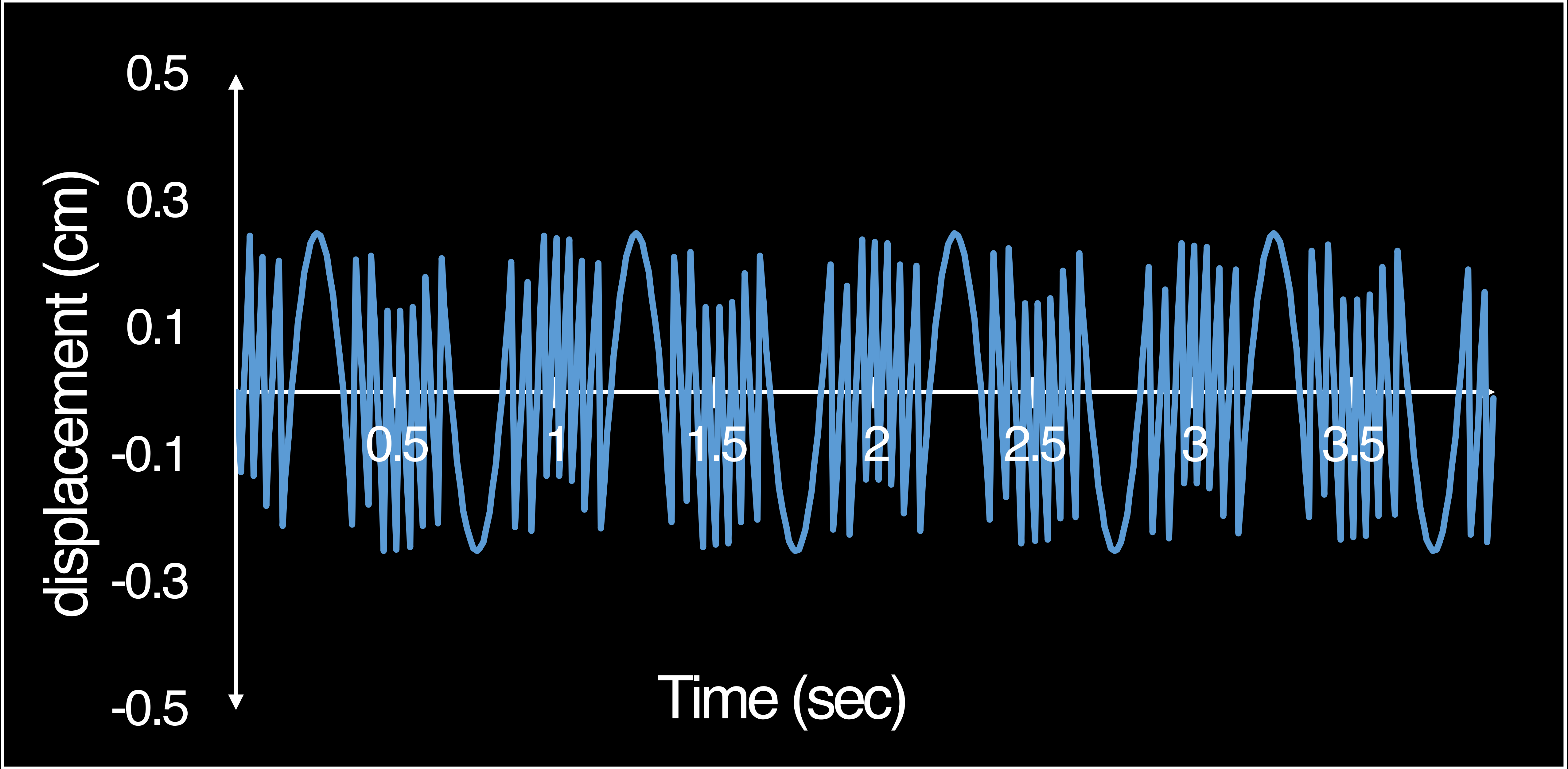
$$Angle = 360 \times \frac{displacement}{wavelength} \; mod \; 360$$

Dealing with Waves

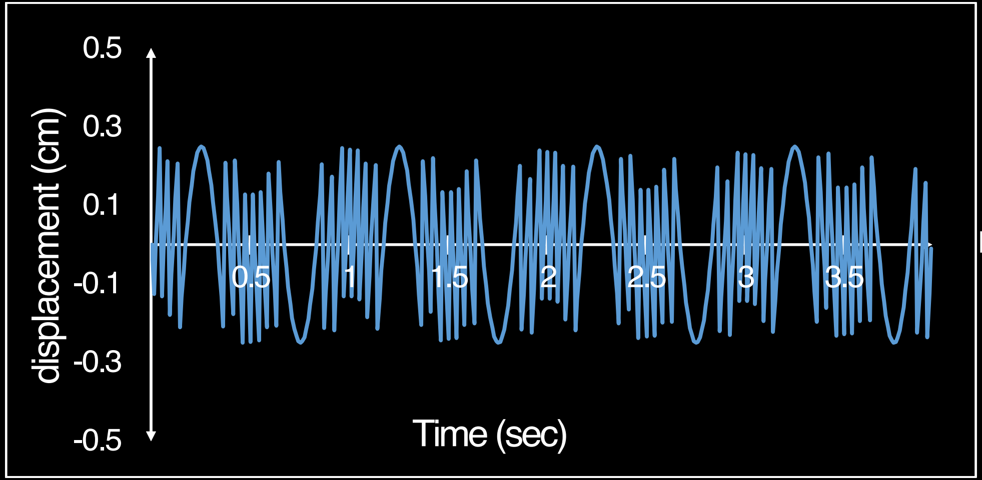
$$\mathit{Angle} = 360 \times \frac{\mathit{displacement}}{\mathit{wavelength}} \quad \mathit{mod}\ 360$$



Dealing with Waves

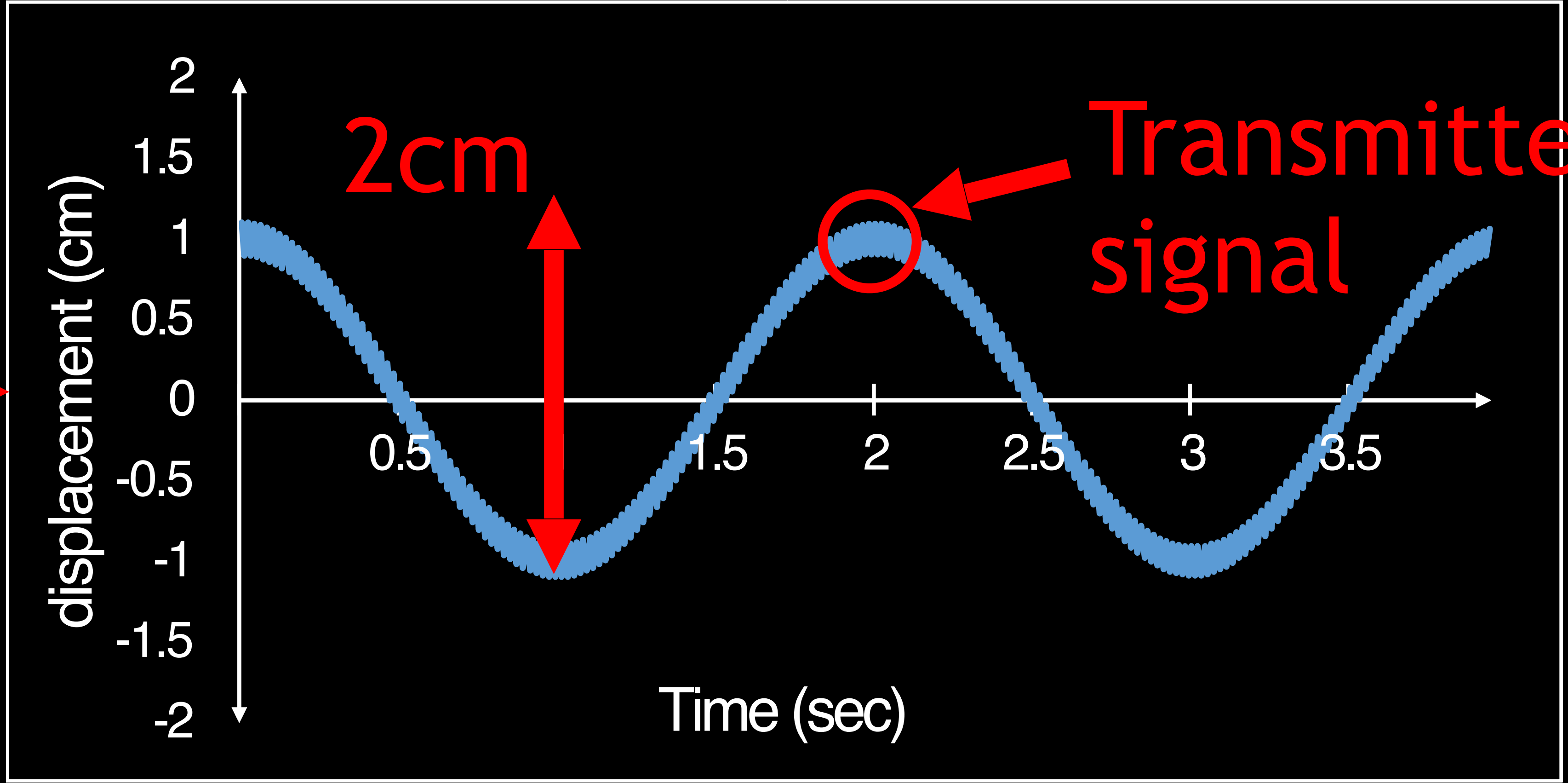


Dealing with Waves



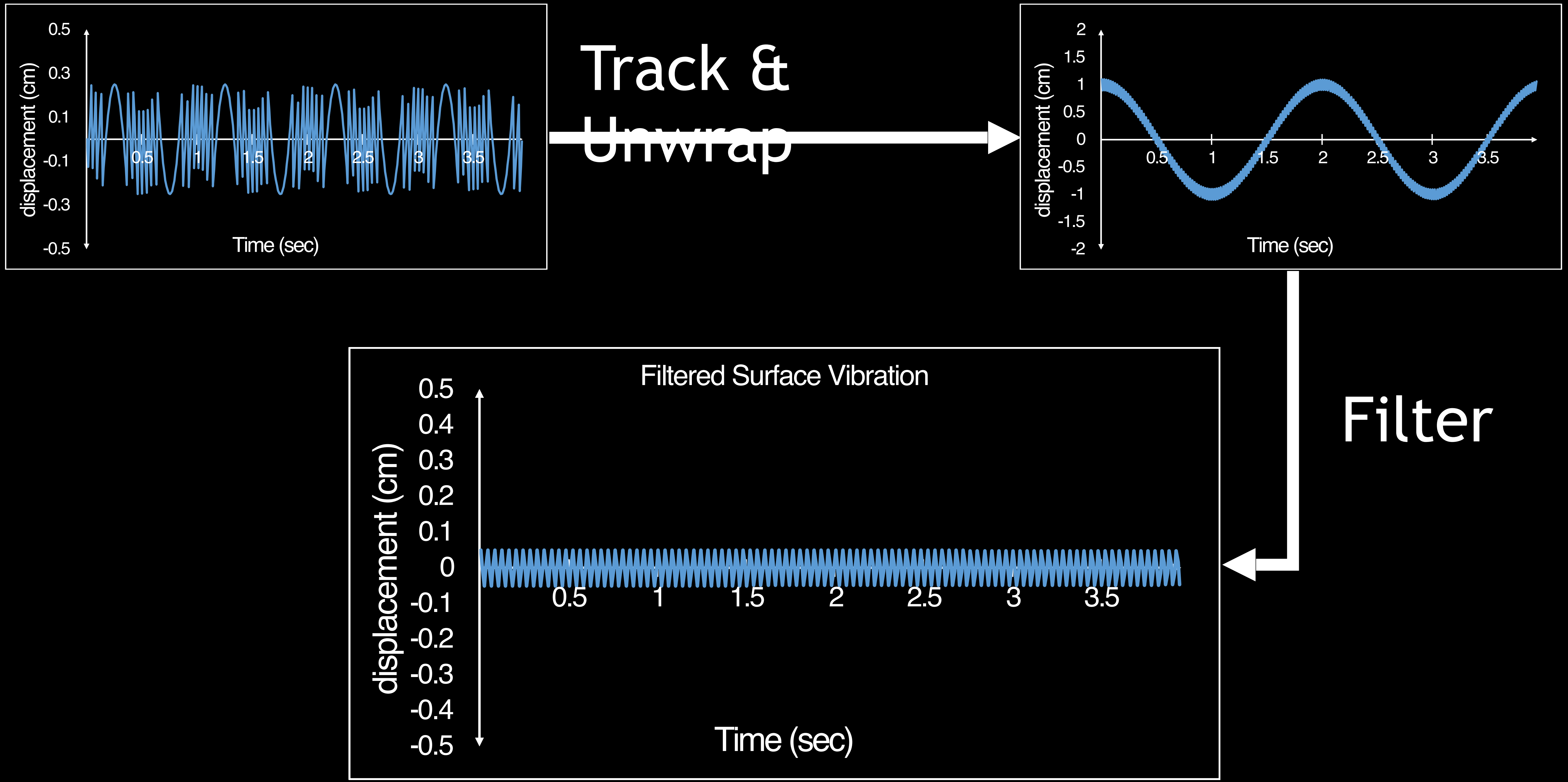
Track & Unwrap

Trend is Water Surface Wave

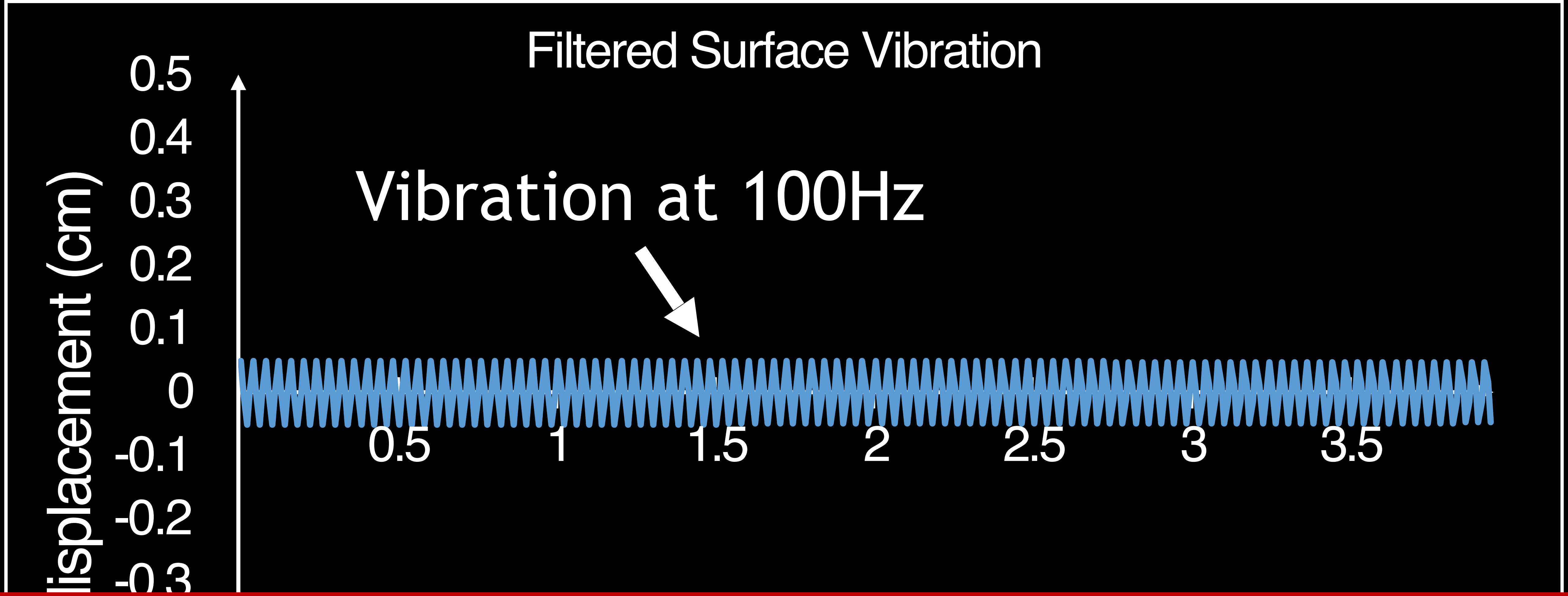


Transmitted signal

Dealing with Waves



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?