CIS 3990

Mobile and IoT Computing

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

Lecture 14: Ocean IoT

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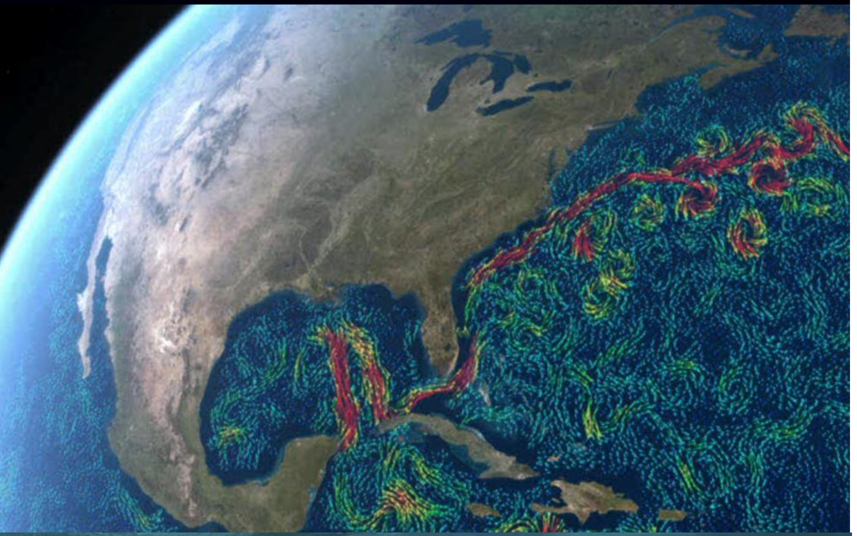
Some material adapted from Fadel Adib (MIT)

Let’s start with some trivia



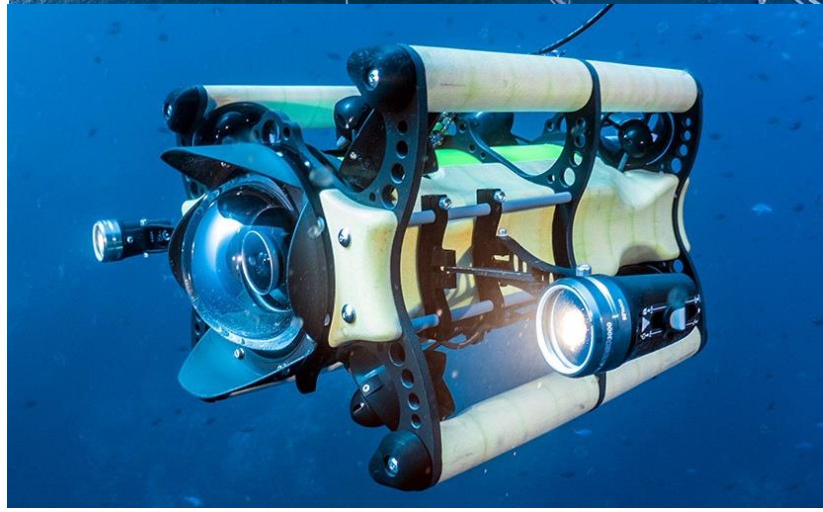
1. What percentage of the ocean floor has never been observed?

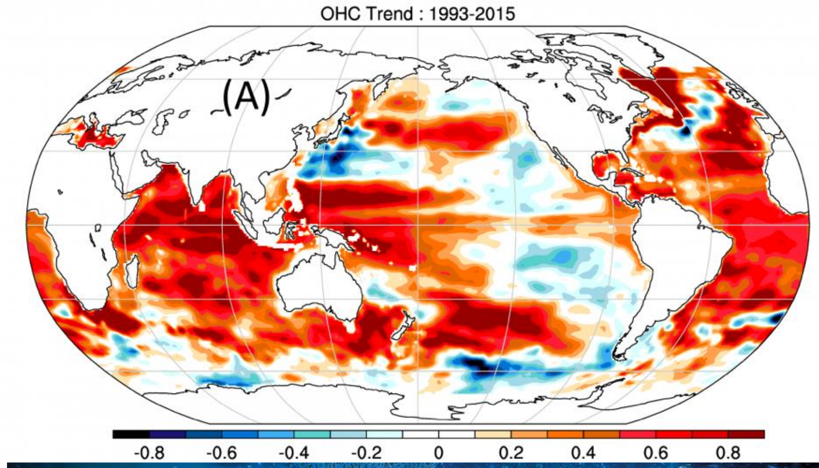
2. Out of every 10 marine organisms, how many have never been discovered?

3. What is the world’s fastest-growing food sector?

4. What has more heat content: the ocean or the atmosphere?

5. Which decade did the UN declare *“Decade of Ocean Science for Sustainable Development”*?





Taking the Internet of Things to the Ocean World

30 bn

IoT Devices

Less than 1 in a million of IoT is in the ocean, even it they covers >70% of the planet and has significant needs for food, climate, etc.

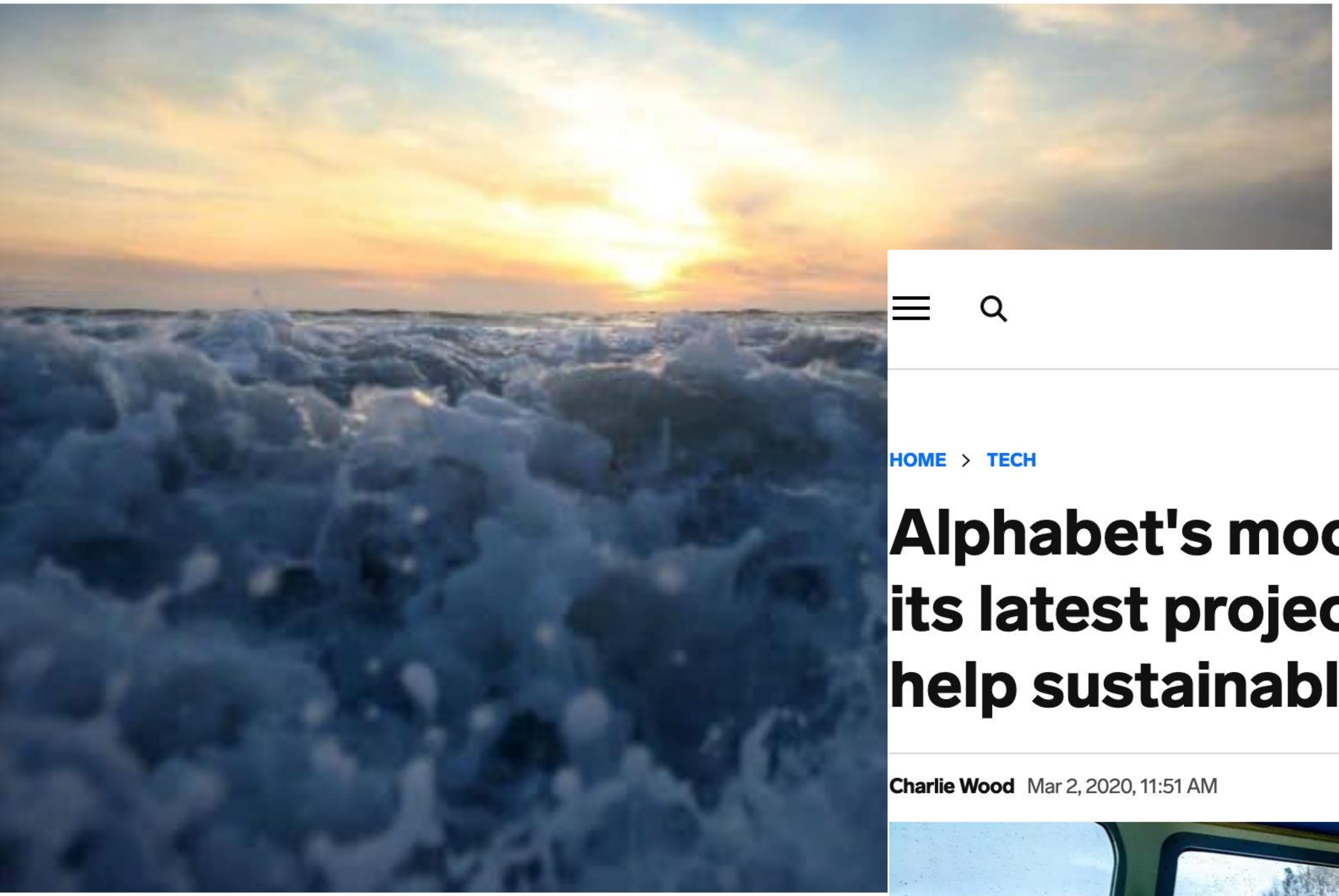
IoT Sensors → **Data** → **Decision Making & Prediction**

The Washington Post

Democracy Dies in Darkness

Energy • Analysis

To Save Earth's Climate, Map the Oceans



What lies beneath? (Photographer: David McNew/Getty Images)

By Dawn Wright | Bloomberg

August 17, 2021 at 2:45 p.m. EDT

Seabed 2030 aims to map the ocean floor by 2030

Forbes

DARPA Progress With 'Ocean Of Things' All-Seeing Eye On The High

David Hambling Contributor

Aerospace & Defense

I'm a South London-based technology journalist, consultant and author

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Alphabet's moonshot division unveils its latest project Tidal, which aims to help sustainable fishing

Charlie Wood Mar 2, 2020, 11:51 AM

FEDERAL NEWS NETWORK

TECHNOLOGY DEFENSE WORKFORCE/MANAGEMENT

NSF's unique R&D effort aims to solve societal challenges

Jason Miller | @jmillerWFED

May 7, 2021 5:28 pm 6 min read

FEDERAL DRIVE

NSF's unique R&D effort aims to solve societal c... POWERED BY podcastone

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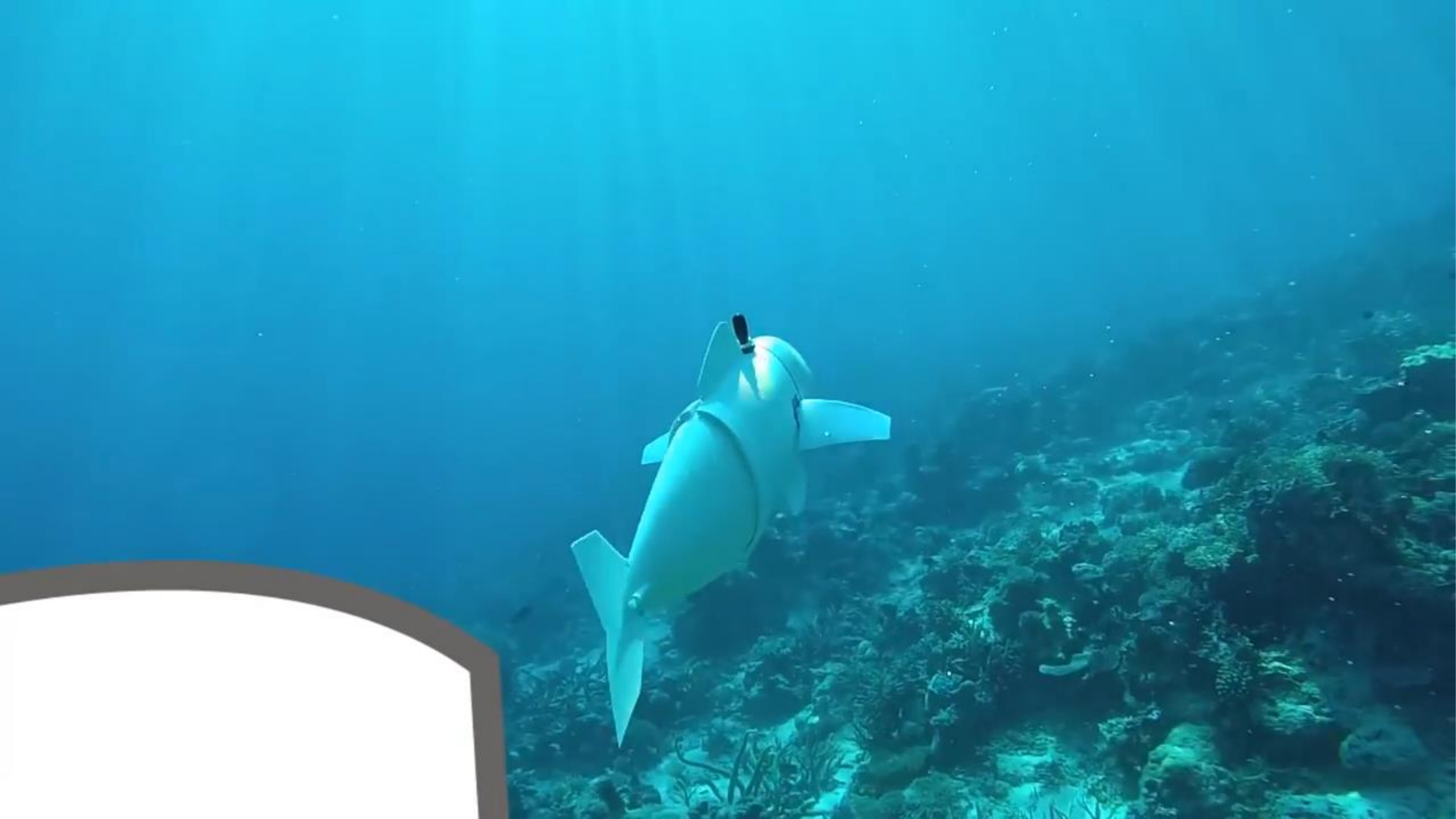
To help solve the challenges around climate change affecting the oceans and around the cybersecurity of communications

Why is bringing IoT to the ocean (esp. underwater) hard?

- **Communication:**
  - Can’t use radio (WiFi, bluetooth)
  - Direct underwater-to-air comms remains challenging
- **Power:**
  - No power outlet (access); hard to replace batteries
- **Sensing:**
  - Can’t use GPS (radio signals) for localization
  - Imaging is challenging (light interferes, refracts, etc.)

Example Ocean Connectivity, Sensing, & Power Technologies


ARGO
PROGRAM
BUREAU OF METEOROLOGY



What did you notice about the "communications element"?

How is underwater IoT different than in-air IoT?

- Can’t use radio (WiFi, bluetooth)
- Can’t use GPS (radio signals)
- Power is scarce
- Direct underwater-to-air comms remains challenging

Will cover two key technologies/areas

1. Underwater backscatter
2. Underwater-to-air communications

Problem: Battery life of underwater sensors is extremely limited

Low-power underwater transmitters consume 100s of Watts

(e.g., WHOI low-power micro-modem 2019)

↓

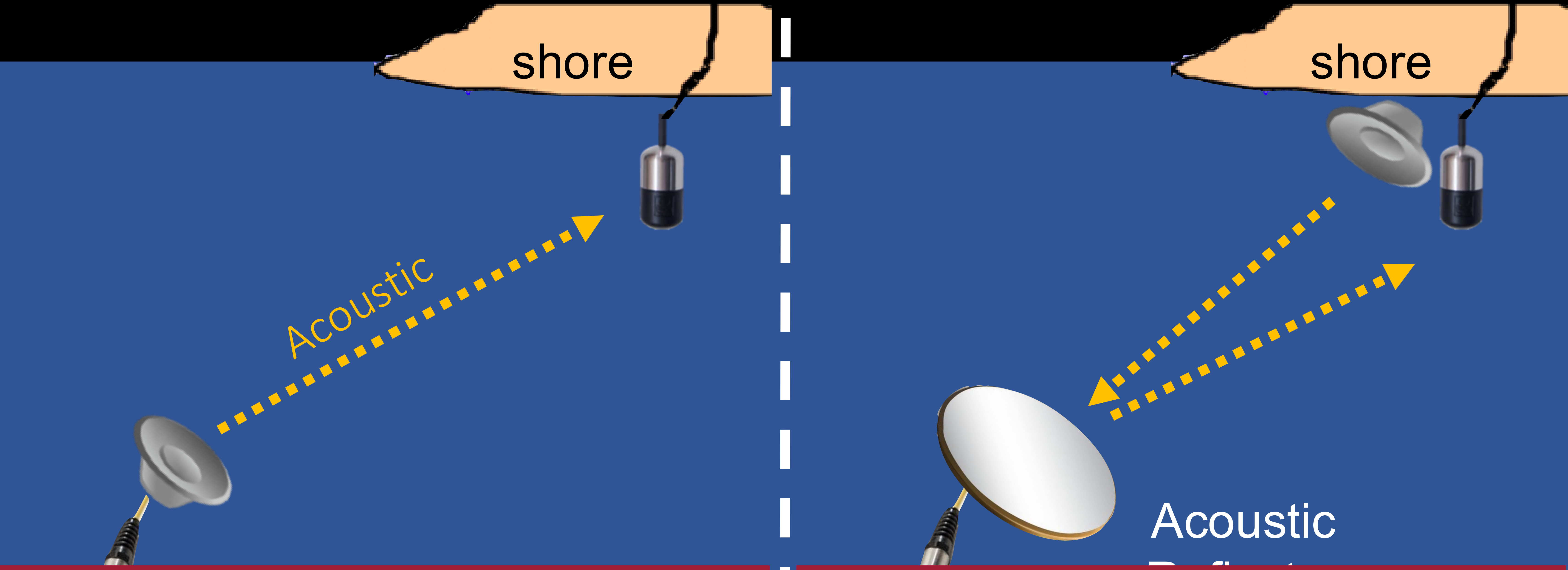
State-of-the-art sensors for tracking marine animals only last for few hours or days

[Animal Biotelemetry'15, Scientific Reports'17]

Technology that Enables Underwater Backscatter (Batteryless) Networking

PAB (ACM SIGCOMM'19)

Traditional Approach | Underwater Backscatter



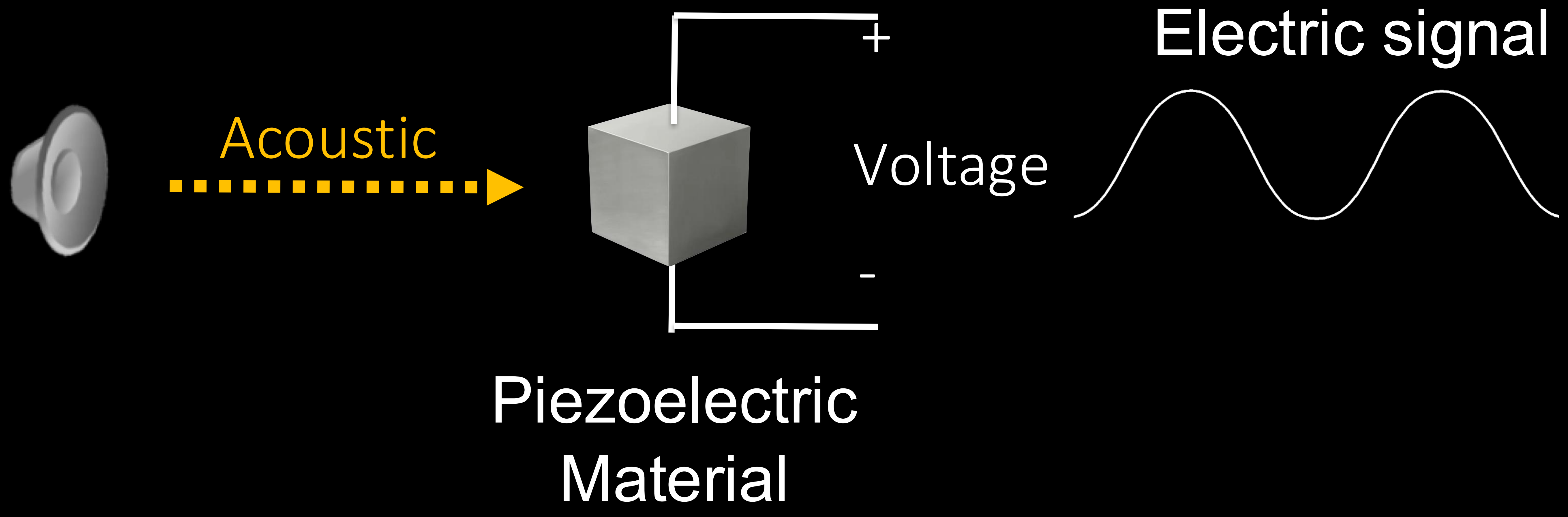
Sensor generates its own acoustic signal

Sensor reflects an existing acoustic signal

How can we control the reflections of acoustic signals?

Key Idea: Use piezoelectricity to design programmable acoustic reflectors

Piezoelectric materials transform mechanical to electrical energy



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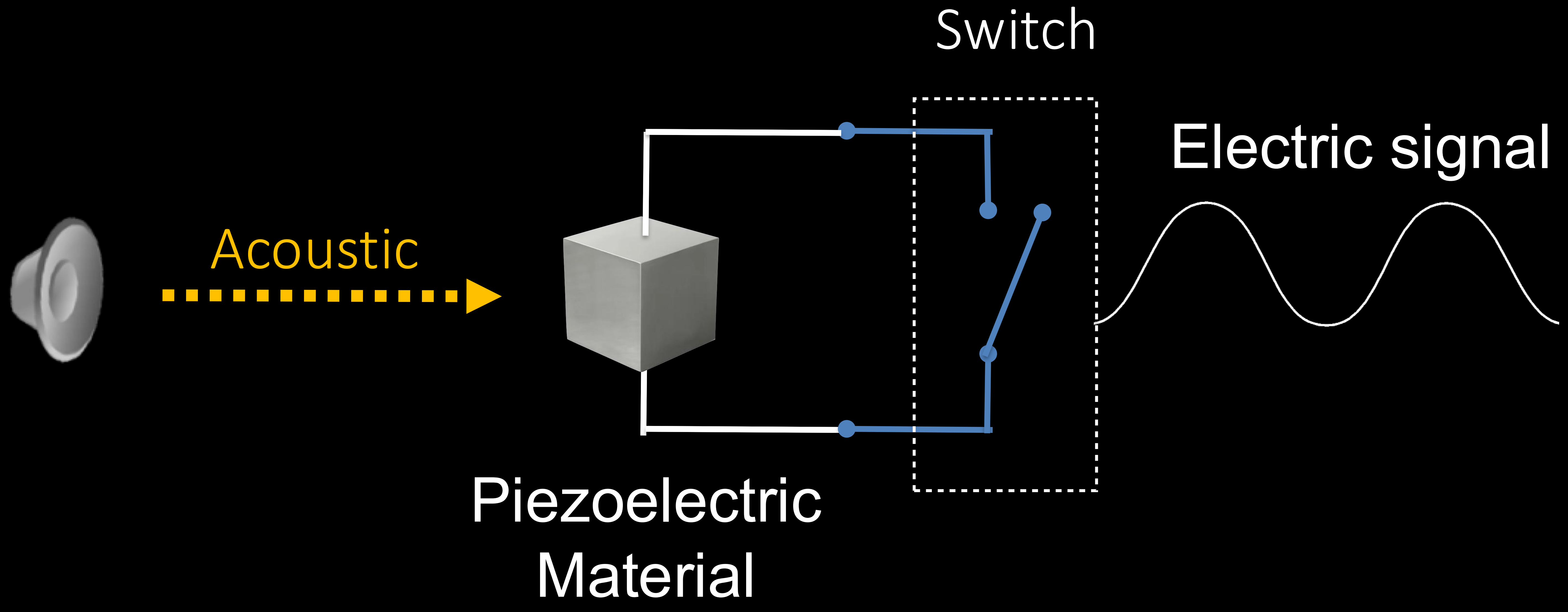

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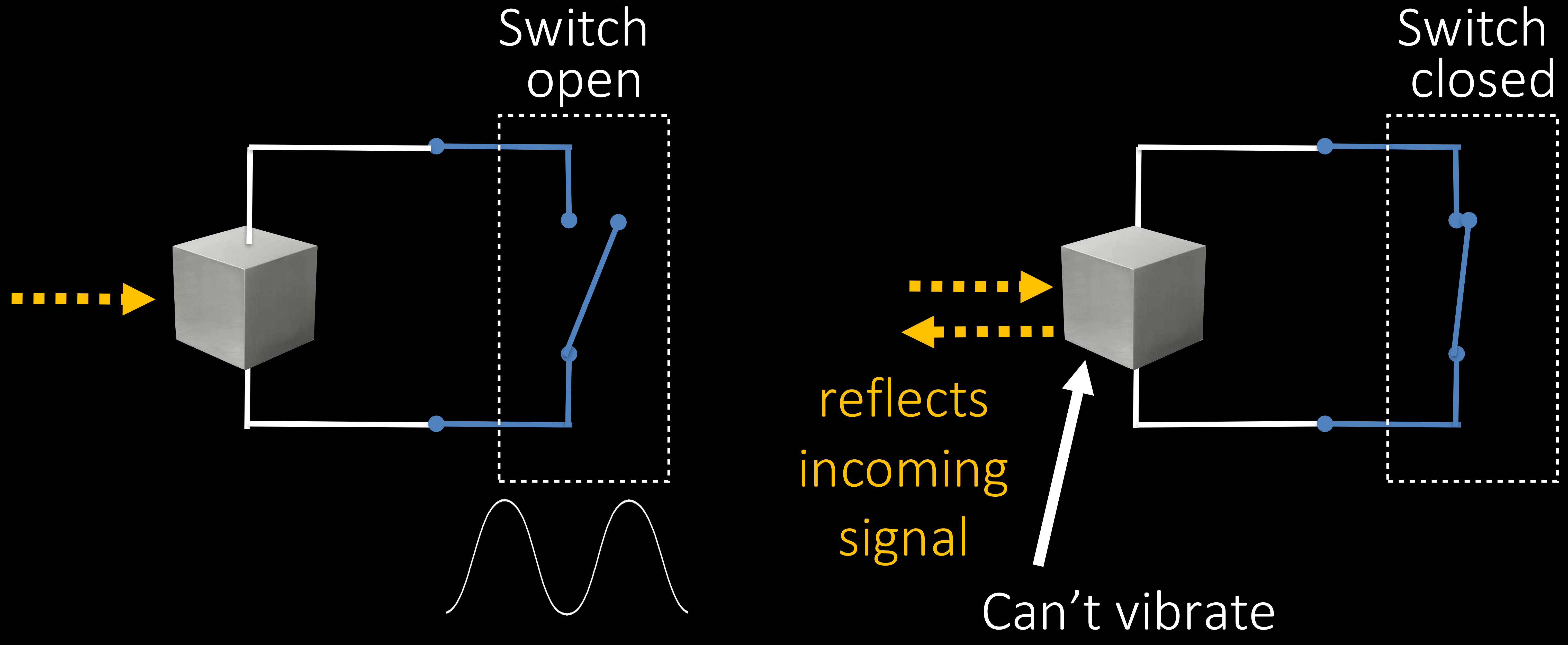
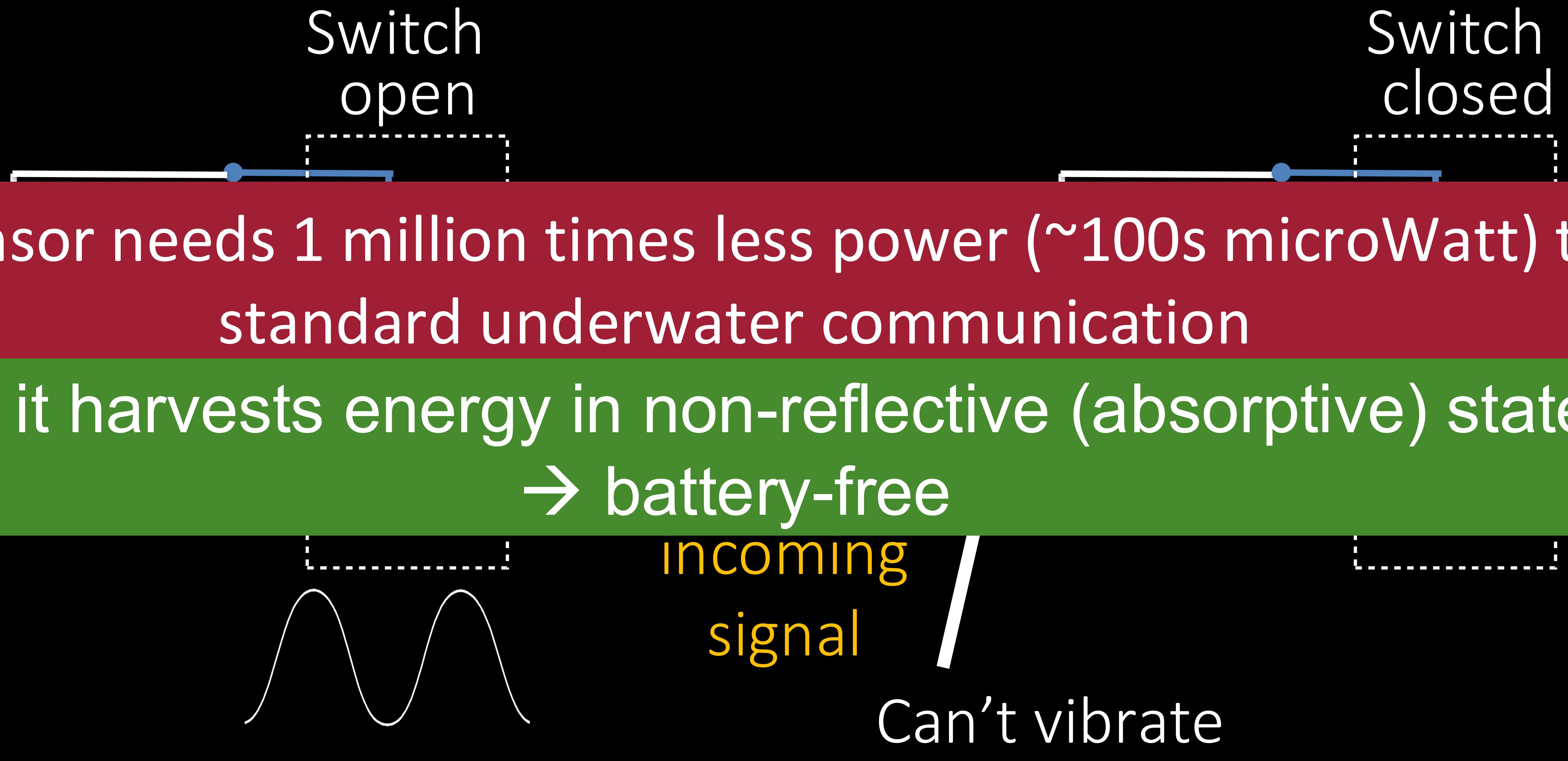
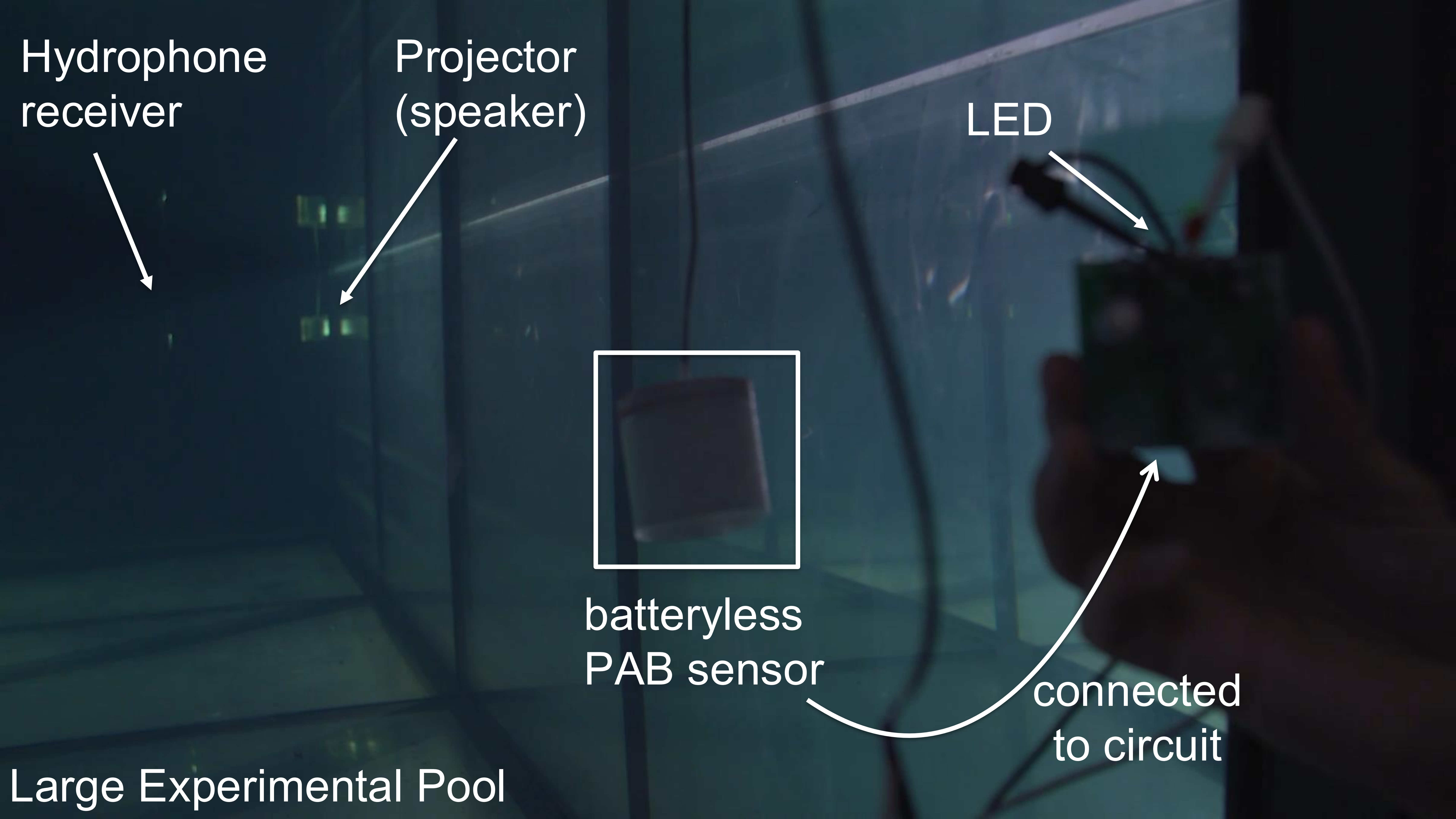


Piezo-Acoustic Backscatter

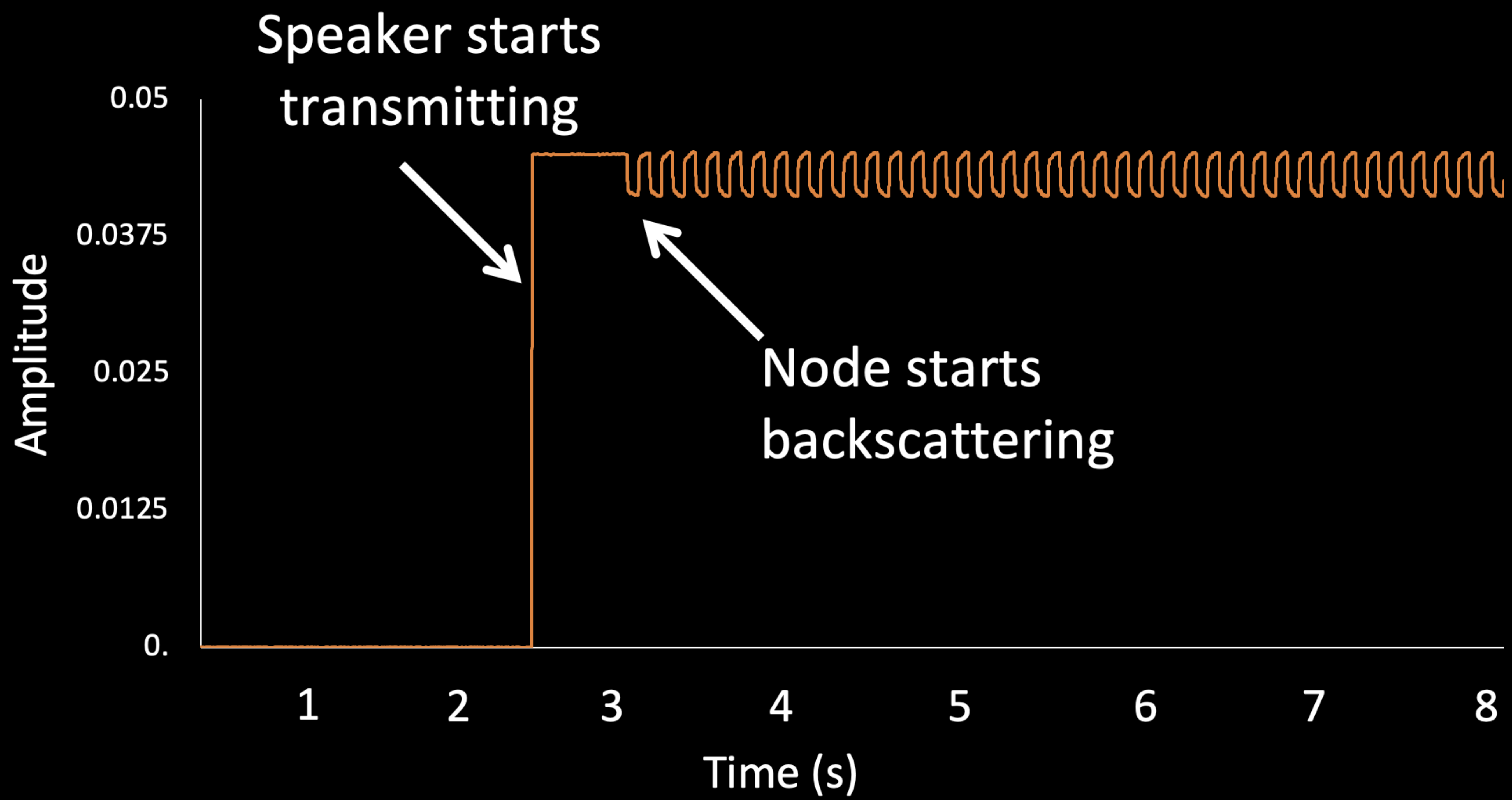


PAB sensor needs 1 million times less power (~100s microWatt) than standard underwater communication

And it harvests energy in non-reflective (absorptive) state → battery-free


Hydrophone receiver
Projector (speaker)
LED
batteryless PAB sensor
connected to circuit
Large Experimental Pool

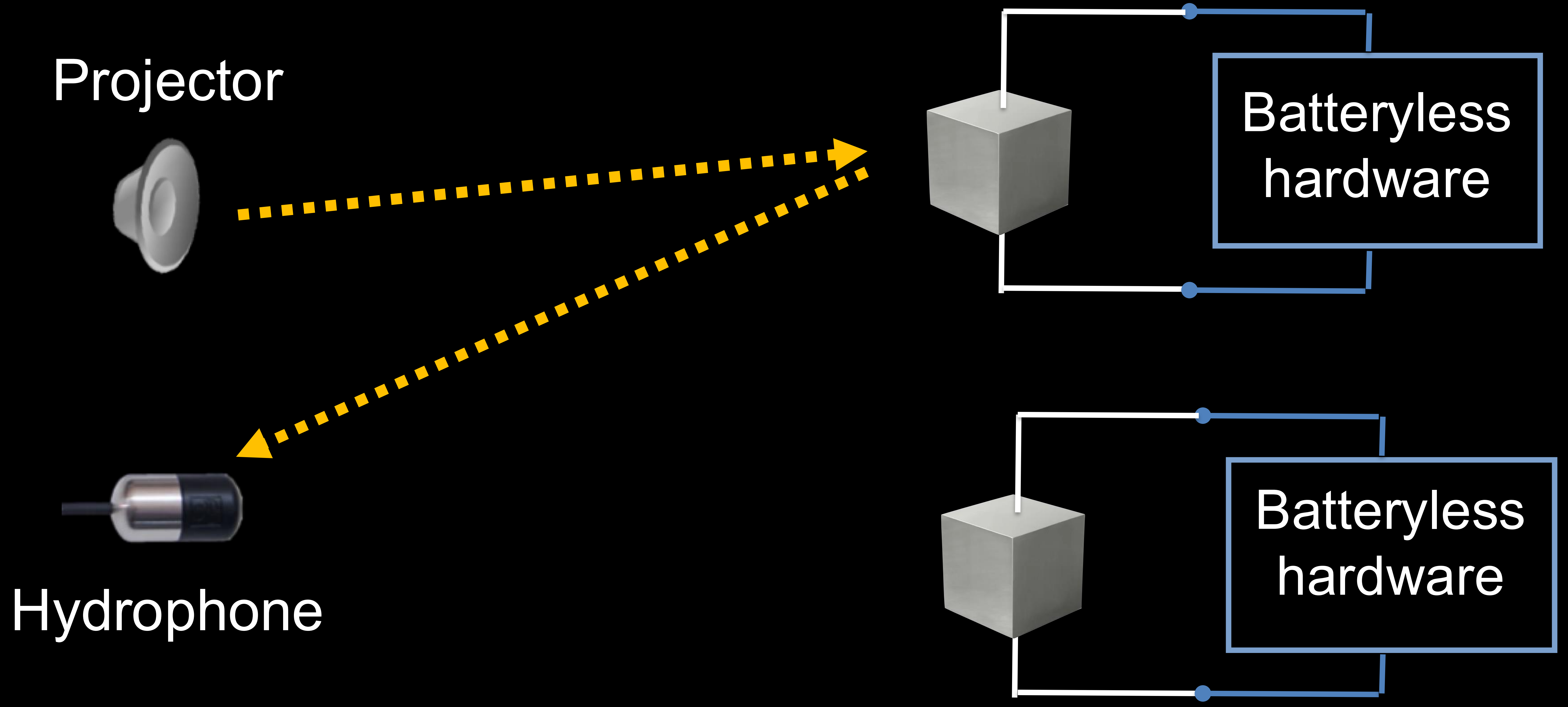
Measuring the Backscatter Signal (by Hydrophone)



How can we extend underwater backscatter to multiple nodes?

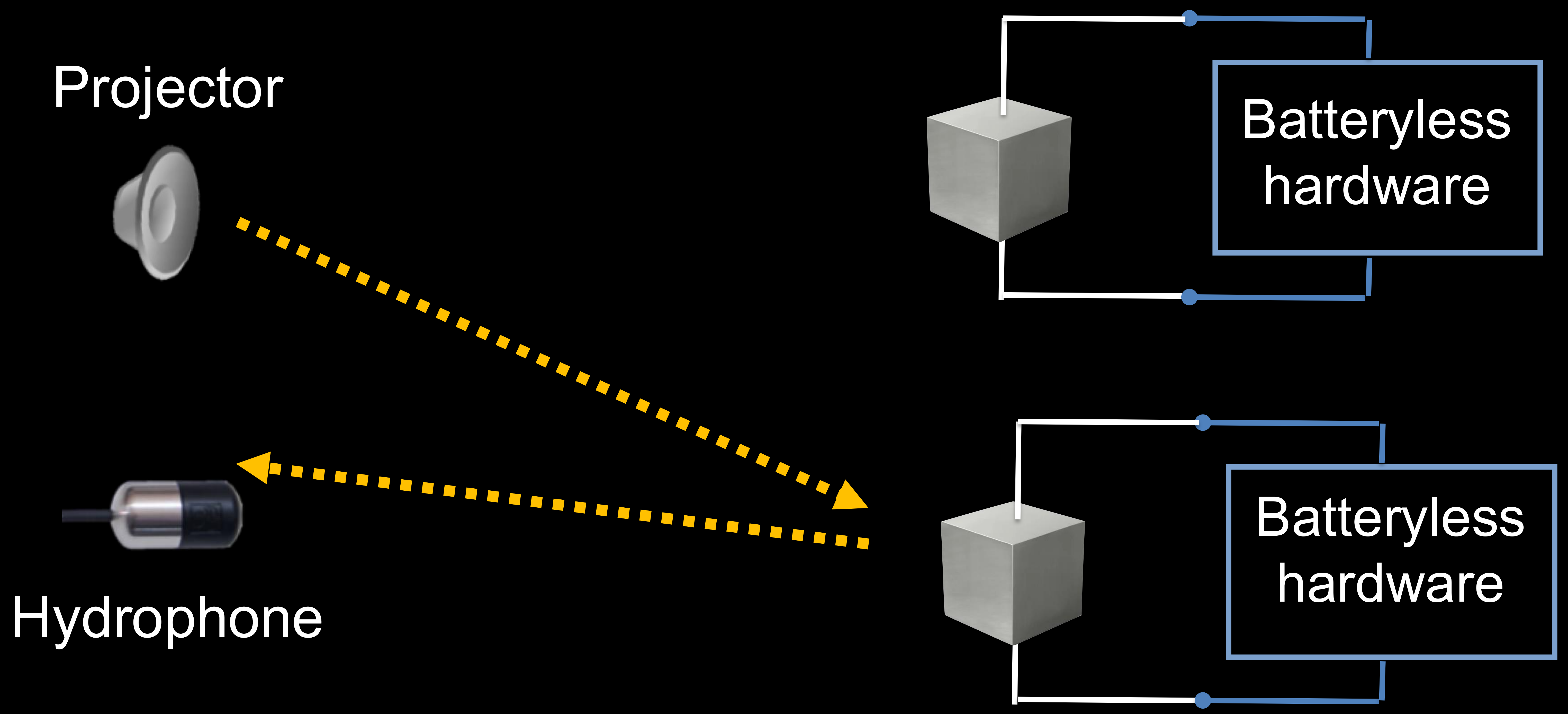
Extending to Multiple Nodes

Option 1: Time Division Multiplexing



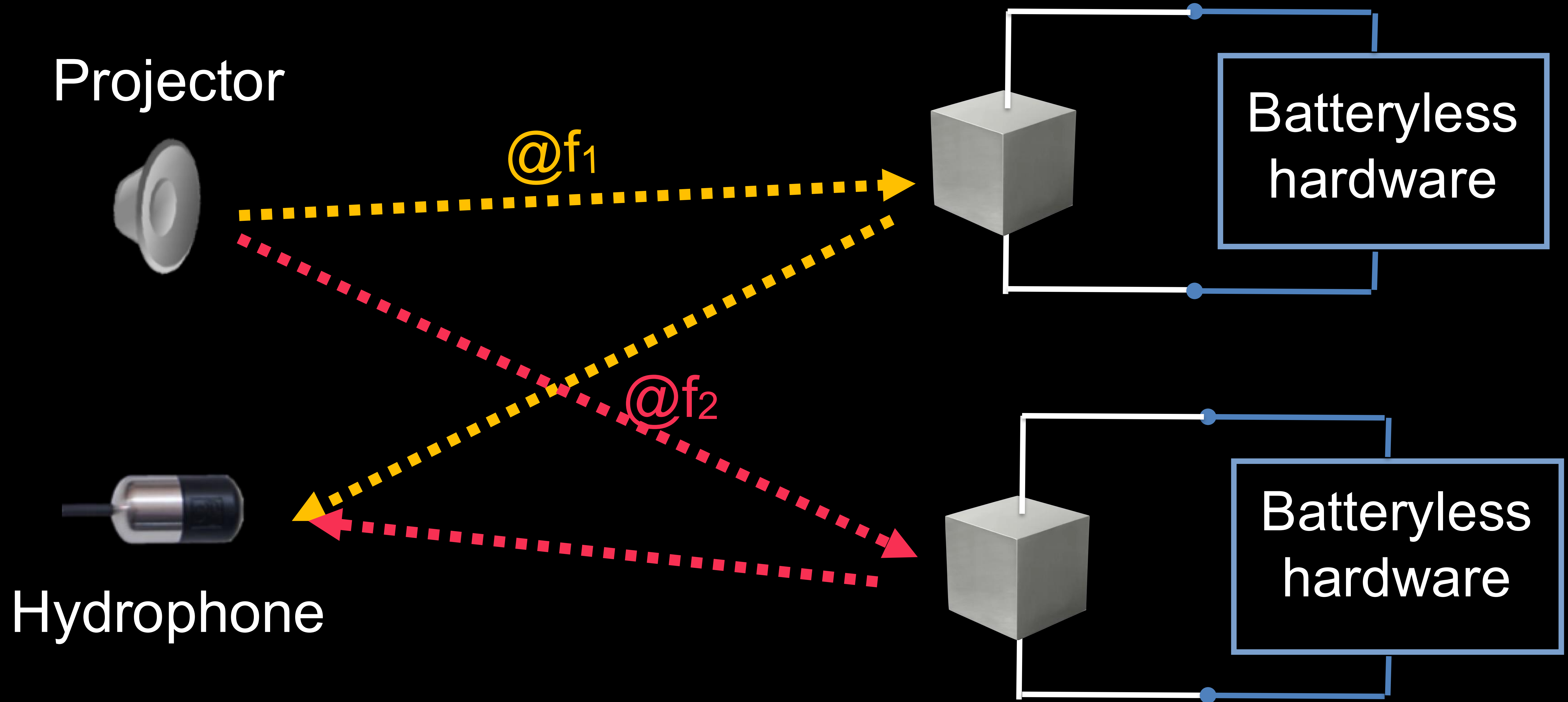
Extending to Multiple Nodes

Option 1: Time Division Multiplexing



Extending to Multiple Nodes

Option 2: Frequency Division Multiplexing



Extending to Multiple Nodes

Problem: Resonance of piezoelectrics limits their bandwidth

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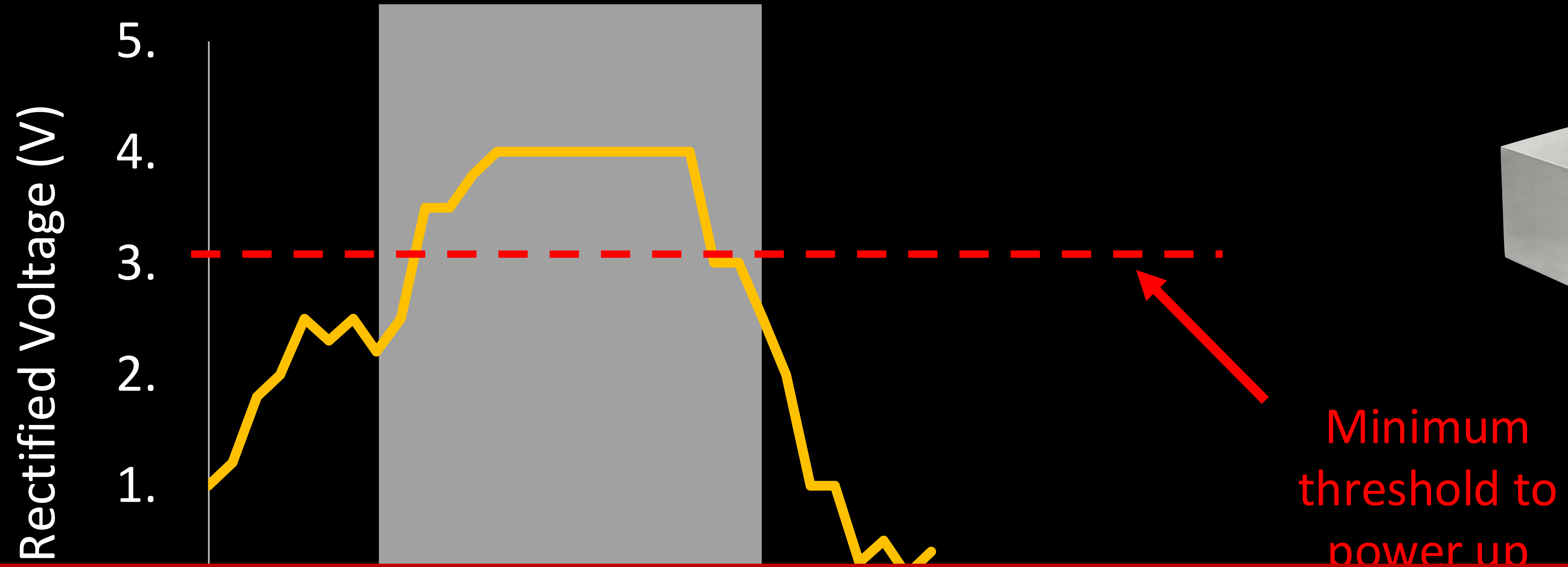
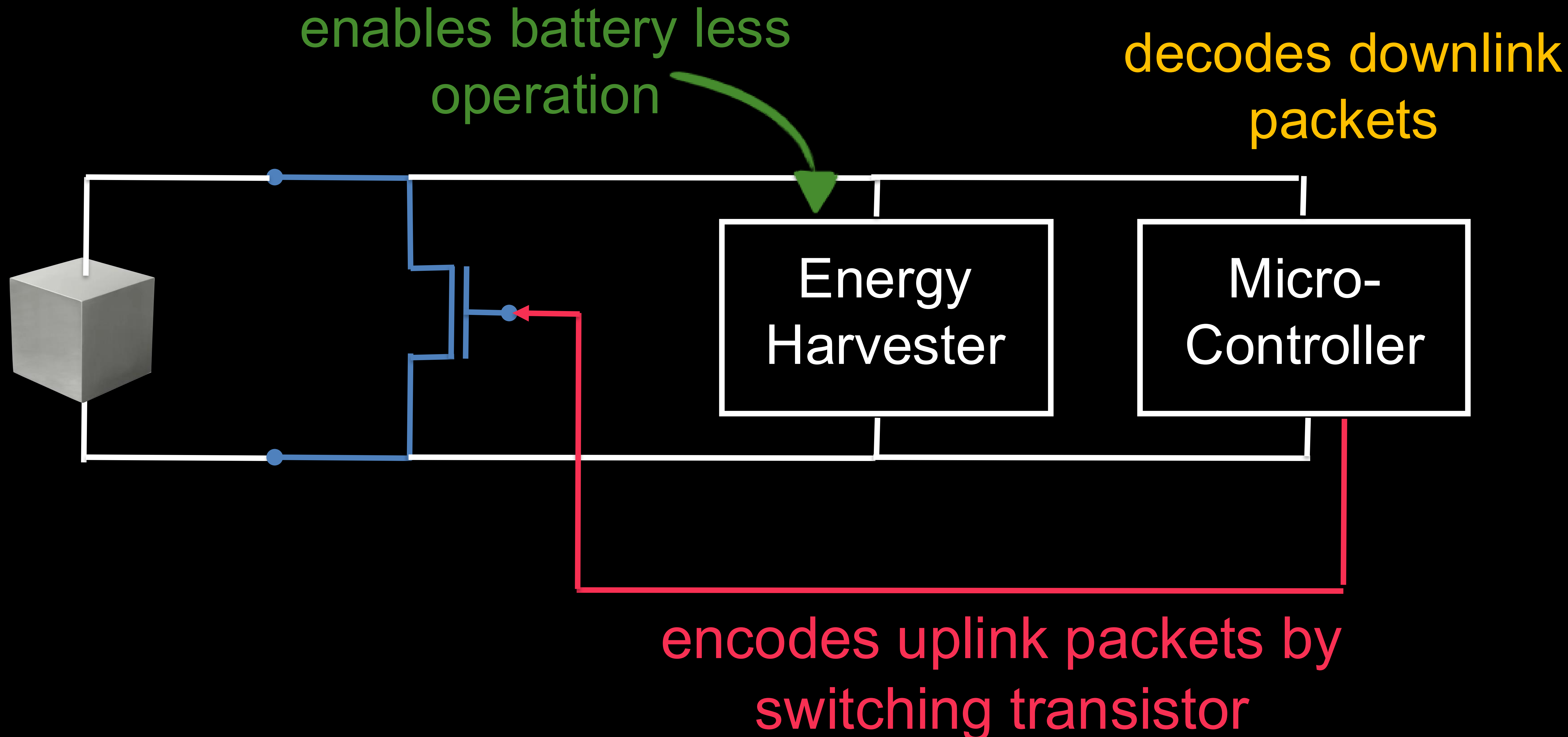


Operating at resonance maximizes energy harvesting but limits concurrent transmissions (and FDMA)

Solution Idea: Shift the resonance frequency *itself* to a different channel

Solution Idea: Shift the resonance frequency itself to a different channel



Solution Idea: Shift the resonance frequency *itself* to a different channel

resonance frequency determined by interaction between piezo & the batteryless circuit

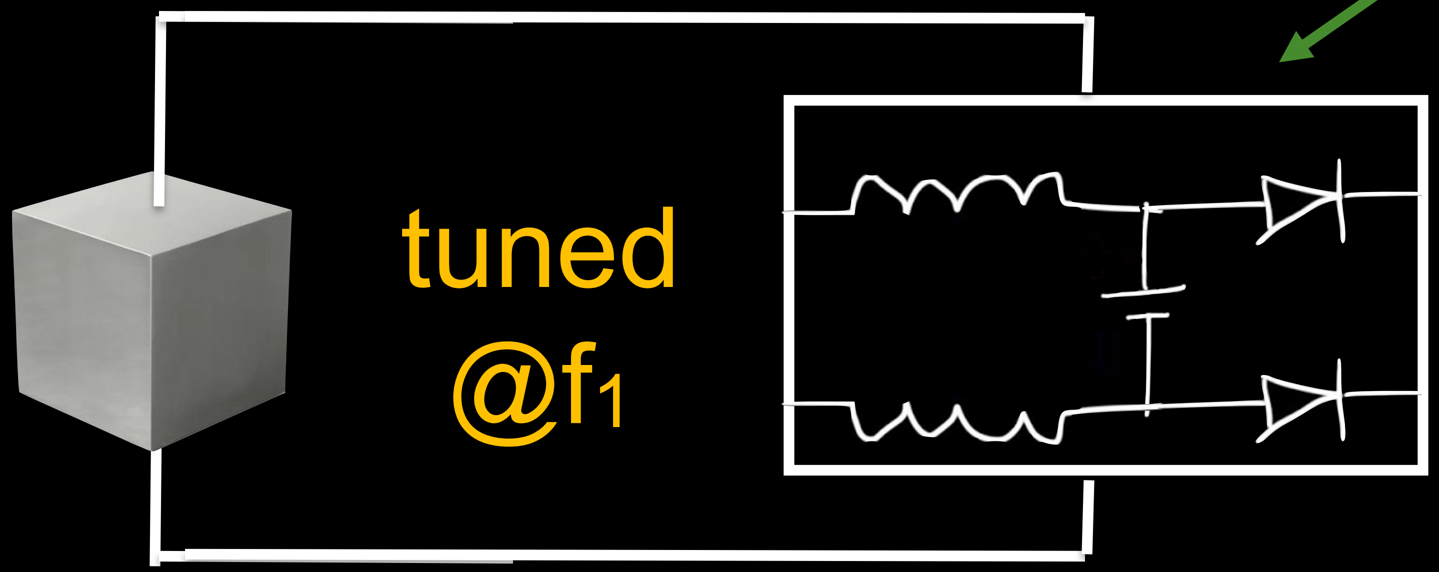
$$Z_{circuit}(f) = Z^{*}_{piezo}(f)$$

frequency dependent

→Tune the circuit to a different frequency

Solution Idea: Shift the resonance frequency *itself* to a different channel

resonance frequency determined by interaction between piezo & the batteryless circuit



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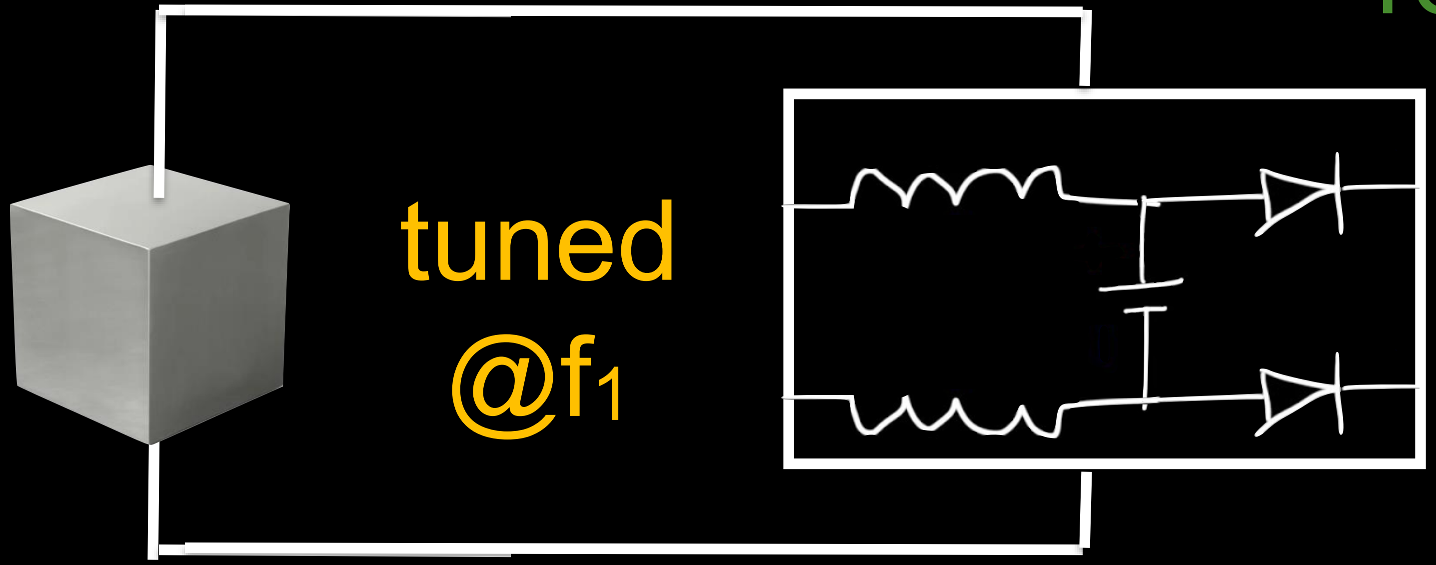

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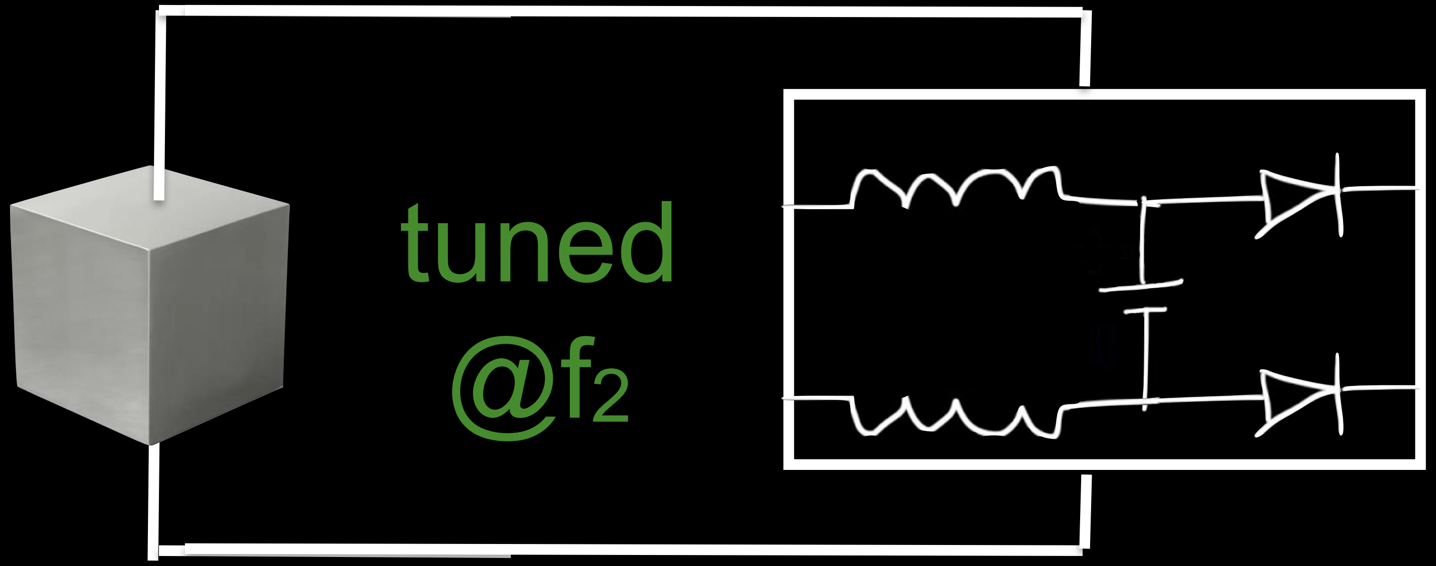

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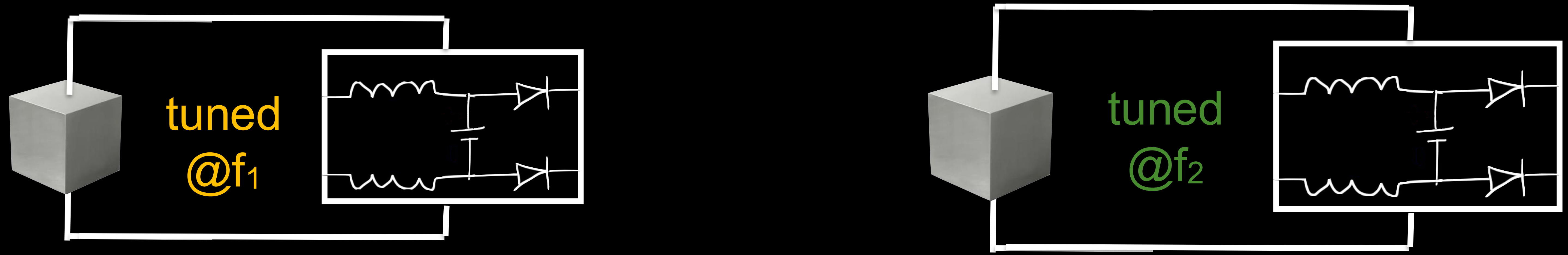
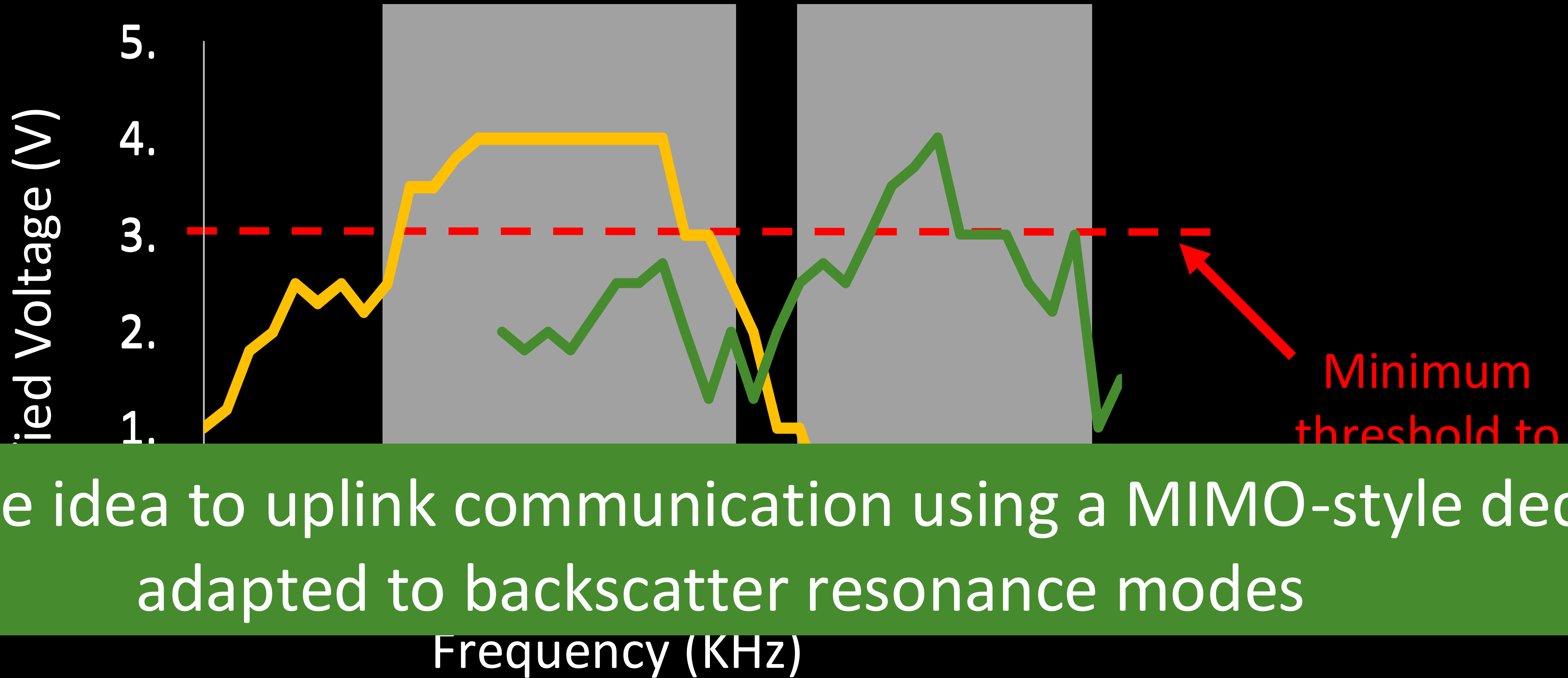
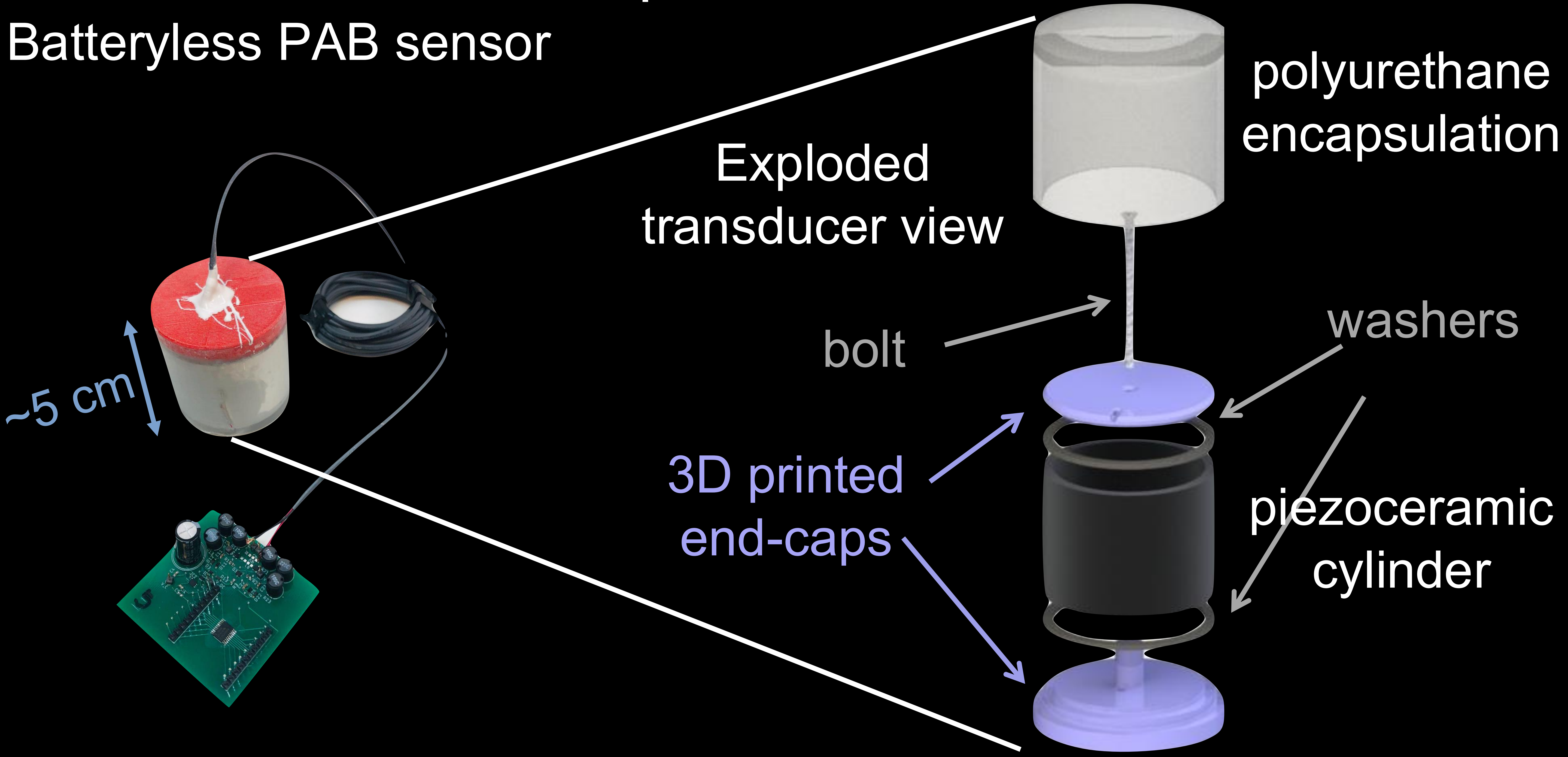




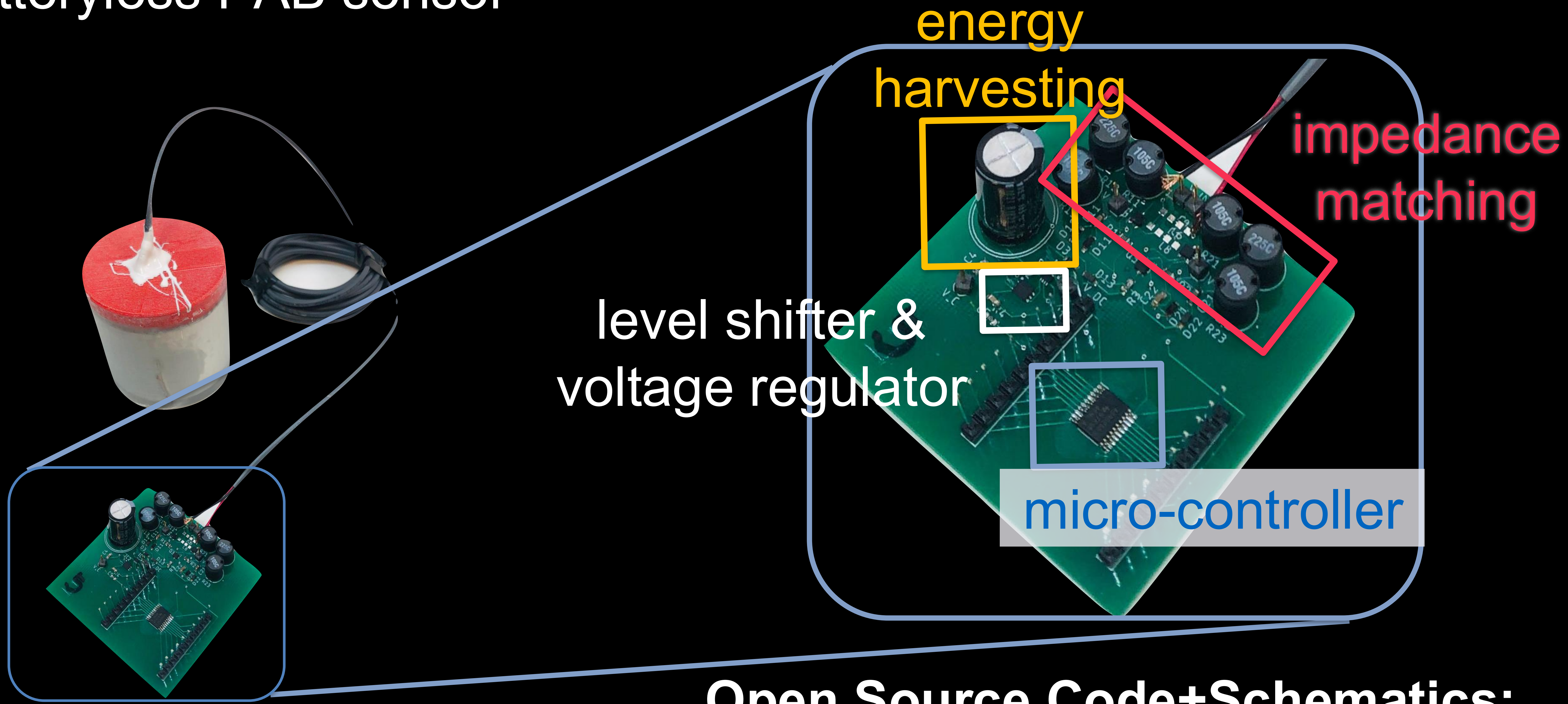
Extend the idea to uplink communication using a MIMO-style decoder adapted to backscatter resonance modes

Implementation



Implementation

Batteryless PAB sensor



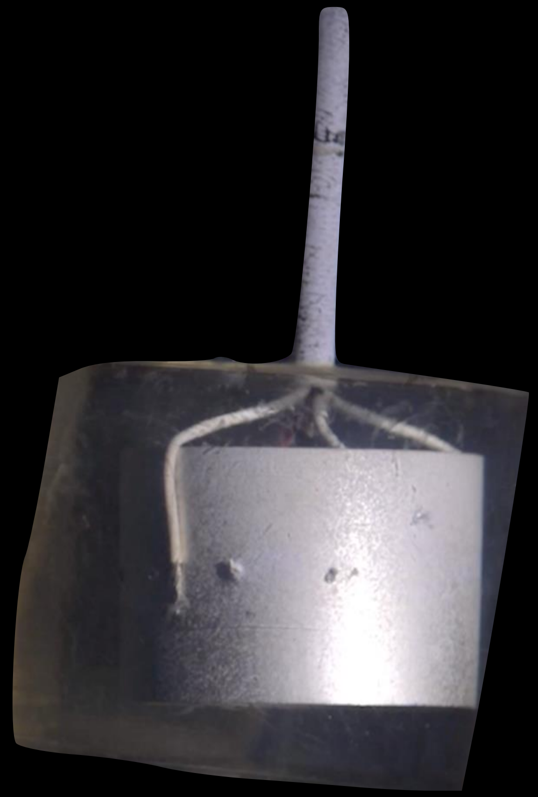
Open Source Code+Schematics:

https://github.com/saadafzal24/Underwater-Backscatter

Implementation

Batteryless PAB sensor

Projector

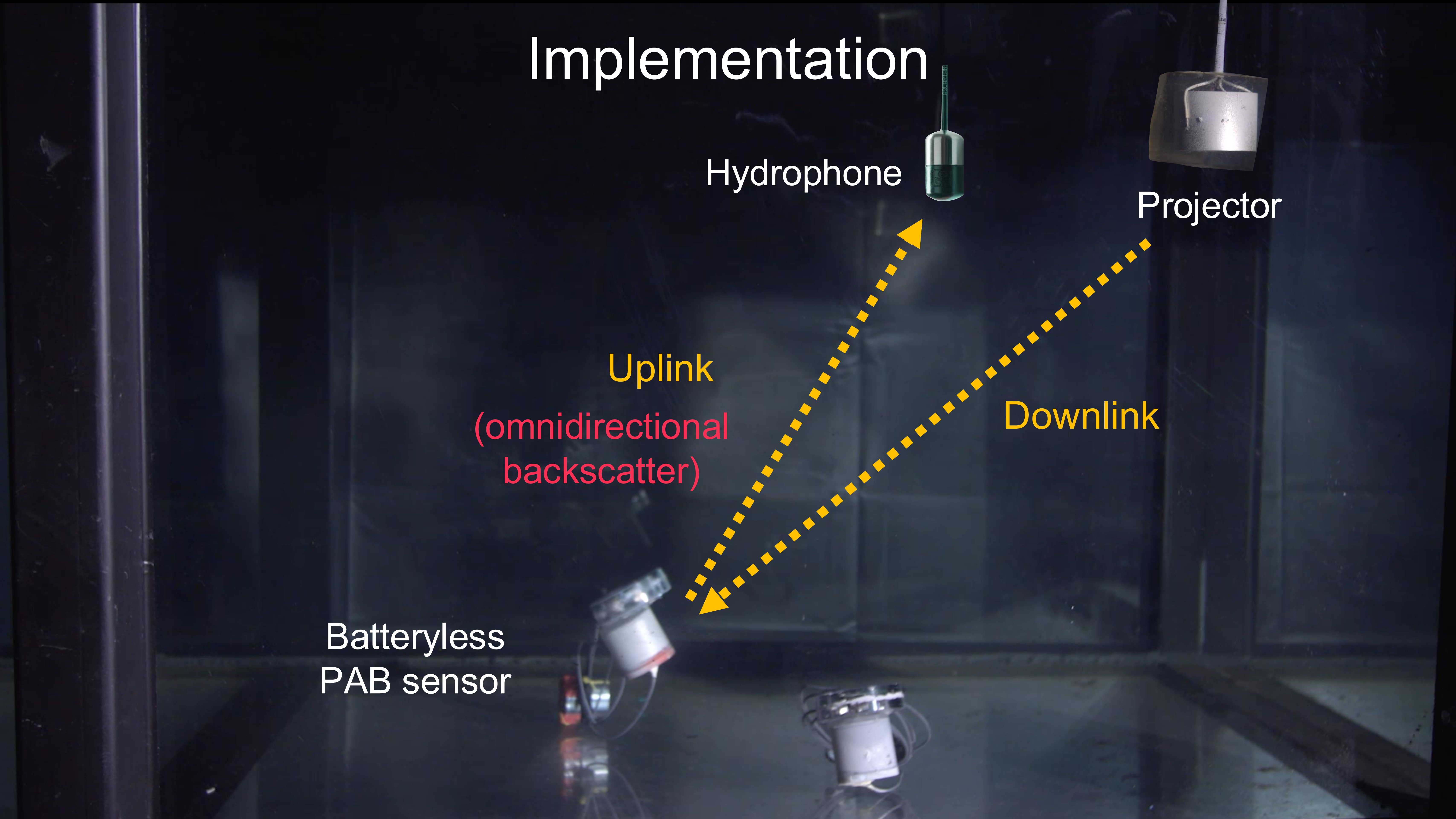


fabricated in-house

Hydrophone

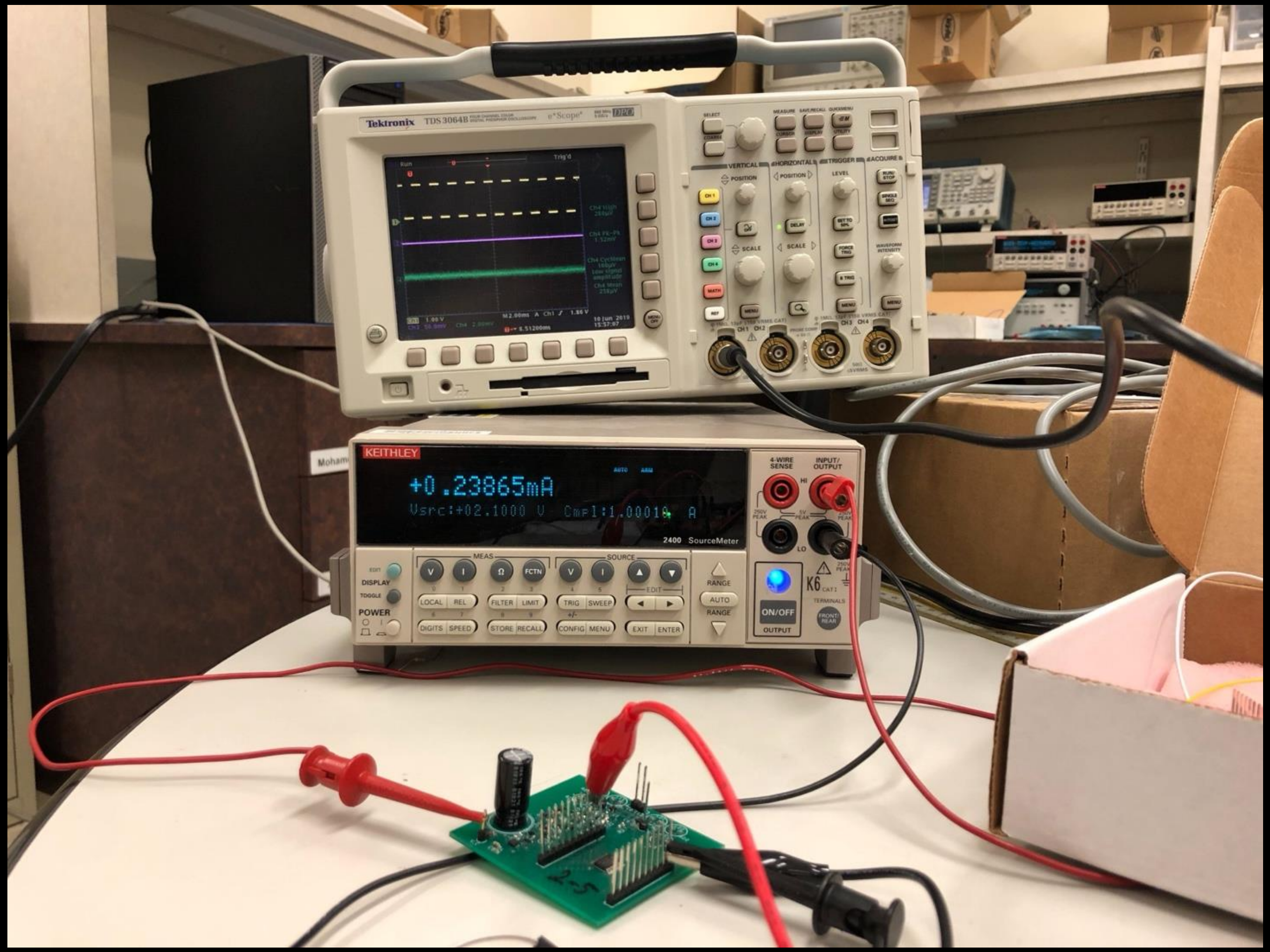
Aquarian H2A

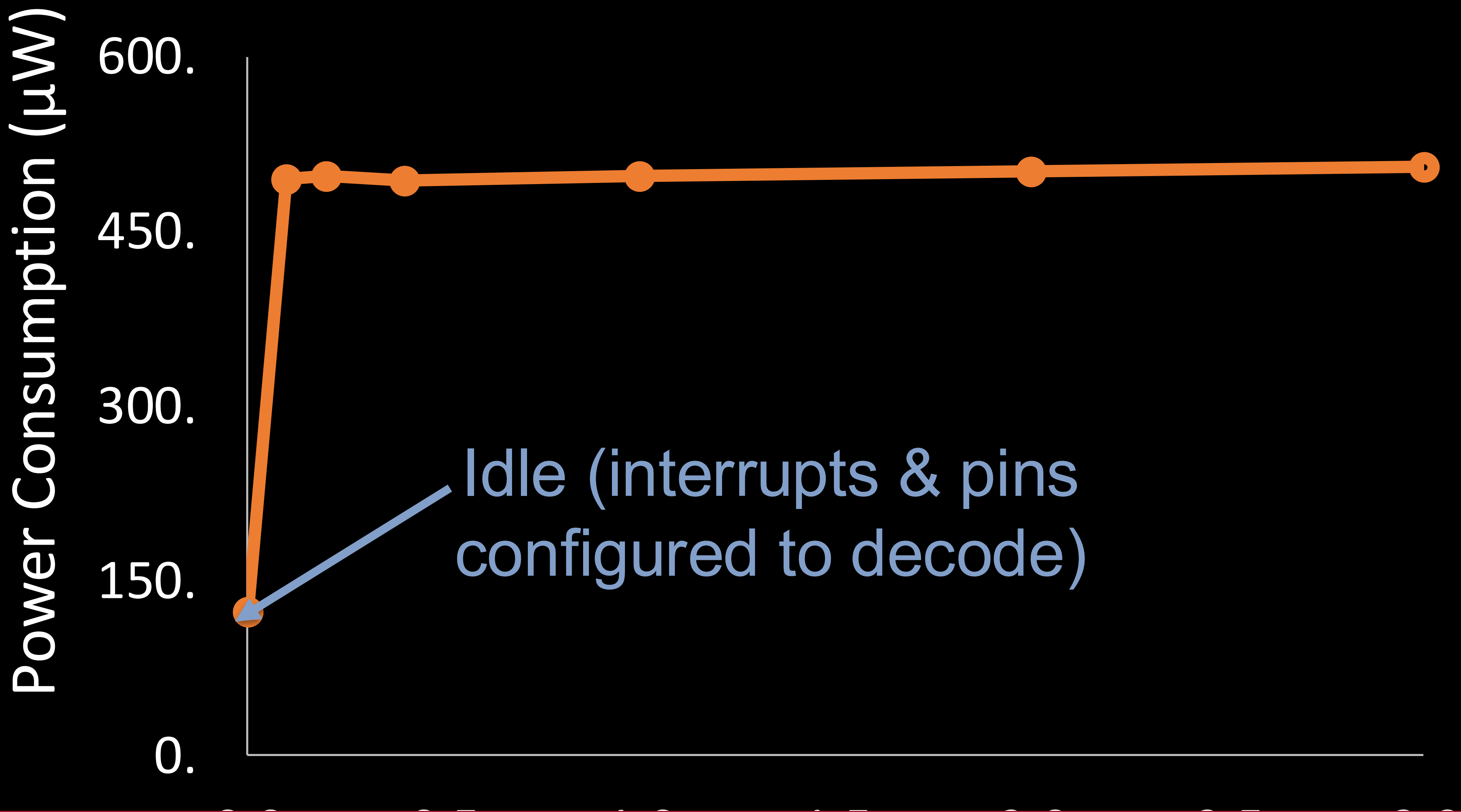
Implementation



Power Consumption

Empirically measured using Keithley 2400 source meter

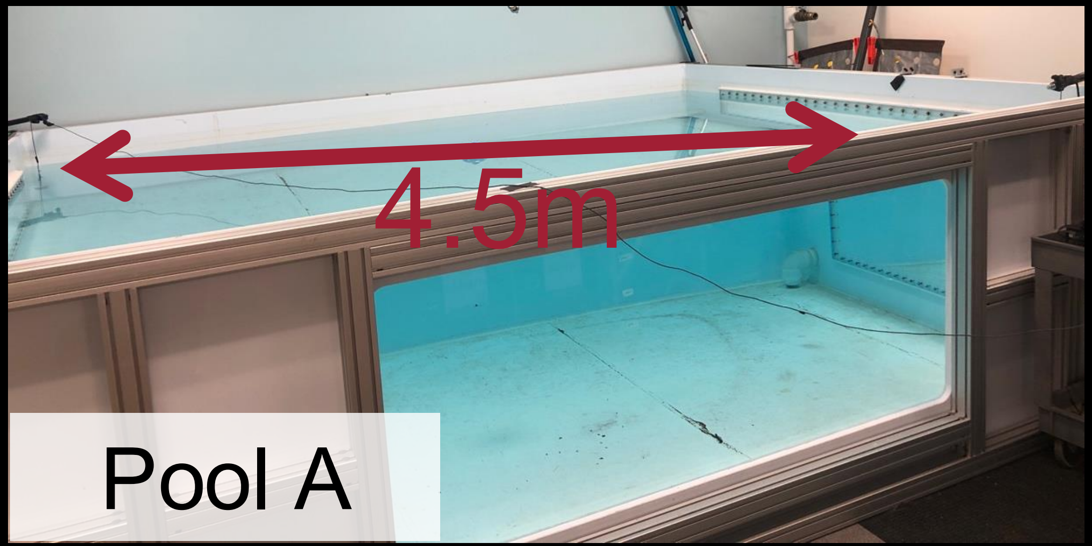


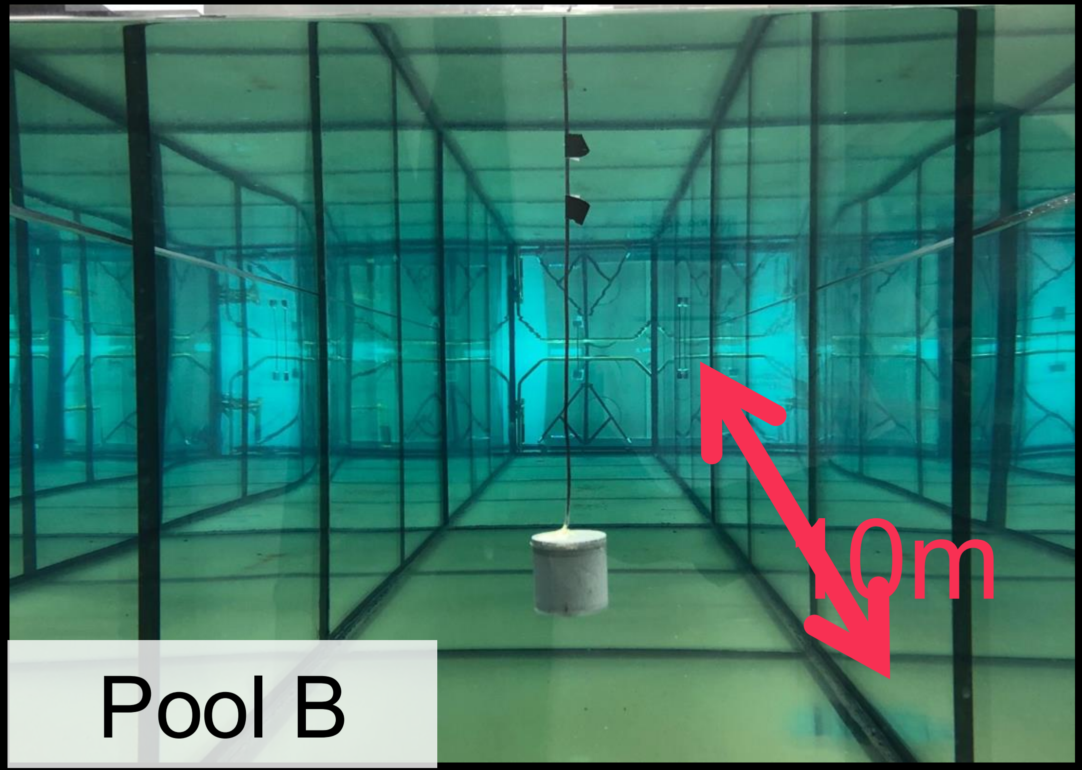


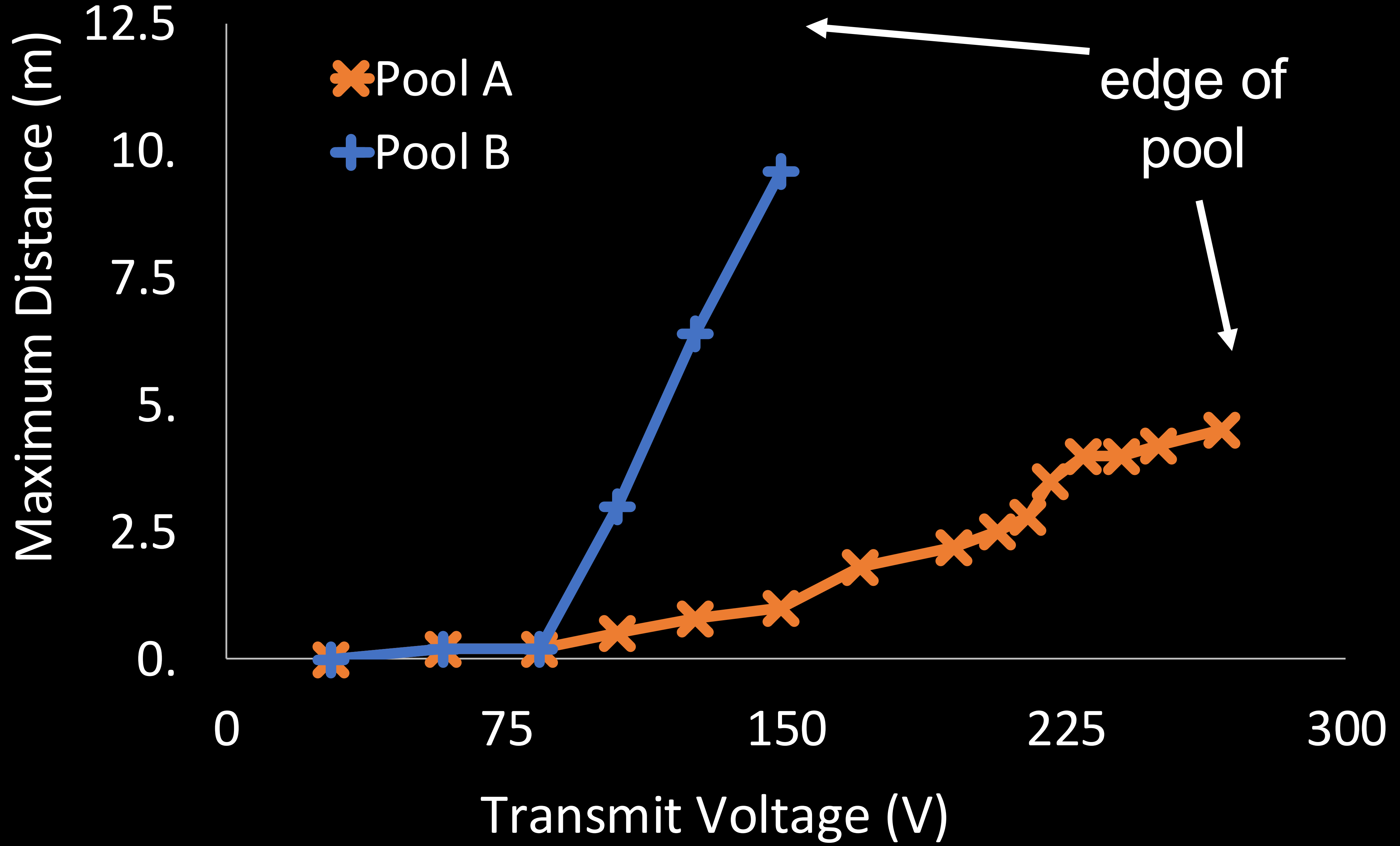
1 million times less power than state-of-the-art low-power underwater sensors [WHOI micro-modem 2019]

Power-up Range

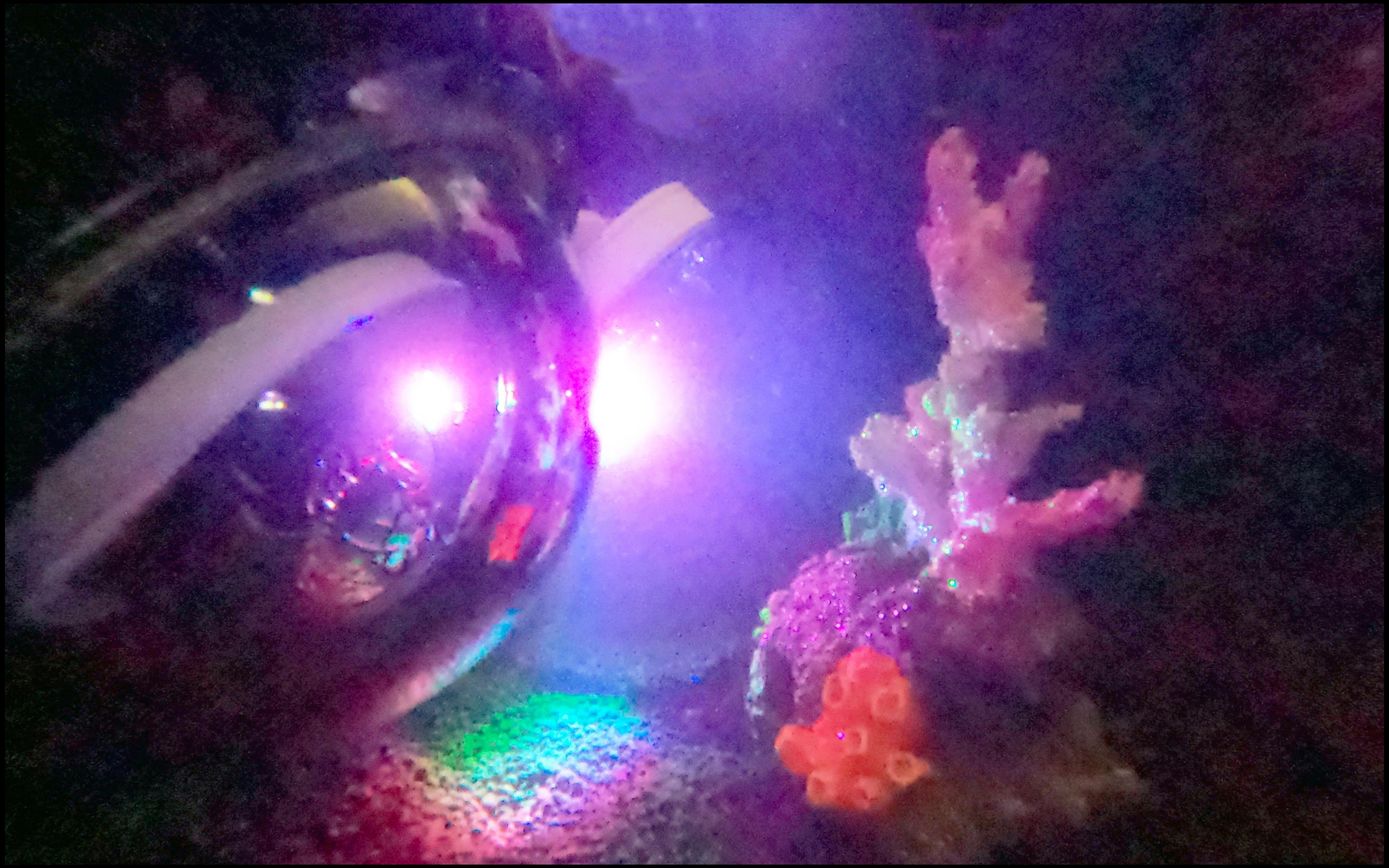
Experiment: Vary power and distance to sensor





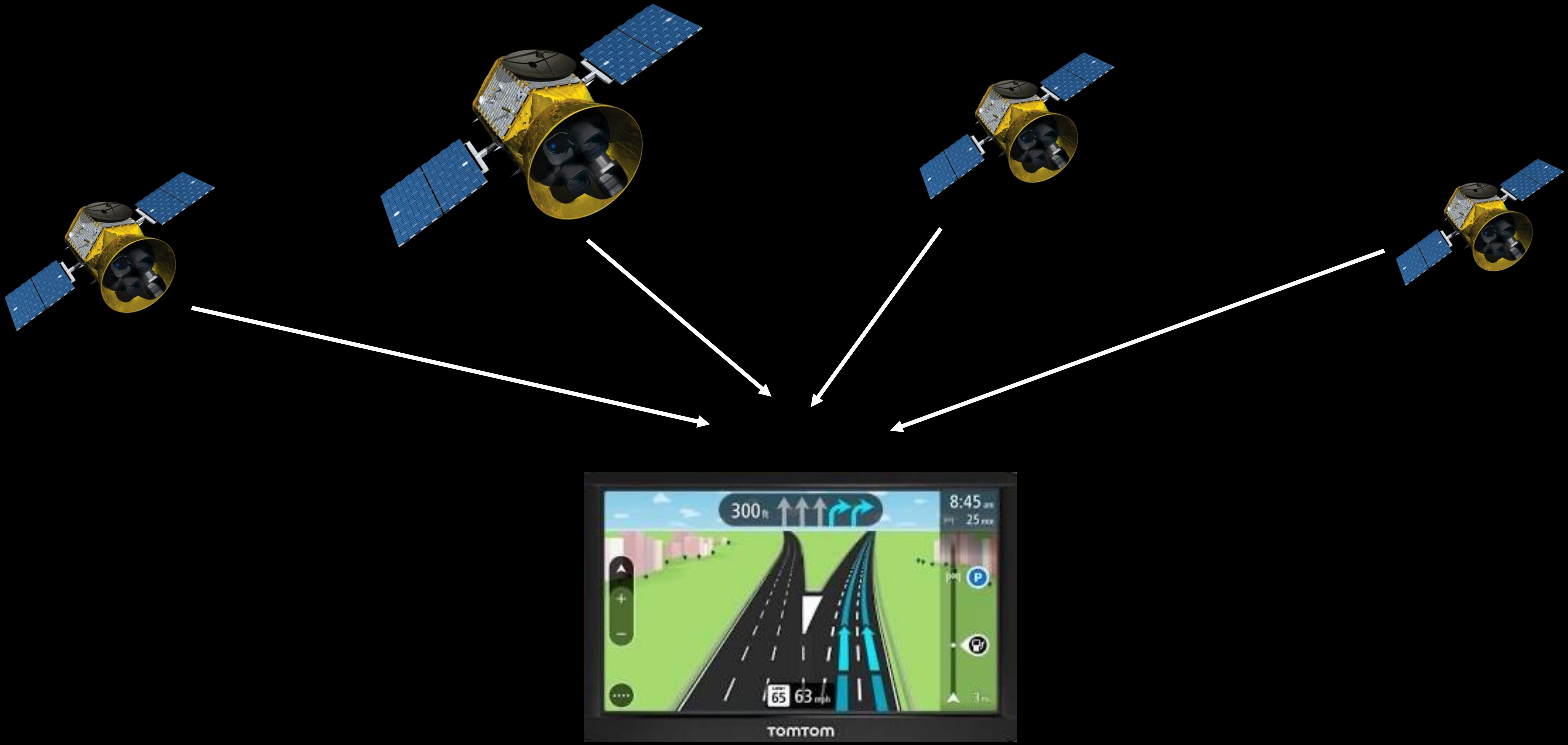


Can we enable battery-free underwater imaging?



Can we enable battery-free underwater localization?

Global Positioning System (GPS)



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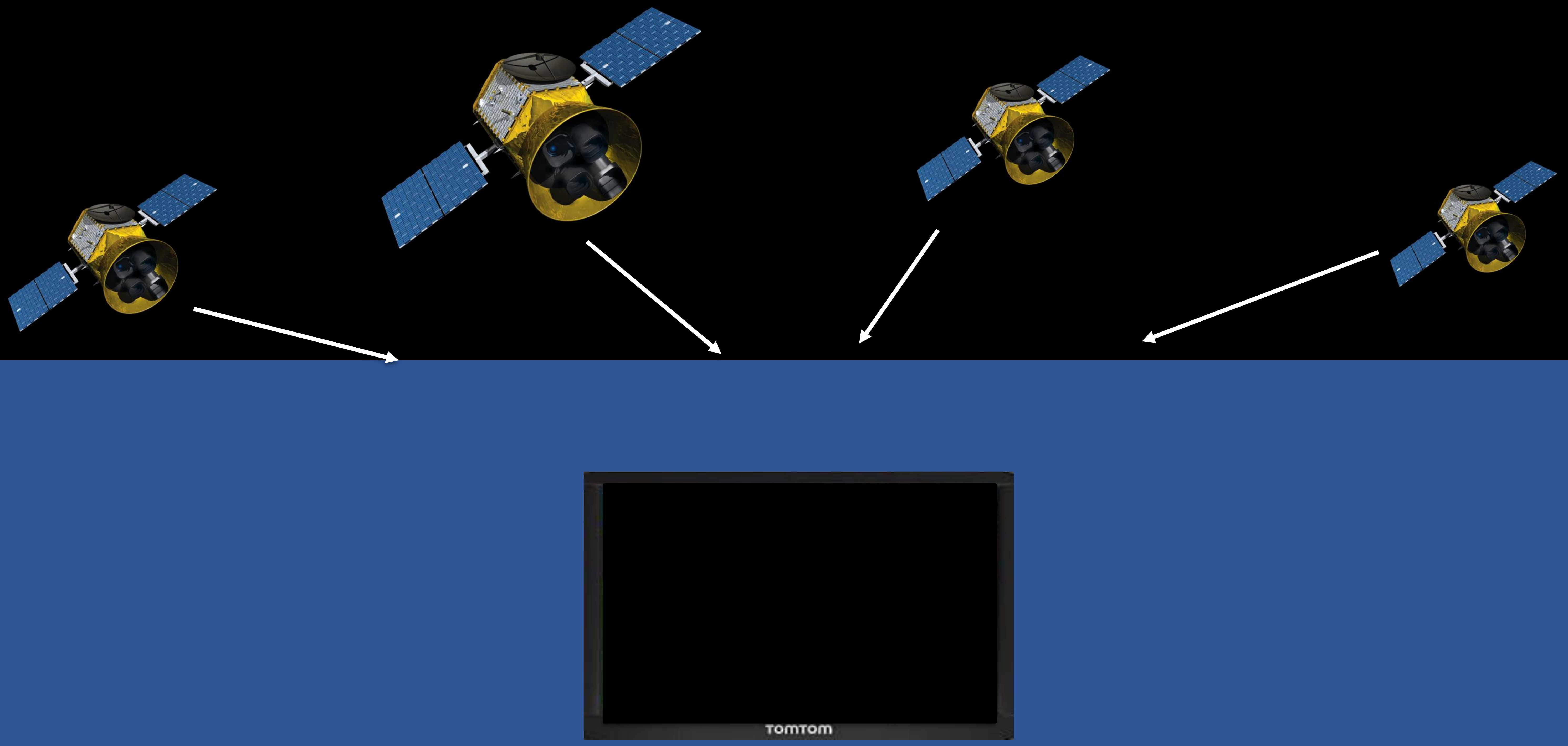
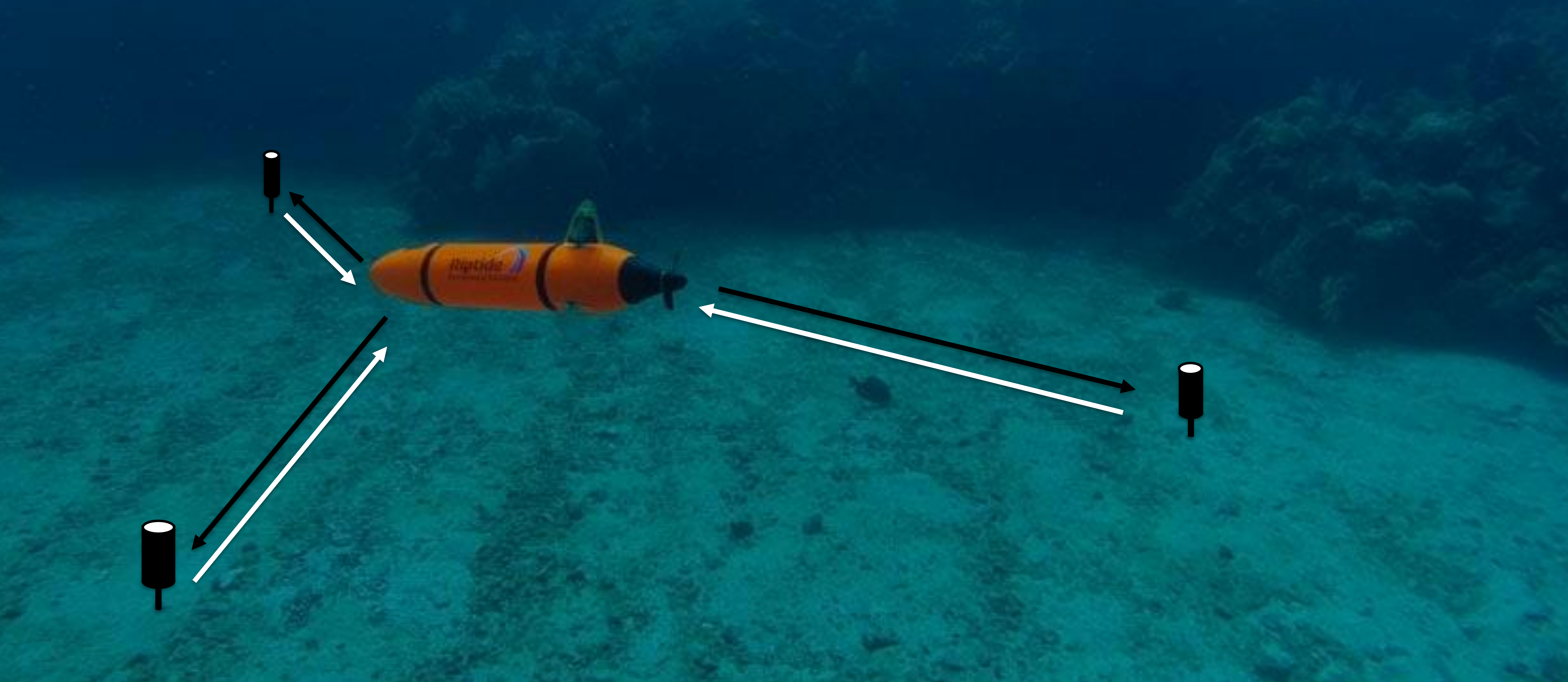


Conventional Underwater Positioning

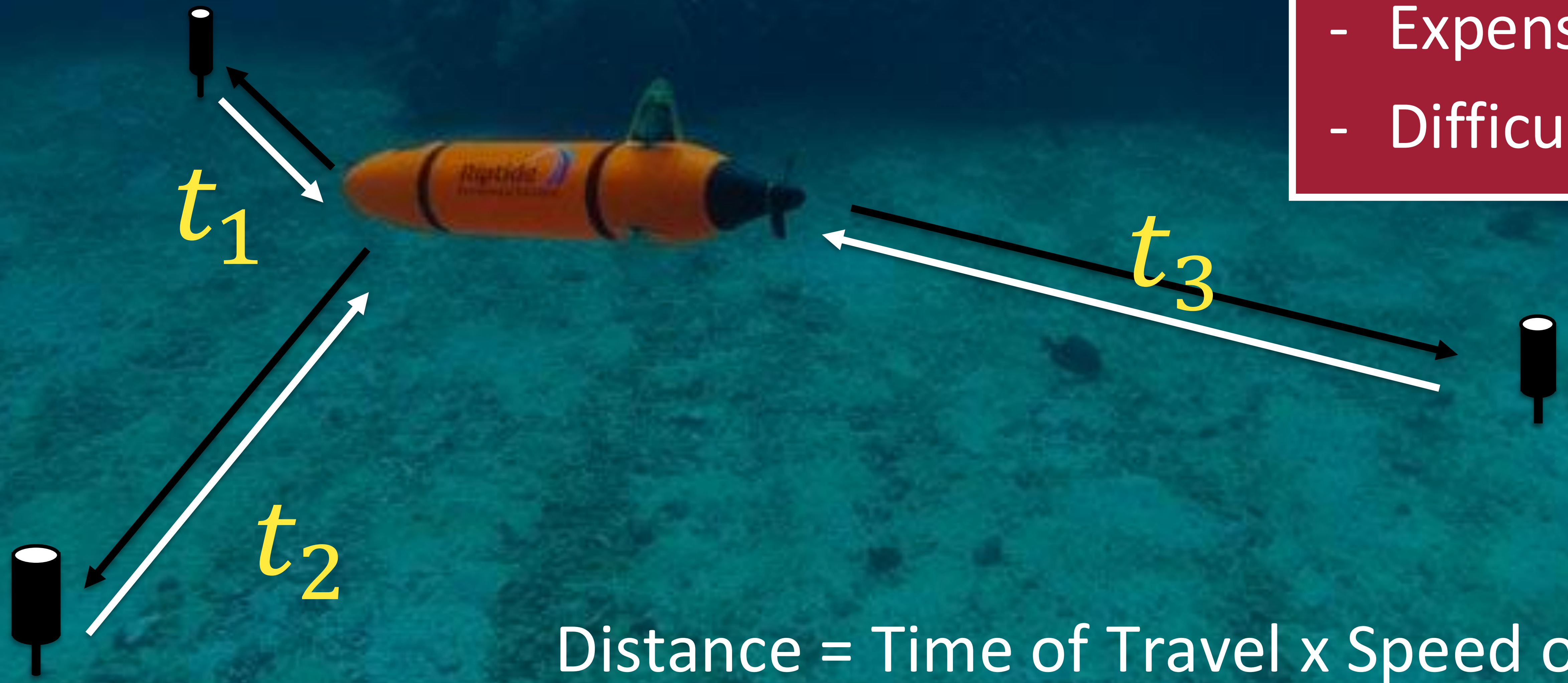
Works by measuring distances to deployed anchors



Conventional Underwater Positioning

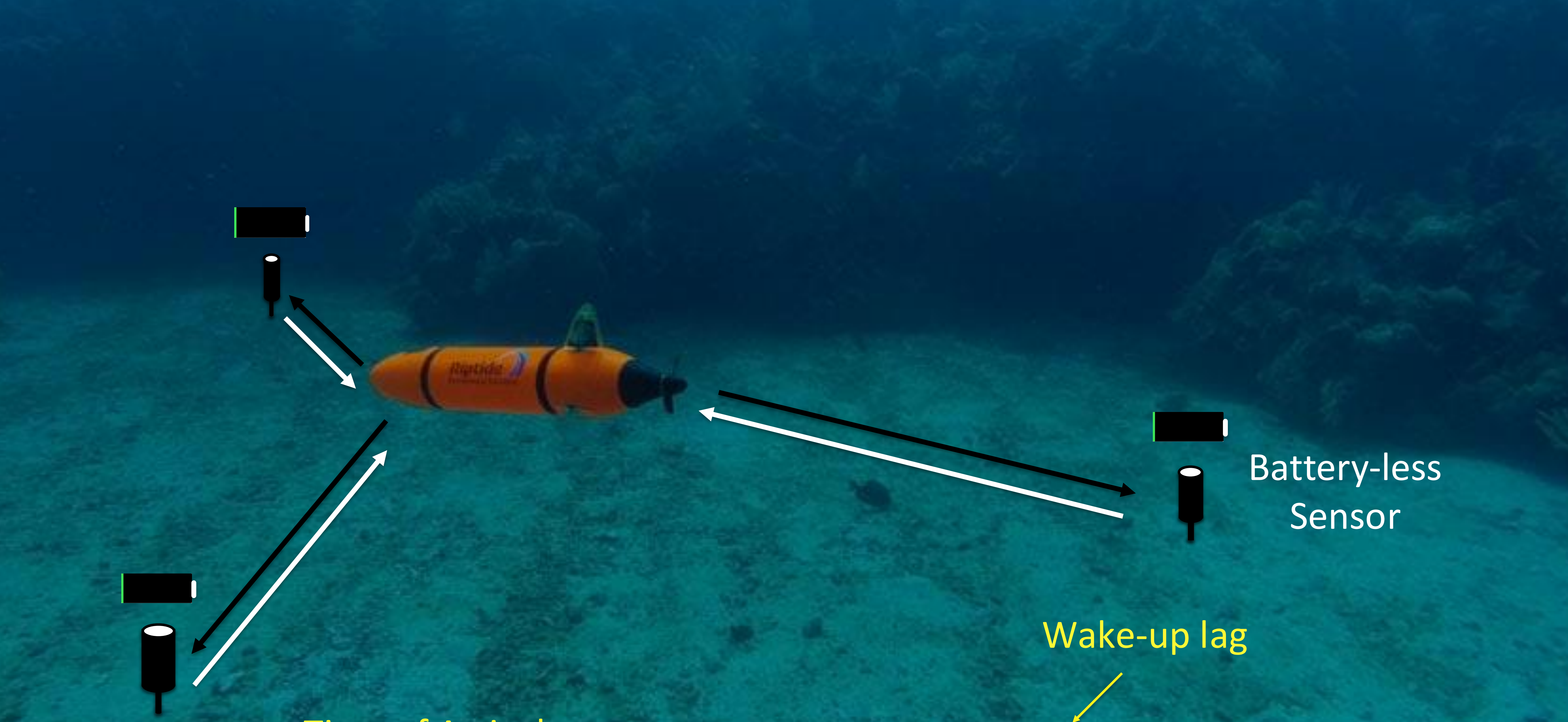
Works by measuring distances to deployed anchors

- Batteries run out of energy
- Expensive packaging
- Difficult to scale



Distance = Time of Travel x Speed of Sound

Batteryless Underwater Positioning

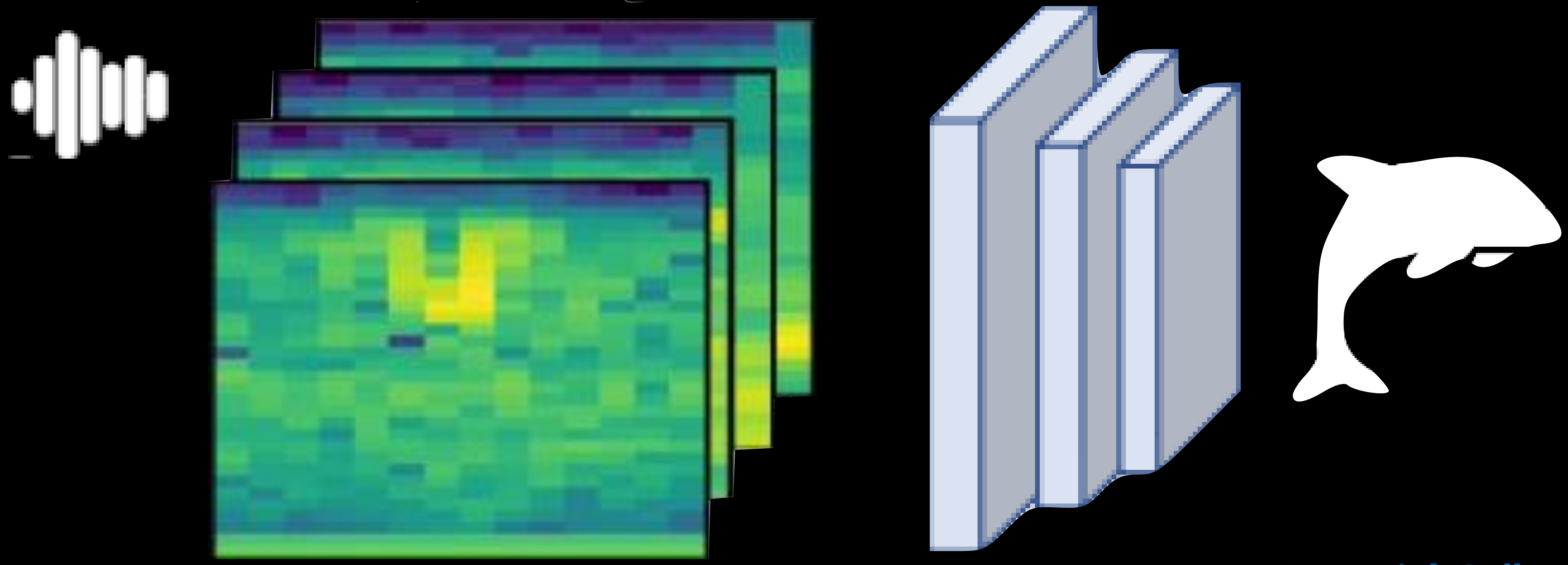


$$t = t_{roundtrip} + t_{Lag}$$

Can we enable battery-free underwater localization?

Can we enable battery-free underwater AI?

Early results demonstrate 85%+ accuracy in identifying marine species (without any batteries)



[ACM HotMobile'22]

Imperial College London

Summary of this Lecture

- Motivation of Ocean IoT & Existing Systems
- Basic Principles of Underwater backscatter
  - Networking
  - Localization
  - Other applications: Imaging, AI, Robotics, Defense, Space
  - Open problems