6.1820 Mobile and Sensor Computing

aka IoT Systems

http://6mobile.github.io

Lecture #15:

Ocean IoT

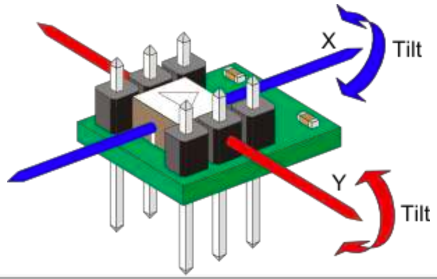
Course Staff	Announcements
Lecturers: Fadel Adib (fadel@mit.edu) Tara Boroushaki (tarab@mit.edu) **TAs:** Waleed Akbar(wakbar@mit.edu) Jack Rademacher (jradema@mit.edu)	1- Grades out - Lab 1 & 2 2- Sign up for project meetings - Next Tue & Thurs 3- Lab 4 due April 8 4- Pset 2 due April 10

Class Timeline

4 Quadrants of IoT

Sensing Tasks & Modalities

- Localization
- Inertial
- Camera-based

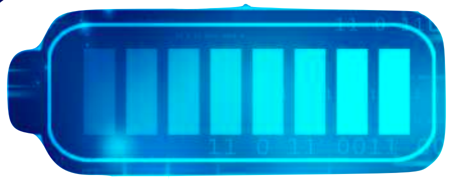


Computation

Sensor Proc. & Fusion (localization, inertial, split proc., fusion)

Power/Energy

Energy management & harvesting

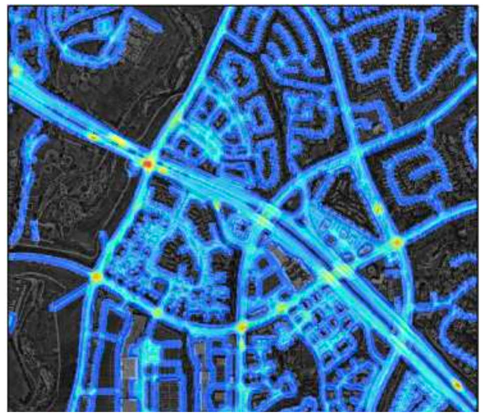


Connectivity

- Connectivity tech
- Mesh architectures
- Battery-free IoT

Emerging Application Domains & Cross-Cutting Topics

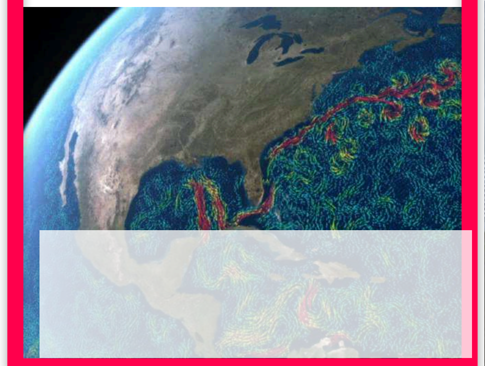
1. Transportation



2. Health

3. Agriculture

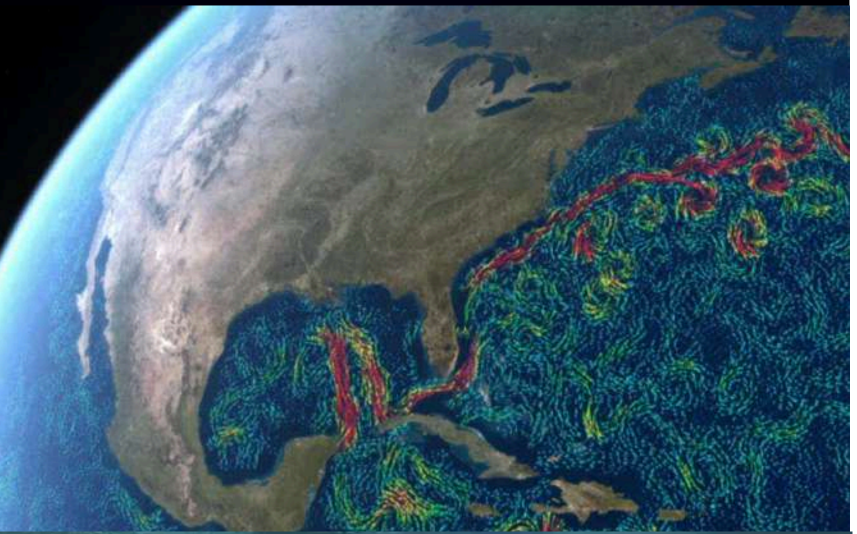
4. Oceans/ Climate



5. Augmented Reality

Let's start with some trivia





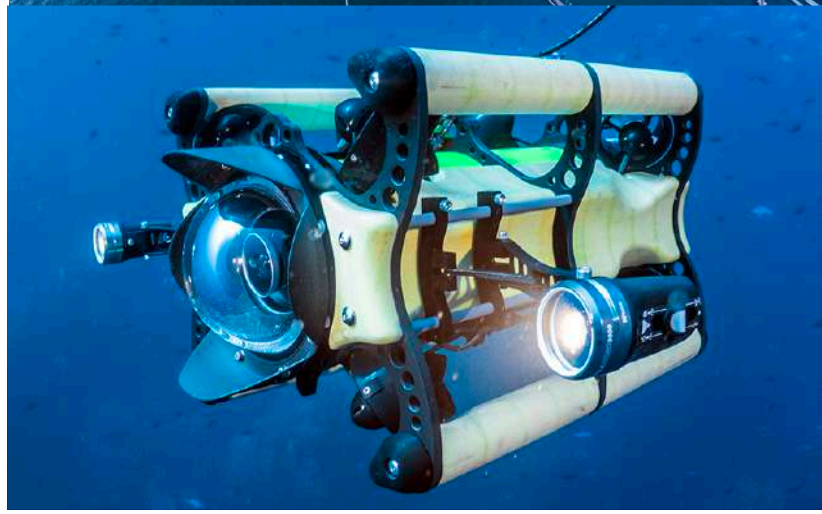
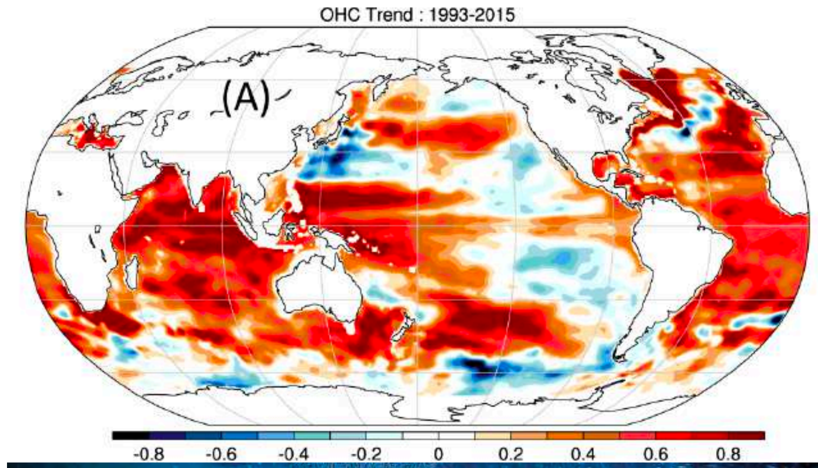

1. What percentage of the ocean floor has never been observed?

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

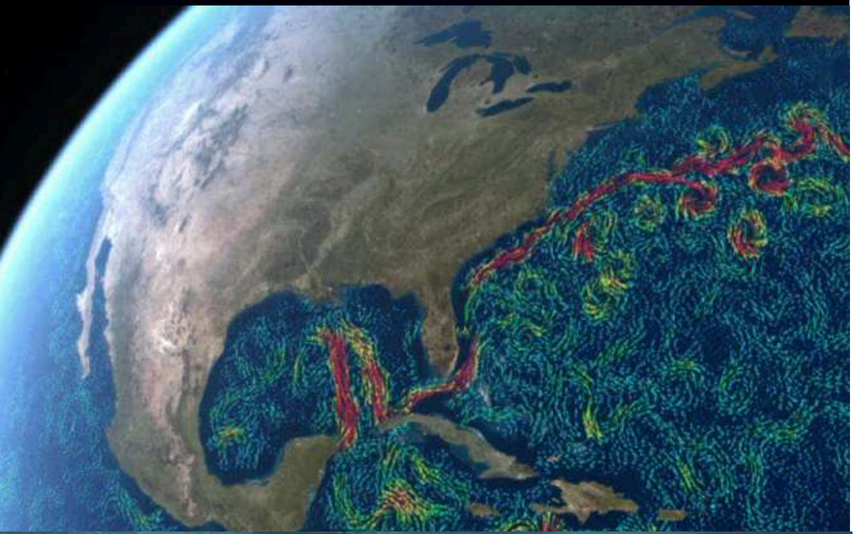
30 bn

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**

How Can IoT help?



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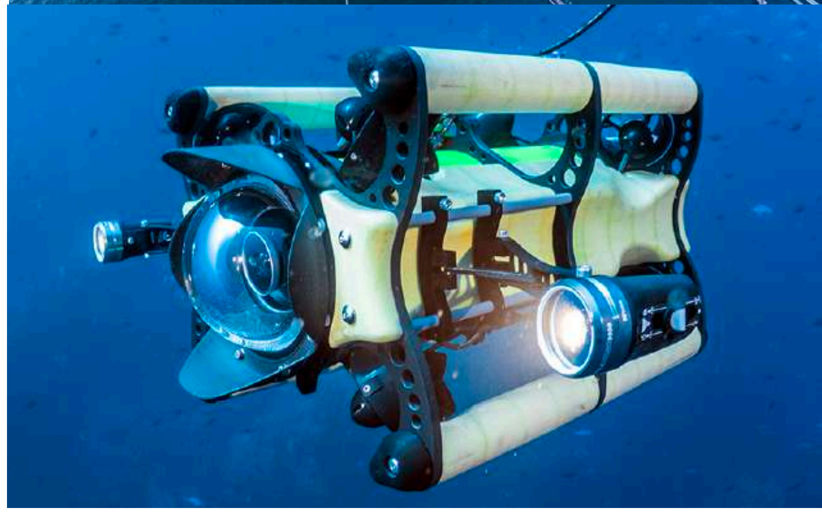
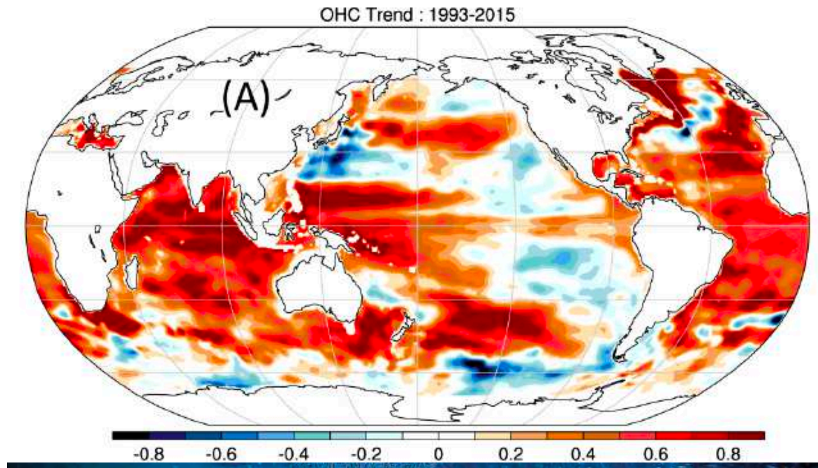


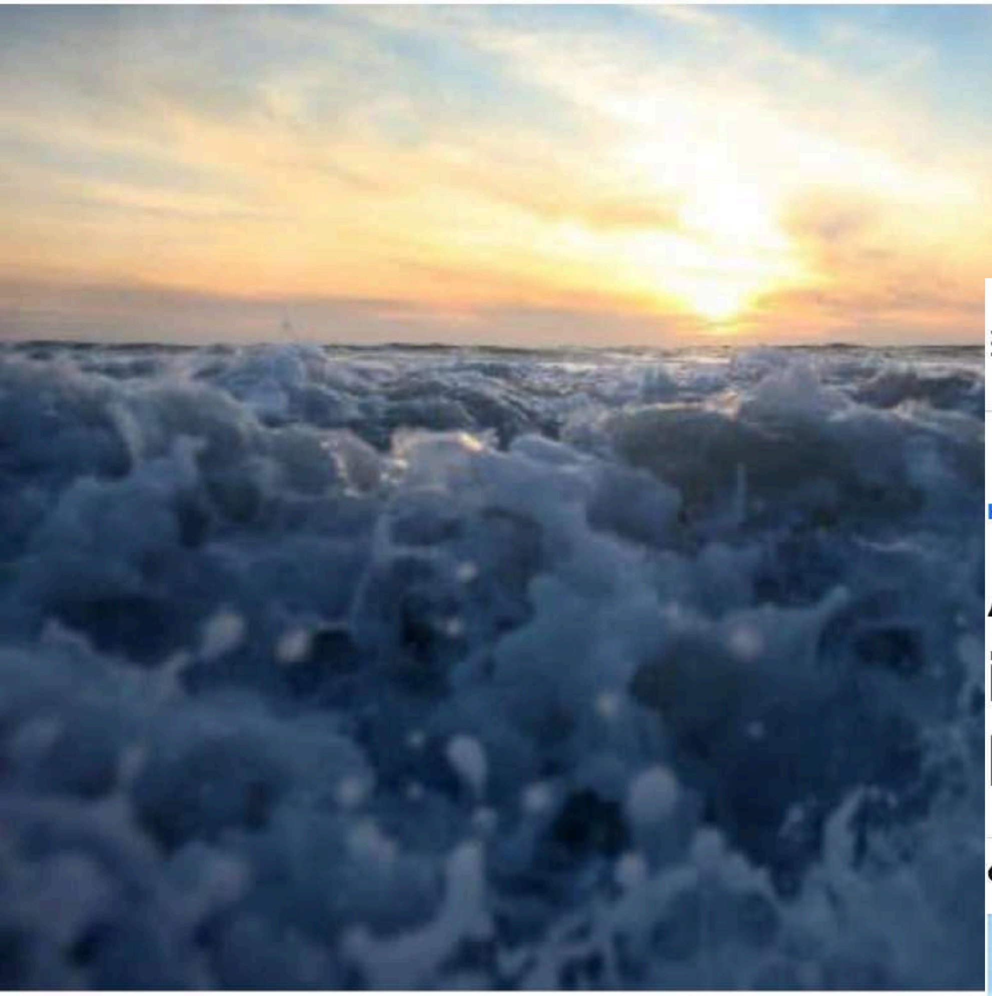


The Washington Post

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

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

as awarded a contract for the next phase of

ent of its Ocean of Things (OoT), a project to

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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

Jet Propulsion Laboratory
California Institute of Technology

SWOT SURFACE WATER AND OCEAN TOPOGRAPHY

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NEWS | December 9, 2024

NASA's PACE, US-European SWOT Satellites Offer Combined Look at Ocean

One Earth satellite can see plankton that photosynthesize. The other measures water surface height. Together, their data reveals how sea life and the ocean are intertwined.

Featured Reso

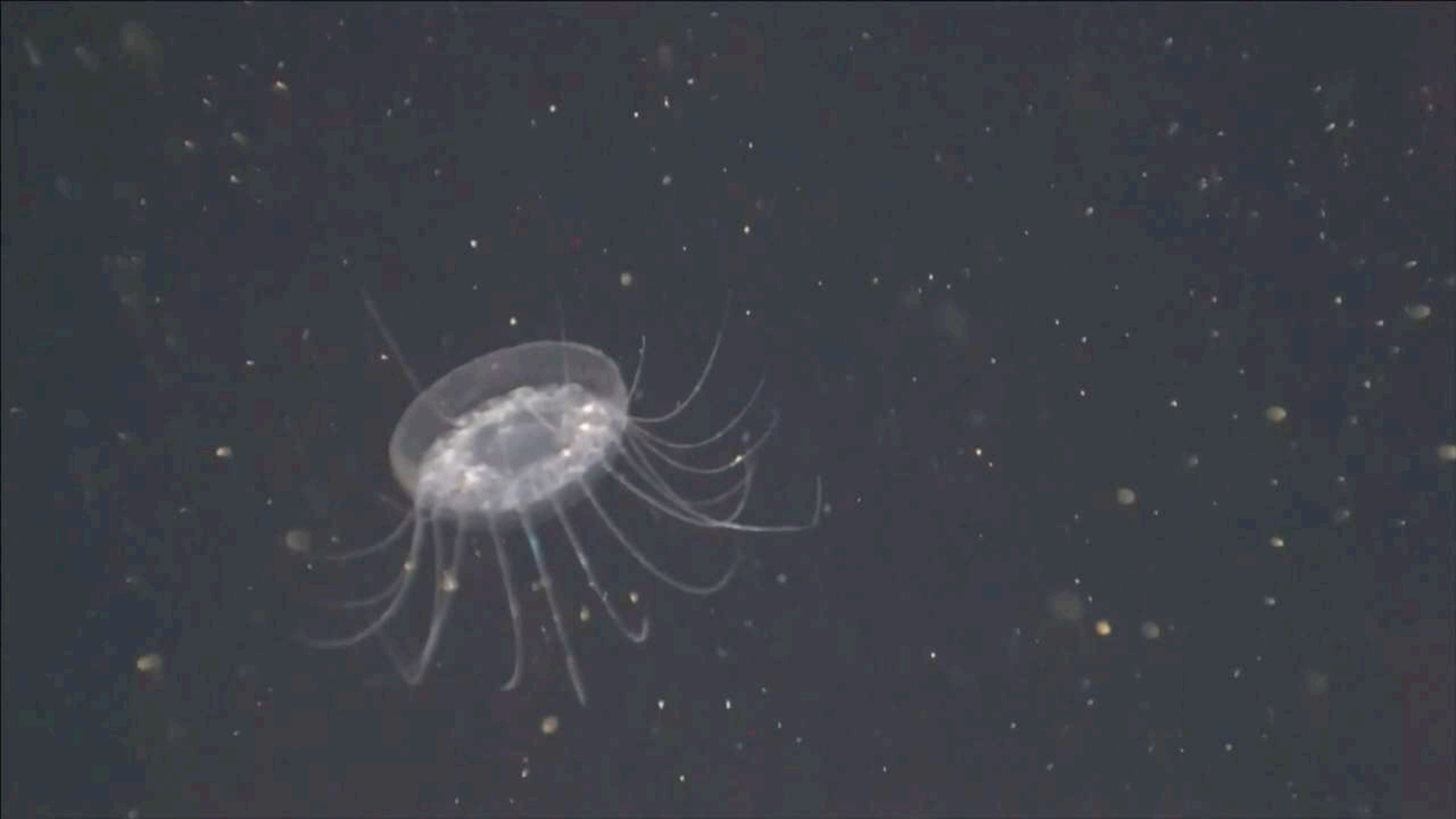
Seabed 2030 aims to map the ocean floor by 2030

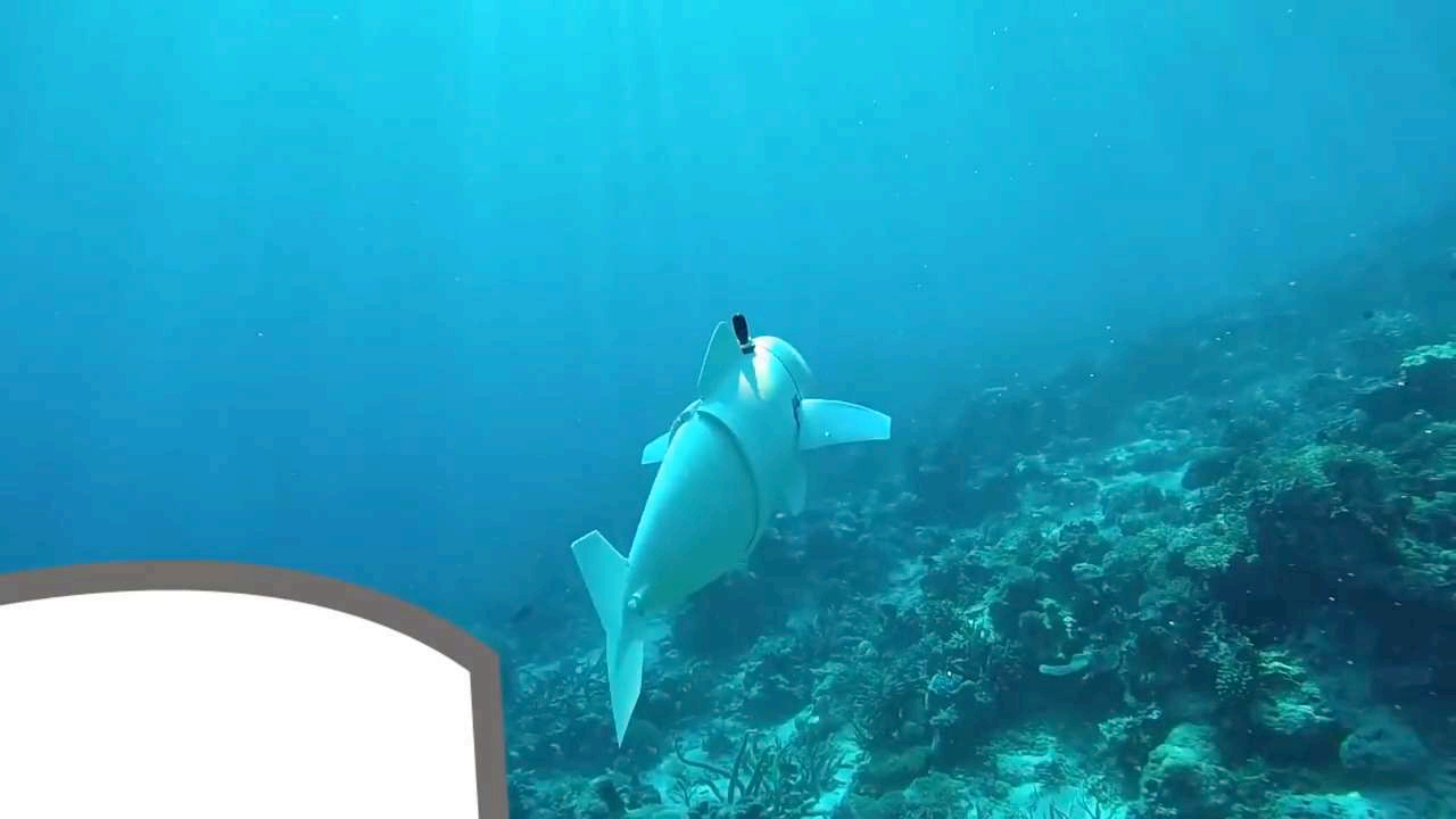
Why is bringing IoT to the ocean (esp. underwater) hard?

- **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





Rest of this lecture: Underwater Backscatter

- Motivation
- Basic Principles
- Networking
- Localization
- Other applications: Imaging, AI, Robotics, Defense, Space

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)

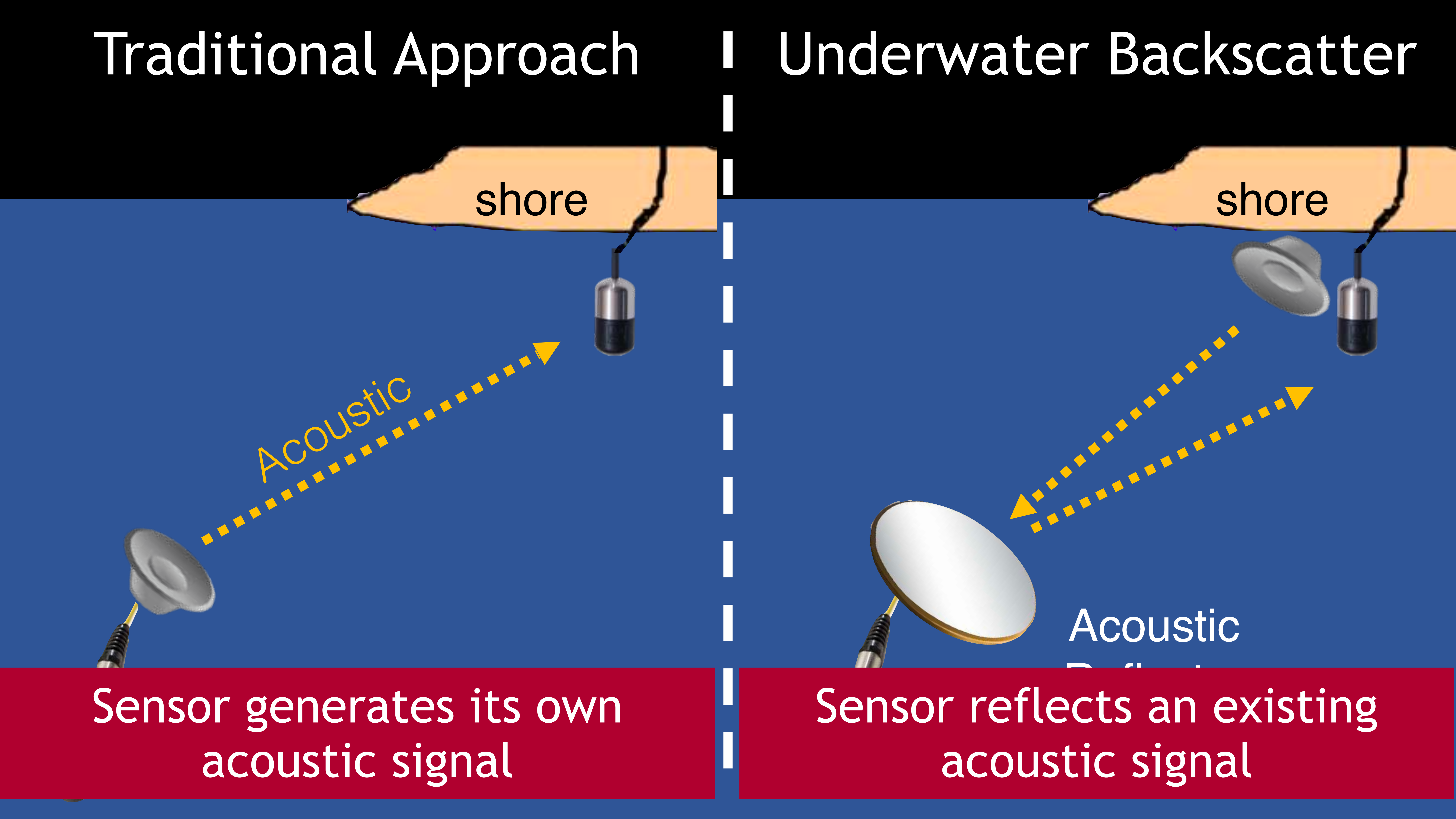
↓

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

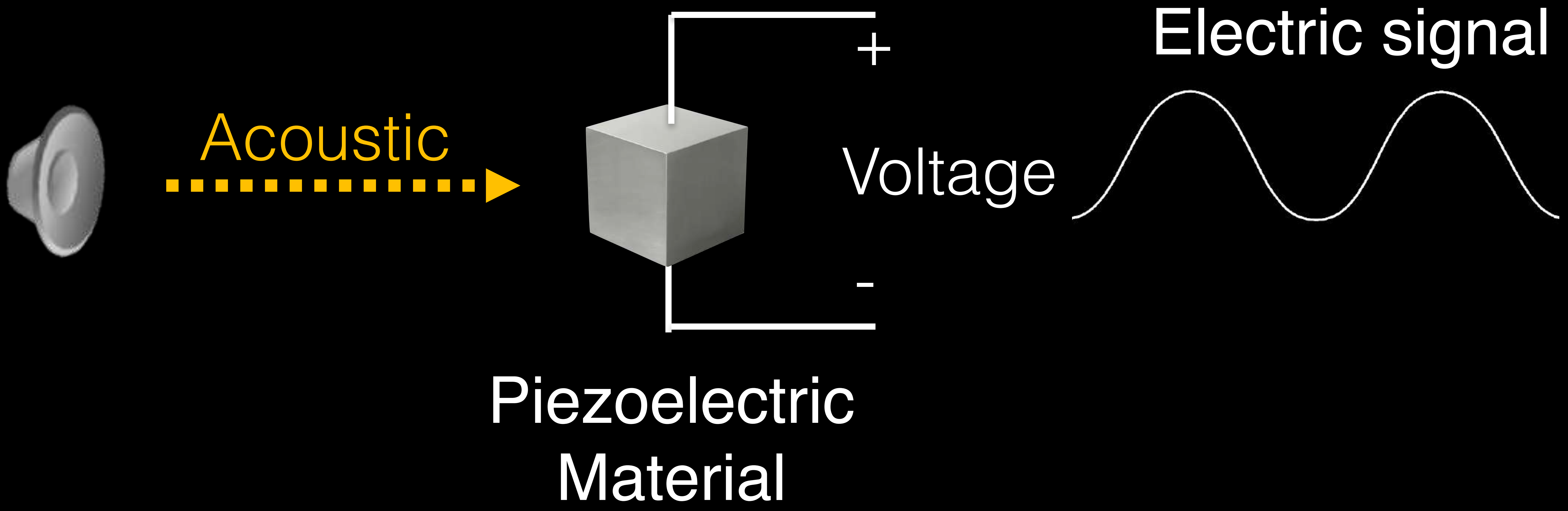
PAB (ACM SIGCOMM'19)


Traditional Approach
Underwater Backscatter
shore
Acoustic
shore
Acoustic
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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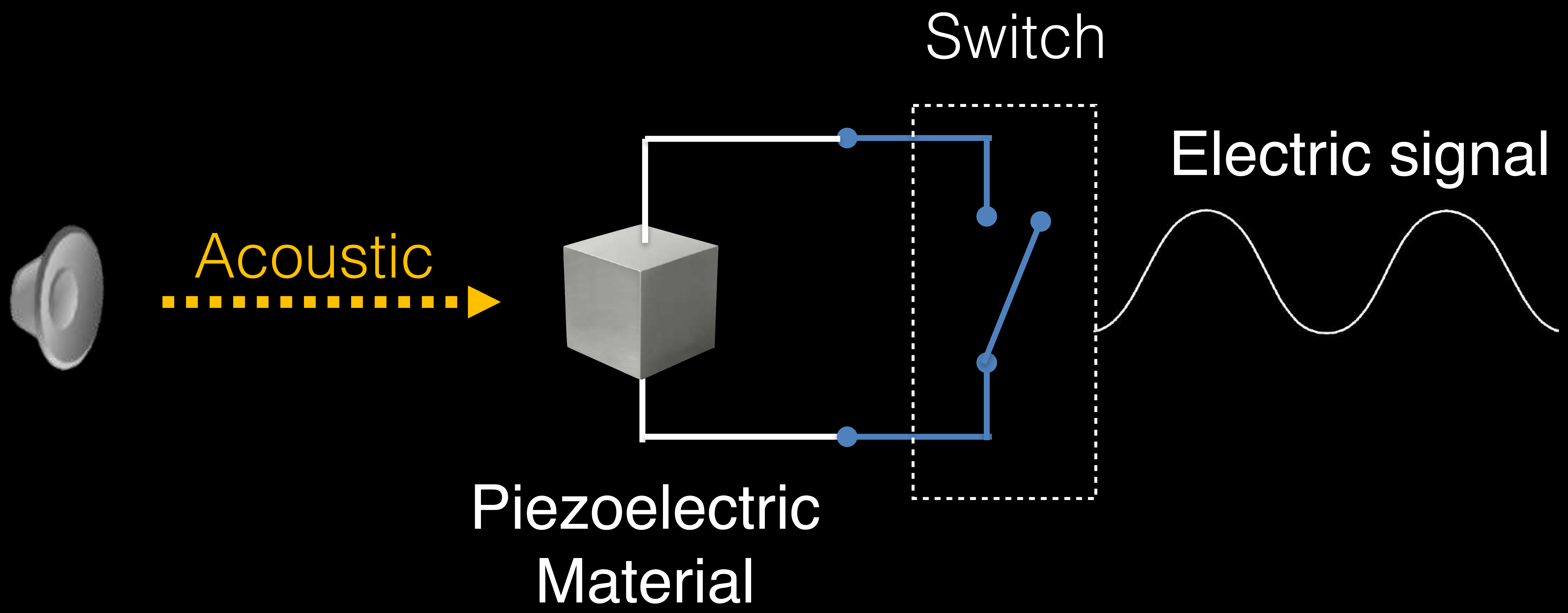

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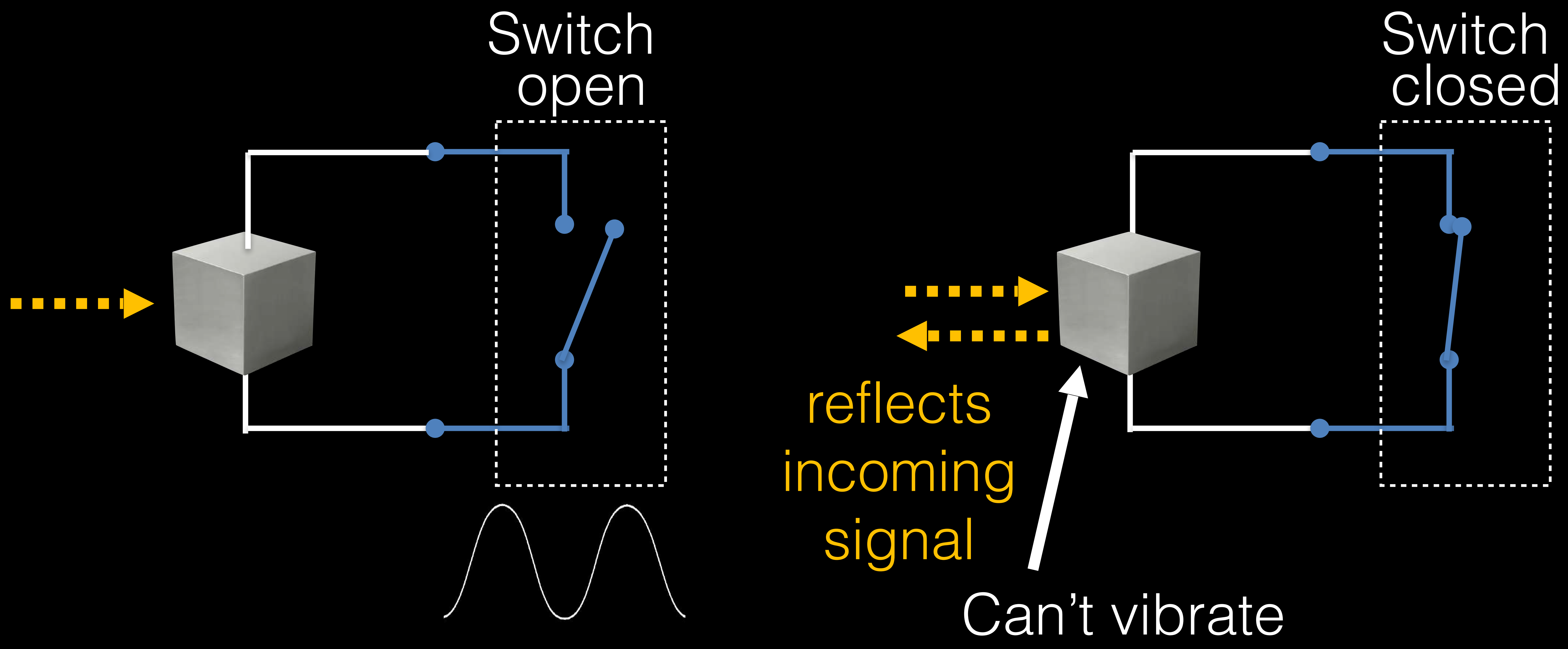
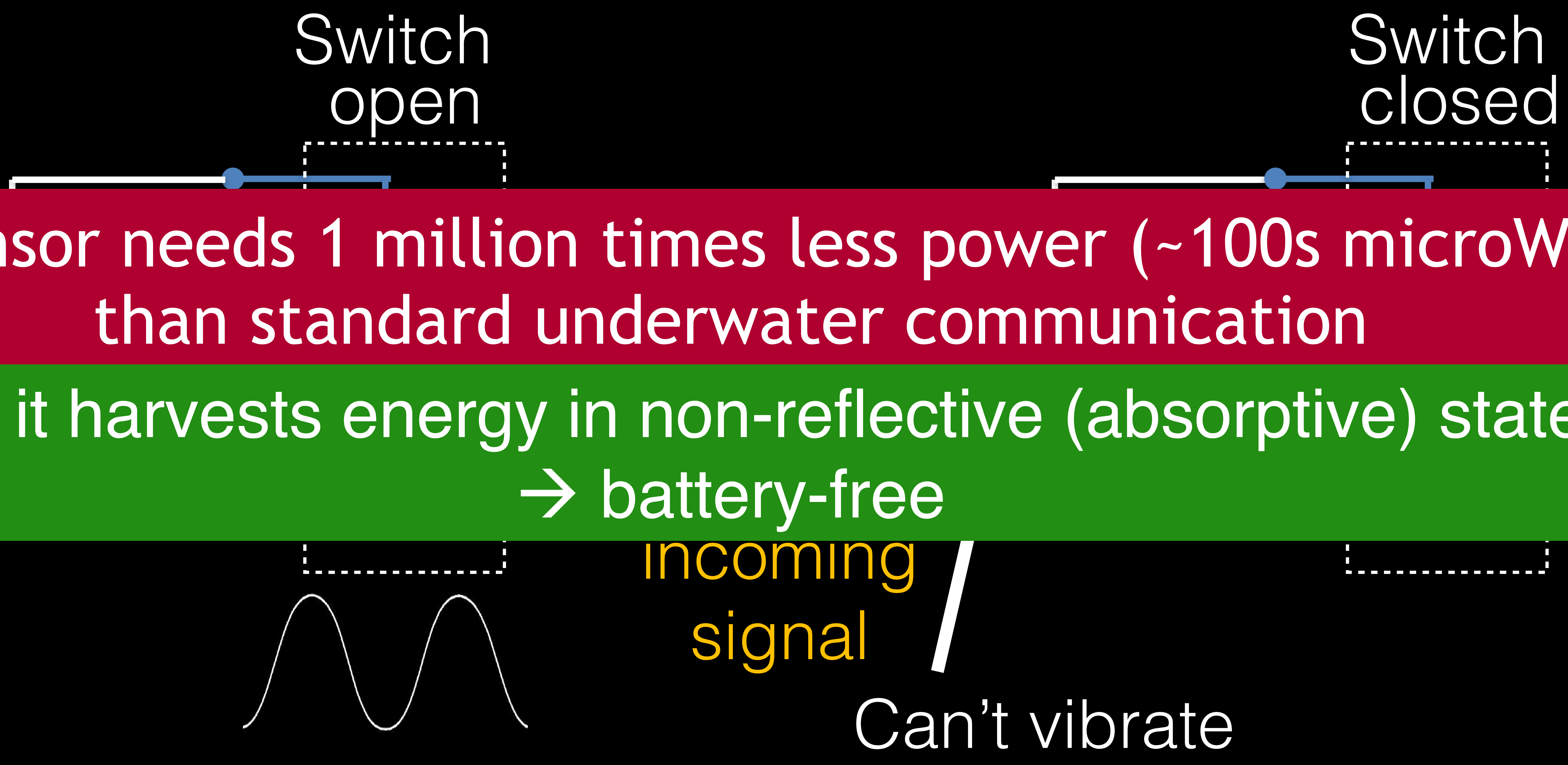
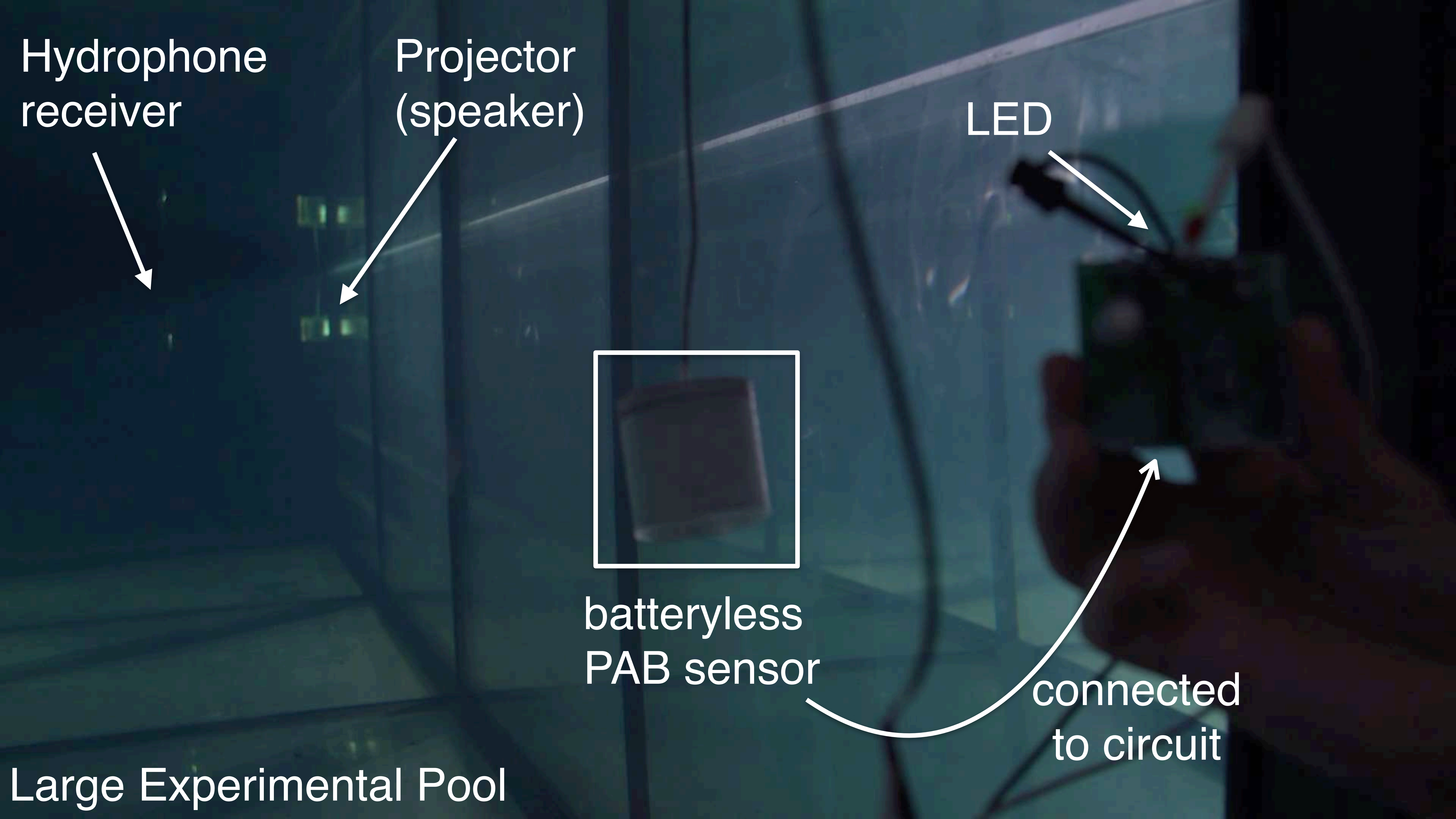


Piezo-Acoustic Backscatter

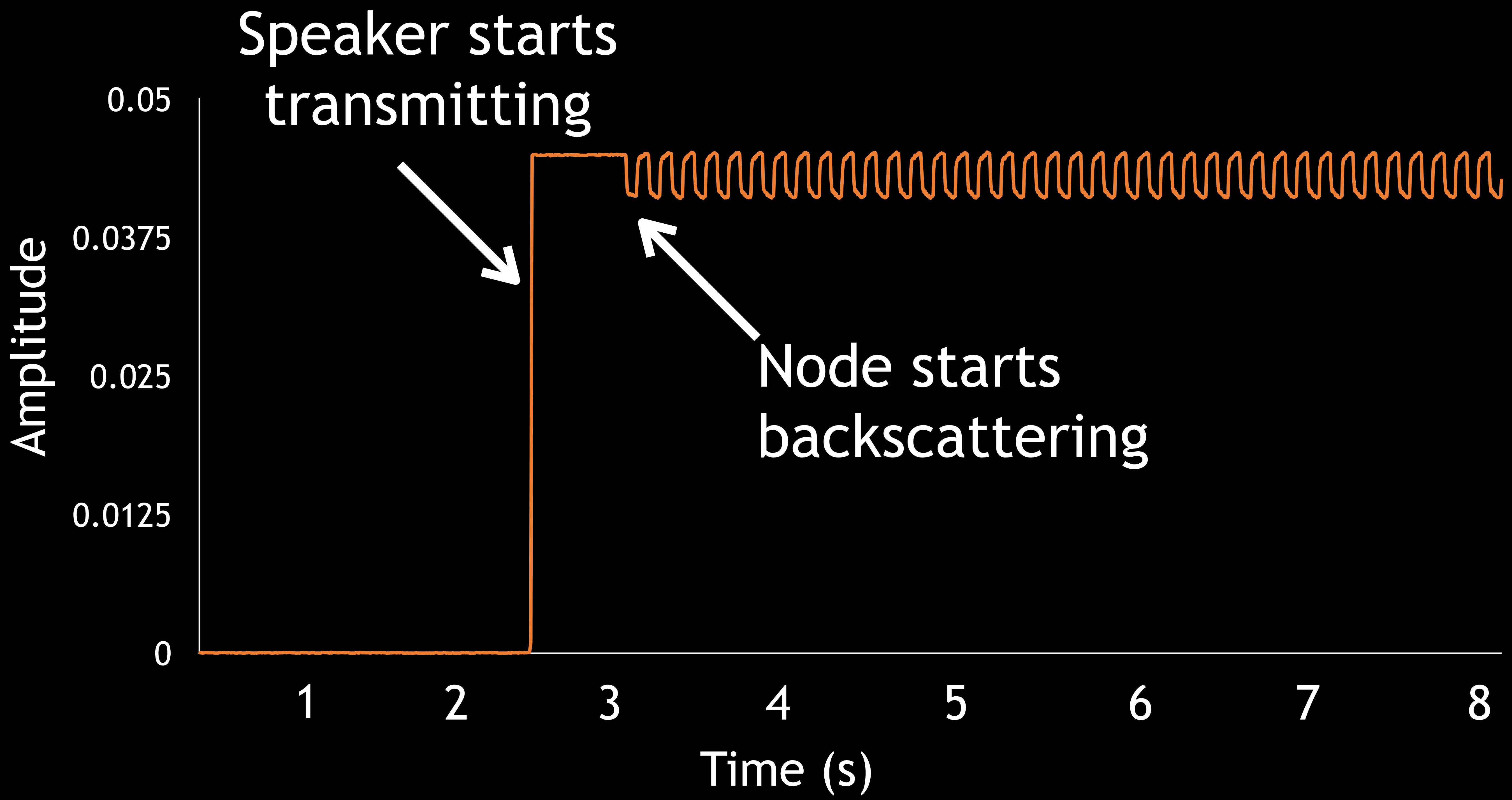
PAB sensor needs 1 million times less power (~100s microWatt) than standard underwater communication

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

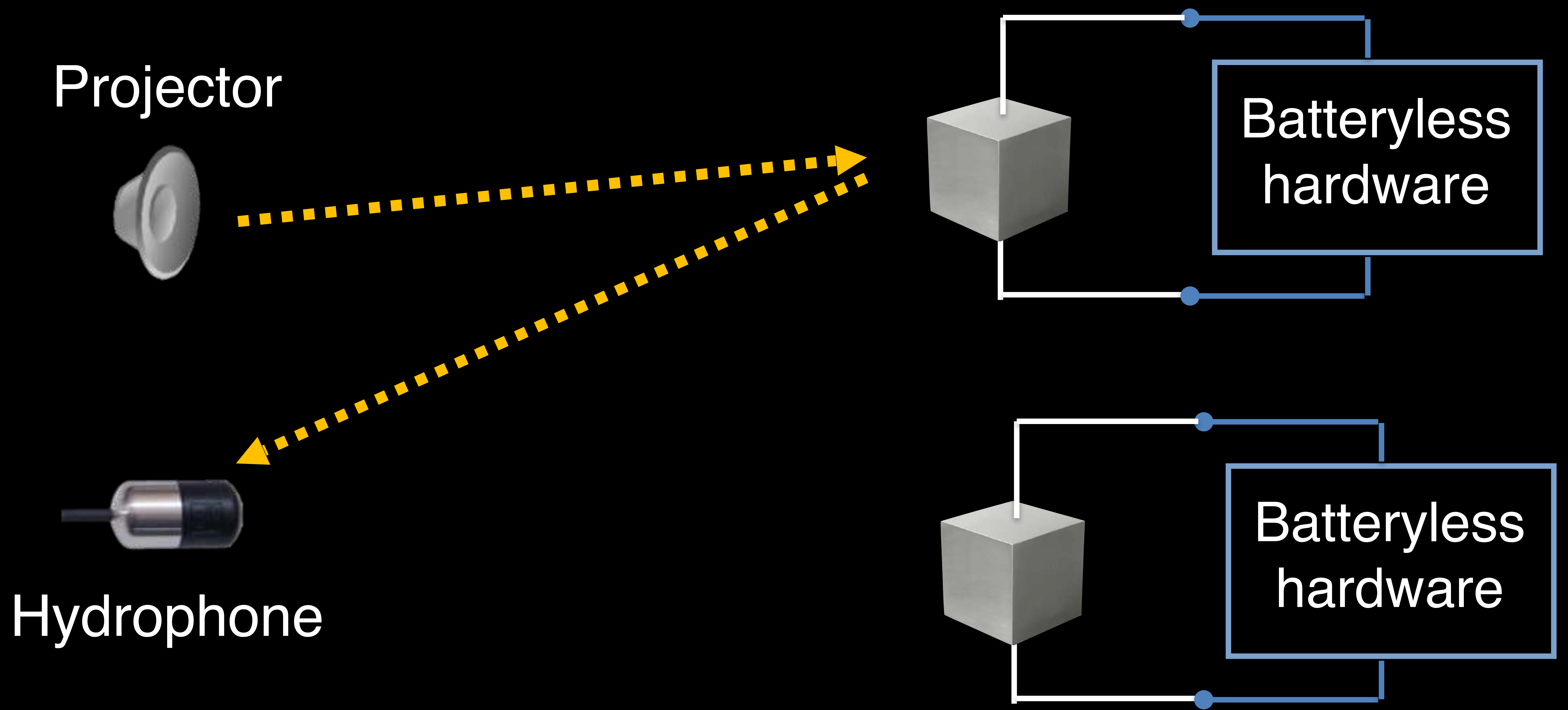
Measuring the Backscatter Signal (by Hydrophone)



How can we extend underwater backscatter to multiple nodes?

Extending to Multiple Nodes

Option 1: Time Division Multiplexing



Extending to Multiple Nodes

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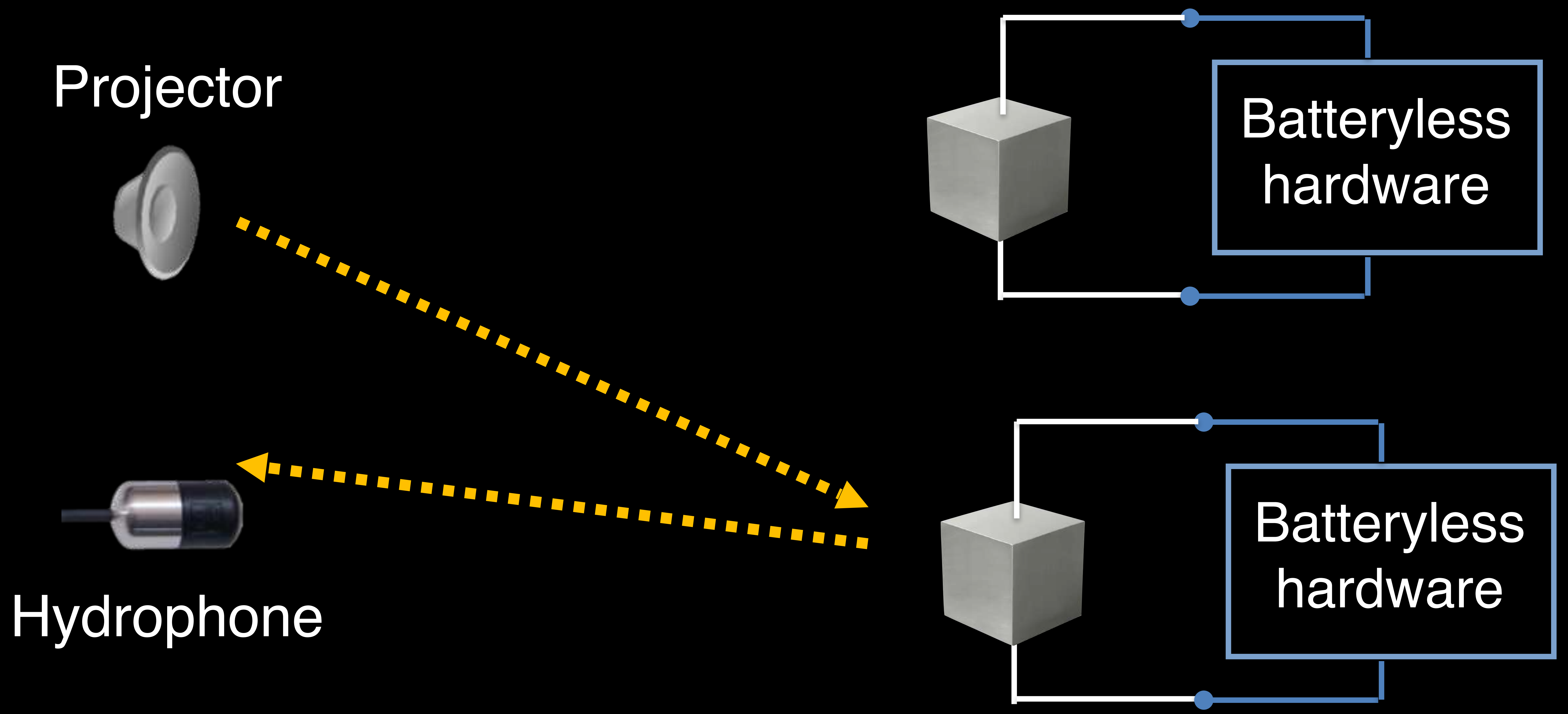
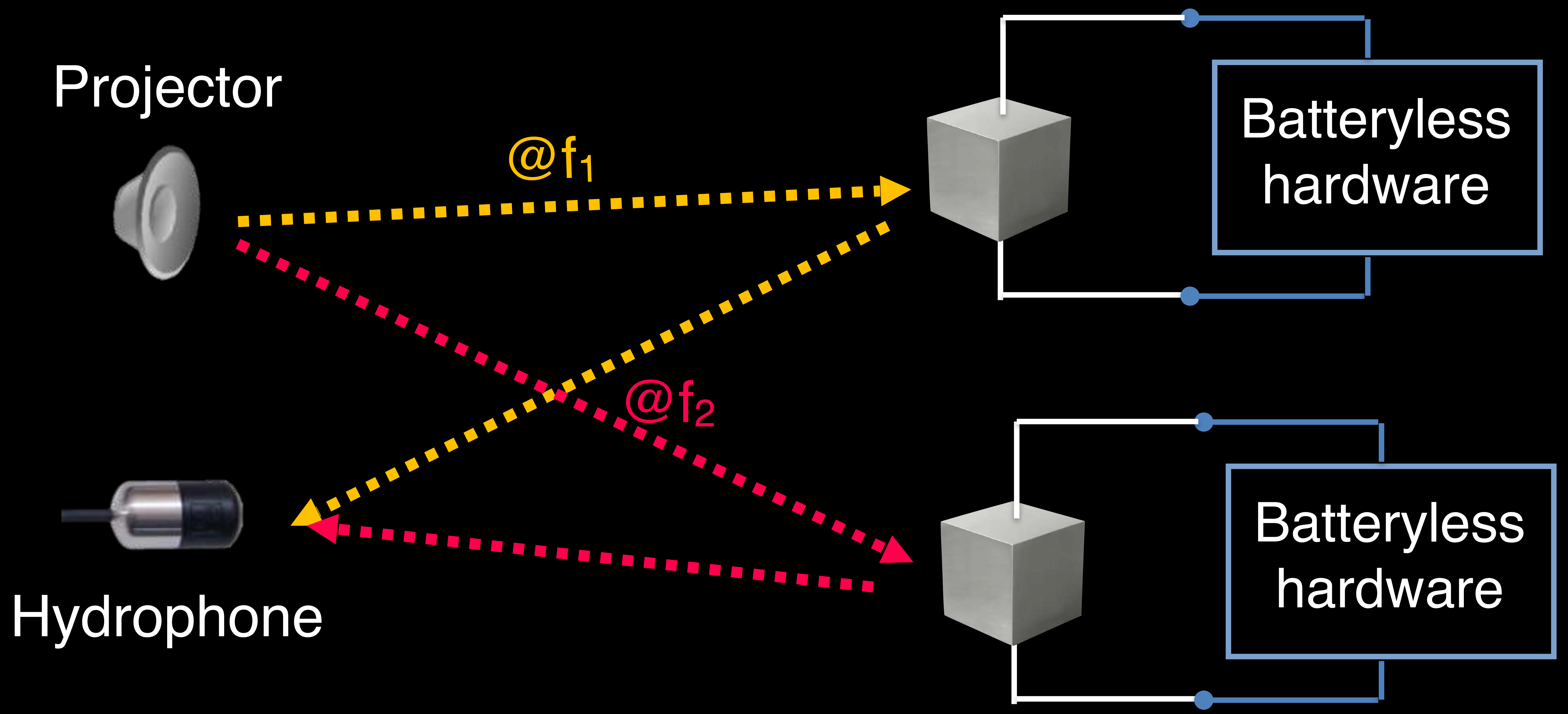


Extending to Multiple Nodes

Option 2: Frequency Division Multiplexing



Extending to Multiple Nodes

<u>Problem:</u> Resonance of piezoelectrics limits their bandwidth

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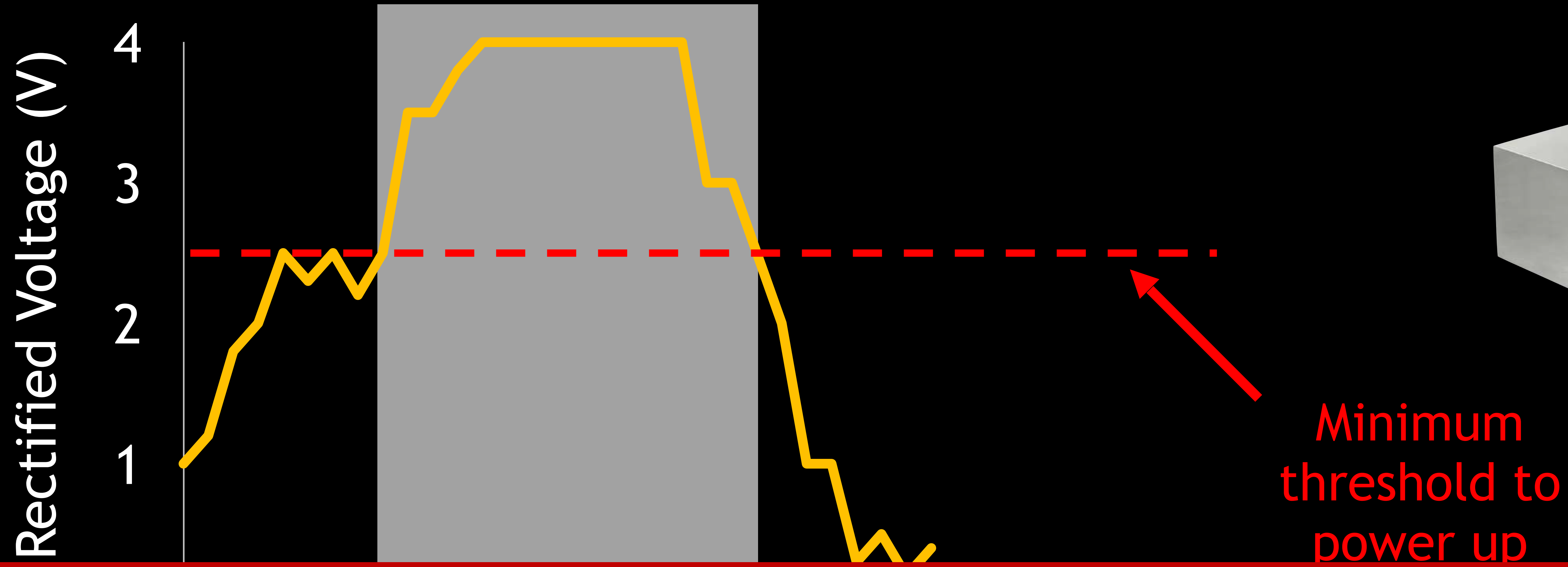
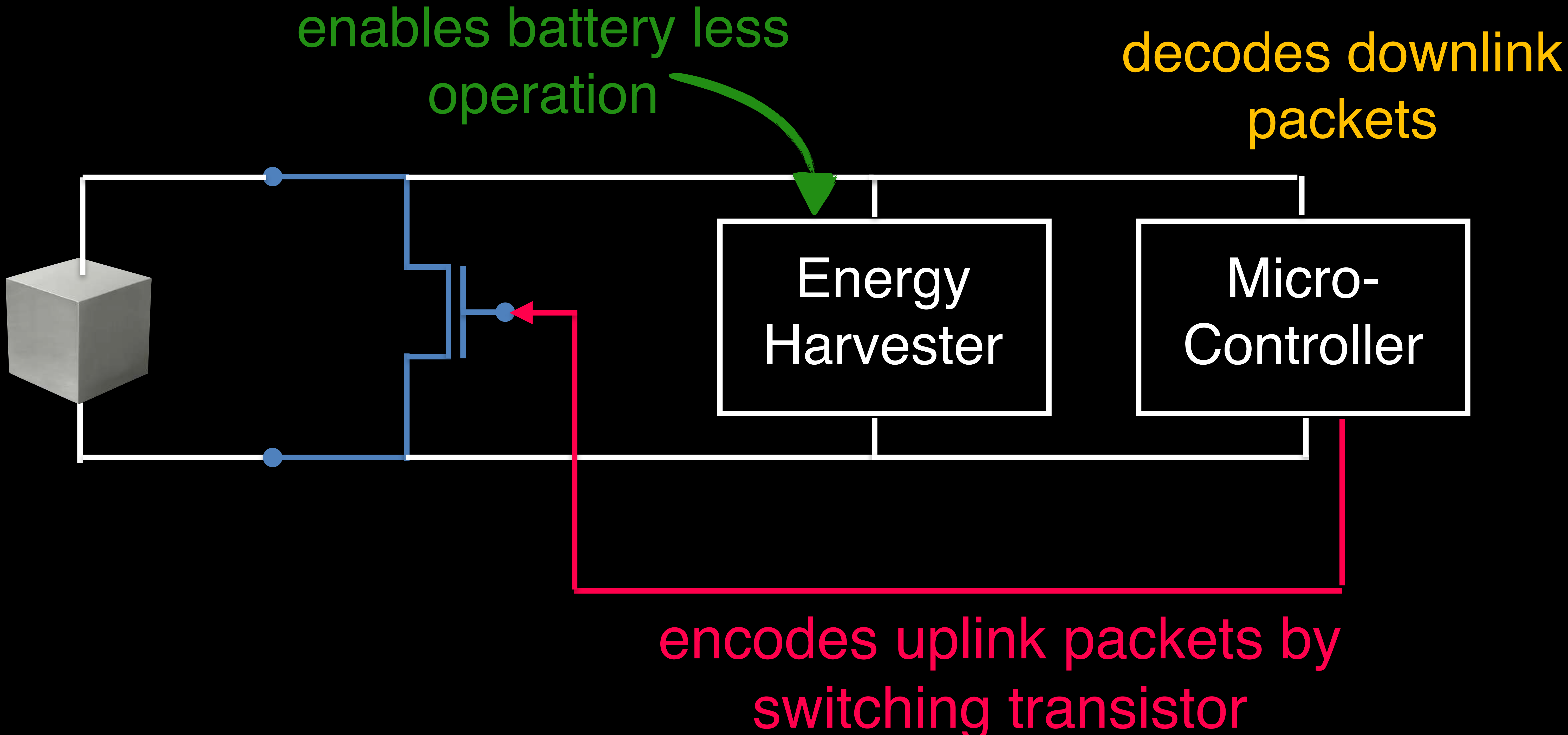


Operating at resonance maximizes energy harvesting but limits concurrent transmissions (and FDMA)

<u>Solution Idea:</u> Shift the resonance frequency *itself* to a different channel

<u>Solution Idea:</u> Shift the resonance frequency itself to a different channel



<u>Solution Idea:</u> 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

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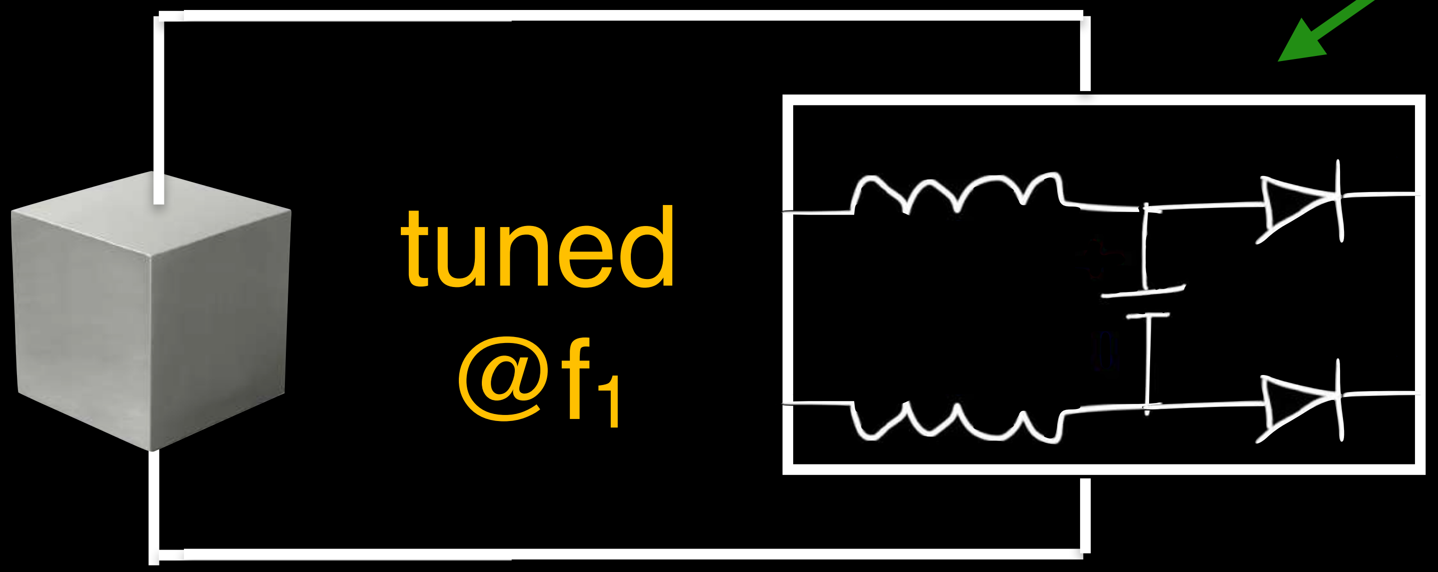

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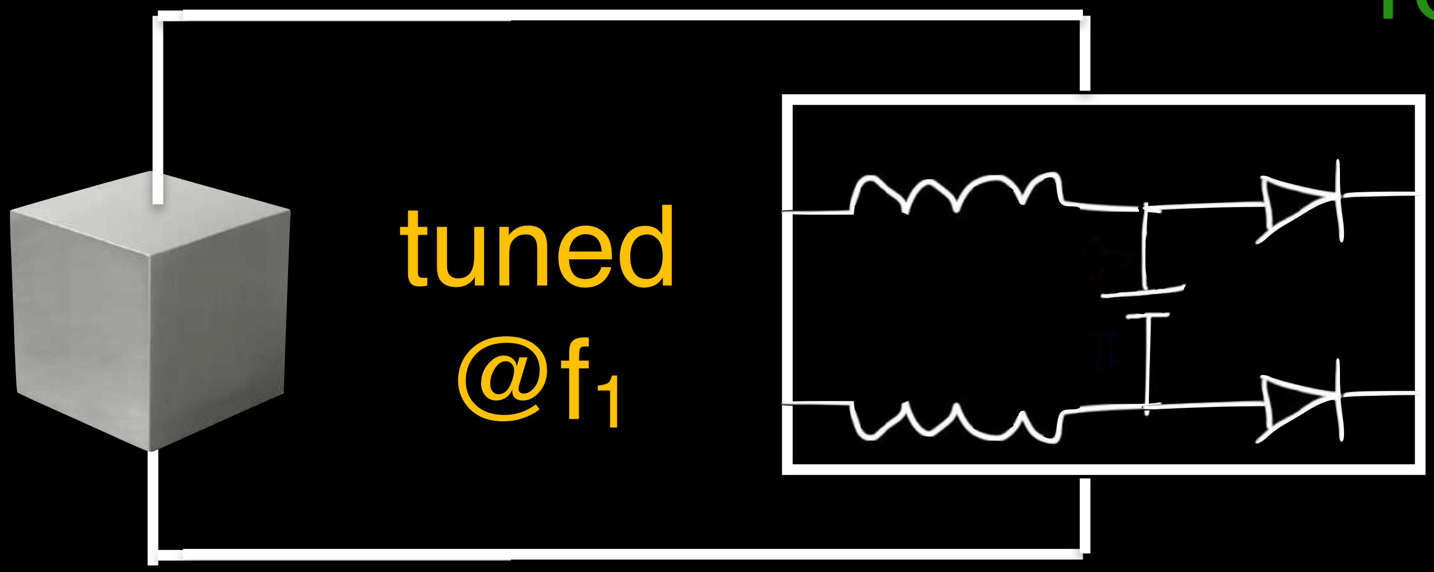

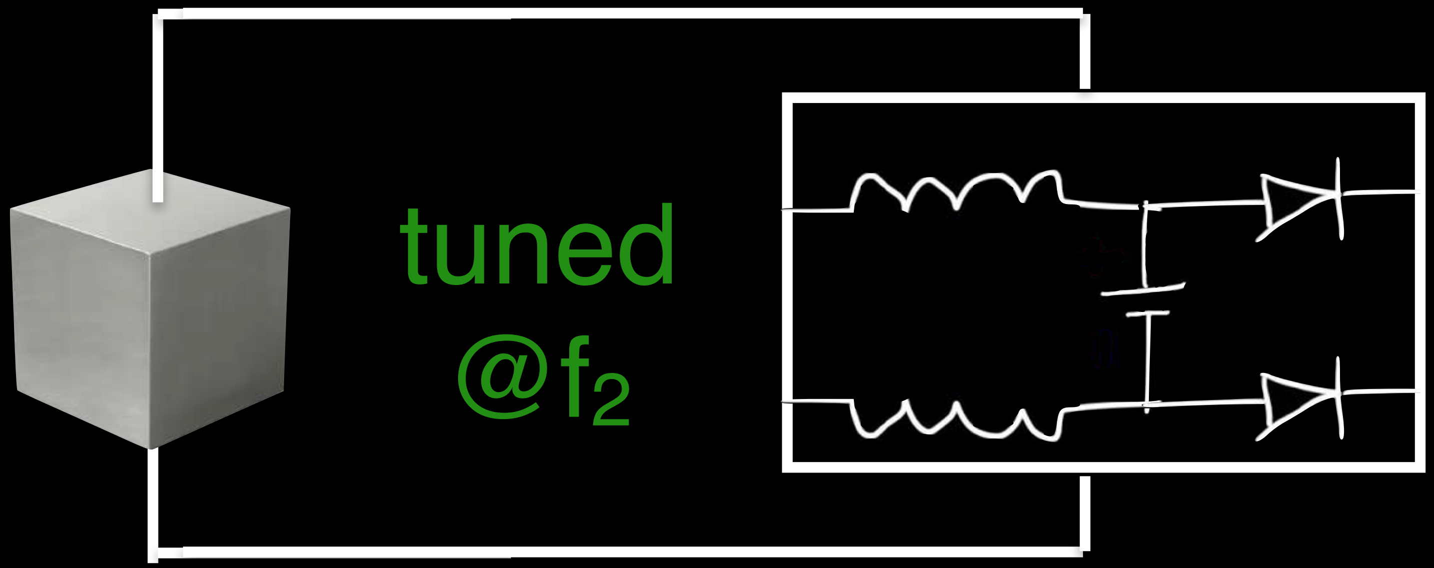

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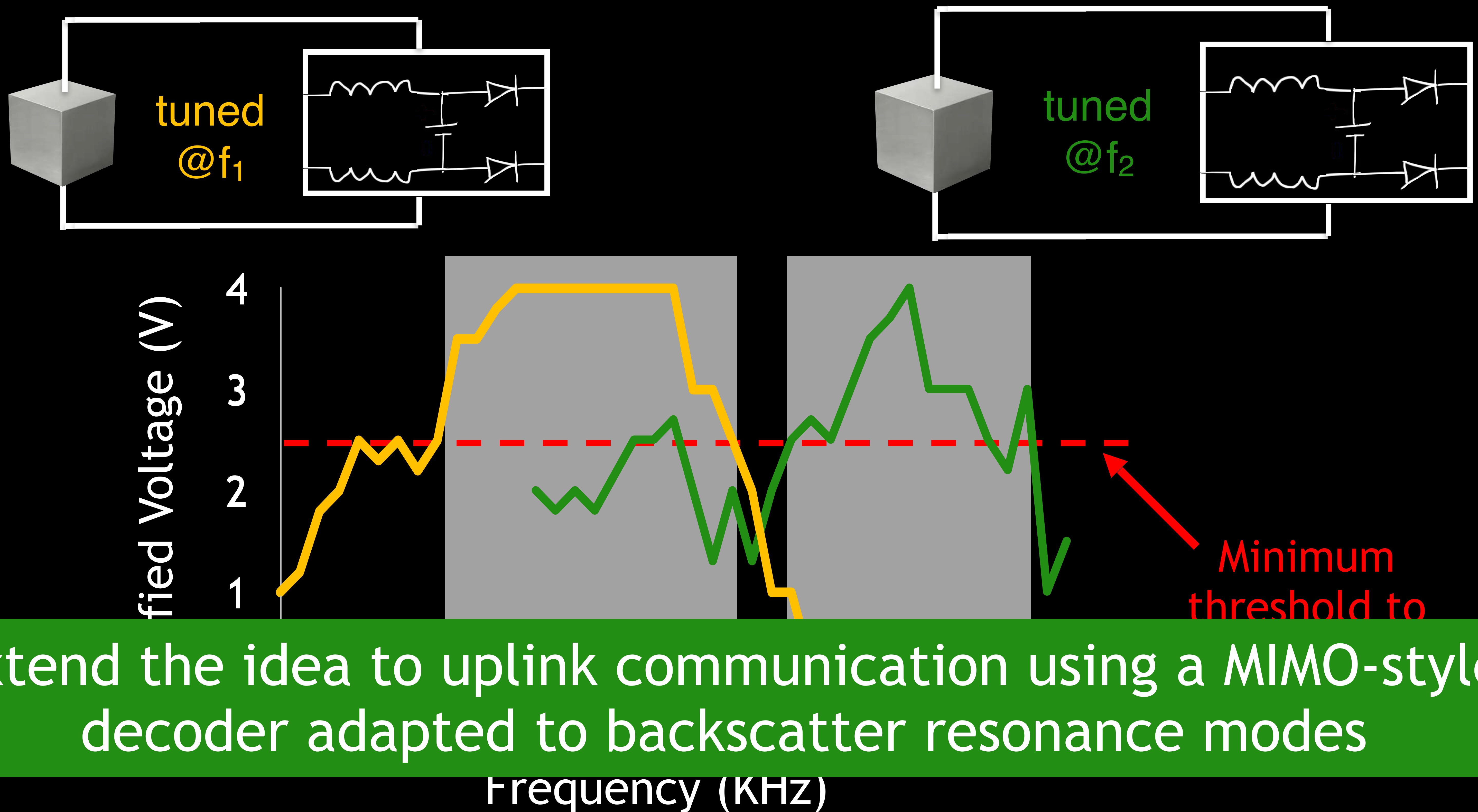
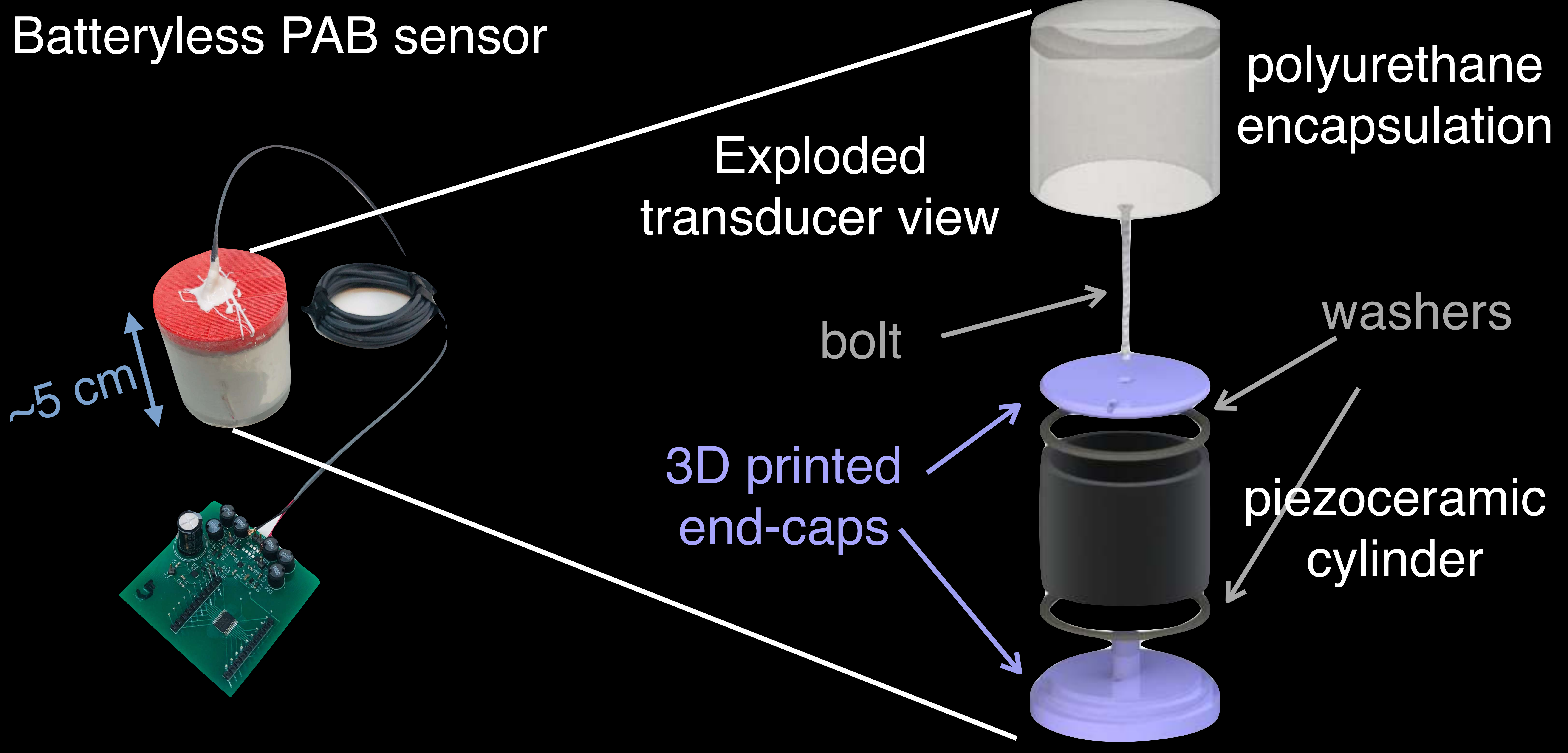


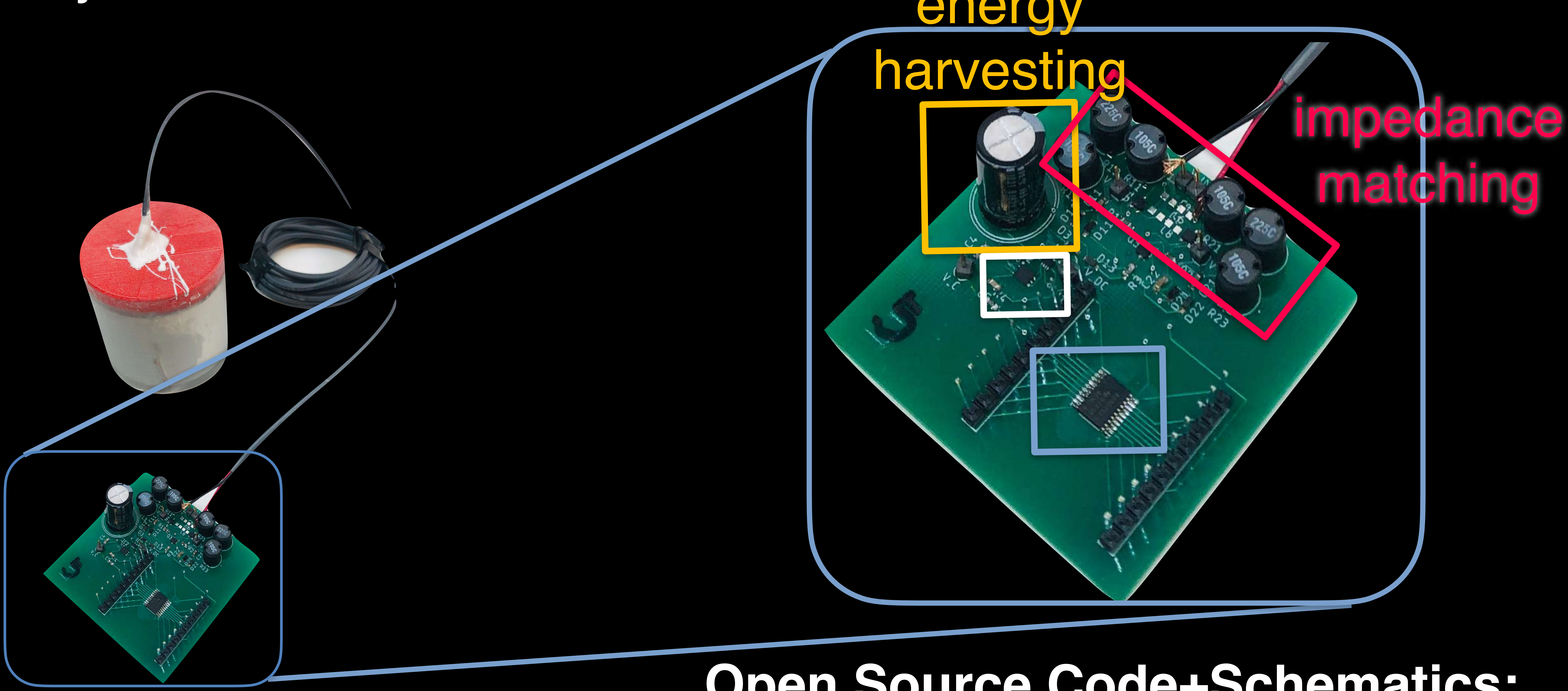
Extend the idea to uplink communication using a MIMO-style decoder adapted to backscatter resonance modes

Implementation



Implementation

Batteryless PAB sensor



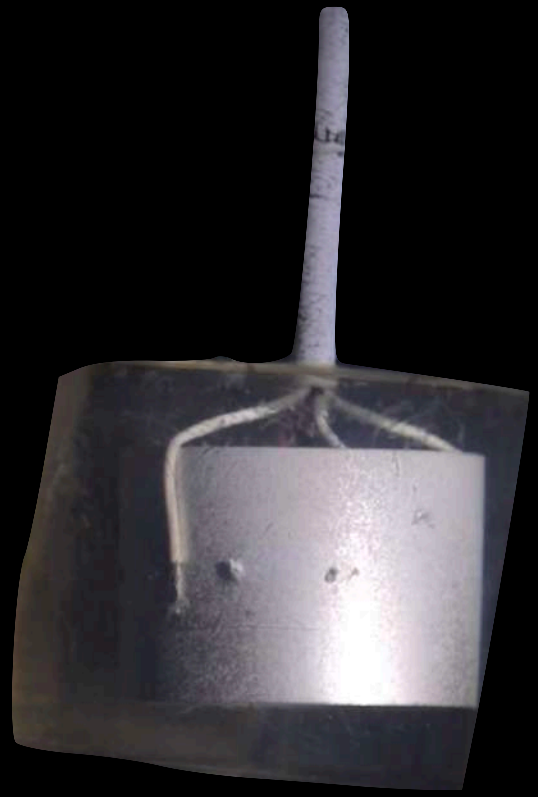
Open Source Code+Schematics:

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

Implementation

Batteryless PAB sensor

Projector

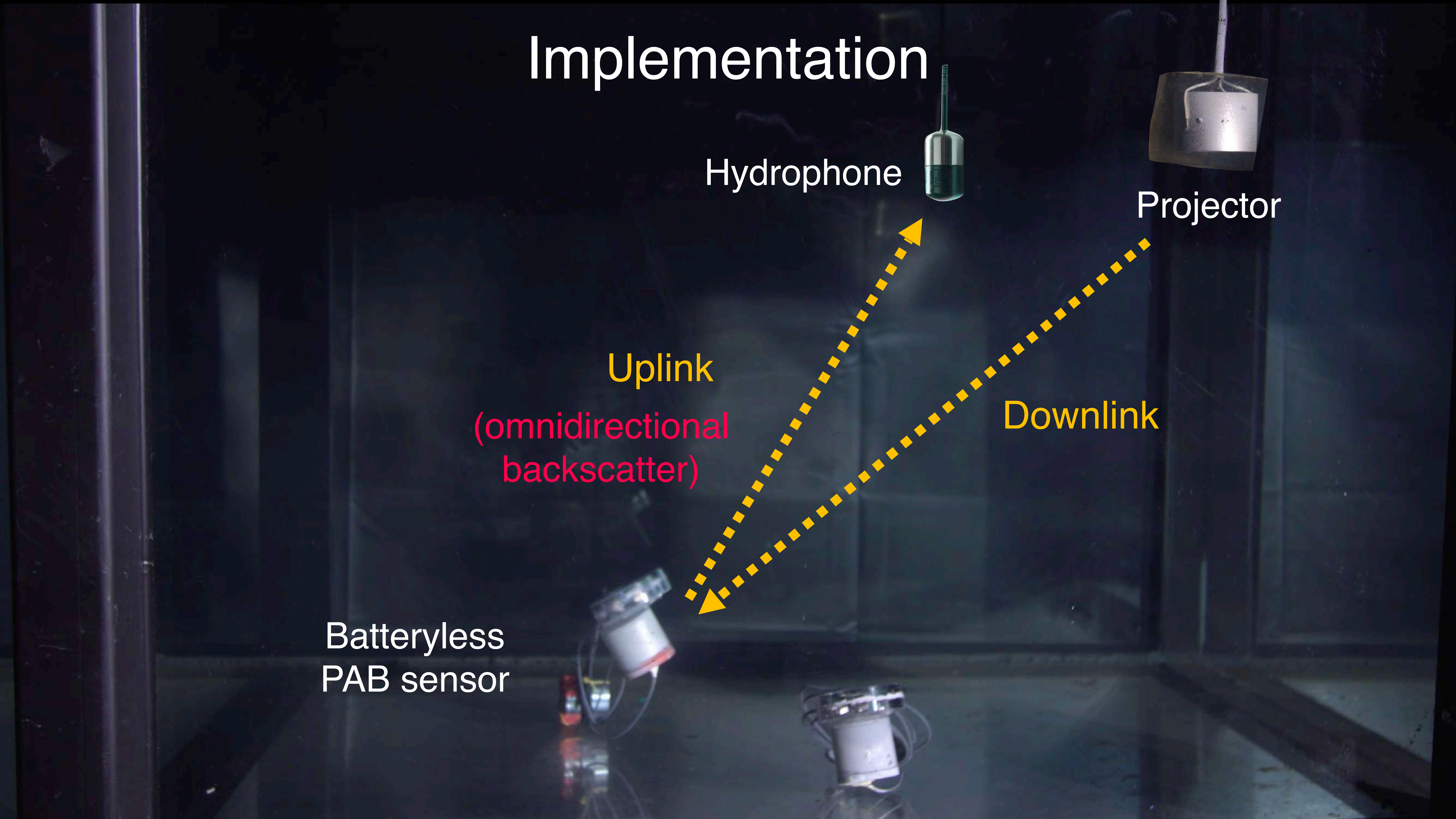


fabricated in-house

Hydrophone

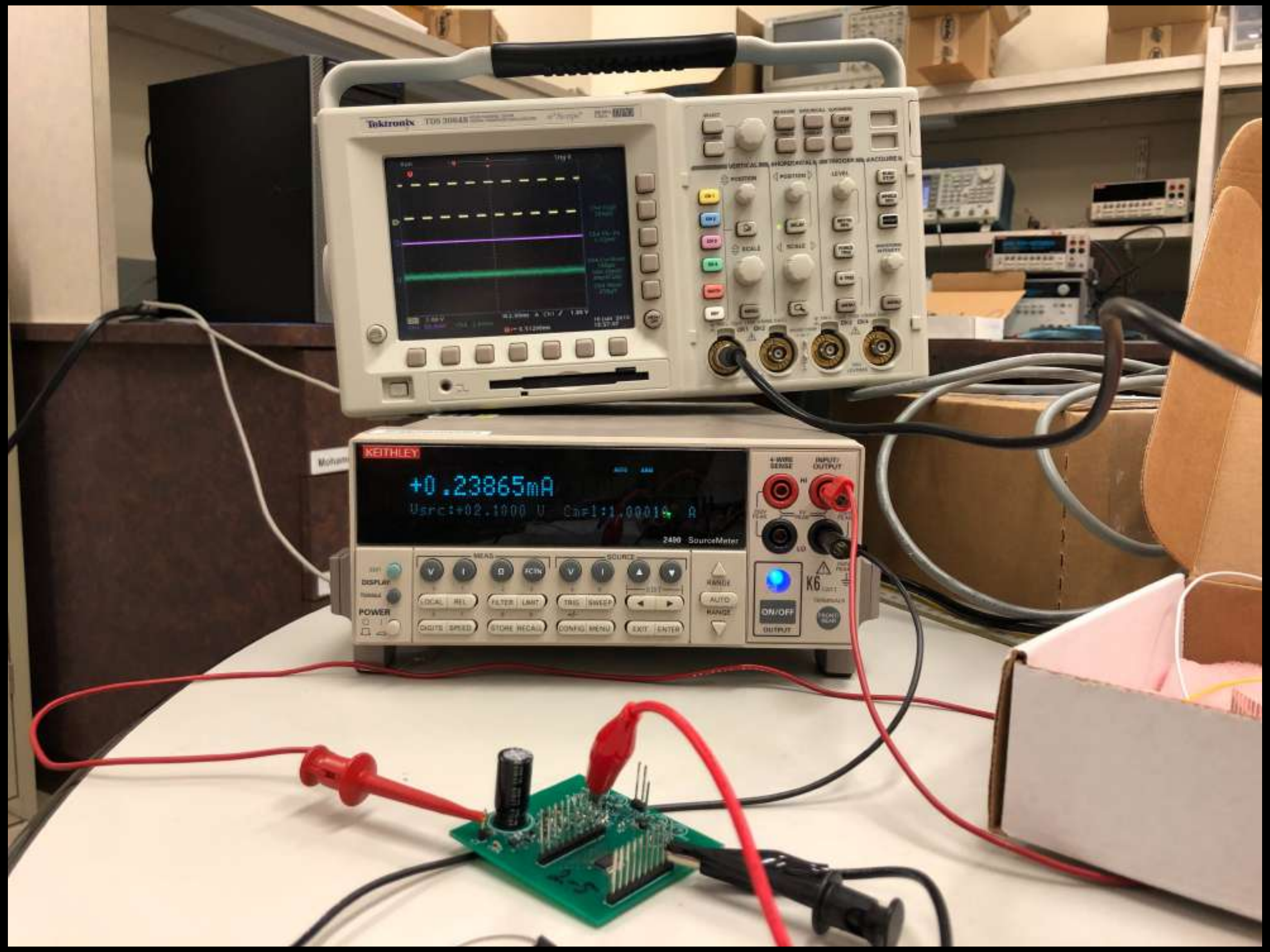
Aquarian H2A

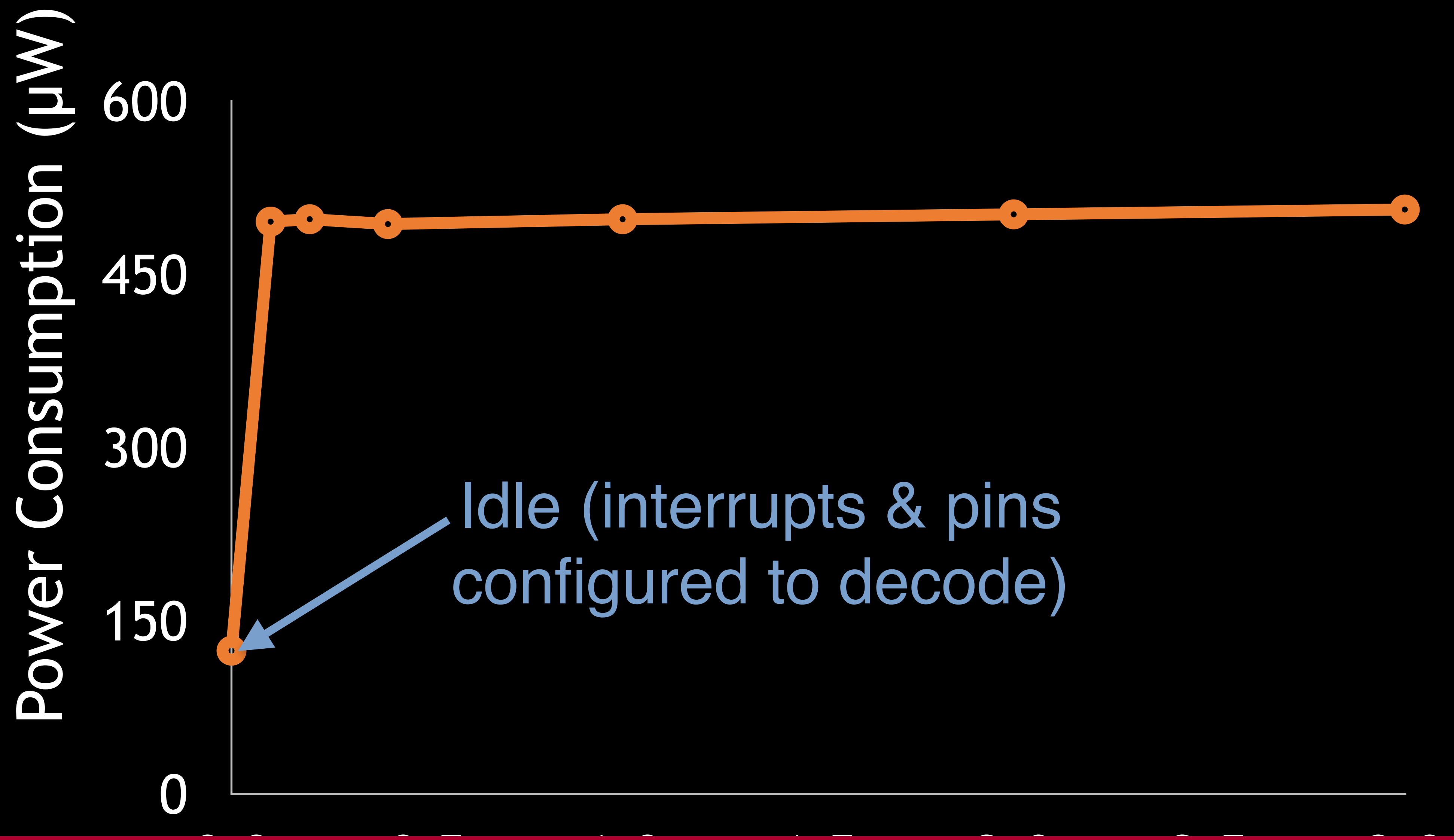
Implementation



Power Consumption

Empirically measured using Keithley 2400 source meter

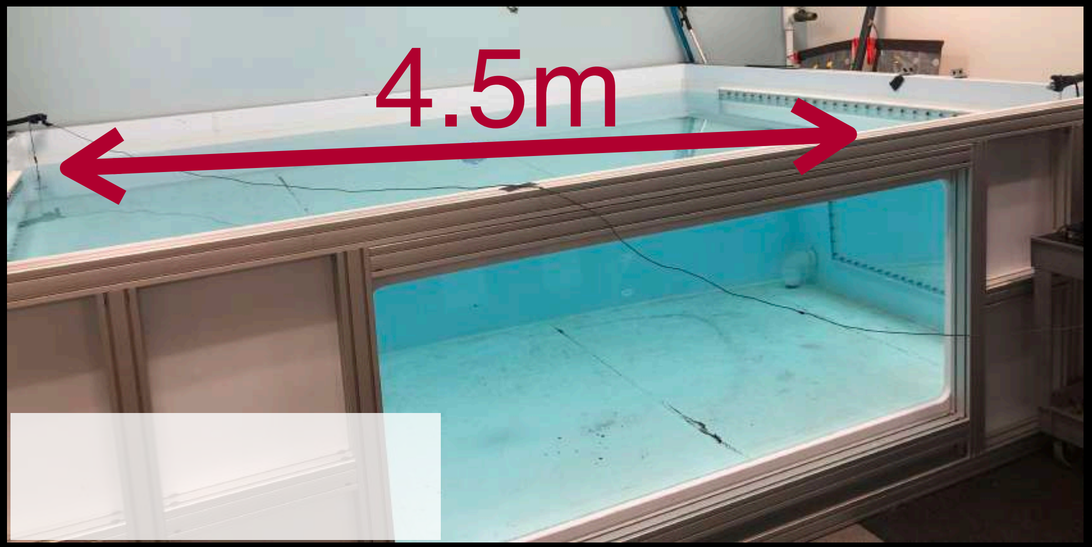


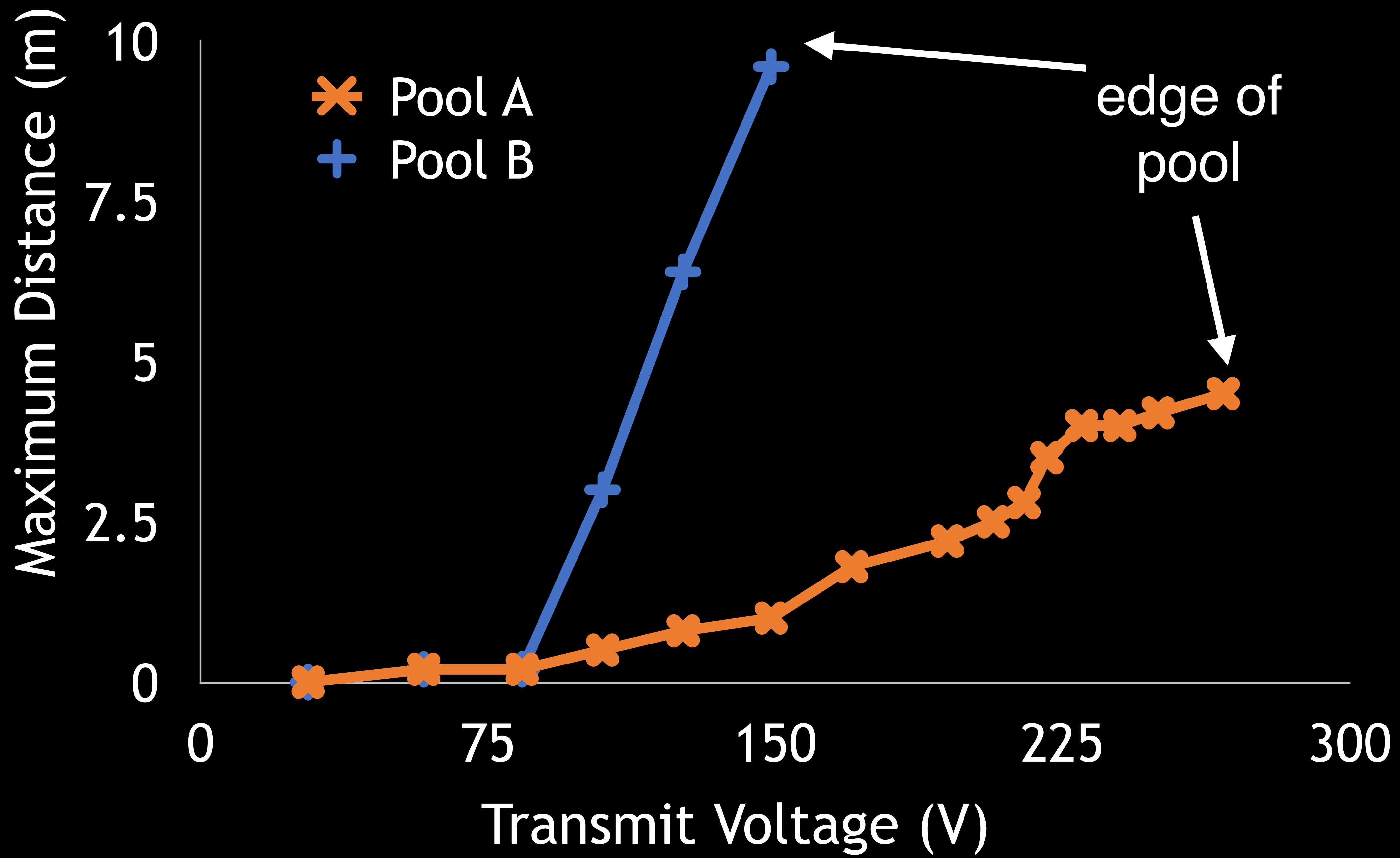


1 million times less power than state-of-the-art low-power underwater sensors [WHOI micro-modem 2019]

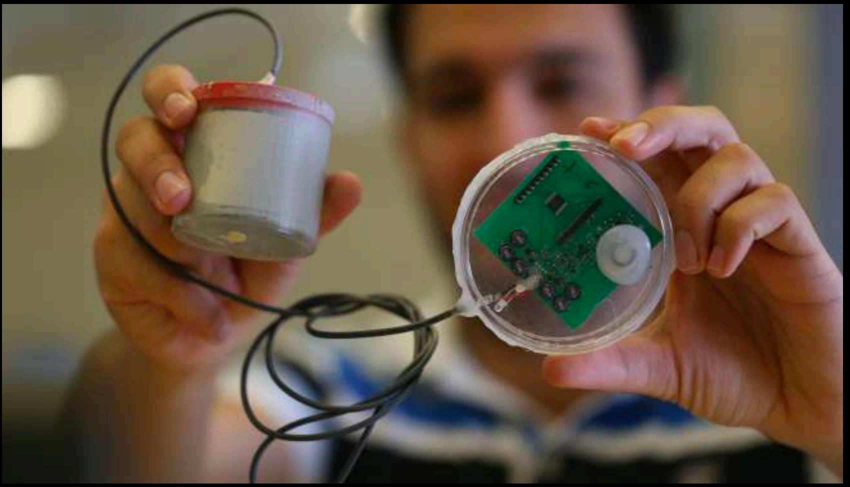
Power-up Range

Experiment: Vary power and distance to sensor





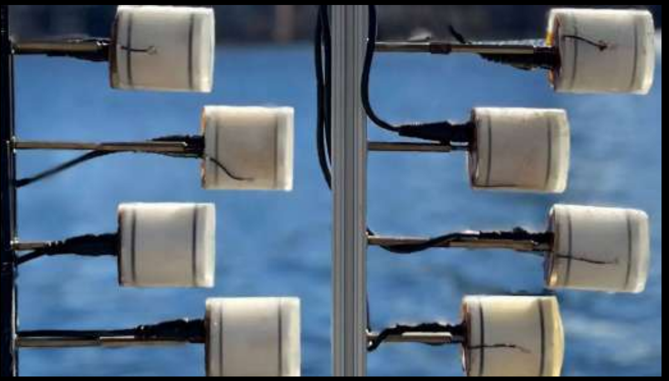
Batteryless
Ocean Sensing
[ACM SIGCOMM’19]



Fabrication
[ACM SIGCOMM’20]

Metamaterials for
UWB (40 kHz)

Communication
[ACM SIGCOMM’23]

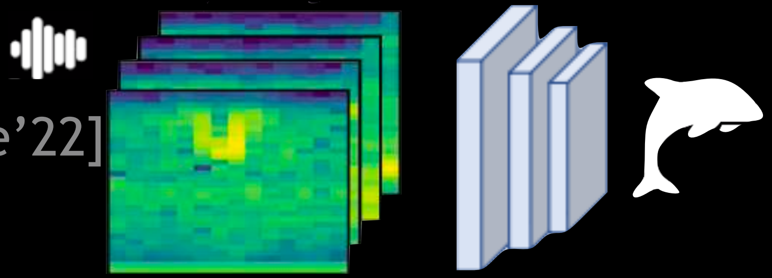


Backscatter Array for
Long-range Comm
(150m+)

Localization
[ACM HotNets’20,
IROS’24]

Battery-free GPS
(~10cm)

AI
[ACM HotMobile’22]

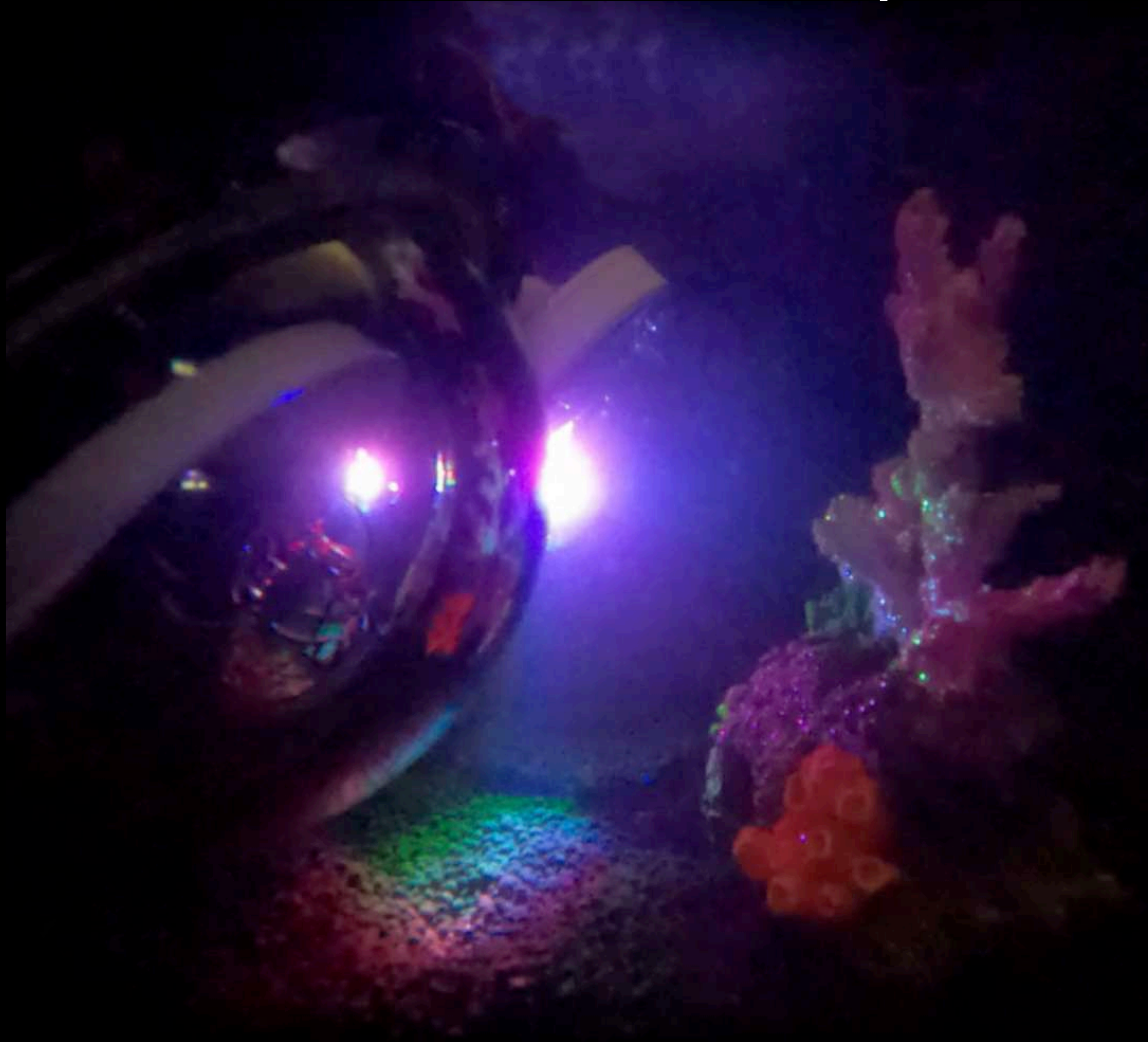


Bioacoustics
(animal/climate
sensing)

Imaging
[Nature Comm’22,
ACM MobiCom’24]

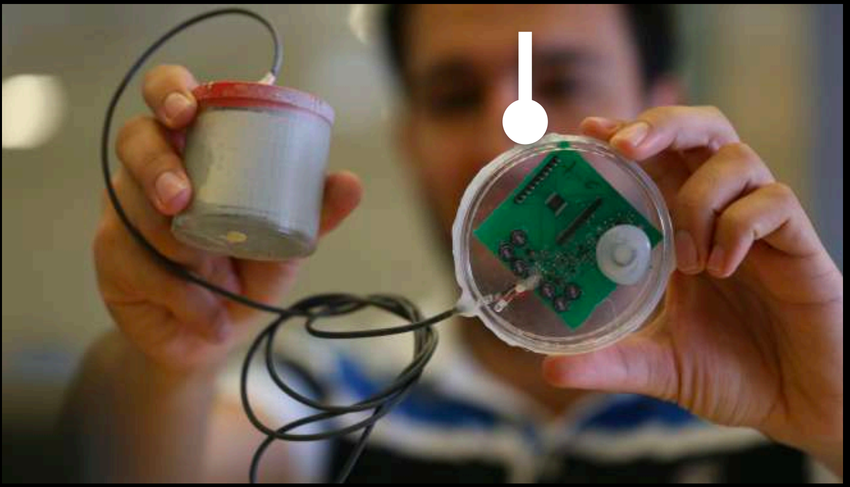
Monitoring for
climate, ecology,
defense

Can we enable battery-free underwater imaging?



Battery-free & Wireless
Underwater Camera

Batteryless
Ocean Sensing
[ACM SIGCOMM'19]



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[ACM SIGCOMM'20]

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Communication
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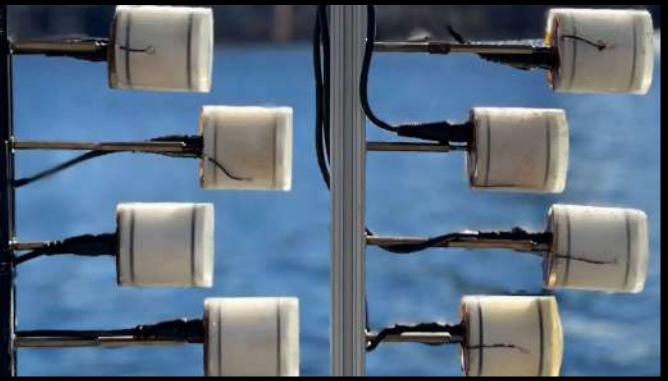

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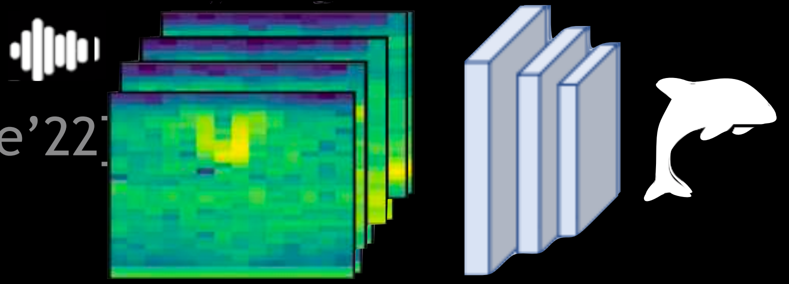

Bioacoustics
(animal/climate
sensing)

Imaging

Monitoring for
climate, ecology,
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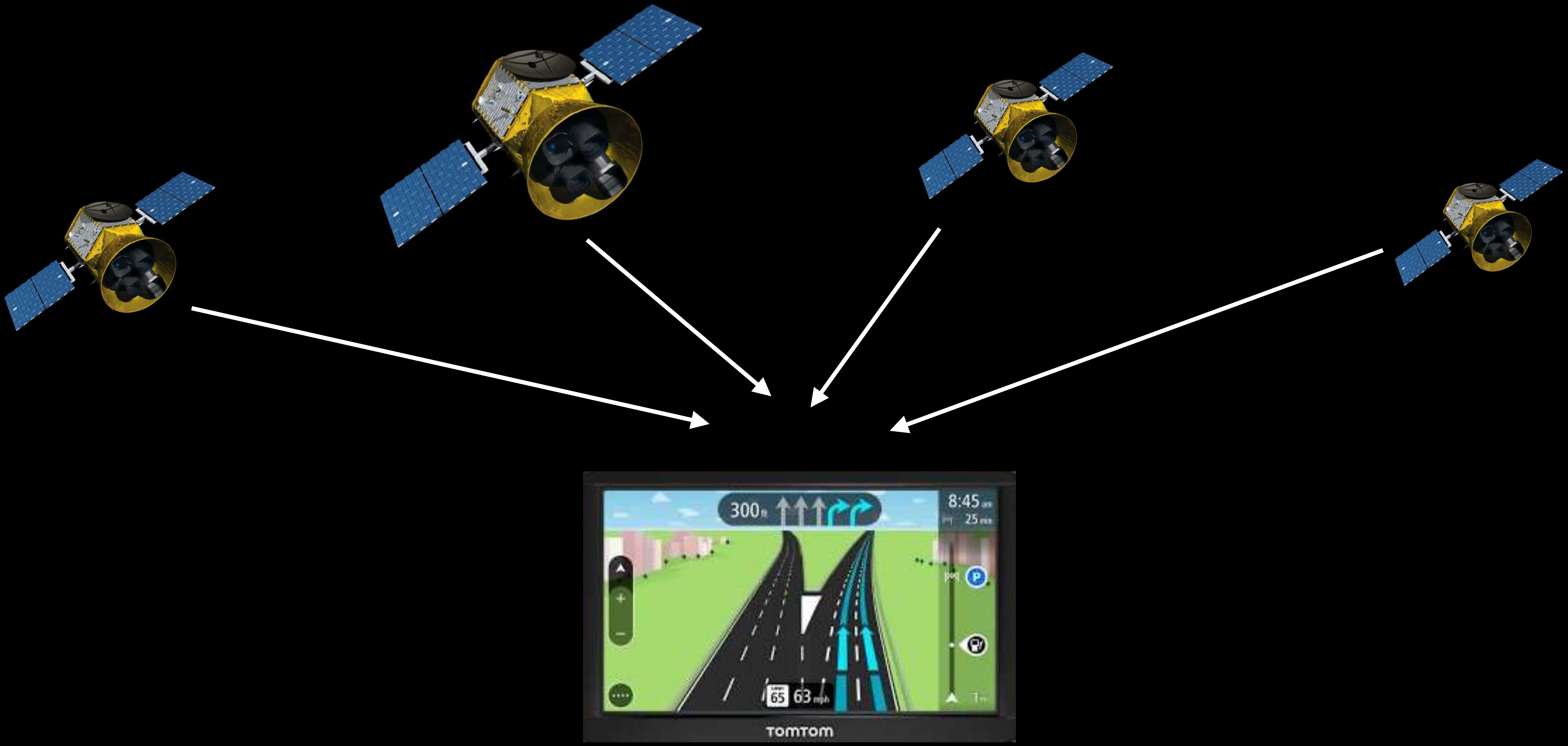
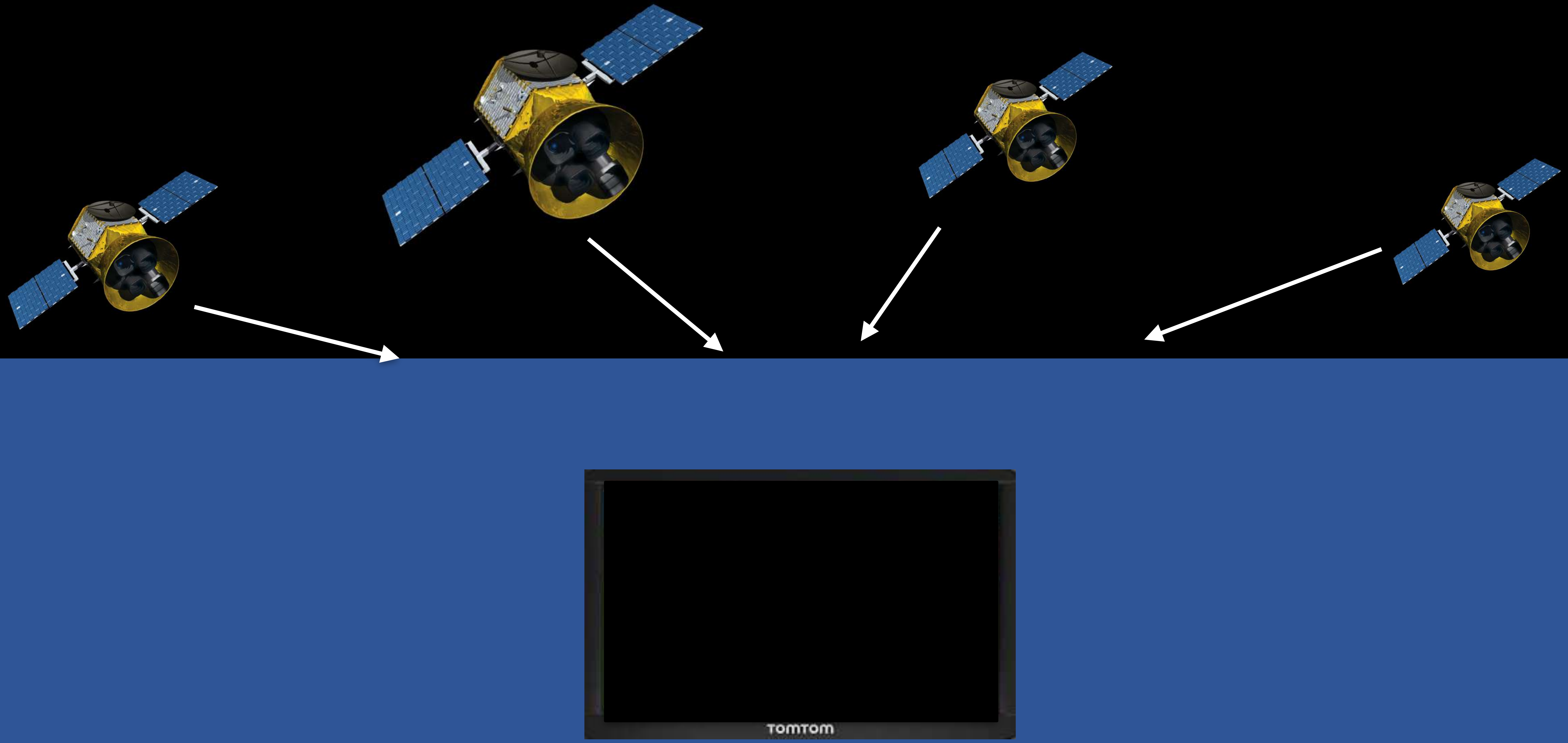
Can we enable battery-free underwater localization?

Global Positioning System (GPS)

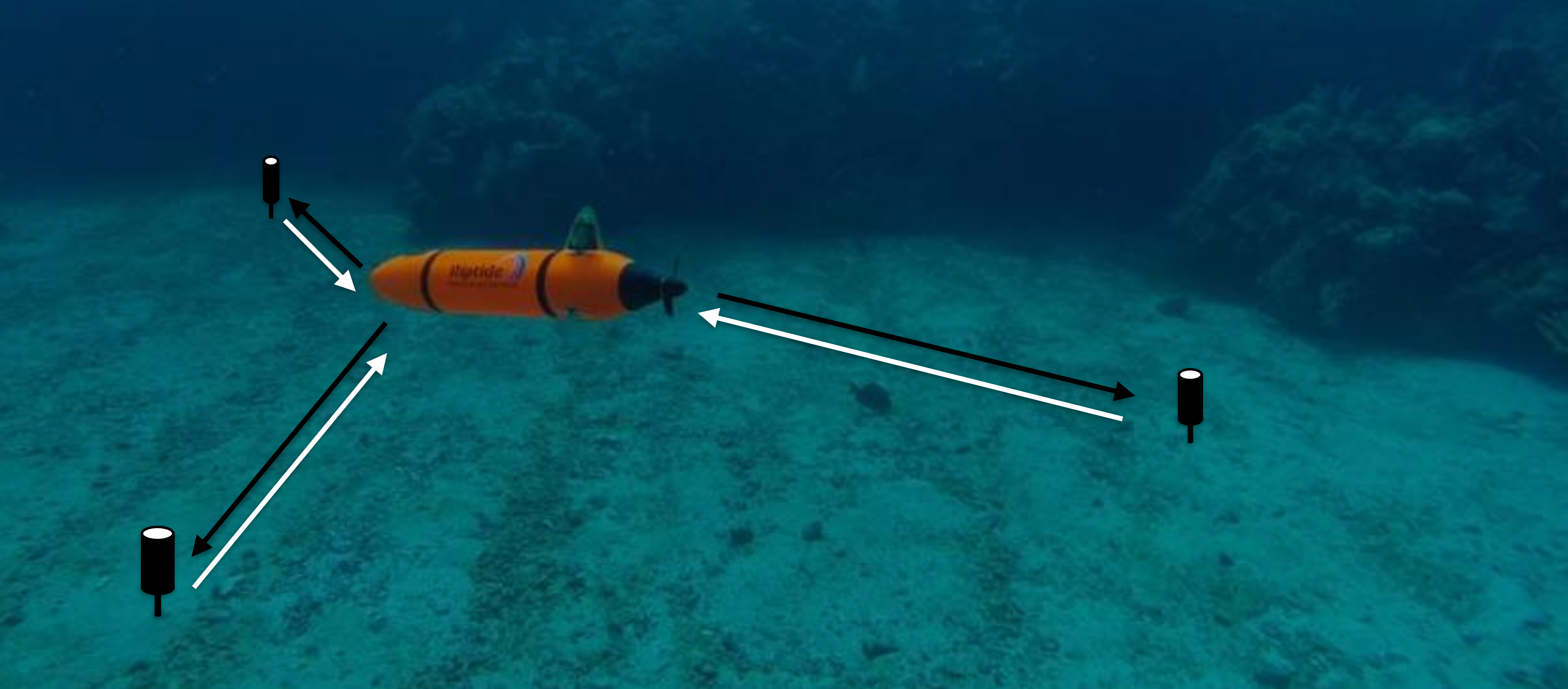


Global Positioning System (GPS)



Conventional Underwater Positioning

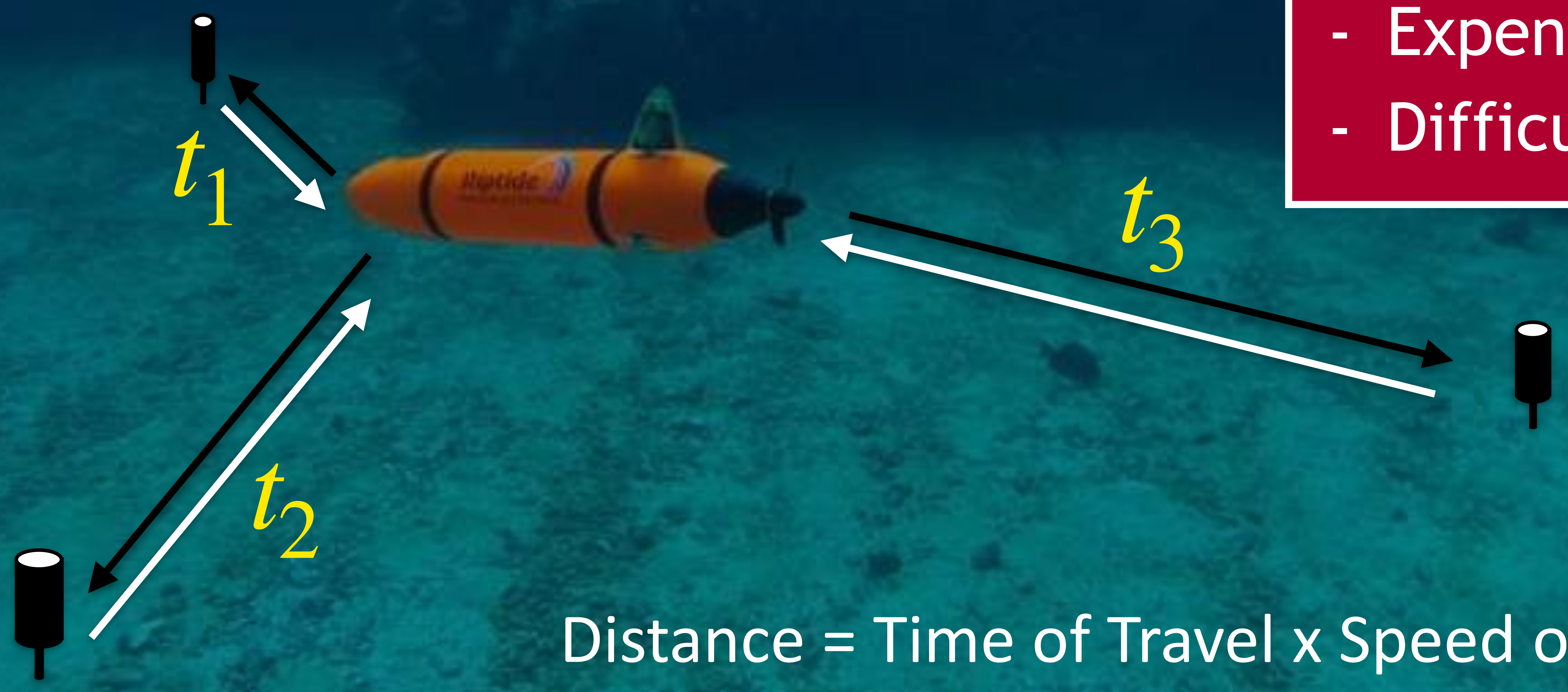
Works by measuring distances to deployed anchors



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

Key Idea: Underwater positioning using backscatter sensor

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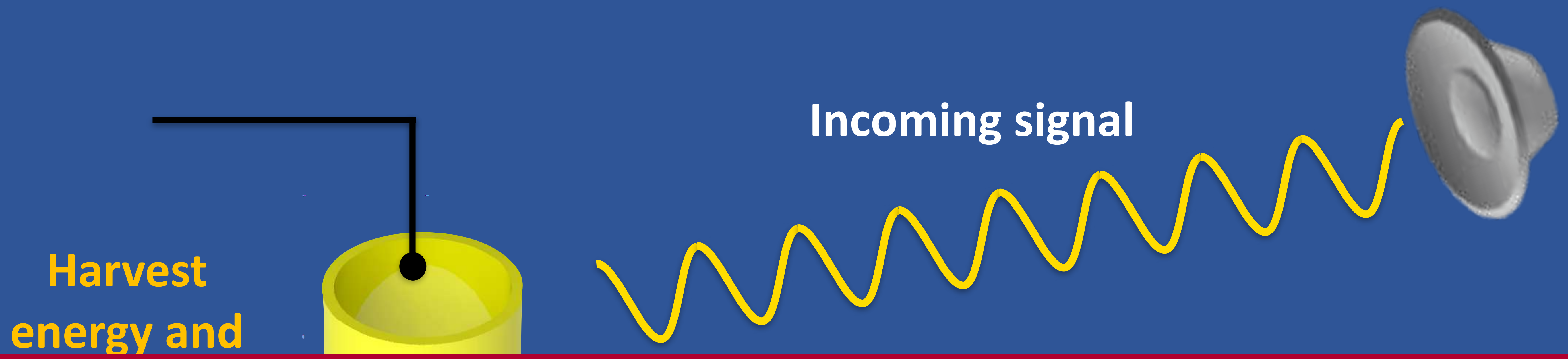
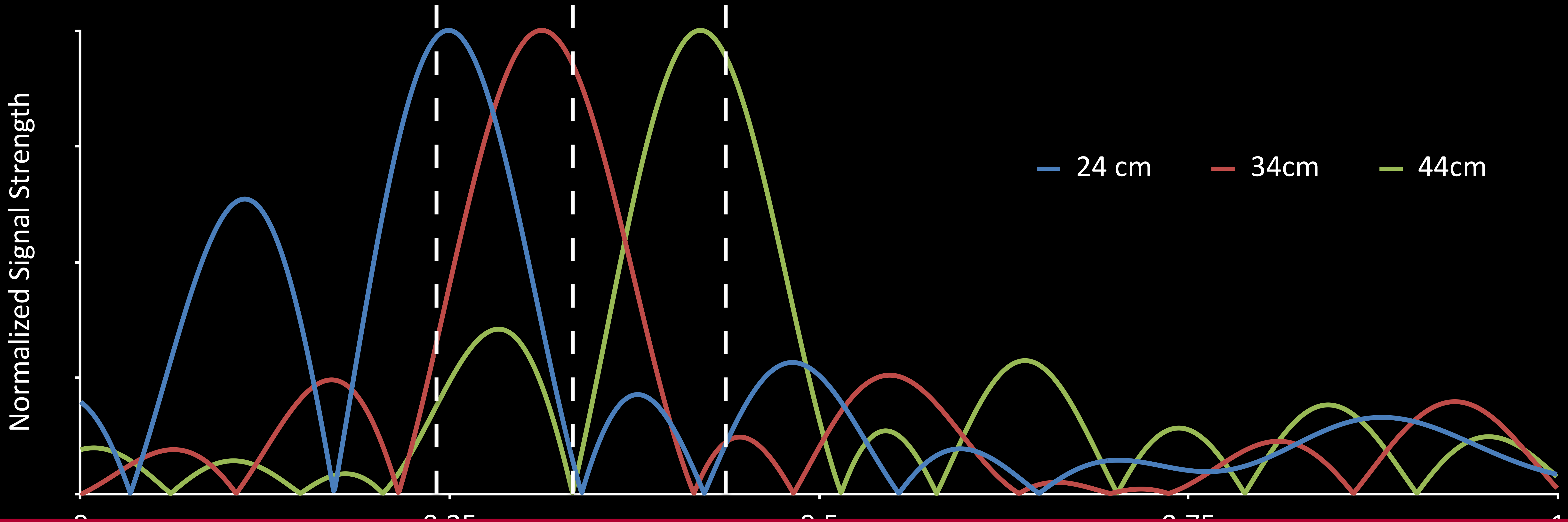
Measure “phase” instead of measuring time



Backscatter acts as a code and the phase of the continuous signal is not impacted by the wake-up lag

Use multi-frequency estimation to compute the time-of-flight from backscatter reflections [ACM HotNets’20]

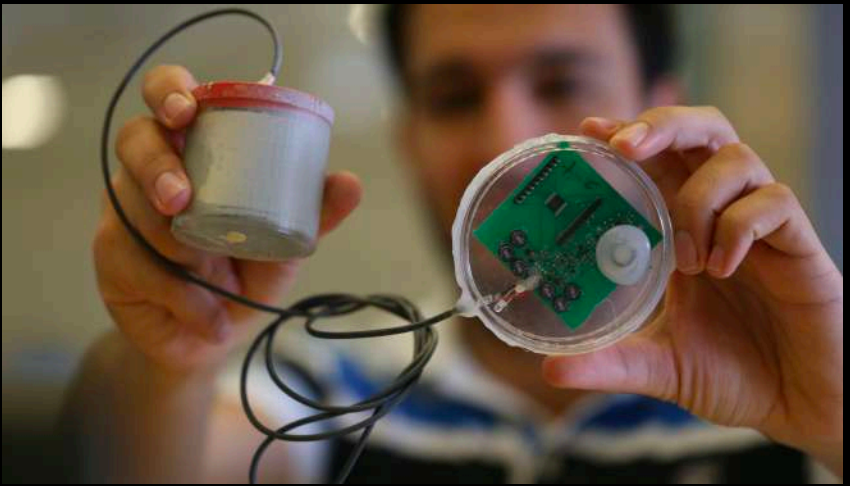
Experimental Evaluation in the River



Early results show localization accuracy of ~10 cm

Can we enable battery-free underwater localization?

Batteryless
Ocean Sensing
[ACM SIGCOMM'19]



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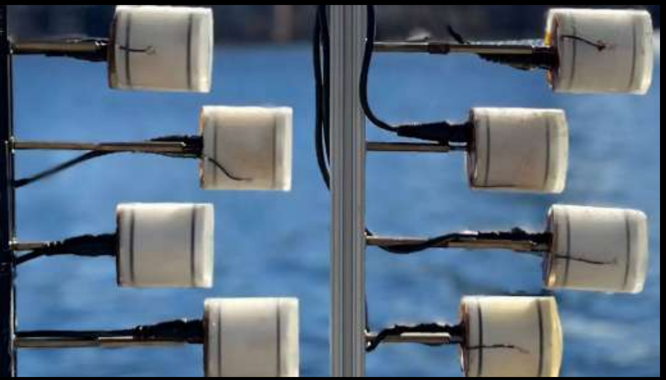

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Long-range Comm
(150m+)

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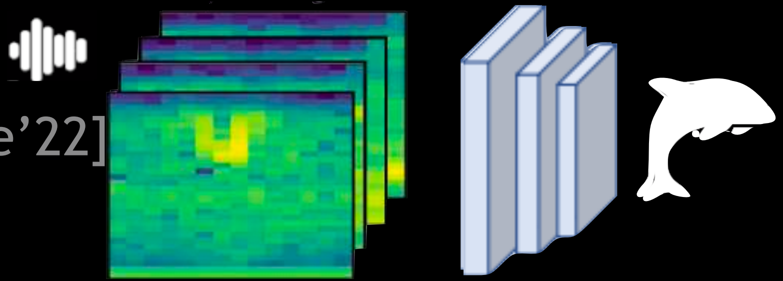
AI
[ACM HotMobile'22]



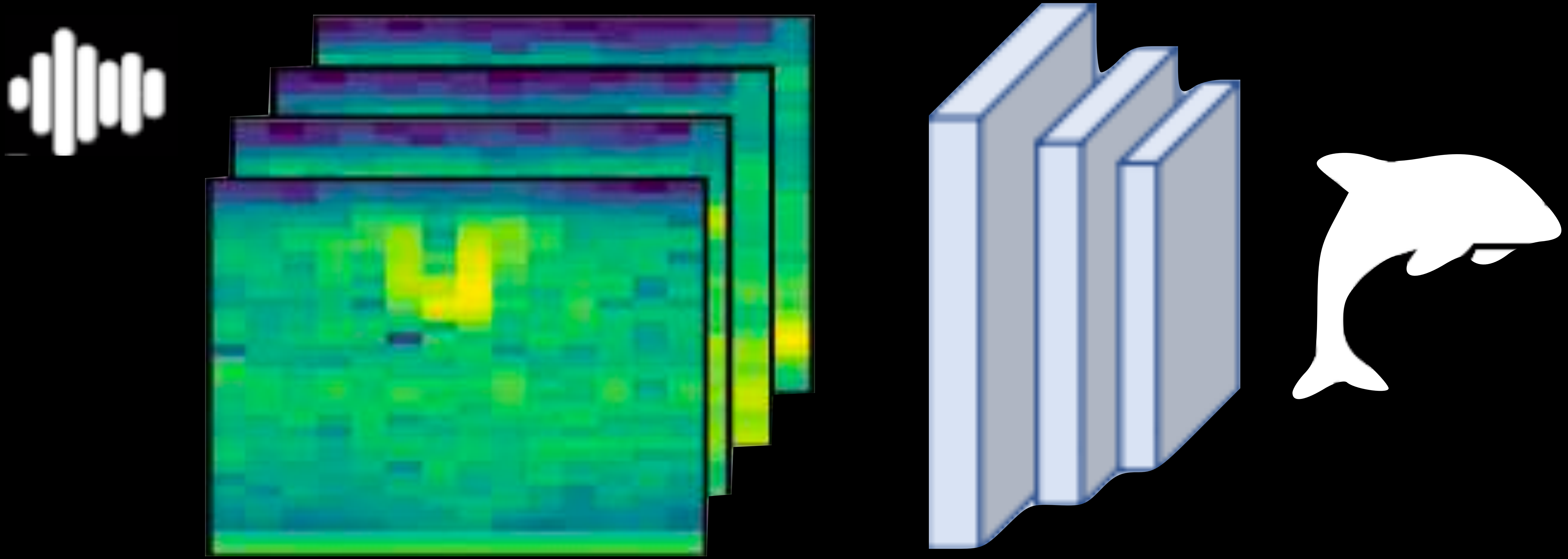
Bioacoustics
(animal/climate
sensing)

Imaging
[Nature Comm'22,
ACM MobiCom'24]

Monitoring for
climate, ecology,
defense

Can we enable battery-free underwater AI?

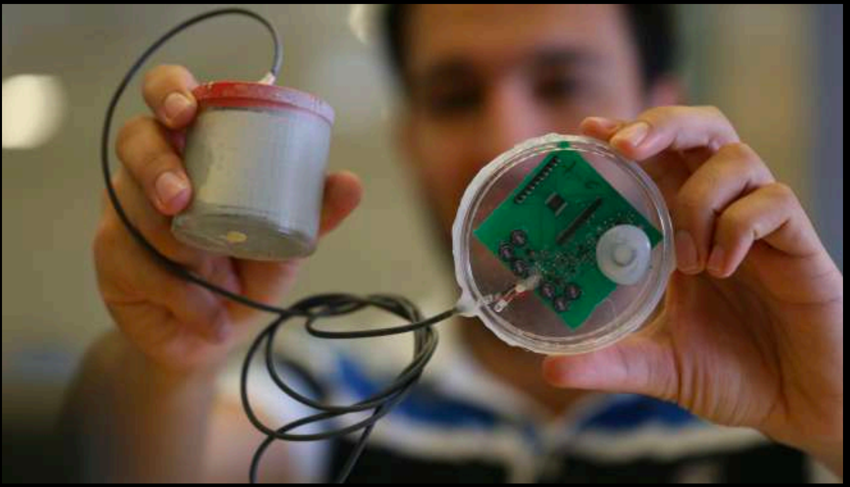
Early results demonstrate 85%+ accuracy in identifying marine species (without any batteries)



[ACM HotMobile'22]

MIT Imperial College London

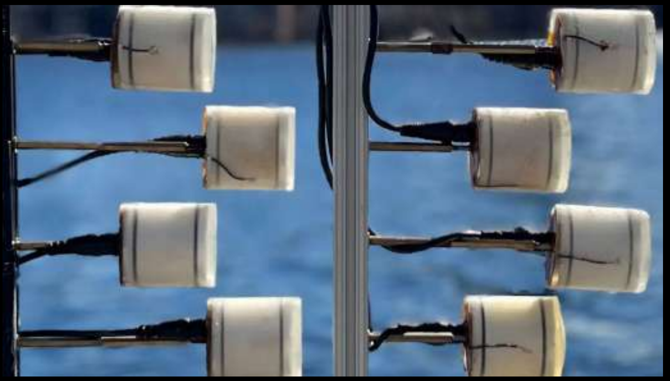
Batteryless
Ocean Sensing
[ACM SIGCOMM'19]



Fabrication
[ACM SIGCOMM'20]

Metamaterials for
UWB (40 kHz)

Communication
[ACM SIGCOMM'23]

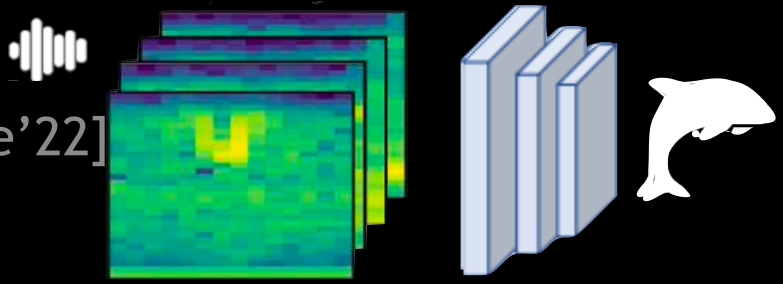


Backscatter Array for
Long-range Comm
(150m+)

Localization
[ACM HotNets'20,
IROS'24]

Battery-free GPS
(~10cm)

AI
[ACM HotMobile'22]



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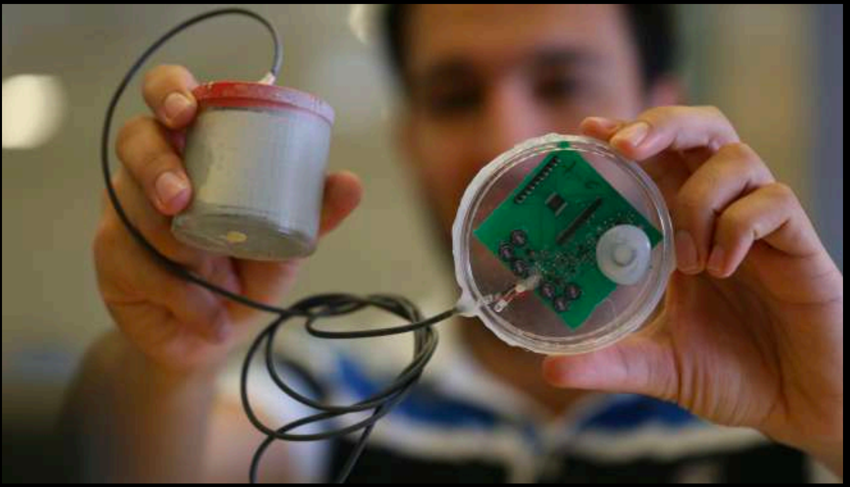


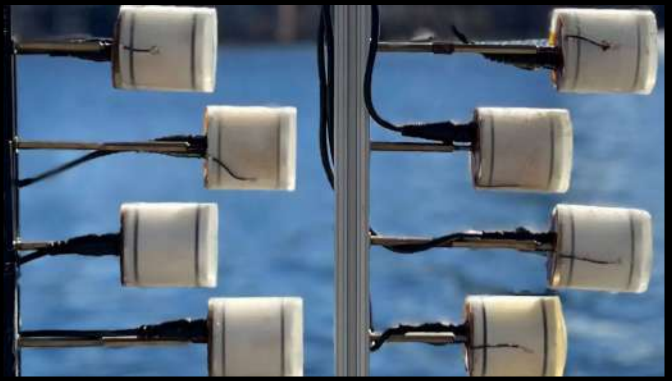
Fabrication

[ACM SIGCOMM'20]

nanoWatt power levels

Communication

[ACM SIGCOMM'23]



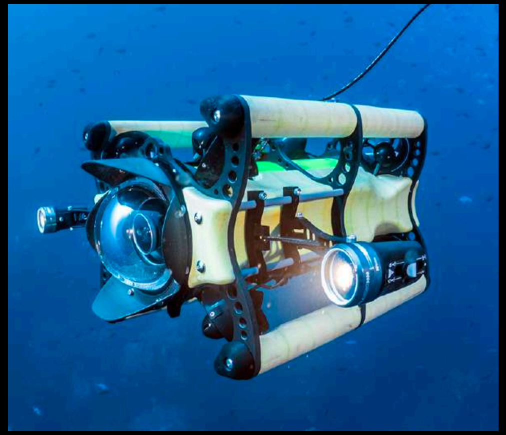
Toward km-scale comms

Woods Hole Oceanographic Institution

Localization

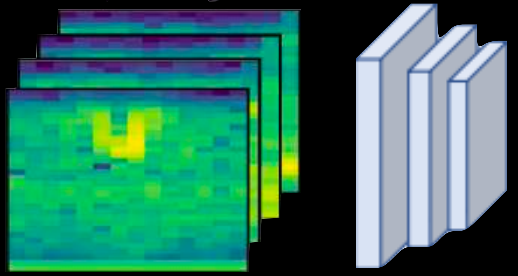
[ACM HotNets'20, IROS'24]

Robotic exploration



AI

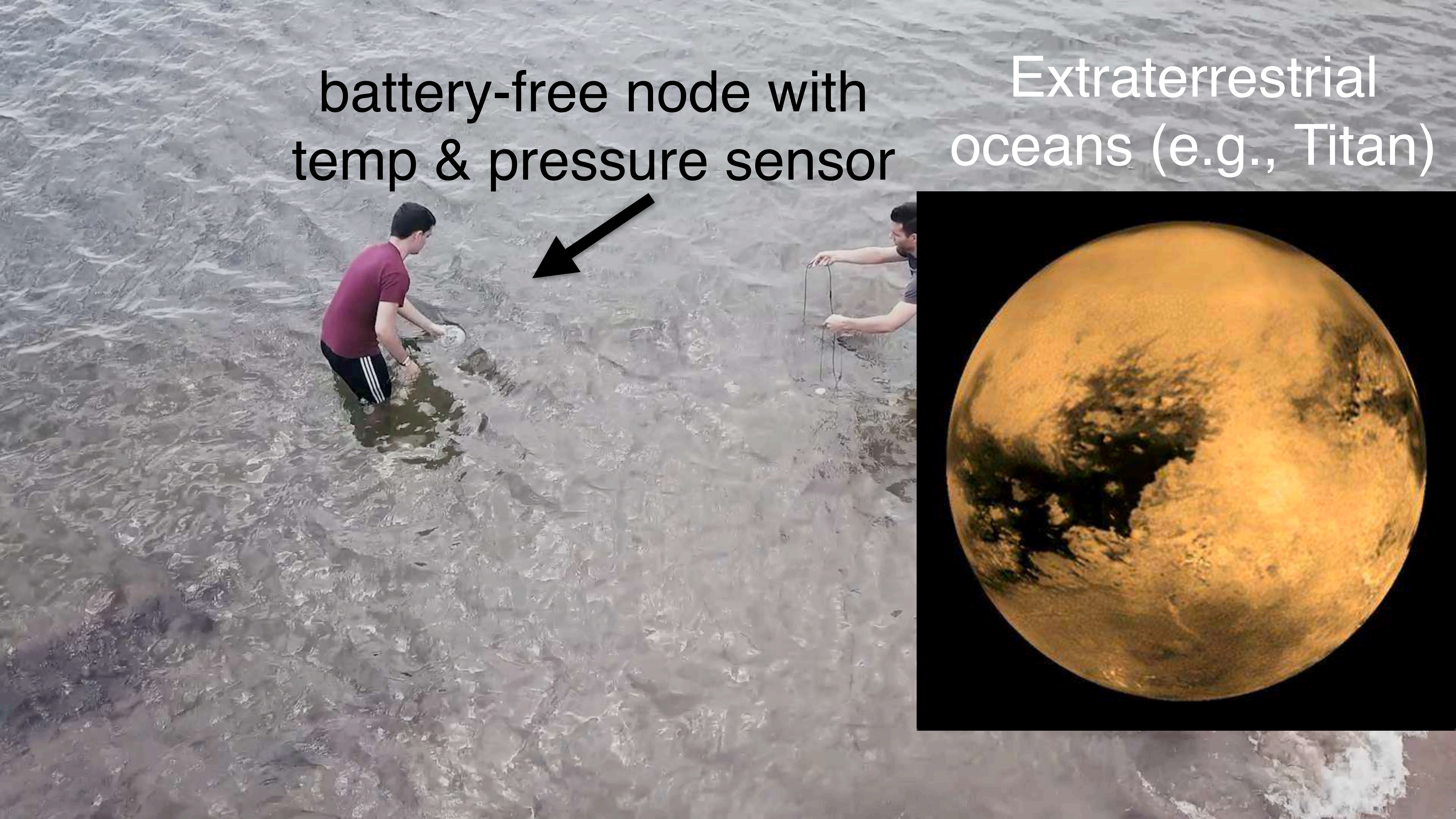
[ACM HotMobile'22]



- Discovering marine species
- Aquaculture
- Climate change monitoring
- Defense
- …

Imaging

[Nature Comm'22, ACM MobiCom'24]


battery-free node with
temp & pressure sensor
Extraterrestrial
oceans (e.g., Titan)

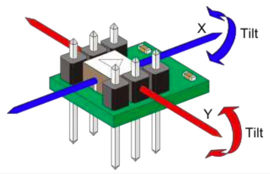
Summary of this Lecture

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

Remainder of the Class

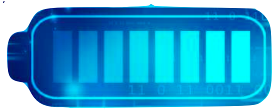
IoT Fundamentals

Sensing



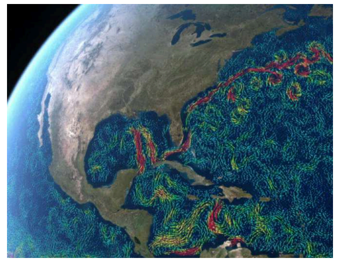
Computation

Power/Energy



Connectivity

Emerging & Cross-Cutting Topics



Project Meetings - Check Slack

1. Labs 0-4
2. PSets 1-2

Lab 4 Due
April 8

PSet 2 Due
April 10

Midterm
April 17

1. Will meet teams weekly
2. Presentations + Q&A on last day of class