Keynote Talk given at the NSF BLUE-UCI on January 12, 2021

Building the Internet of Underwater Things

Fadel Adib

Doherty Chair & Associate Professor

Founding Director, Signal Kinetics

@fadeladib

Taking the Internet of Things Underwater

30 bn

IoT Devices

- McKinsey, Deloitte, BCG, 2020

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

Forbes

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

David Hambling Contributor

Aerospace & Defense

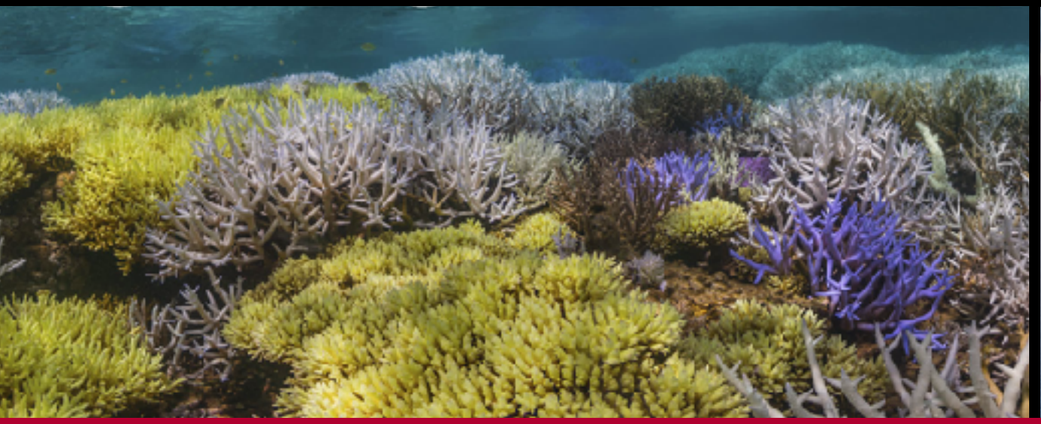
I'm a South London-based technology journalist, consultant and author

DARPA has awarded a contract for the next phase of development of its Ocean of Things (OoT), a project to seed the seas with thousands of floating sensors, monitoring everything that passes from aircraft to submarines.

Taking the Internet of Things Underwater

"More than 80% of ocean remains unobserved and unexplored."

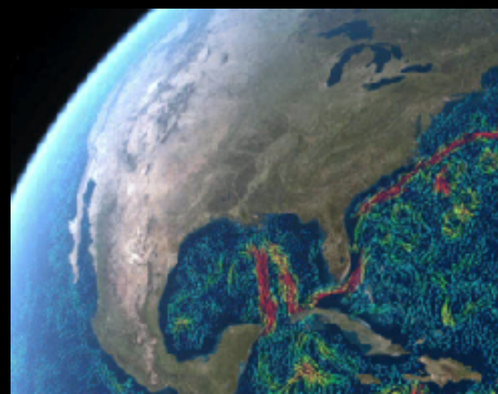
- NOAA, 2018



Less than 1 in a million of IoT is underwater, even though oceans cover more than 70% of the planet

Aquaculture is the "fastest growing food sector"

- UN Food & Ag org, 2010



Building the Internet of Underwater Things

TECHNOLOGIES

- Batteryless Underwater IoT & Localization
- Underwater-to-air comms

COMMUNITY/POLICY

- Open Source
- Organization & Policy Engagement

Building the Internet of Underwater Things

TECHNOLOGIES

- Batteryless Underwater IoT & Localization
- Underwater-to-air comms

COMMUNITY/POLICY

- Open Source
- Organization & Policy Engagement

Problem: Battery life of underwater sensors is extremely limited

Low-power underwater transmitters consume 10s-100s of Watts and cannot be recharged easily

Most 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

Published in: ACM SIGCOMM'19, ACM SIGCOMM'20, IEEE/MTS OCEANS'20, ACM HotNets'20

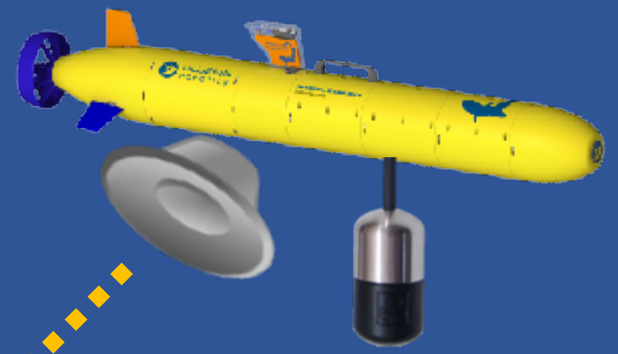
Traditional Approach

Underwater Drone

Acoustic

Sensor generates its own acoustic signal

Our Technology



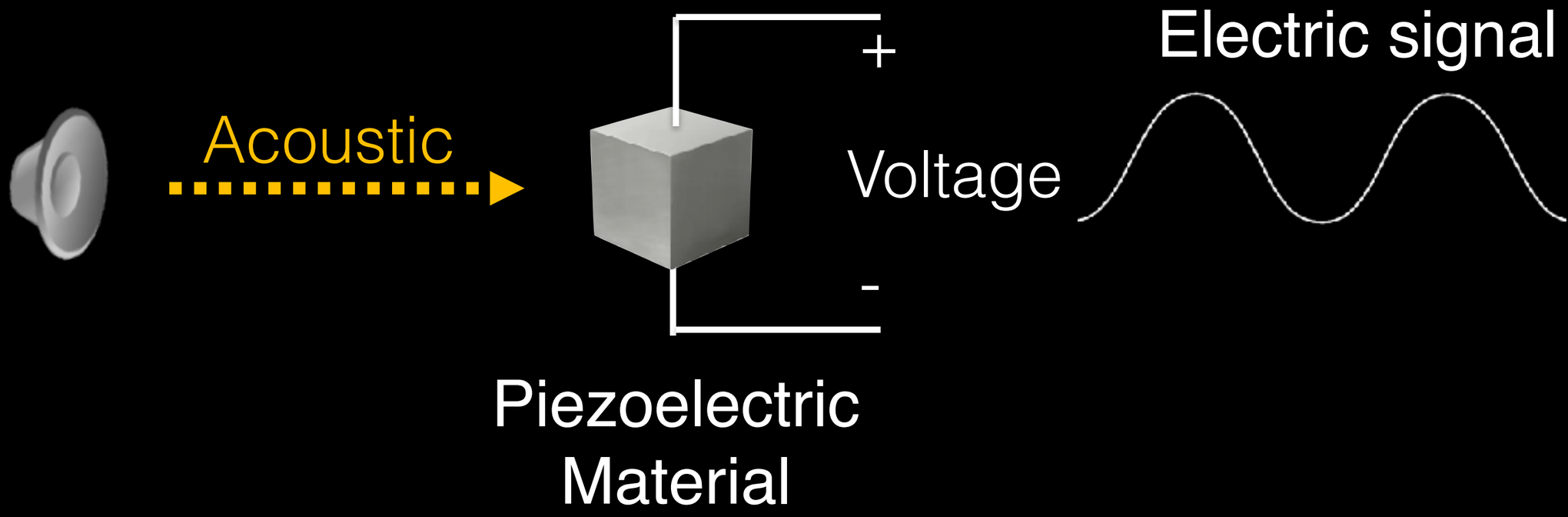
Acoustic

Sensor reflects an existing acoustic signal

How can we control the reflections of acoustic signals?

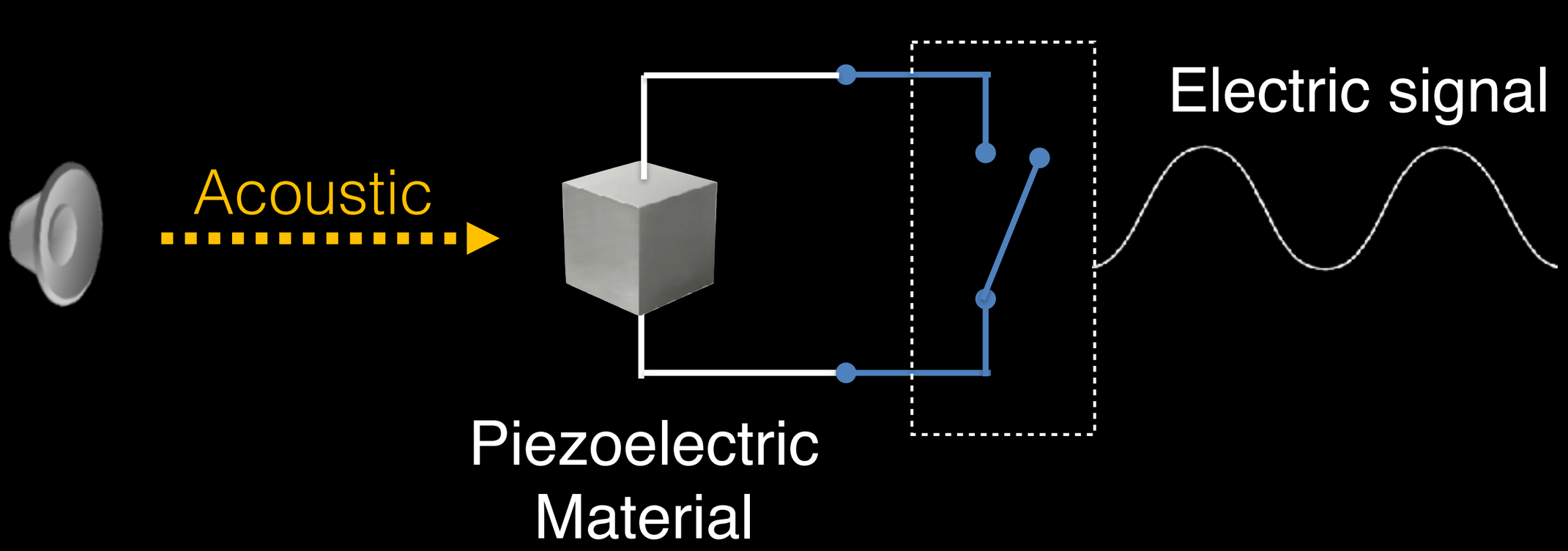
Key Idea: Use piezoelectricity to design programmable acoustic reflectors

Piezoelectric materials transform mechanical to electrical energy



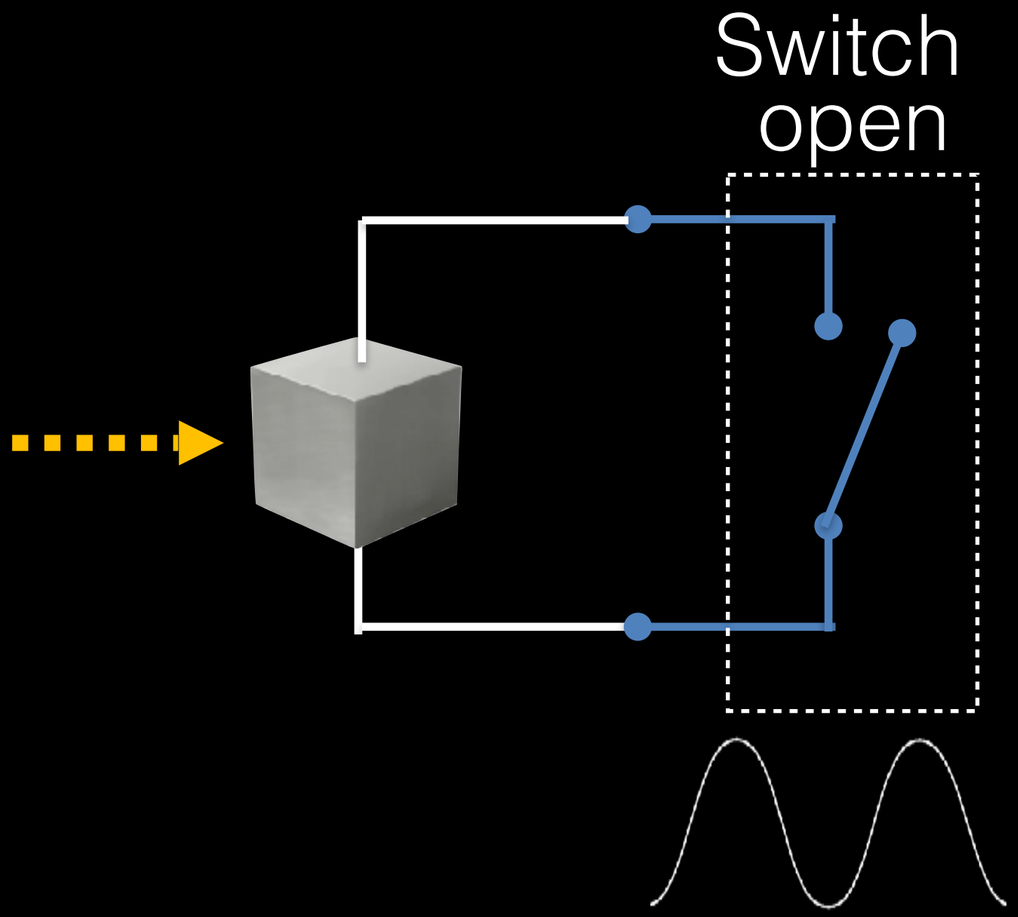
Key Idea: Use piezoelectricity to design programmable acoustic reflectors

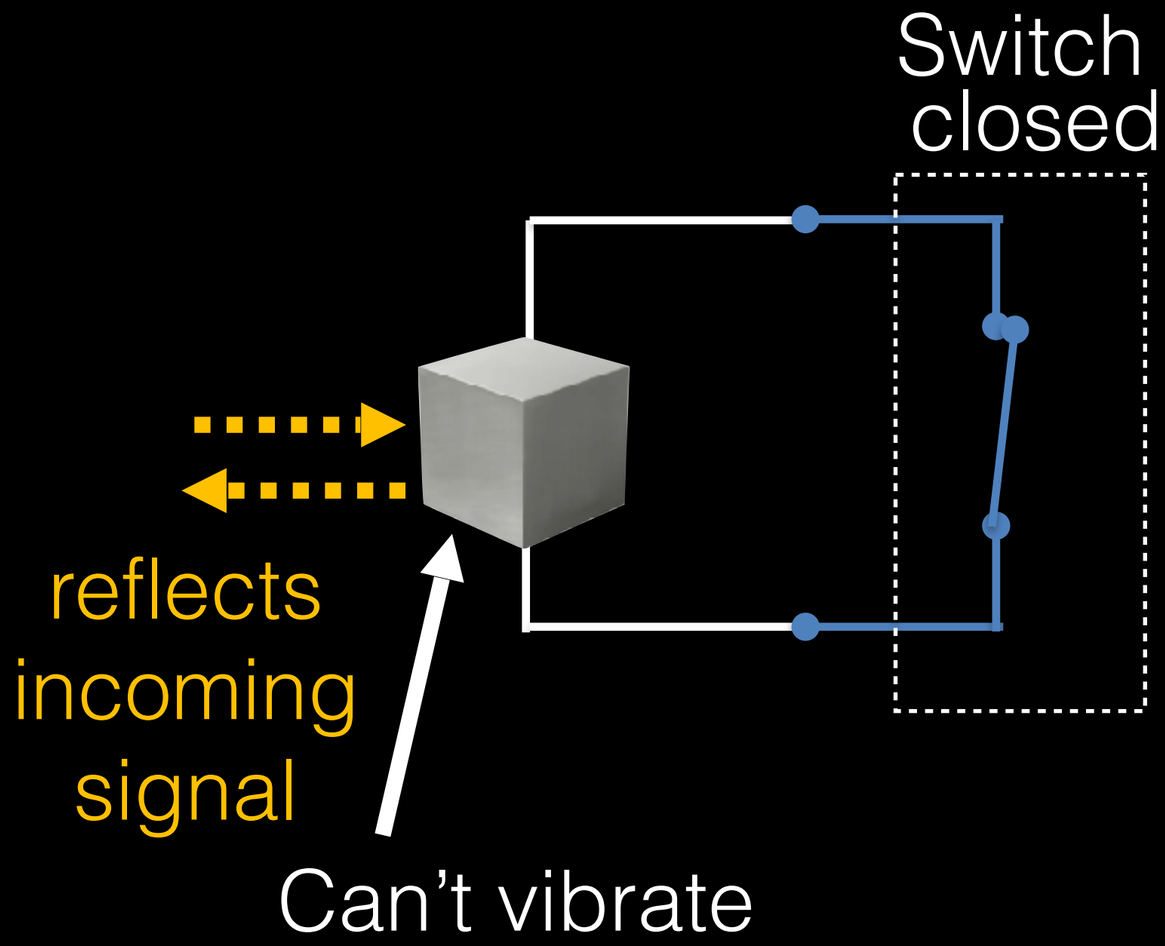
Piezoelectric materials transform mechanical to electrical energy



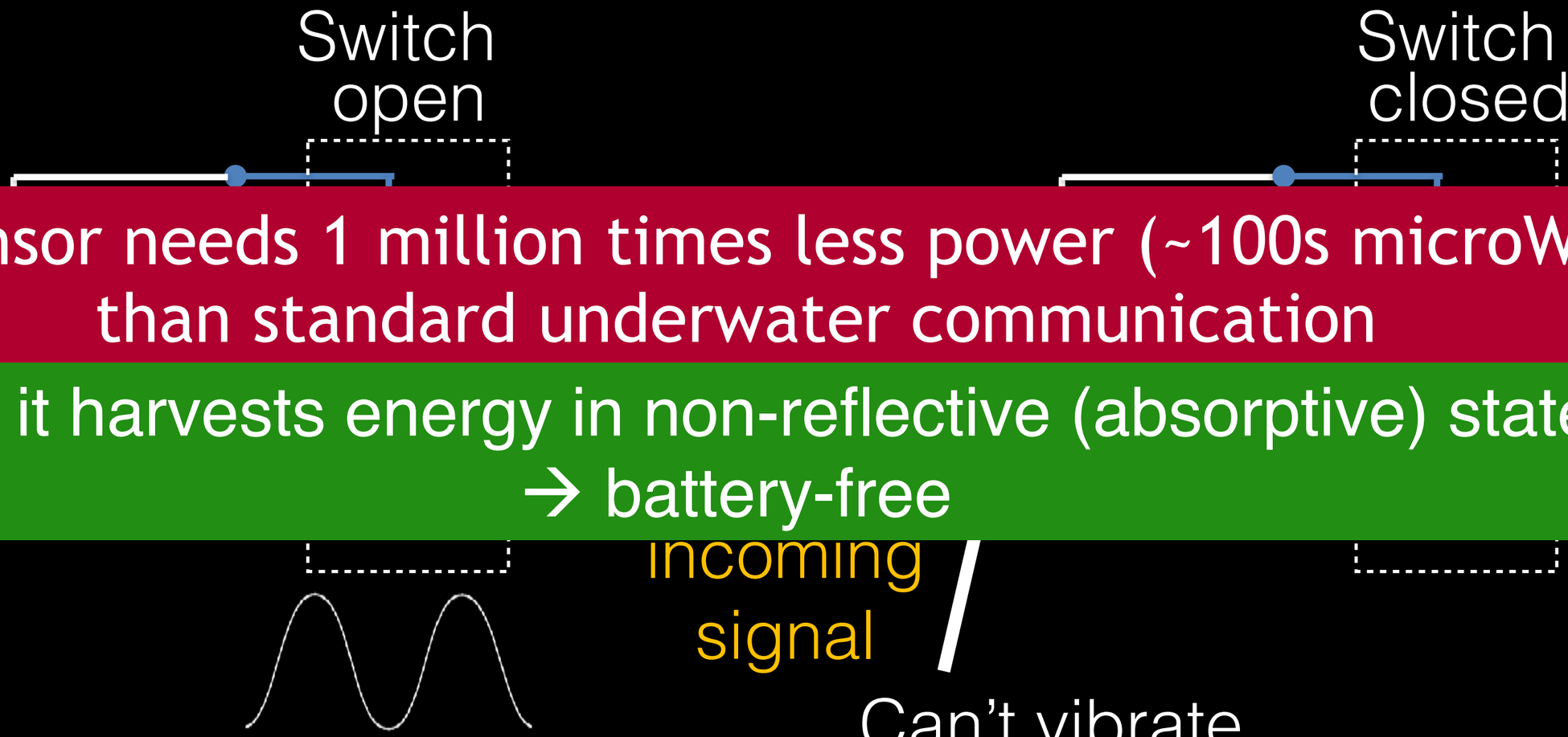
Key Idea: Use piezoelectricity to design programmable acoustic reflectors

Piezoelectric materials transform mechanical to electrical energy



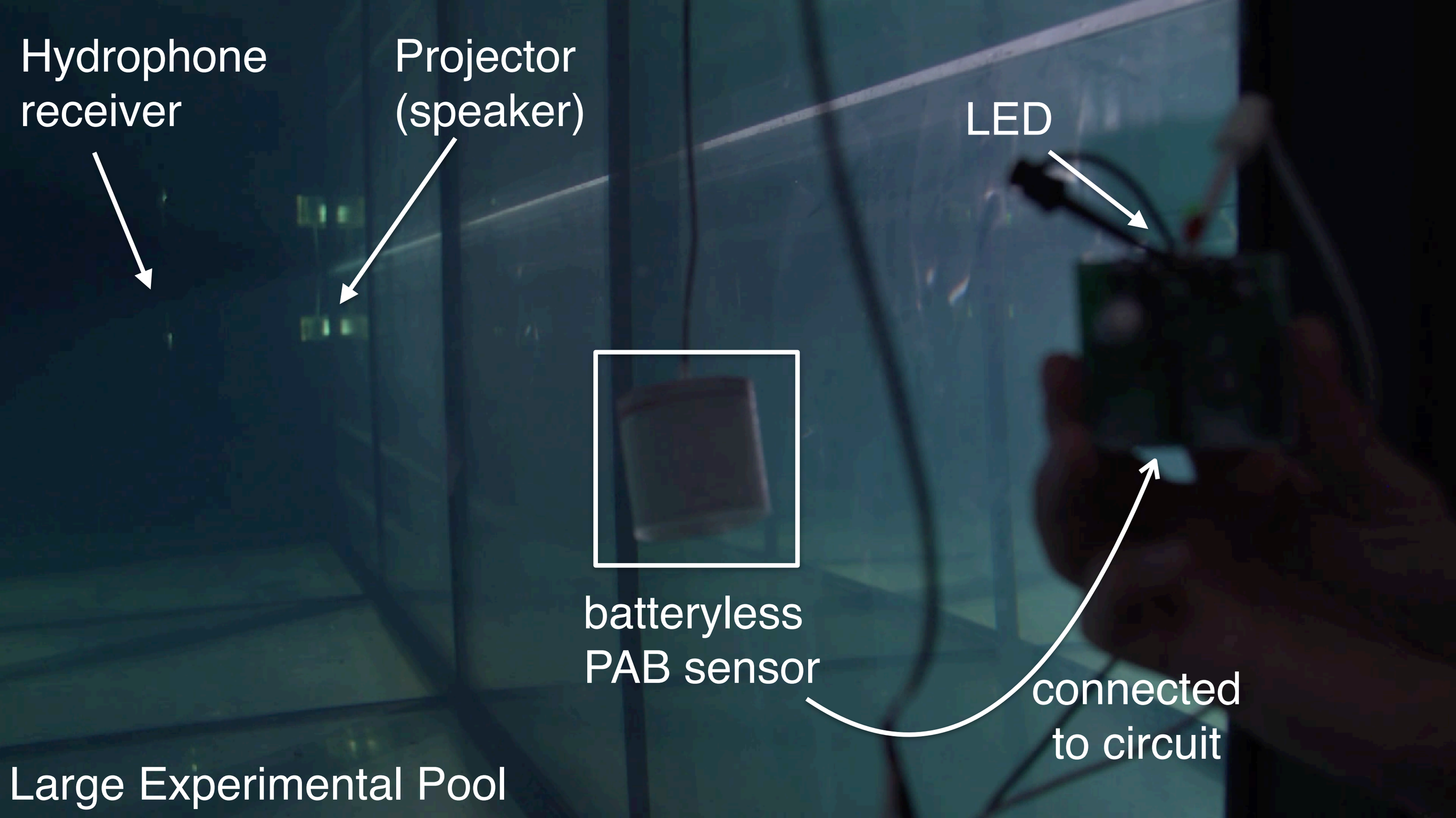


Piezo-Acoustic Backscatter

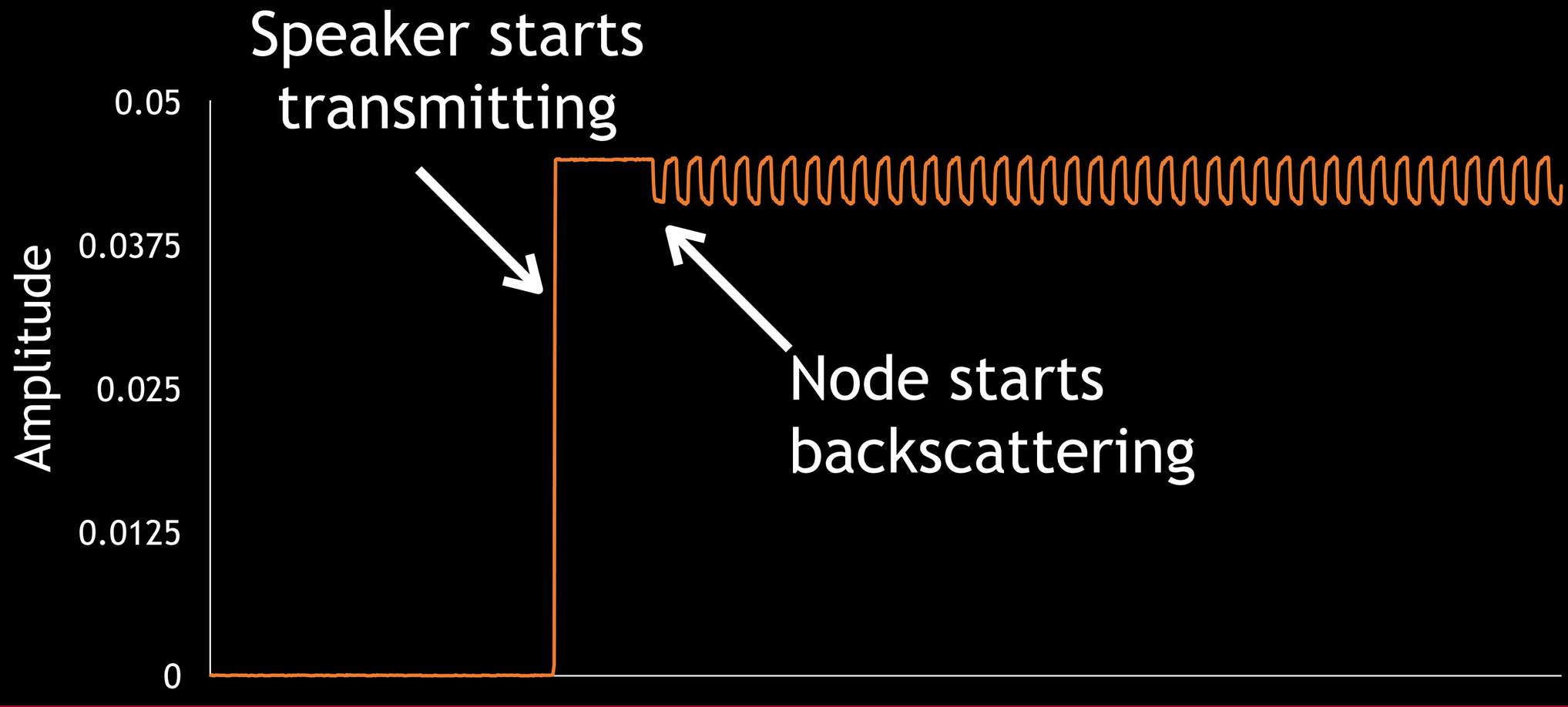


Our sensor needs 1 million times less power (~100s microWatt) than standard underwater communication

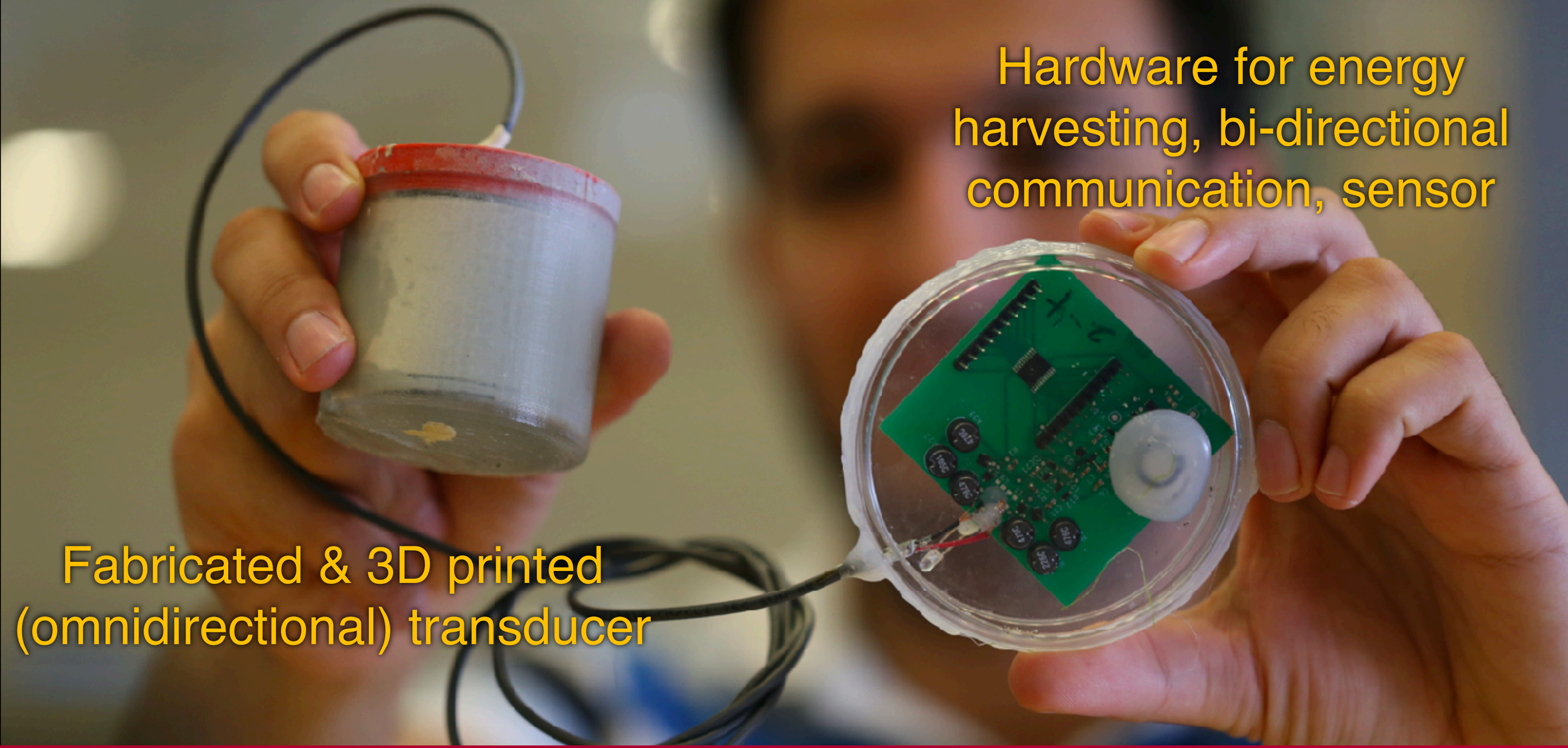
And it harvests energy in non-reflective (absorptive) state
→ battery-free


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

Measuring the Backscatter Signal (by Hydrophone)



Algorithms and techniques to scale to many nodes and deal with other reflections in the environment



Costs ~$100. Consumes 100 of micro-Watts, i.e., 1 million times less power than state-of-the-art low-power underwater modems

Experimental Evaluation in River (with snow & rain)

- 500+ experimental trials at different ranges, throughputs, and number of nodes

- Throughput: 20kbps
- Range: 62m
- Concurrent nodes: 10
  - *before spatial reuse*
- Localization accuracy: centimeter-scale

Code+Schematics+Tutorials:
https://github.com/saadafzal24/Underwater-Backscatter

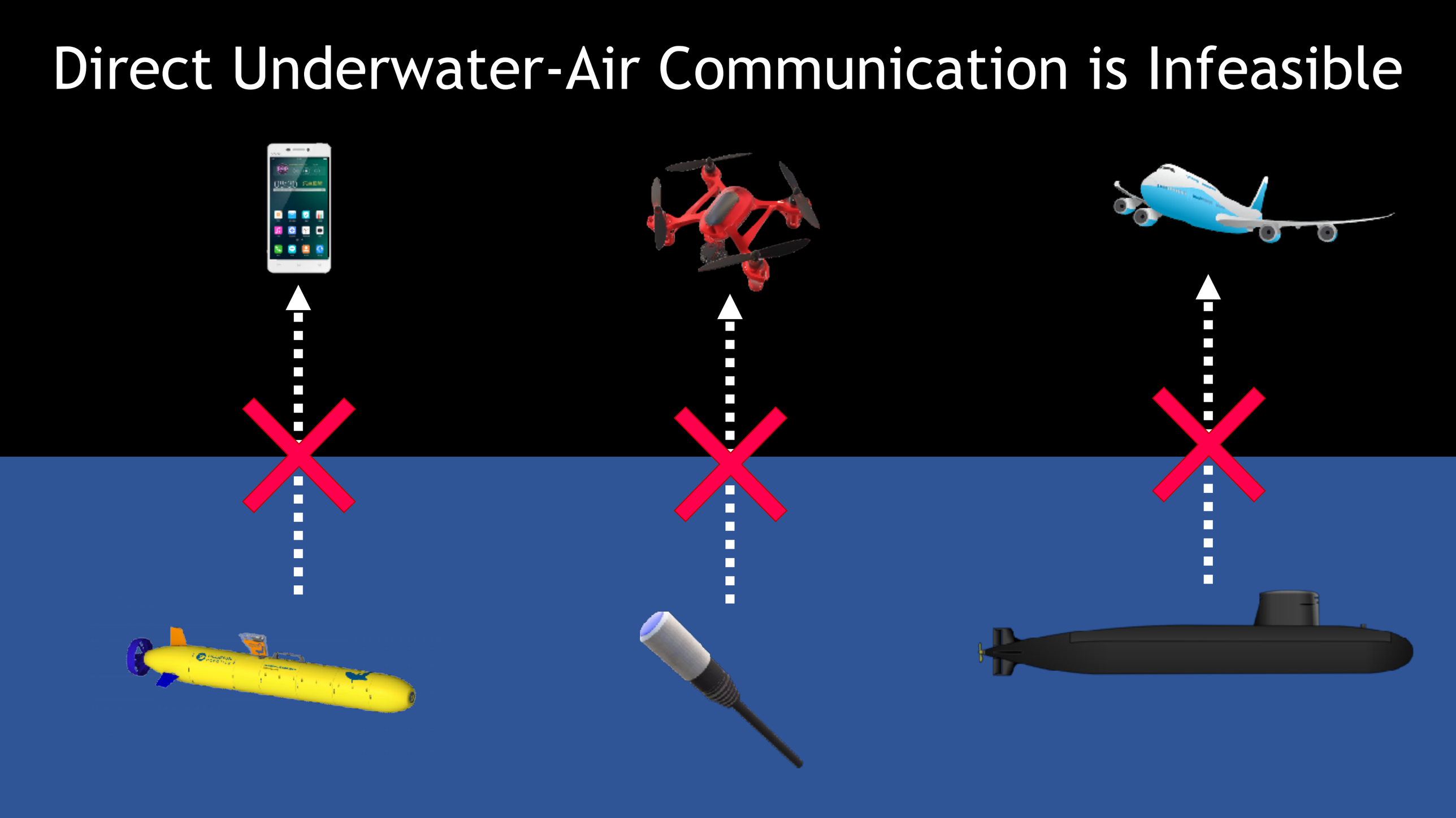
Open Problems in Underwater Backscatter

1. How can we scale the range and throughput?
2. Can we build multi-hop architectures?
3. Can we build accurate simulators?
4. How can we further reduce the energy consumption?
5. How can we go beyond net-zero power to zero pollution?

Localization, Navigation, Sensing

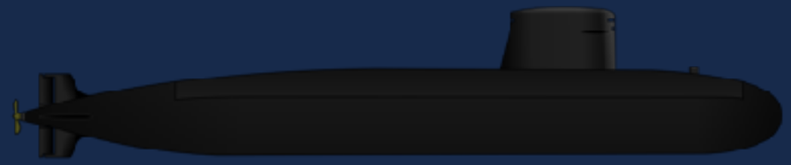
How can we send the sensed information to outside the ocean?

Direct Underwater-Air Communication is Infeasible



Direct Underwater-Air Communication is Infeasible

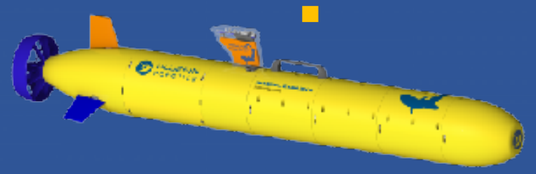
Wireless signals work well only in a single medium

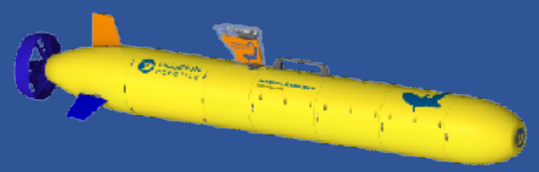


Use Acoustic signals?

Reflects off the Surface

Acoustic





Use Acoustic signals?

Use Radio Signals?

Reflects off the Surface

Radio Signals Die in Water

Acoustic

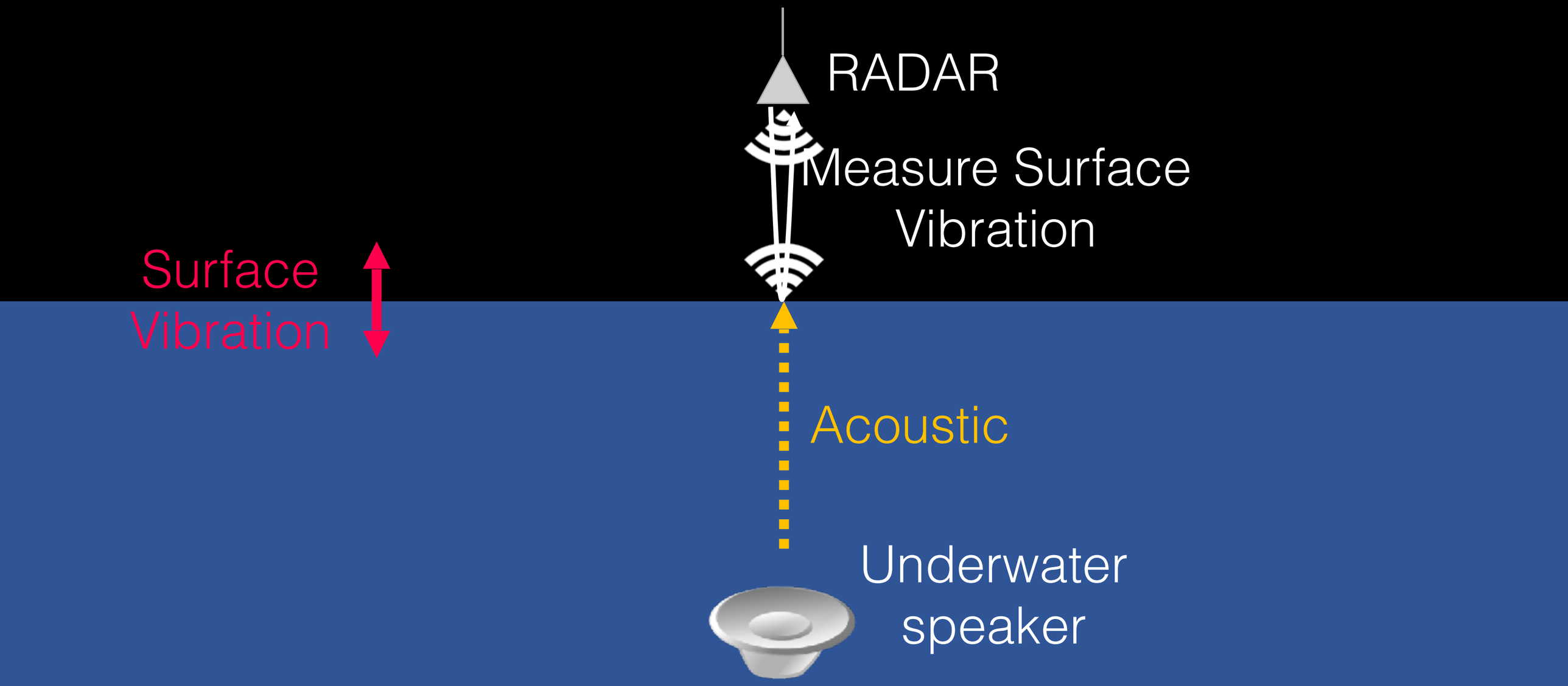
Radio

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

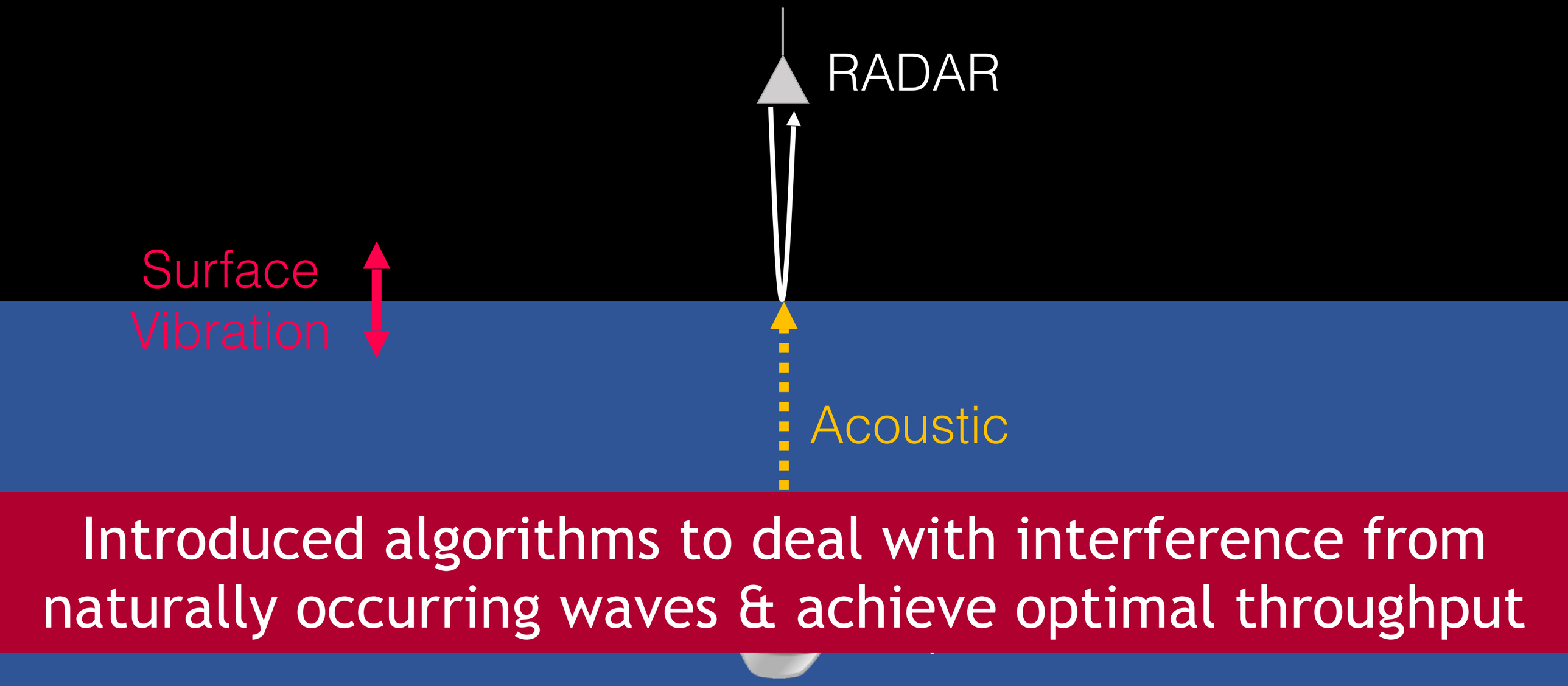
Technology that Enables Compact Sensors to Wirelessly Communicate Across the Water-Air Boundary

Published in: ACM SIGCOMM'18

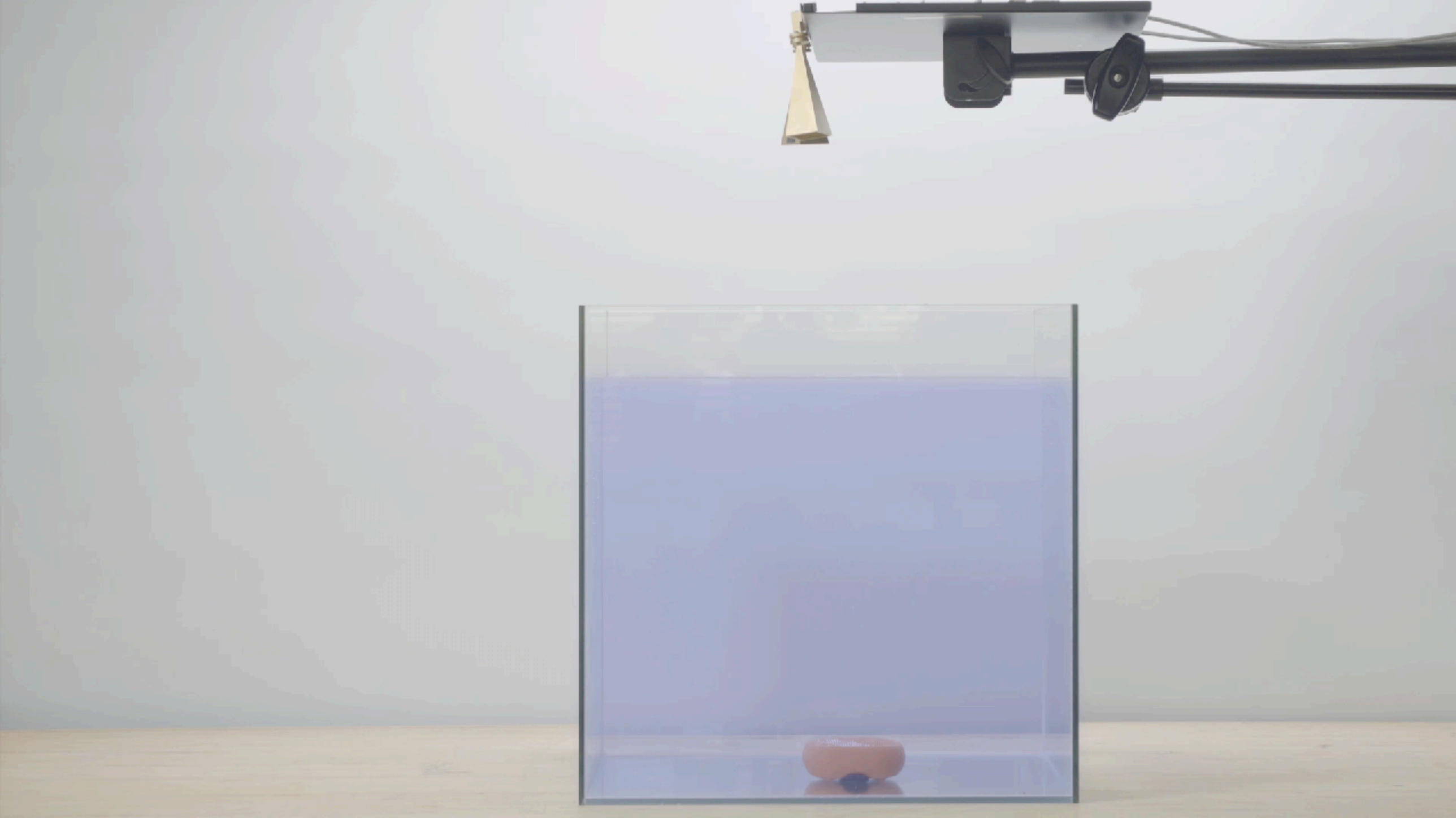
Technology that Enables Compact Sensors to Wirelessly Communicate Across the Water-Air Boundary



Translational Acoustic RF Communication (TARF)

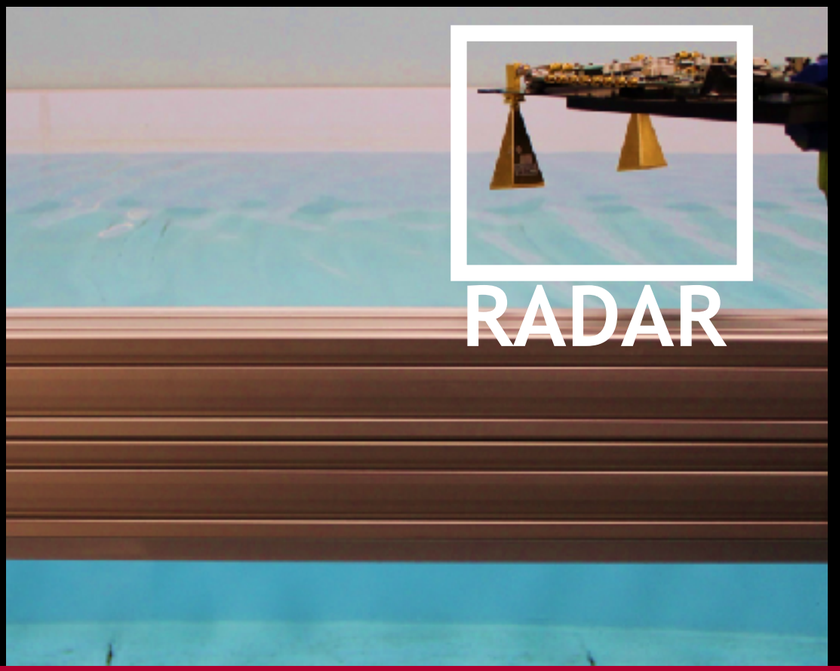


Introduced algorithms to deal with interference from naturally occurring waves & achieve optimal throughput

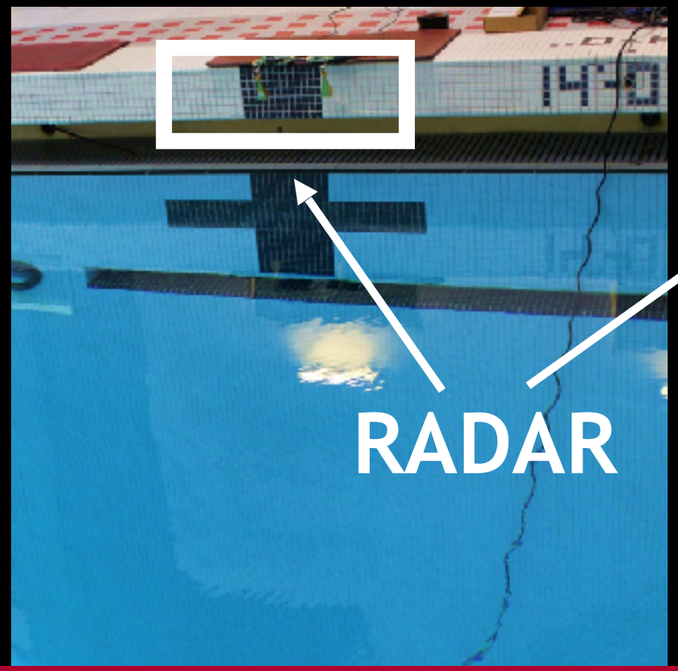


Evaluation in Different (Controlled) Environments

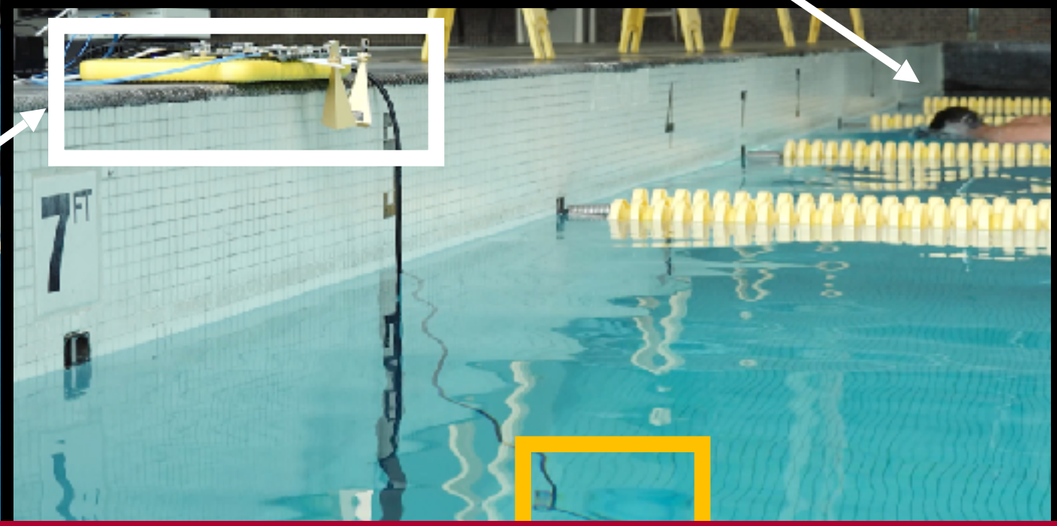
Water Tank



Swimming Pool



Swimming Pool with swimmers



Our technology can communicate (100s of bps) even in the presence of natural surface waves that are 1,000x larger than the acoustic vibrations

Building the Internet of Underwater Things

TECHNOLOGIES

- Batteryless Underwater IoT & Localization
- Underwater-to-air comms

COMMUNITY/POLICY

- Open Source
- Organization & Policy Engagement

Smart Oceans 2020

Oct. 5-9, 2020

Convergence Accelerator
use-inspired and goal-oriented

Convergence Accelerator could help to meet "An Ocean of Need"

Innovative NSF program aims to address major ocean-related societal issues

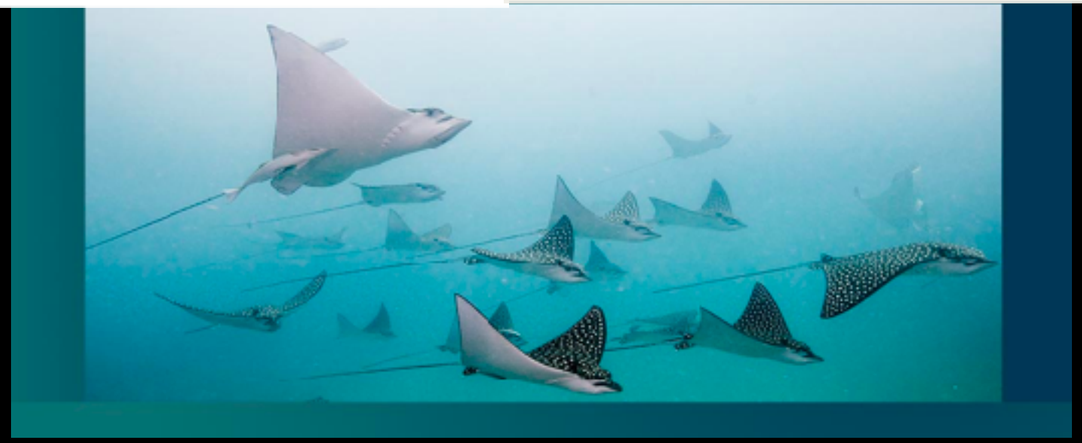
By Randy Showstack | November 19, 2020

Use-inspired
vs
curiosity-driven

http://www.mit.edu/~fadel/papers/Executive_Summary_Ocean_IoT.pdf

The National Academies of SCIENCES ENGINEERING MEDICINE

Ocean Decade U.S.

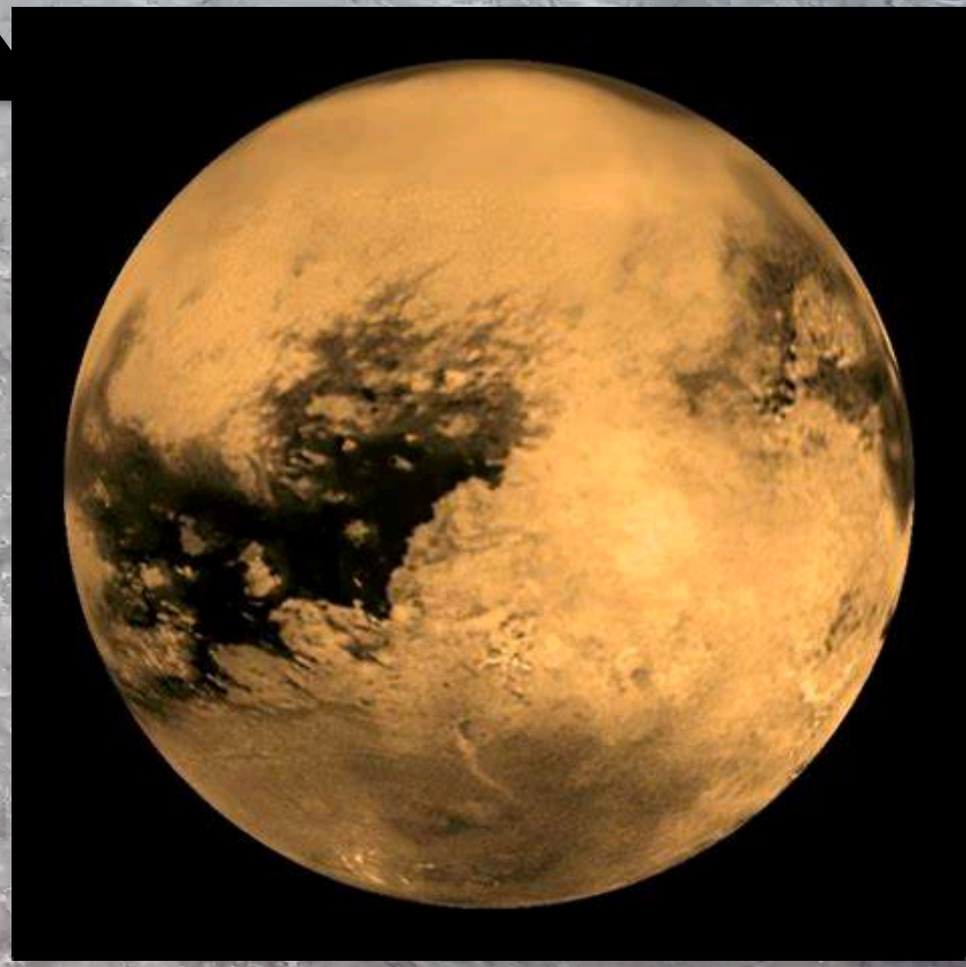


50+ state senators & legislators

Batteryless Ocean IoT selected as “ocean-shot”

batteryless node with
temp & pressure sensor

Saturn’s moon
Titan



The Economist

Menu

Science & technology

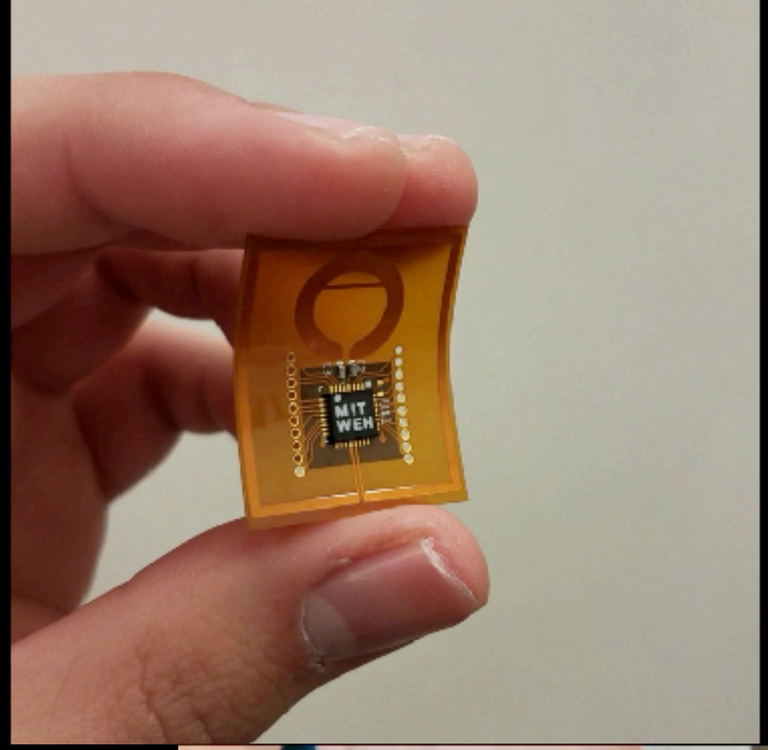
Oct 17th 2020 edition ›

Good vibrations

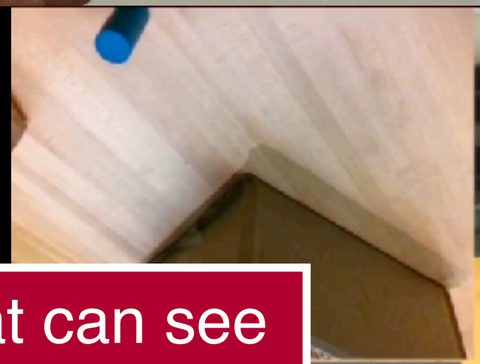
How to send underwater messages without batteries

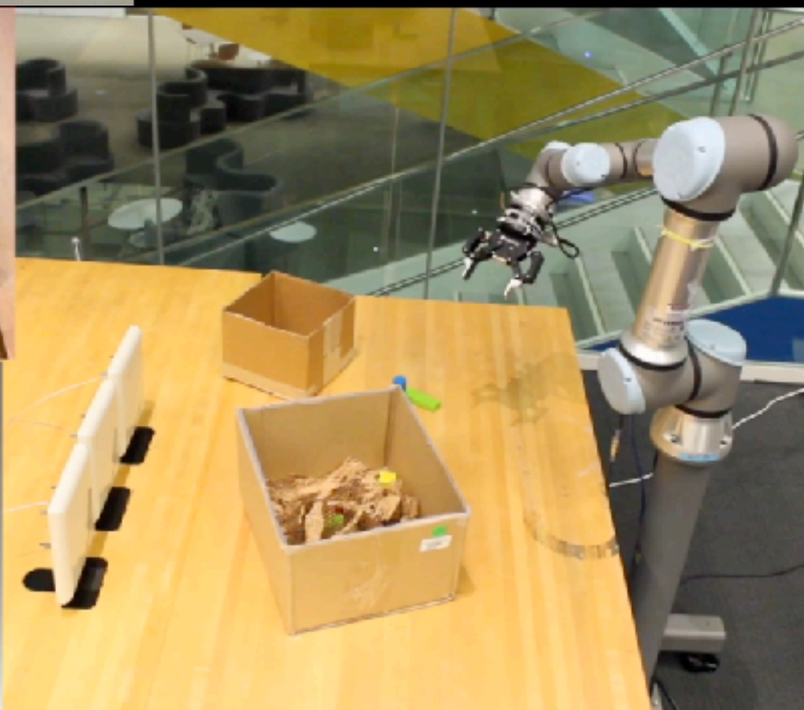
A new device extracts energy from ambient noise

Oct 17th 2020



Batteryless IoT micro-implants inside the human body





Robotics that can see the invisible via batteryless IoT sensors


Mario Doumet
Mergen Nachin
Haris Brkic
Waleed Akbar
Andrew McCall
Muhammed Sulema S Thaniana
Joshua Craig Anderson
Unsoo Ha
Osvy Rodriguez
Monica Liu
Tara Boroushaki
Sayed Saad Afzal
Holly Birns
Isaac Perper
Mohamed Radwan Abdelhamid
Reza Ghaffarivardavagh

Building the Internet of Underwater Things

Smart Oceans 2020

@fadeladib

@signalkinetics