Underwater Ultrasonic Wireless Power Transfer: A Battery-less Platform for IoUT

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MAS.S62 Lecture 3

Sep 27, 2021

Underwater IoT systems will soon explode like air-based IoT sensors

Underwater IoT will soon explode with:

- Sensors
- Wireless communication systems
- Actuators
- Rotors and Propellers

<u>Average Power Consumed</u>

- Non-propulsion: 30W
- **Propellers or other mechanical components: 15-110W**

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❗ Problem 1: More power needed

Traditional Power Sources for IoT

❶ Batteries

Batteries don’t last as long because **more energy is required for underwater communication** compared to ground counterparts

❷ Wireless Power Transfer

Wireless transfer involves the use of acoustic waves. **Ultrasonic waves** are the most feasible because the **node and charger can be further apart.**

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- Deploying vessels to change batteries
- Automatic retrieval and insertion mechanisms
  - Battery has to be sealed against corrosive waters

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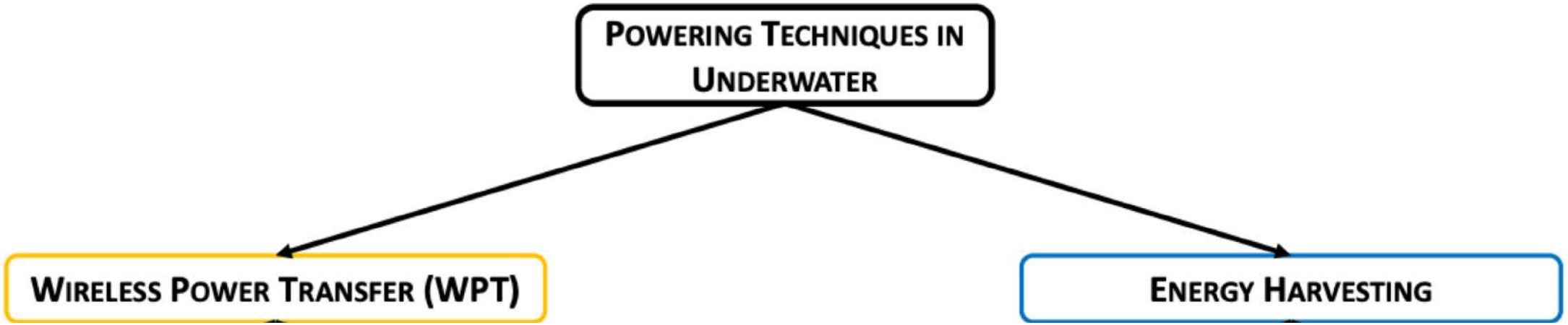
❗Problem 2: Battery recharging is inefficient and expensive

2 Power techniques underwater: **Energy Harvesting** AND **Wireless Power Transfer (WPT)**



Energy Harvesting

Kinetic energy from *underwater currents*, *tides*, *waves* and *vibrations* (piezoelectric materials, turbines and rotors)

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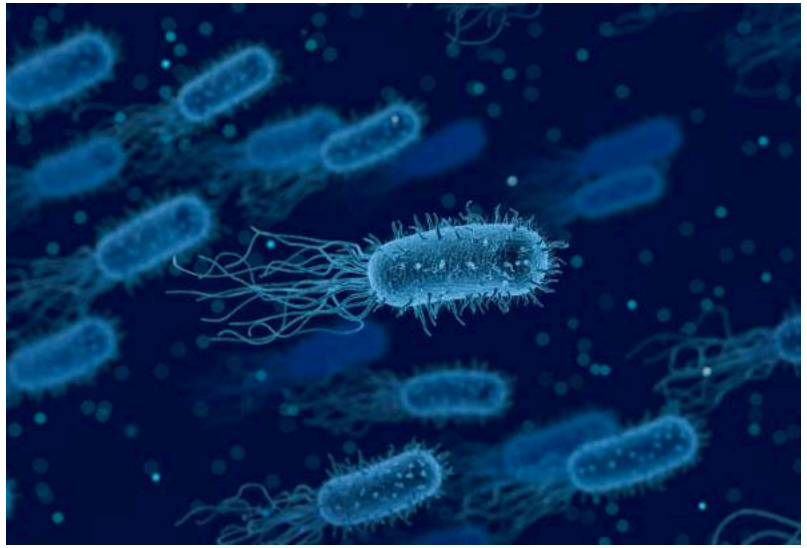

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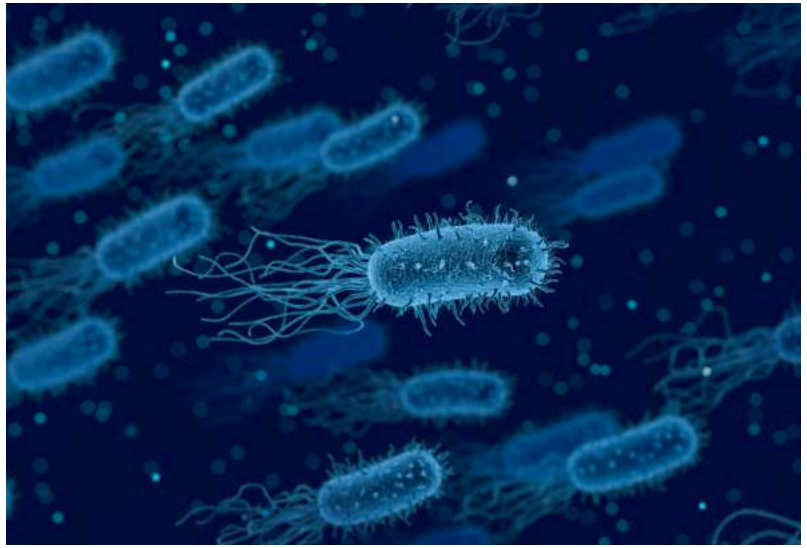

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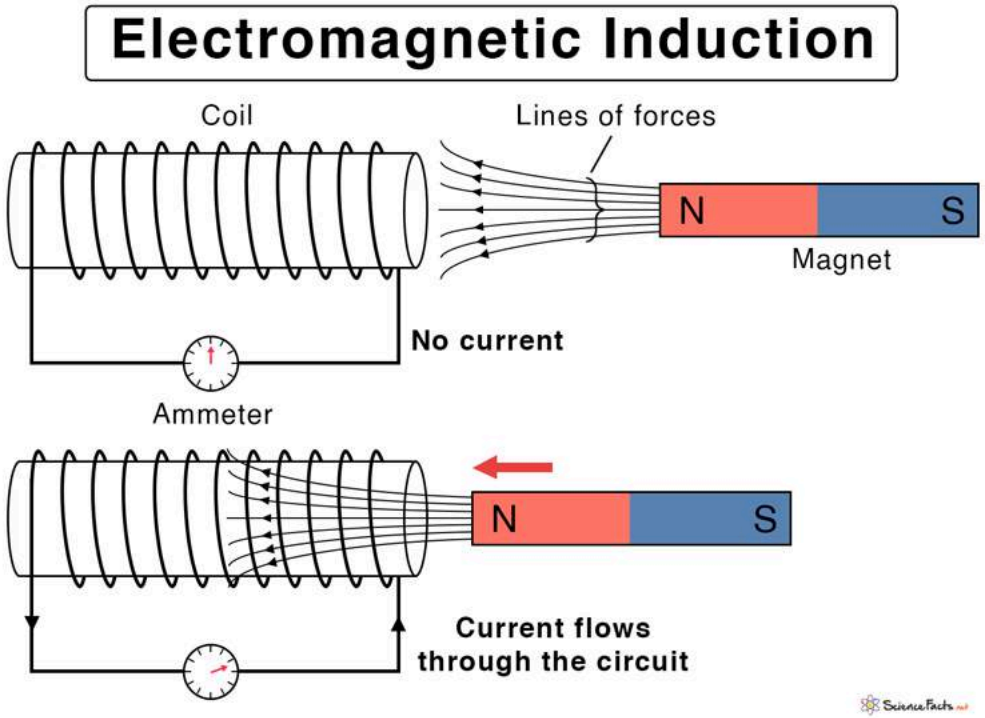
Solar energy in superficial applications

Wireless Power Transfer (WPT)



Wireless Power Transfer using spiral inductors

- Inductive Coupling
- Magnetic Resonance

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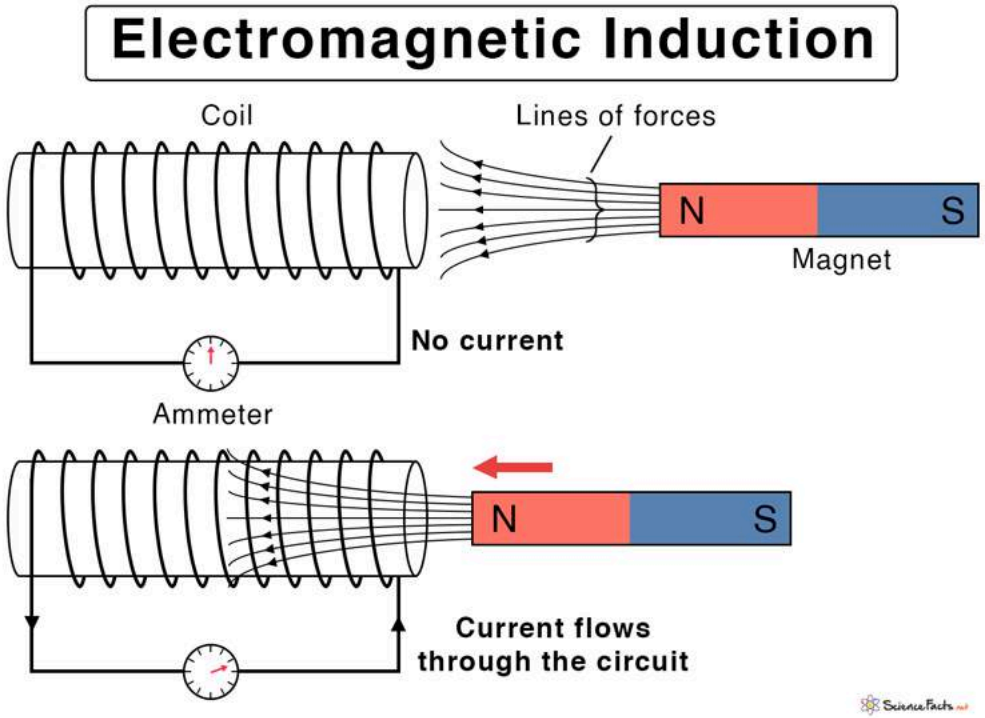

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Ultrasonic WPT

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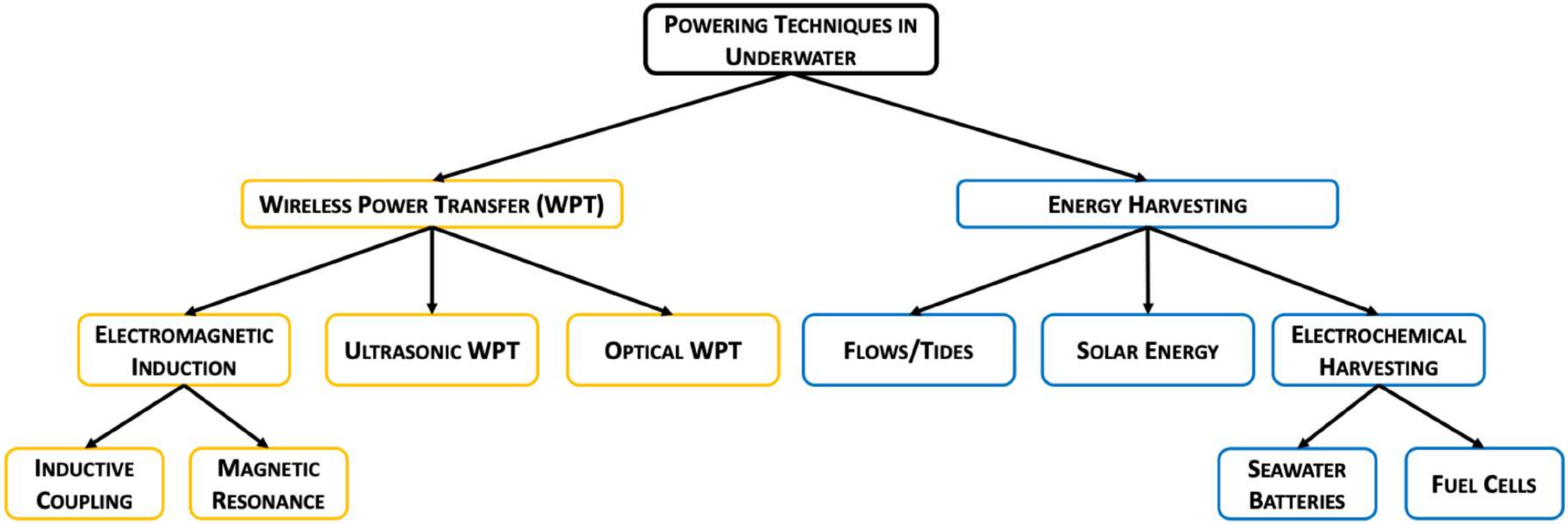

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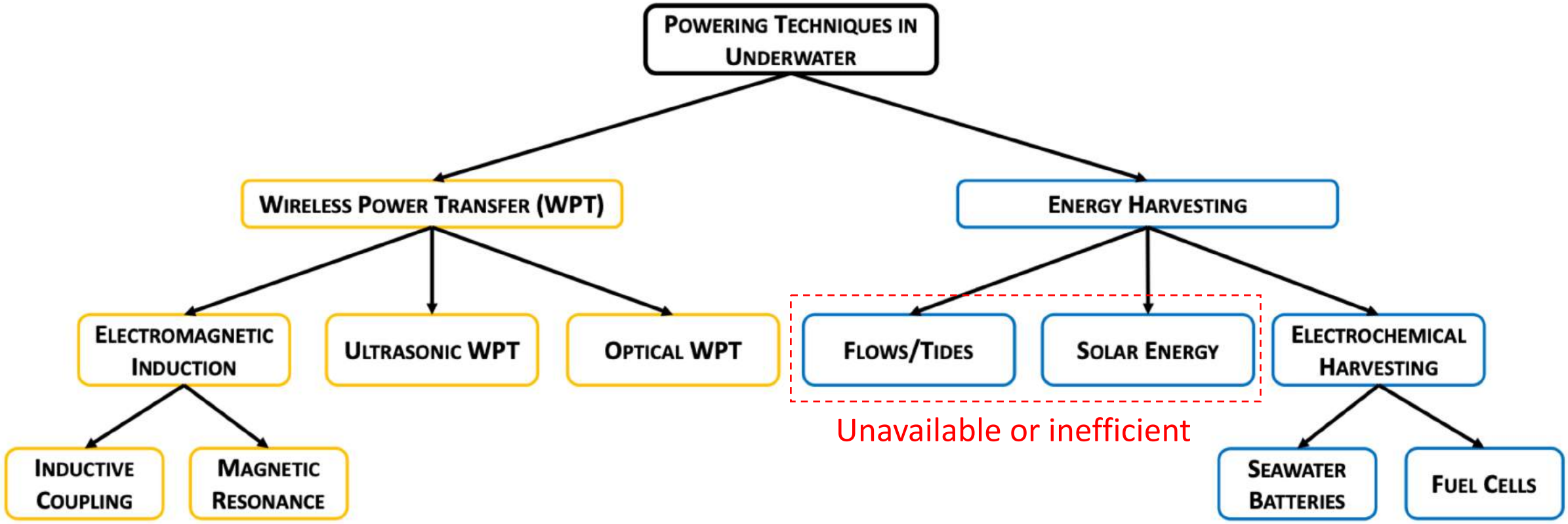

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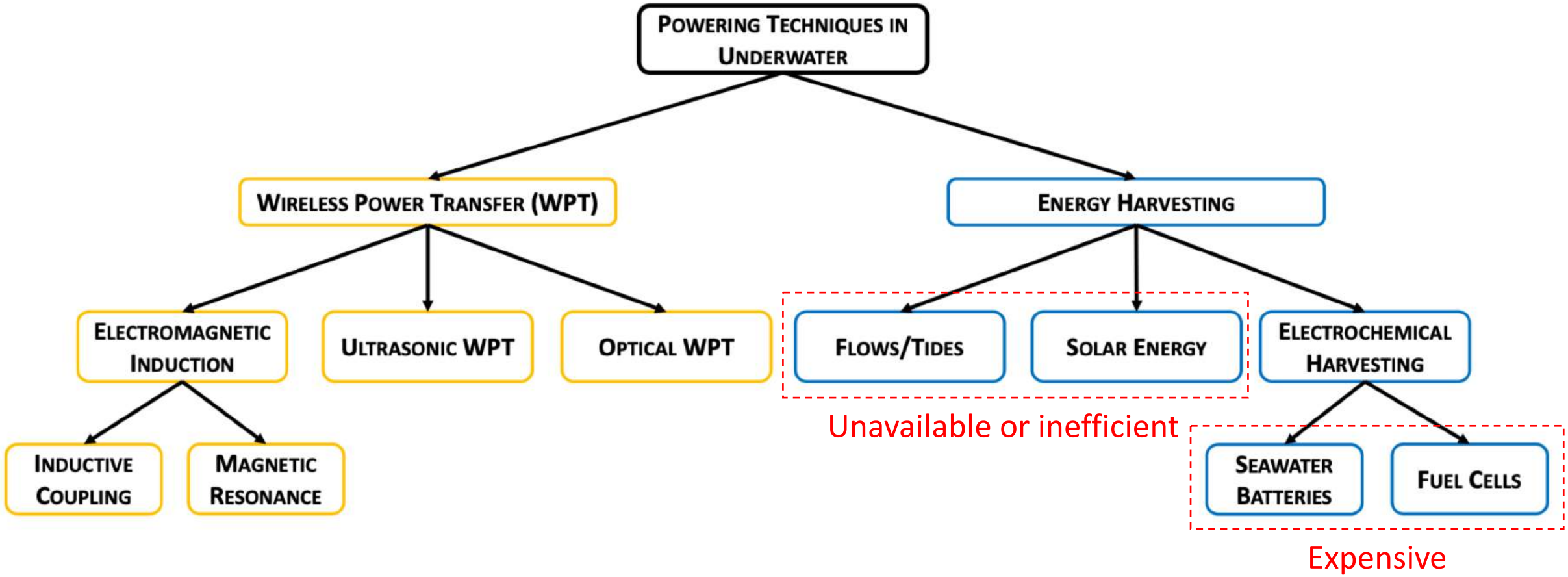

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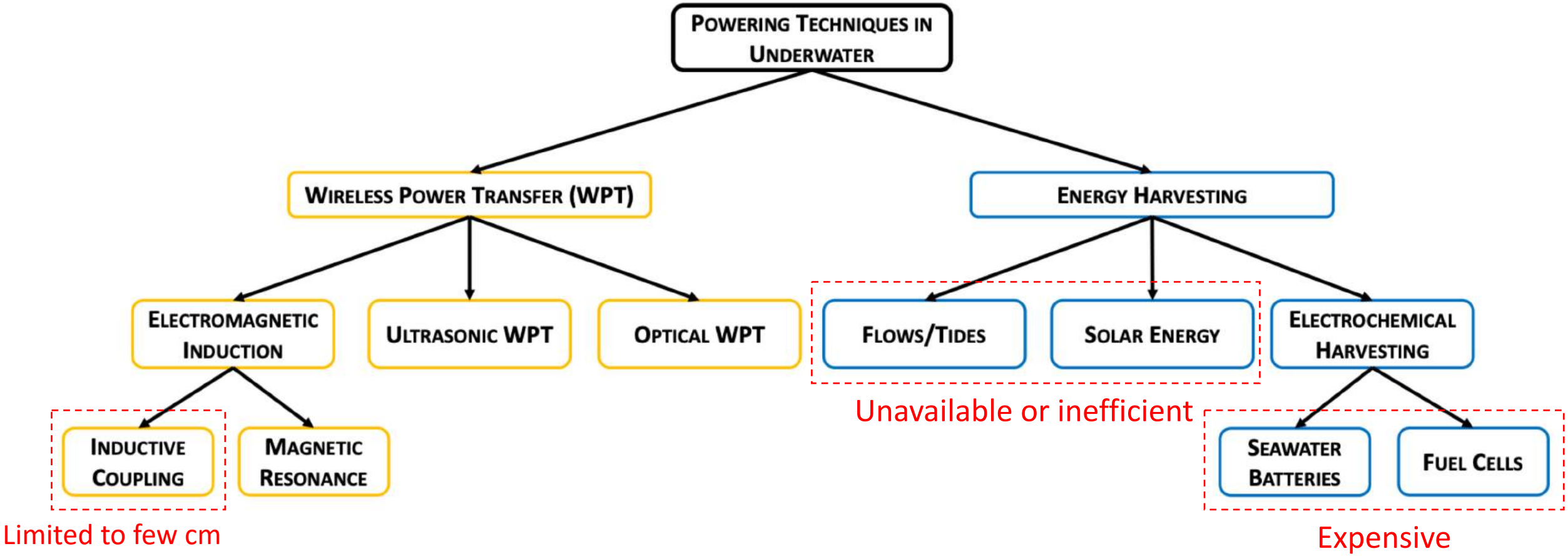

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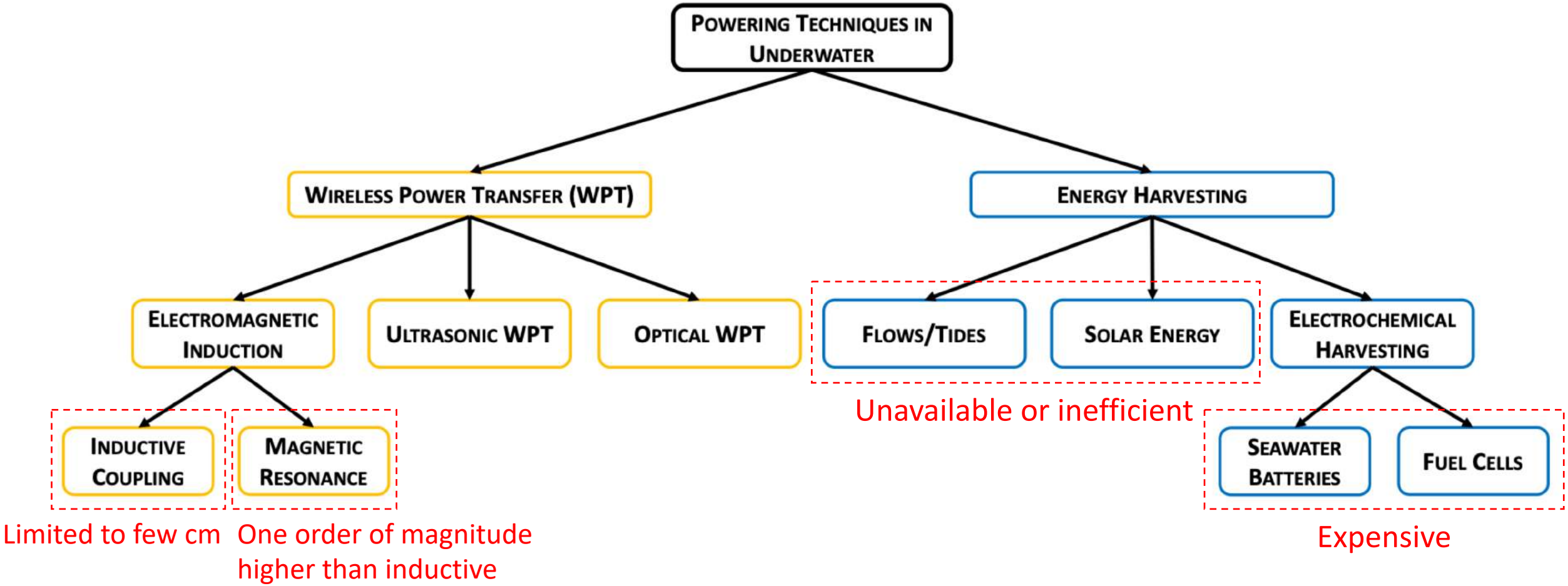

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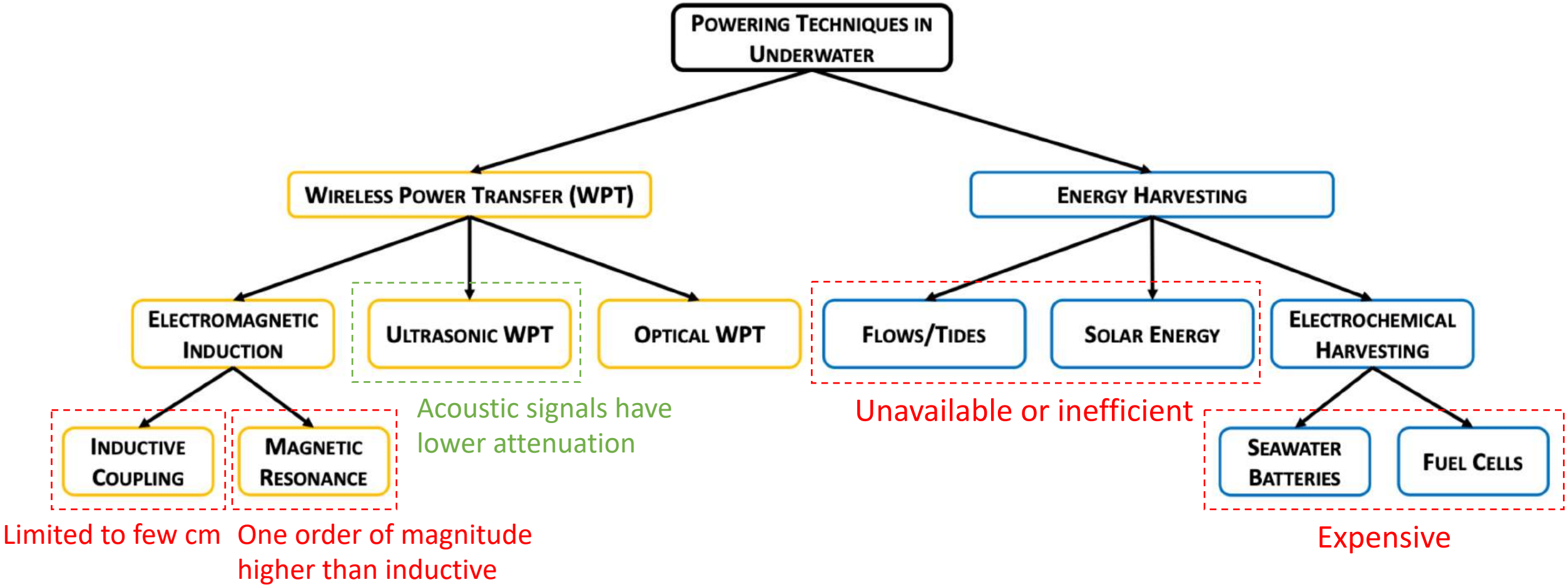
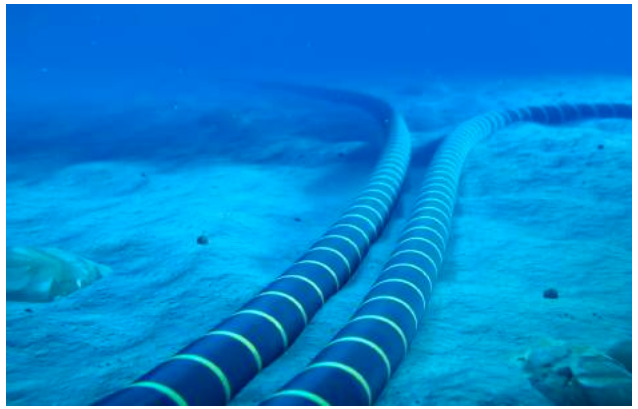


Comparison between WPT techniques underwater

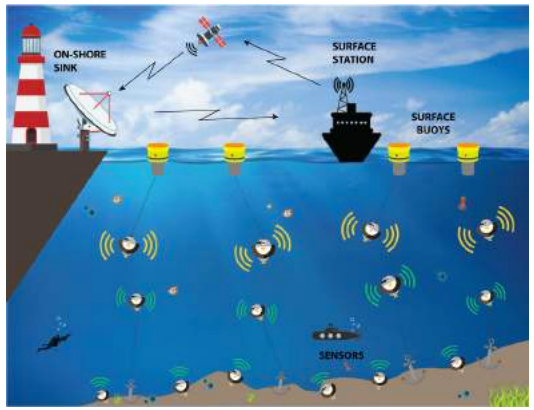
Ref.	Type	Distance [cm]	Tx/Rx power	Eff. (%)
[24]	Inductive coupling	4 7	Tx=−25 dBm Tx=−3 dBm	50
[25]	Inductive coupling	-	Rx=10 kW	91
[6]	Inductive coupling	5	-	60–75
[22]	Inductive coupling (simul.)	8–13	-	65–80
[26]	Eddy current propagation	10 5	- -	60 50
[27]	Magnetic coupling	0.2	-	90
[23]	Magnetic coupling	15 (simul.) 26 (exper.)	Rx=3 kW -	~80 ~65
[28]	Ultrasonic WPT	100	Rx=~mW	-

The values reported in the table are for experimental results if not differently indicated.

Advantages of Ultrasonic WPT



Avoid cables normally required to power devices



Charge **multiple nodes** simultaneously

Remove human-in-the-loop interference

Reuse hardware components to reduce size, complexity and cost of platform

Model for electromagnetic propagation in water

propagation constant

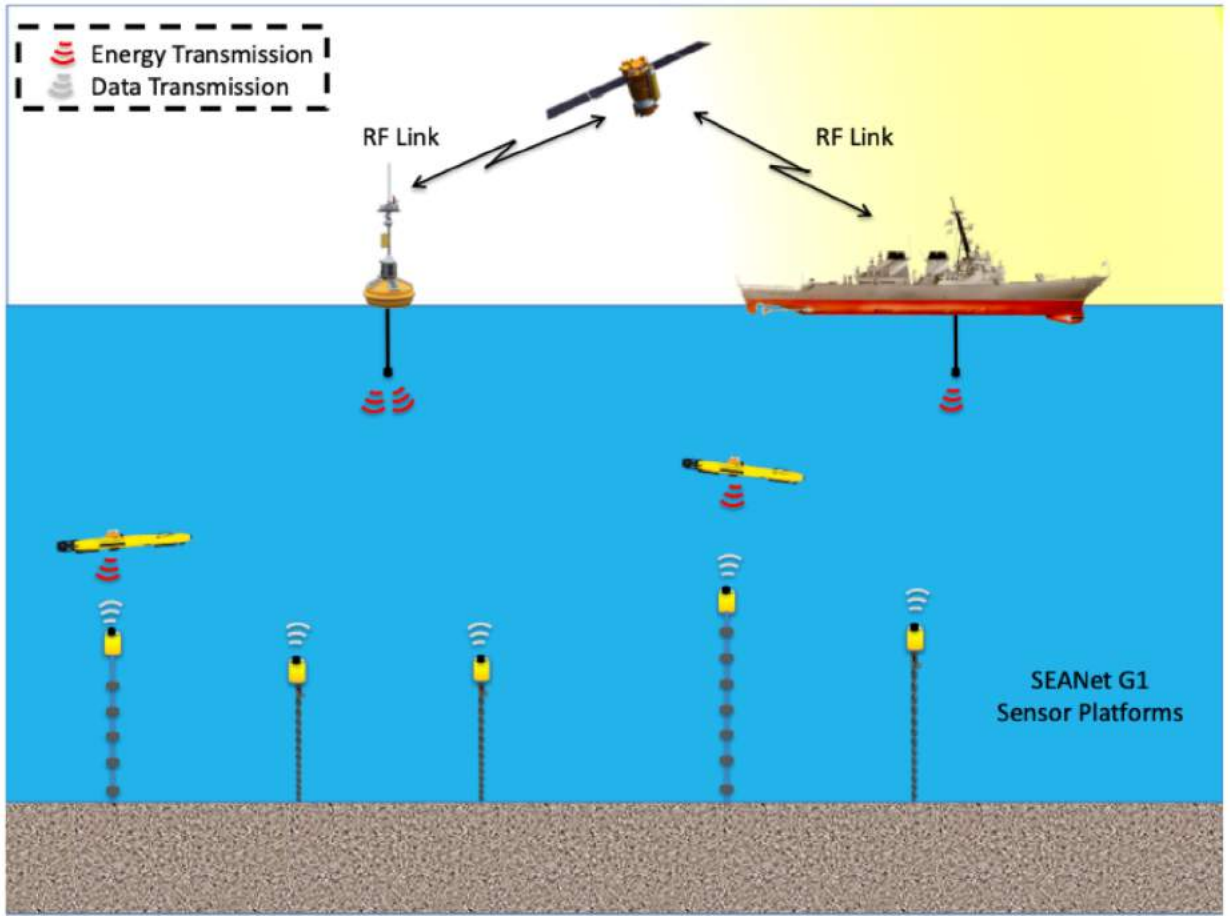
$$E_x = E_0 \cdot e^{(j\omega t - \gamma z)}$$ ← Electric Field Strength

$$H_y = H_0 \cdot e^{(j\omega t - \gamma z)}$$ ← Magnetic Field Strength

phase factor; angular frequency; conductivity; attenuation factor; permeability; permittivity

$$\gamma = \alpha - j\beta = j\omega\sqrt{\epsilon\mu - j\frac{\sigma\mu}{\omega}},$$

SEANet



✓Ultrasonic waves: **carry energy to remote** UW **modem** (battery-less and wirelessly powered)

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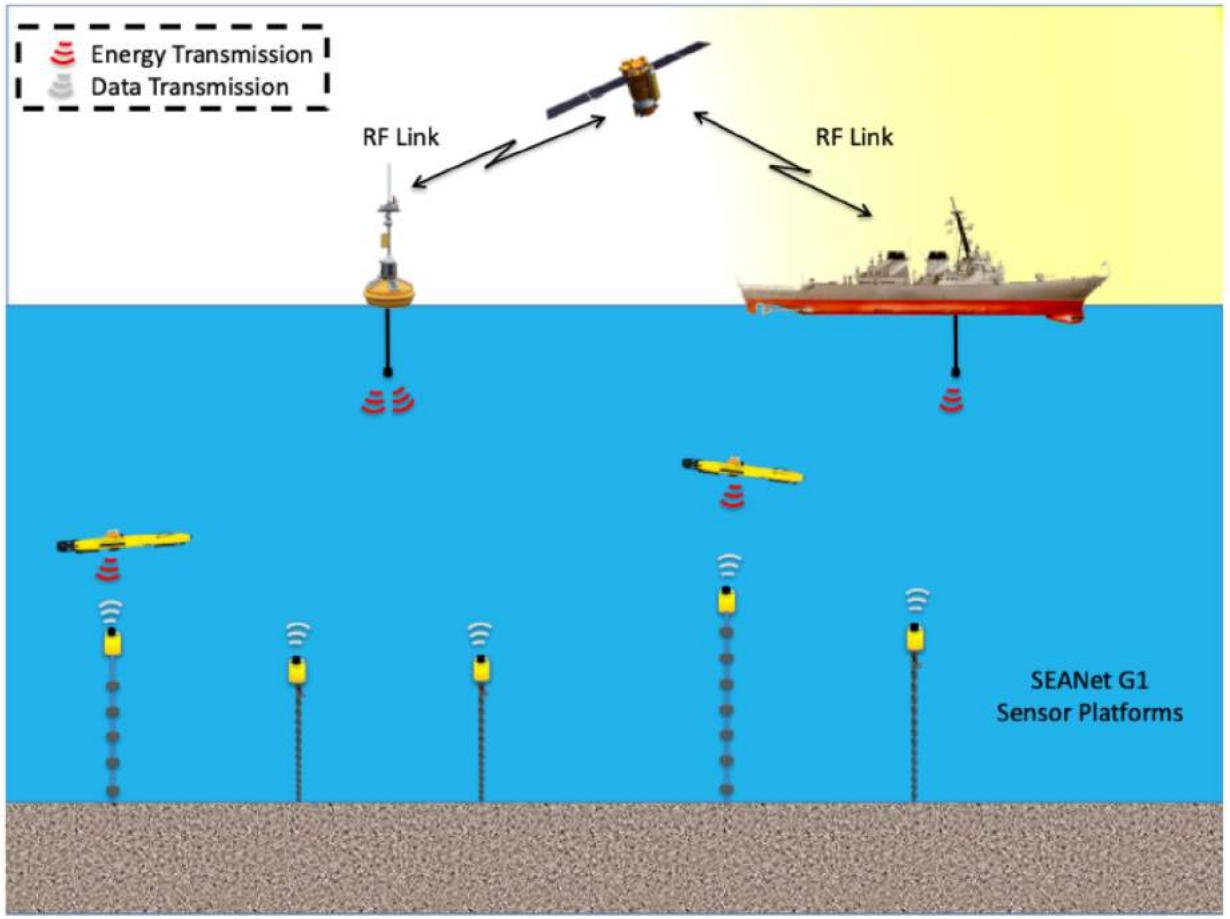

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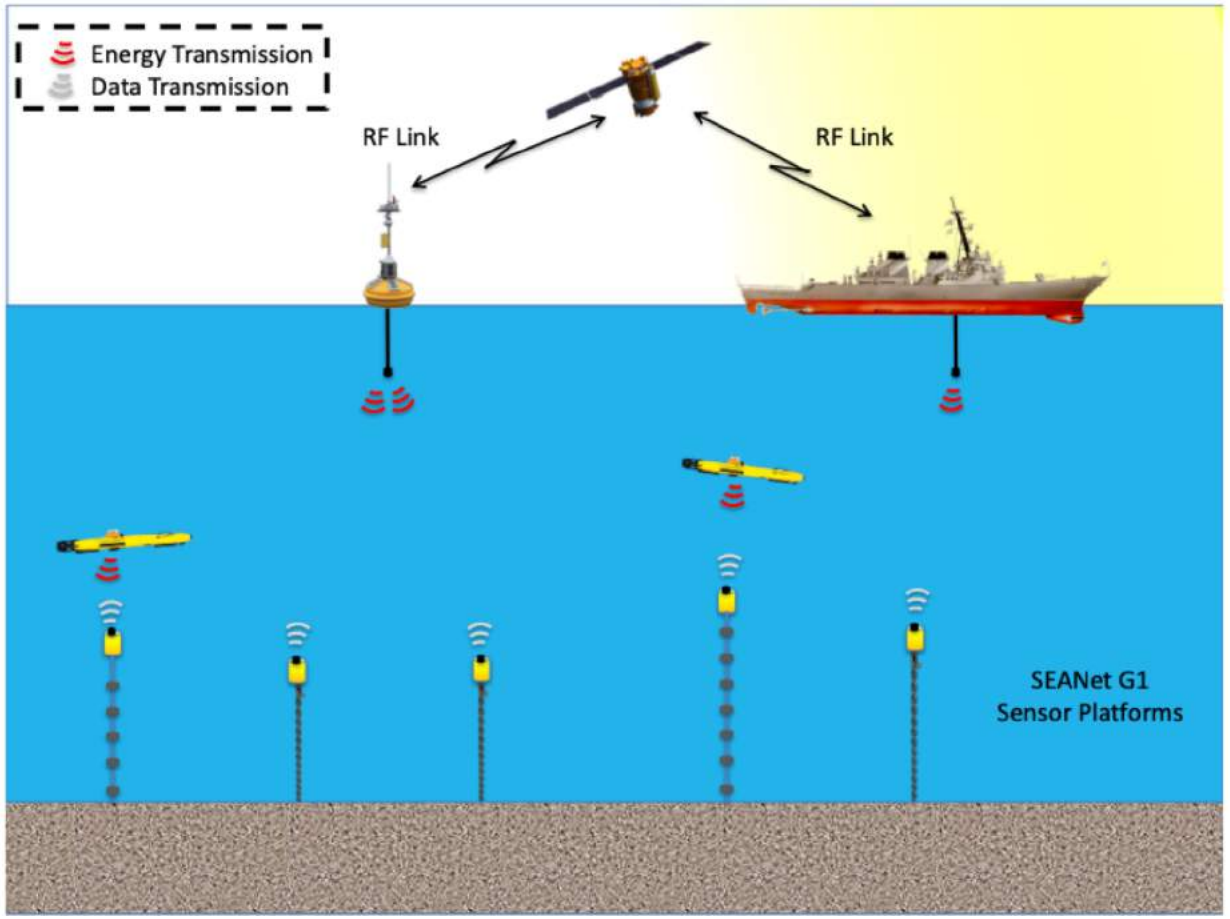

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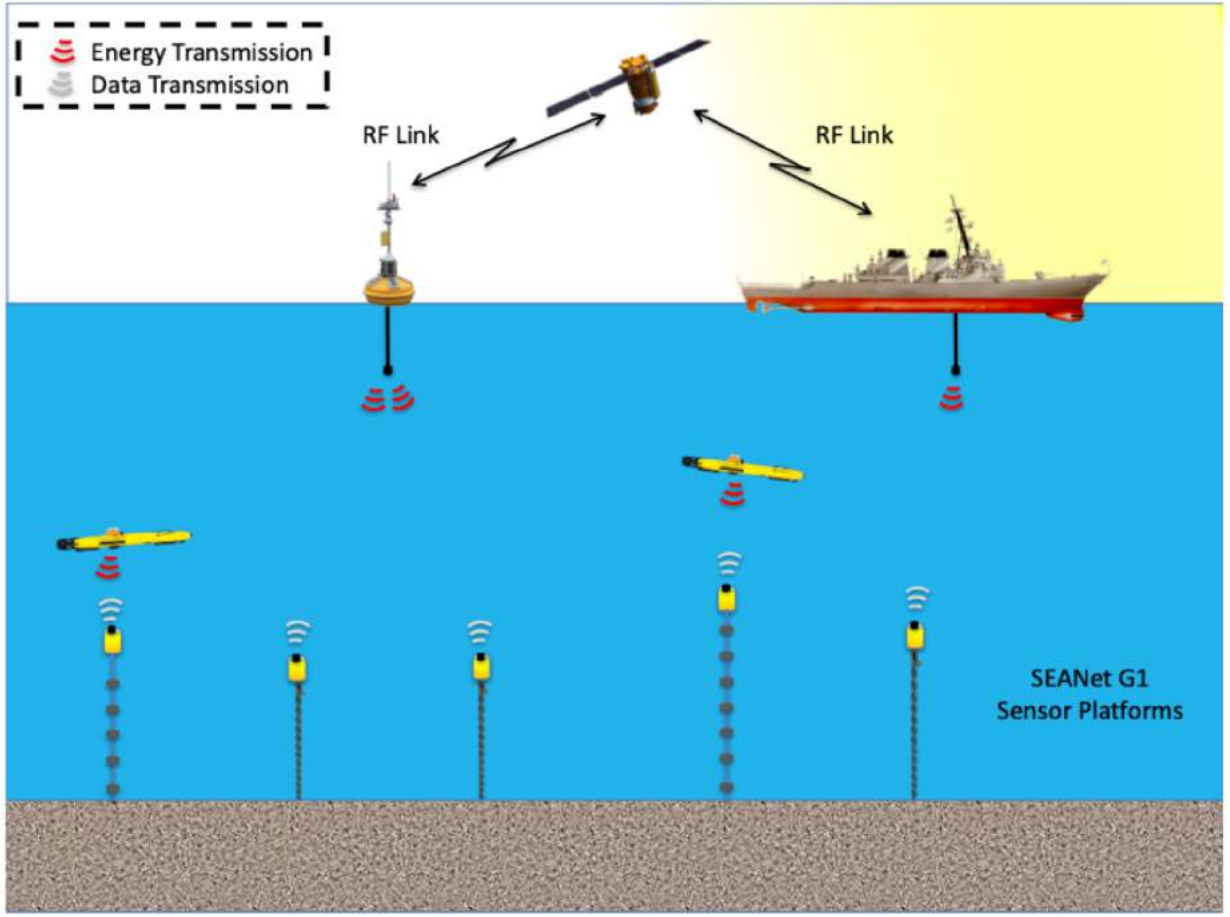

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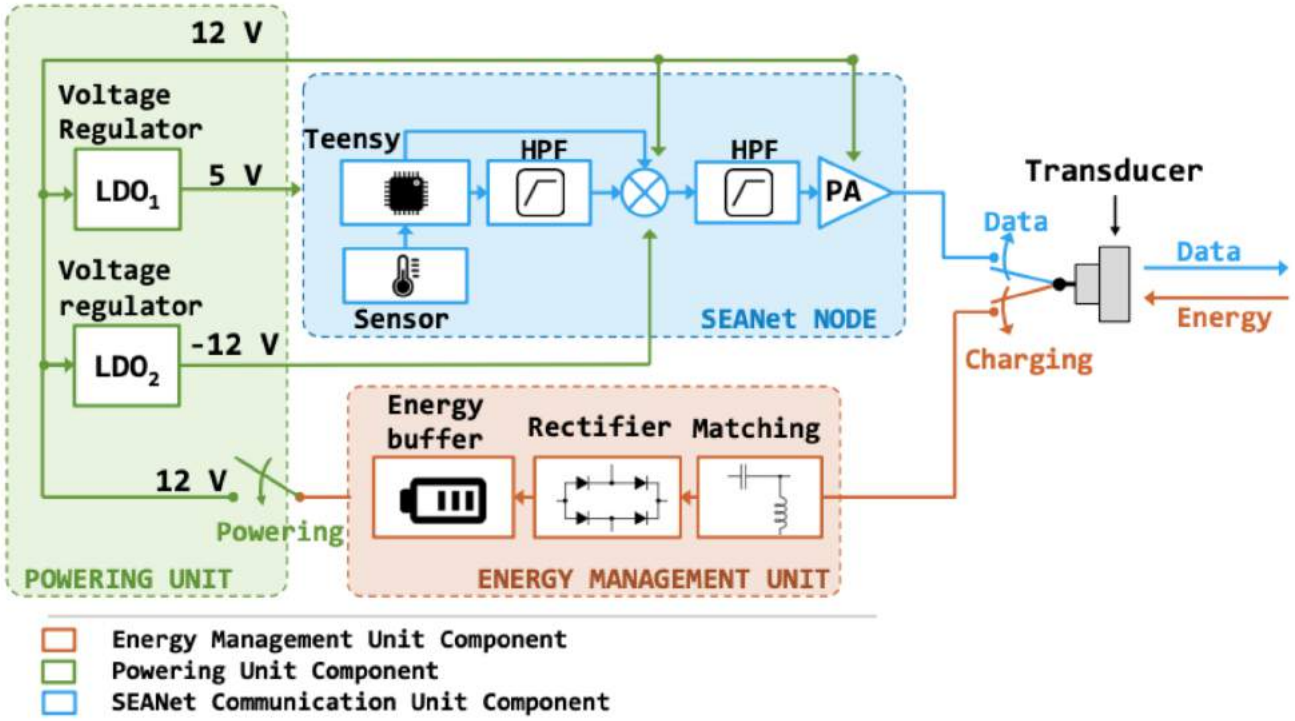
- ✓**One transducer for both charging and communication ->** save space, weight and cost

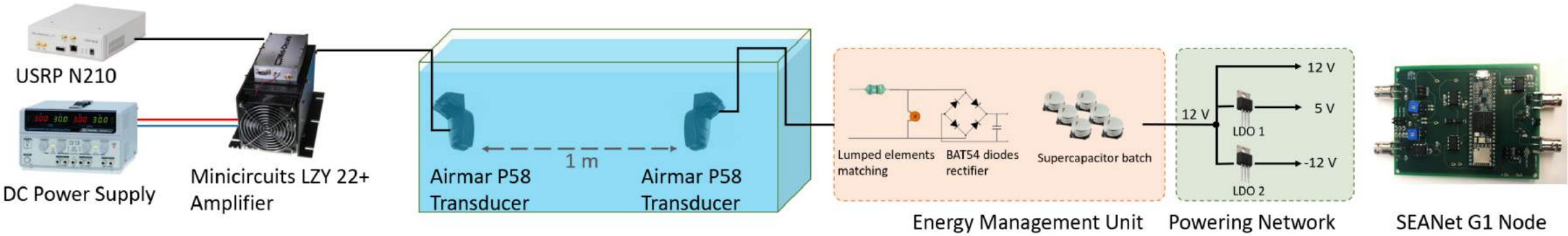
SEANet Components



1. **SEANet node** for underwater communication and sensing
2. **Energy Management Unit** to receive, convert and store energy
3. **Powering Unit** to power the platform components

System Architecture and Design

Software-defined underwater modem generates signals in 35-65kHz frequency range



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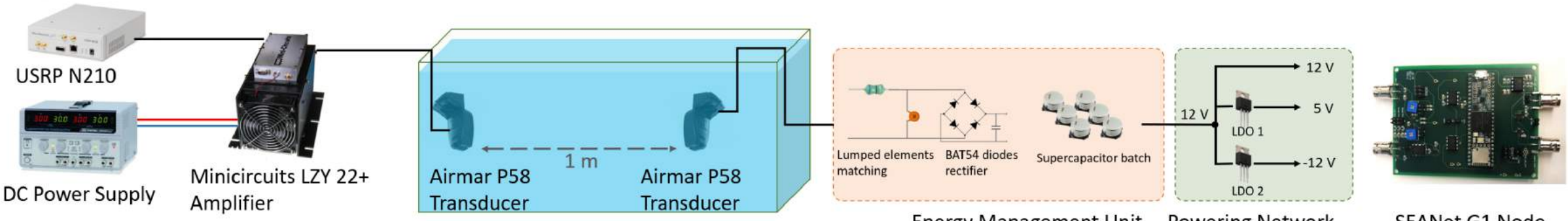

Amplifies waveform (50kHz sinusoidal signal)

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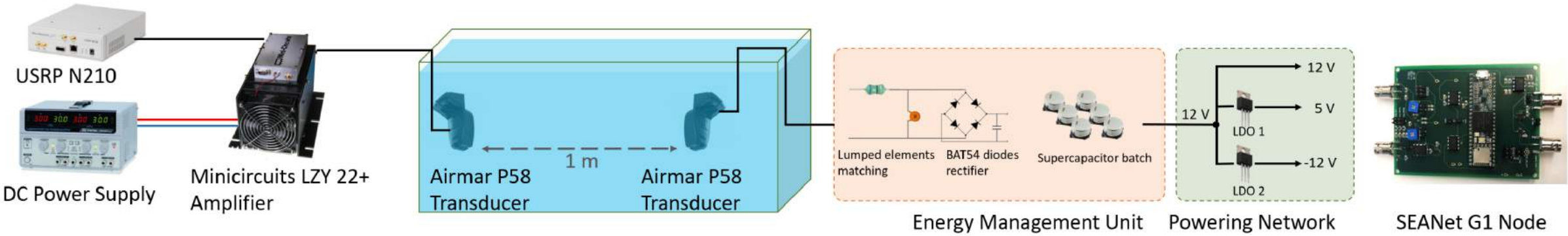

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Electric -> Acoustic conversion and transmission

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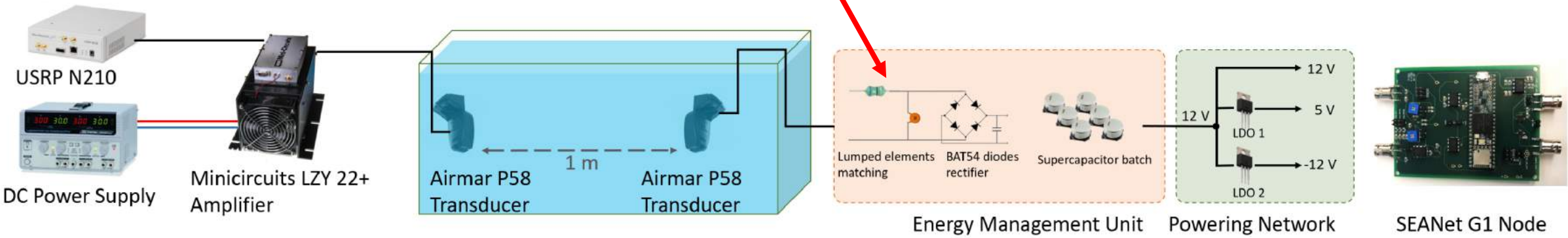
Limit signal leakage and reflections to maximize power



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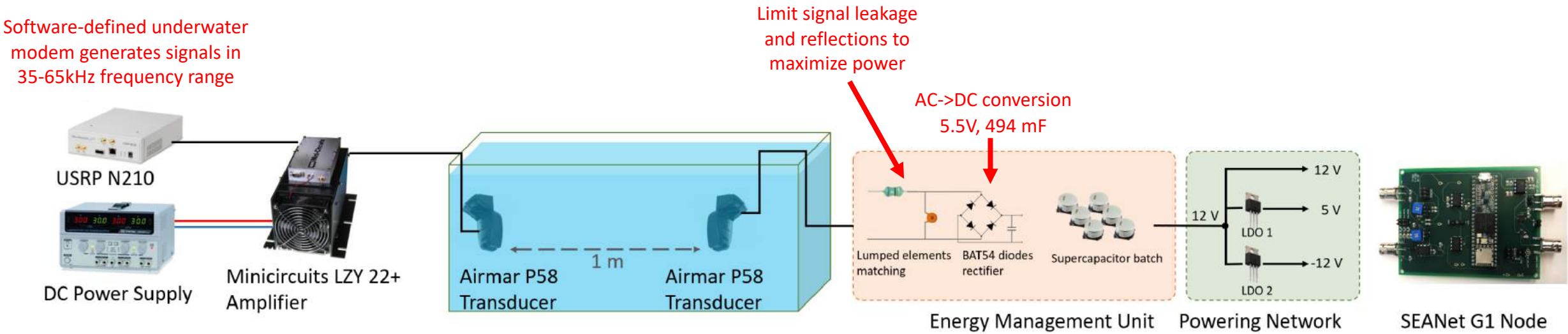

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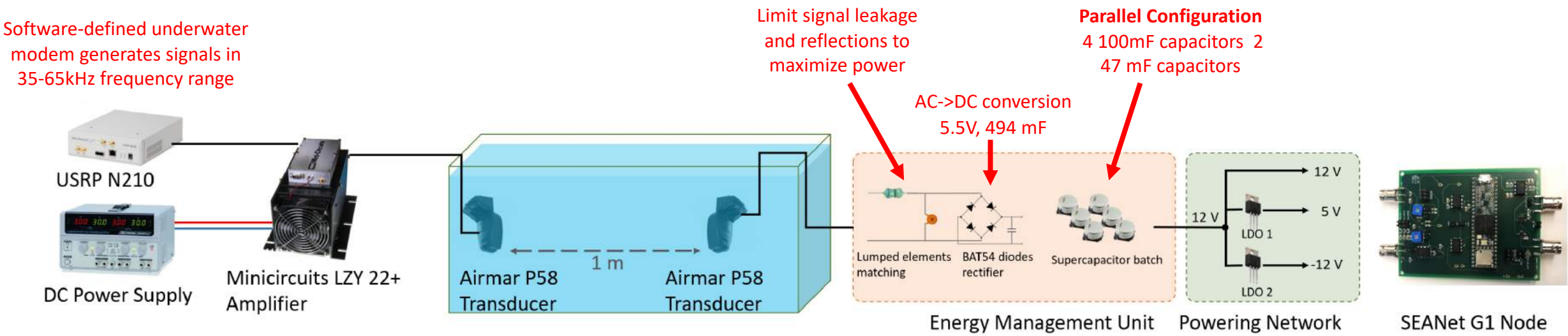

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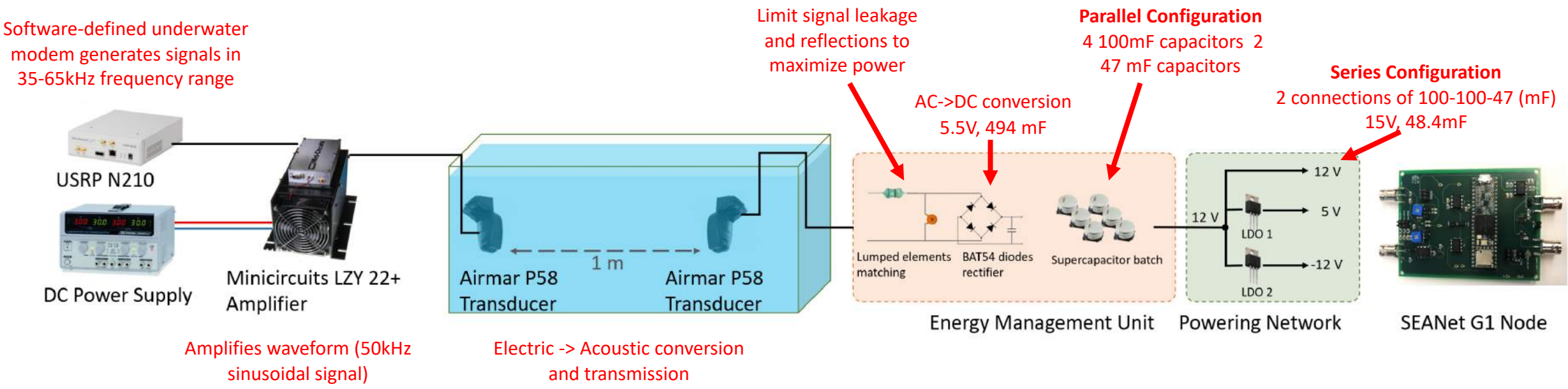

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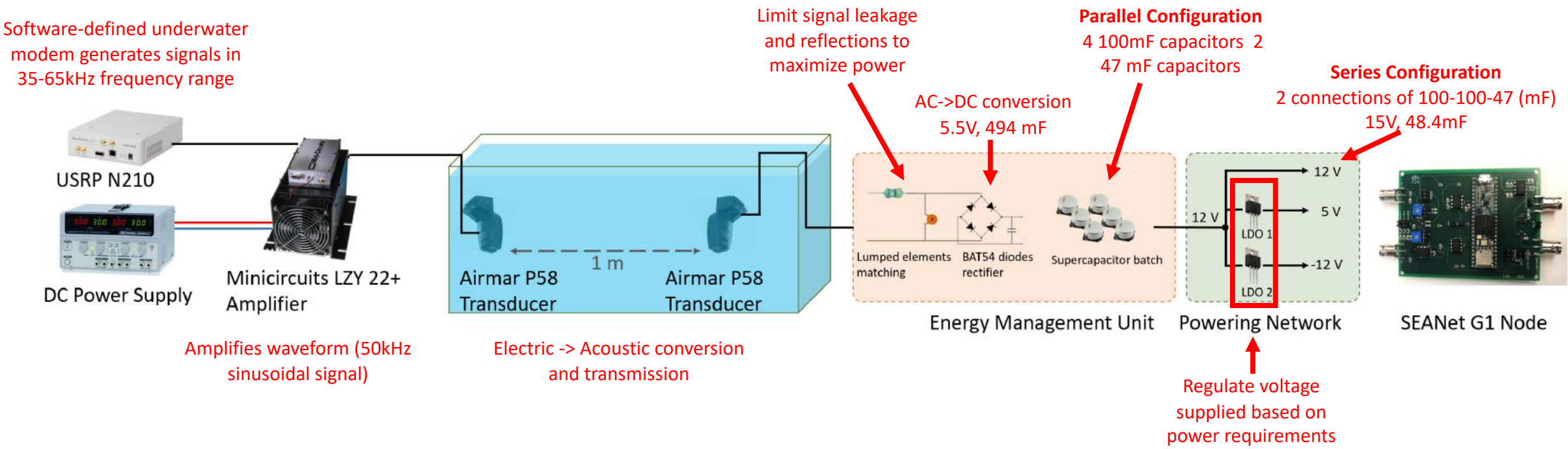

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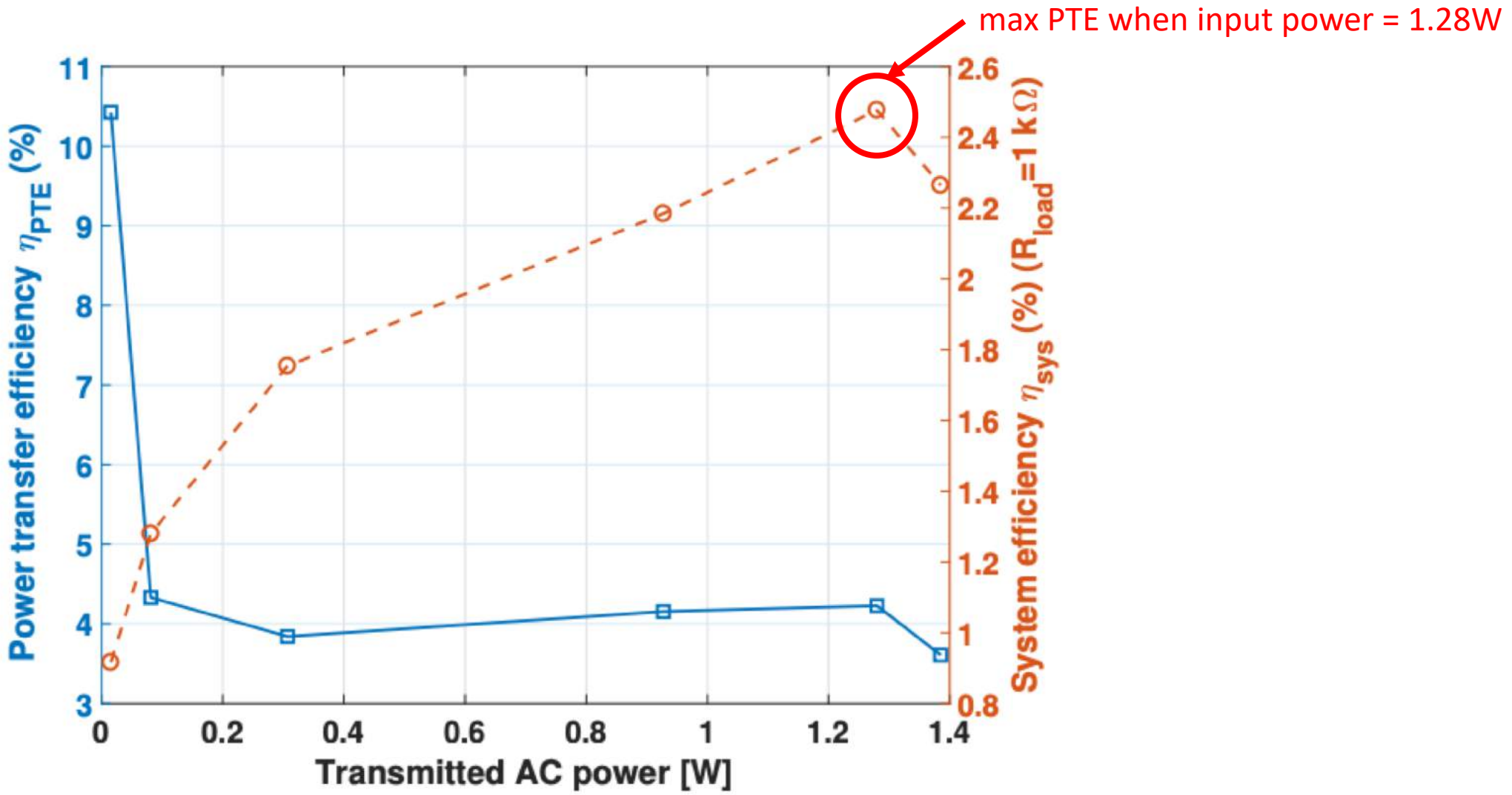
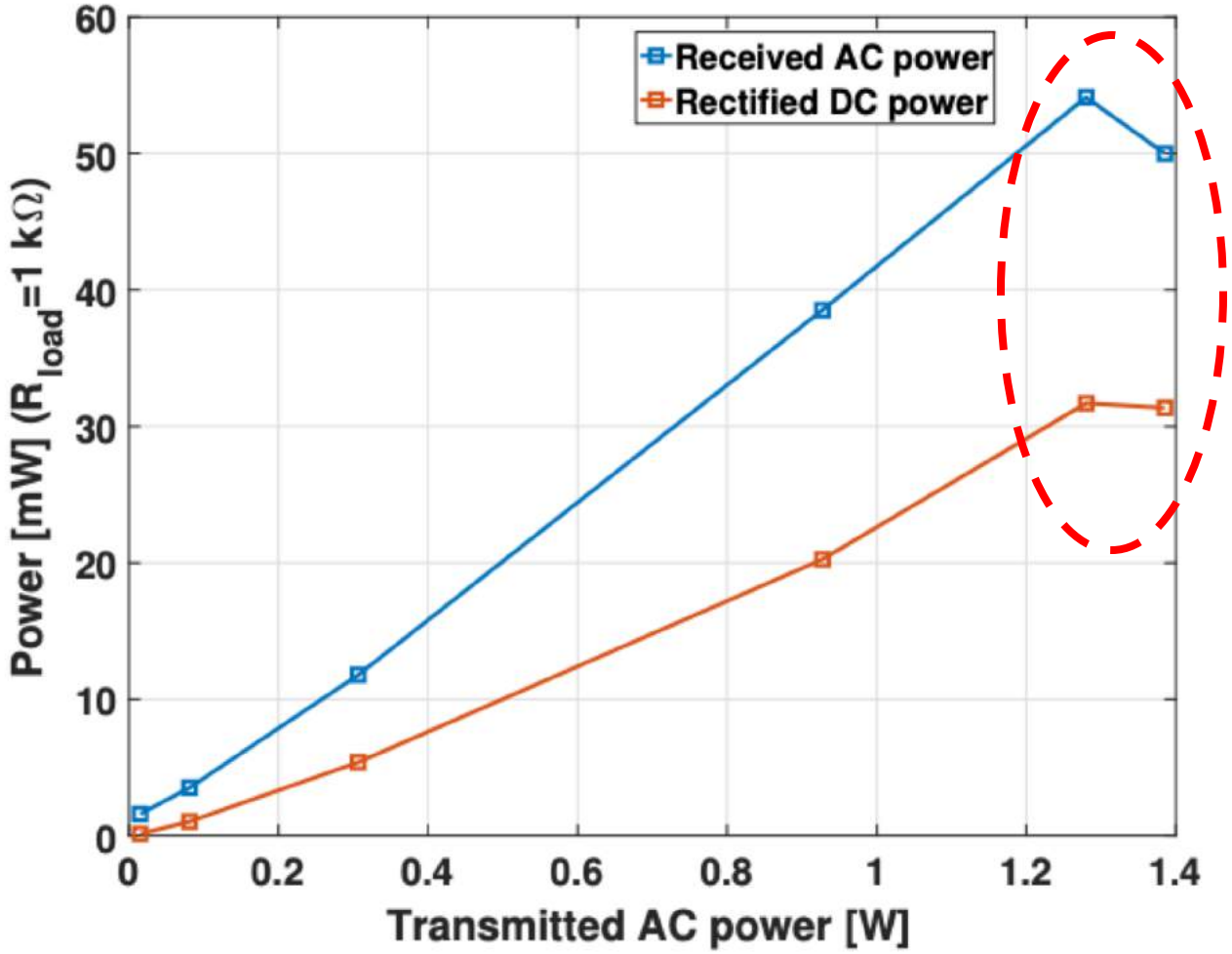
- **Global System Efficiency** — Rectifier efficiency * 100

Wireless Link Efficiency and System Efficiency vs. Transmitted Electrical Power



Received and Rectified Power vs. Transmitted Power



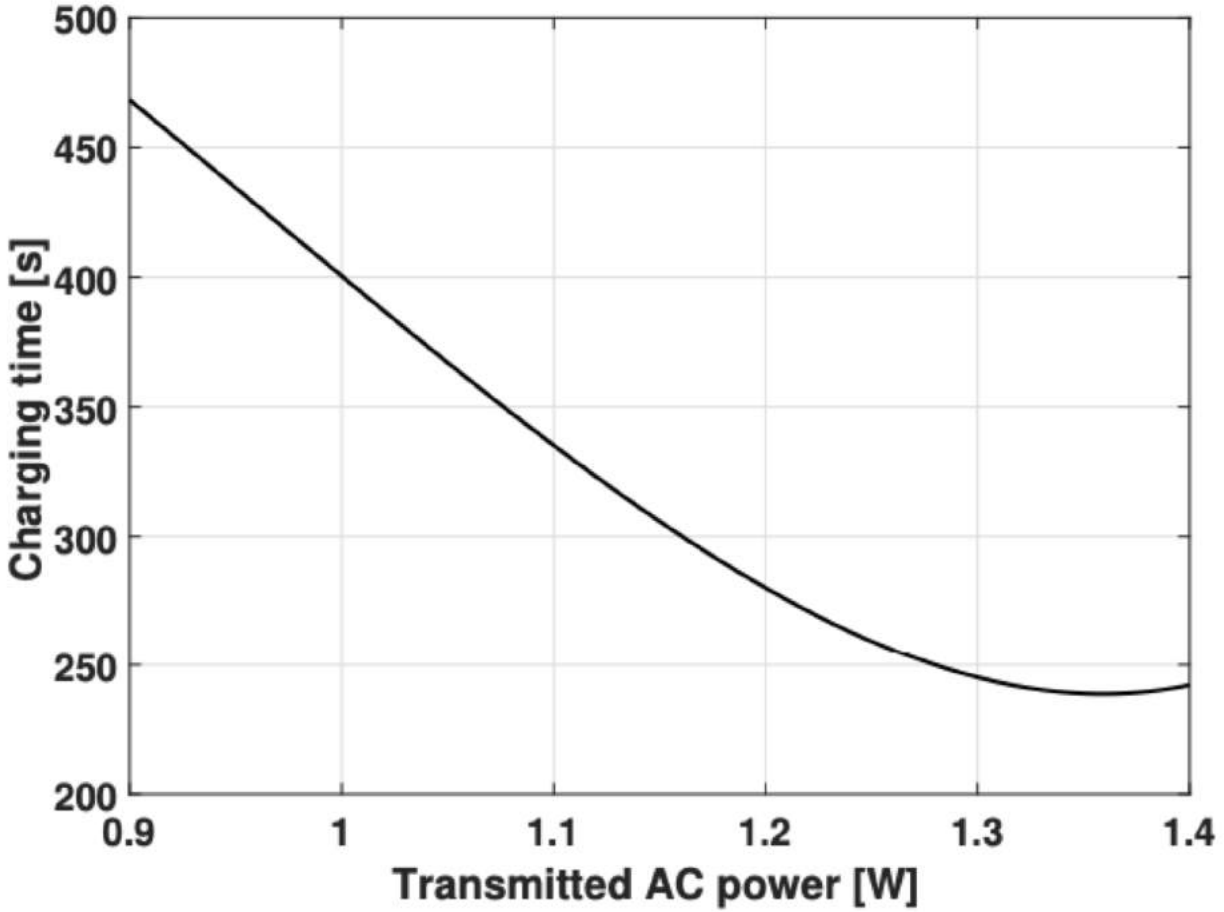
Received power levels decrease or stay the same if transmission power level increases above 1.28W.

Two possible explanations:

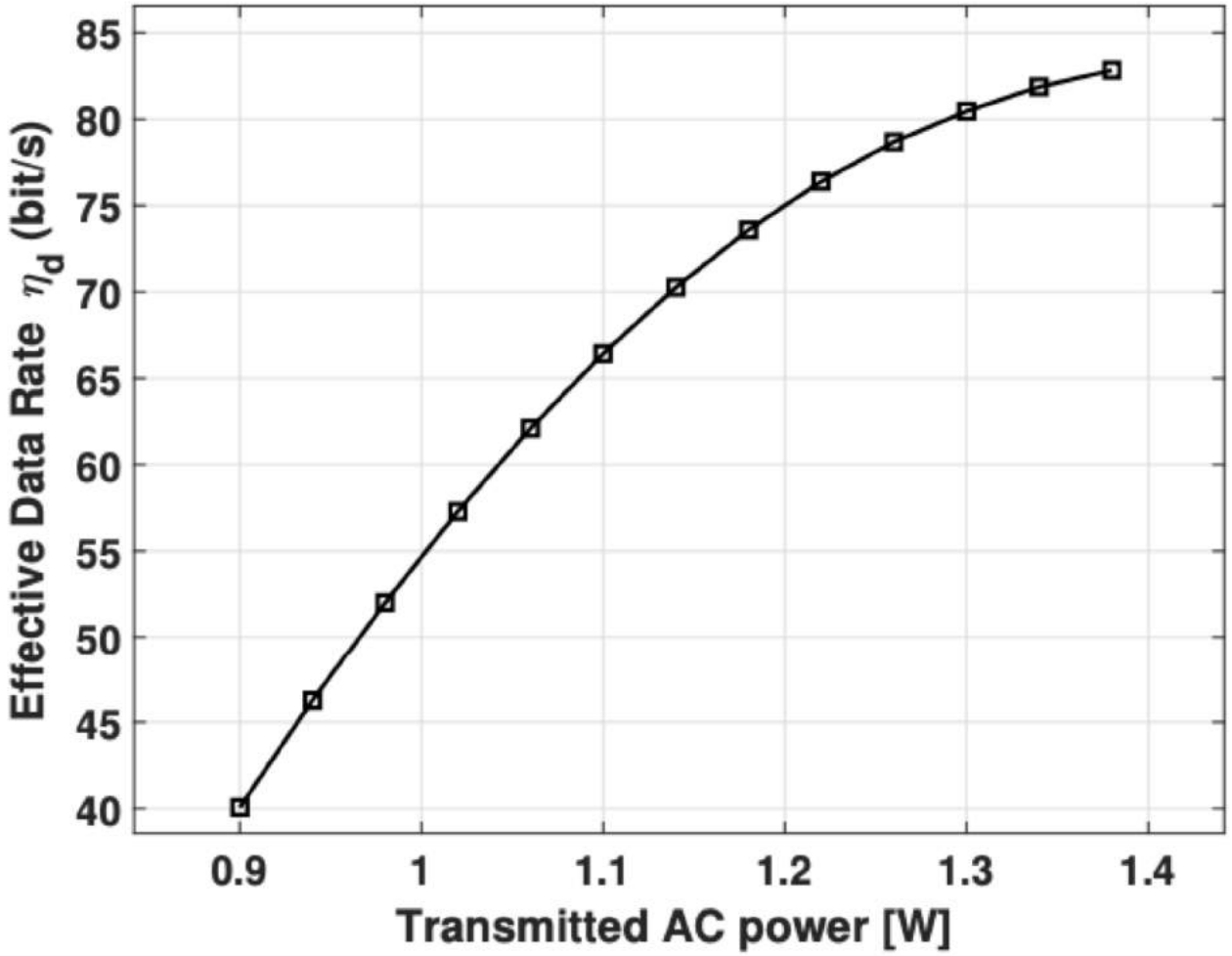
1. Transducer reaches peak source level and starts saturating.

2. Cavitation – rapid pressure changes that lead to formation of small vapor-filled cavities or voids. At higher power levels, these voids surround the transducer and weaken its ultrasonic pressure levels.

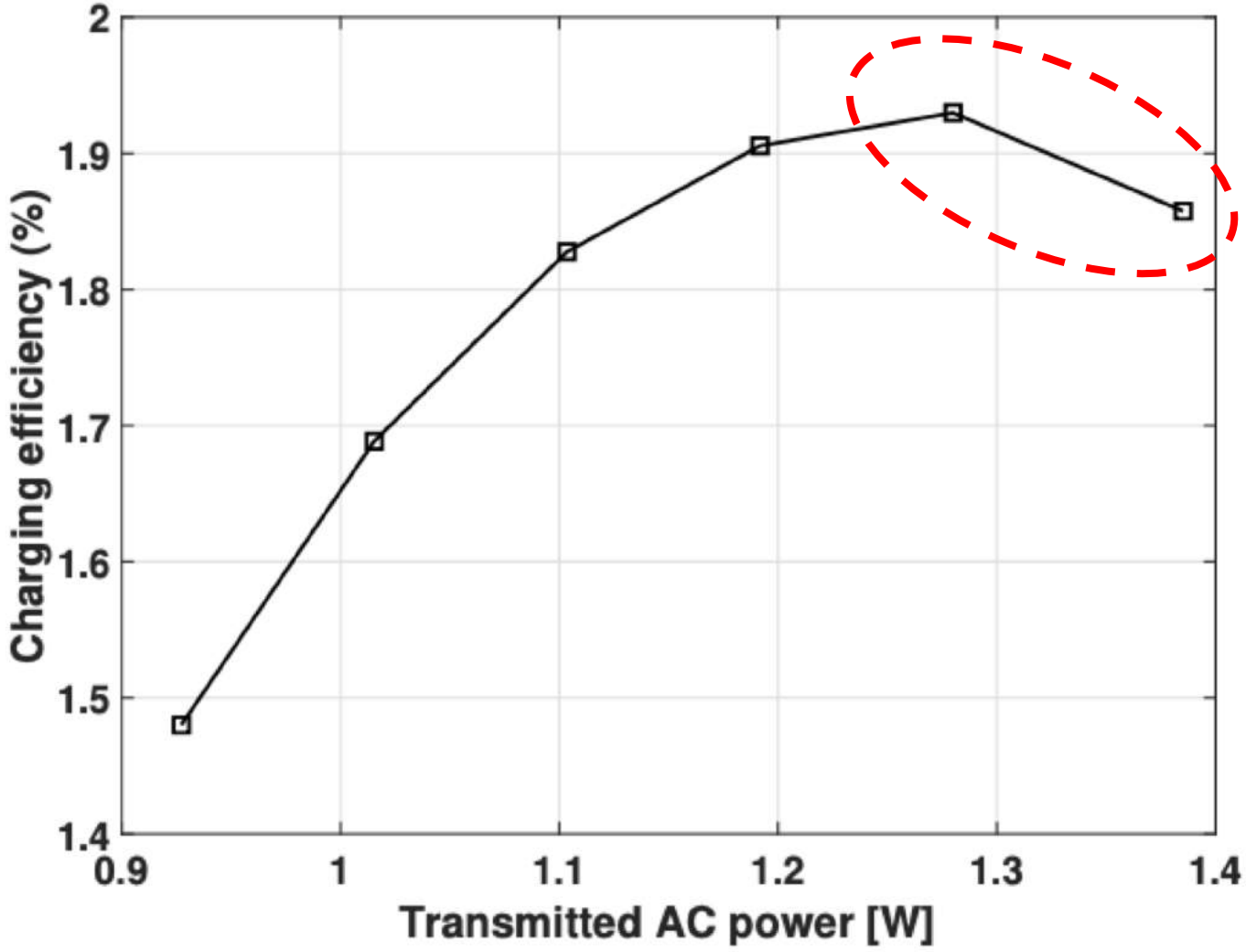
Charging time decreases with increasing transmitted AC power



Higher transmitted power translates into higher effective data rates (due to lower charging time)



Charging efficiency vs transmitted AC power



Since energy accumulated is constant and we observe that charging time decreases with increasing transmitted power, the decrease of charging efficiency is due to the decrease of the power transfer efficiency.

Summary

- SEANET can be used to **wirelessly power multiple nodes** via underwater wireless power transfer (Underwater WPT)

- The system replaces traditional batteries with **supercapacitors** which are **lighter, easier, faster to recharge**.

- Unfortunately, SEANet cannot communicate during its charging phase. Also, a certain grade of alignment is required between the Tx and Rx of the transducers.