# Poster: Near-Zero Power Underwater Acoustic Networks Using Scatter Communications Principles

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***Abstract*—Wireless communications under the surface of the water is challenging as electromagnetic waves –predominantly used for over-the-air communications– cannot travel more than a few centimeters through water. Acoustics is usually the preferred option. However, existing acoustic modem technology is mostly limited to point-to-point communications, while for applications that require large numbers of modems to get widespread deployed in the field, the monetary and energy costs for each modem can become prohibitive for their operation. In this work, we propose to build near-zero power underwater acoustic wireless sensor networks. To that end, we develop and test modem prototypes that consume less than $4\,\mathrm{mW}$ for communications and less that $0.5\,\mathrm{mW}$ in idle mode. Our early-stage modem prototype demonstrates low communication rates of $100\,\mathrm{bps}$ at small distances of $15\,\mathrm{cm}$.**

***Index Terms*—Underwater IoT, backscatter communications**

## 1. Introduction

The number of terrestrial IoT sensors that connect to the internet to enable machine-to-machine communications is growing every day. However, the deployment of underwater communications sensors remains limited. Collection and analysis of data from an Internet of Underwater Things (IoUT) may enable a plethora of applications for marine conservation, coastal resilience, aquaculture, offshore energy, defense, to name a few [1].

The vast majority of underwater IoT sensors today are battery-powered and can only connect to the internet when they re-surface. Their lifespan is limited by their battery life. As a result, underwater IoT sensors must be either physically retrieved each time their battery runs out or when data needs to be processed. Other sensors require tethers to connect to the internet, therefore provide limited mobility and may pose risk to marine life and boat traffic. Other major issues when considering large-scale widespread deployment of underwater IoT are cost-per-sensor and cost for maintenance and/or operation of a fleet of IoT sensors.

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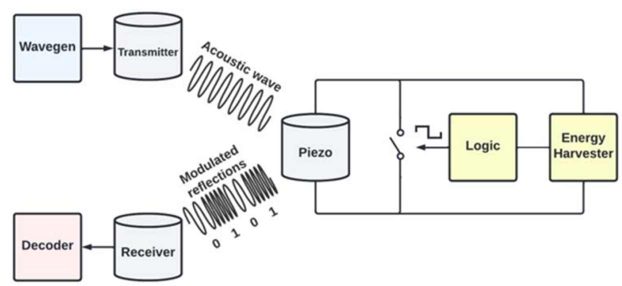


Figure 1. Near-zero power underwater acoustic network system overview.

In this paper, we propose the development of a near-zero power underwater wireless sensor network, that employs passive sensor/tags in a bistatic topology (i.e., carrier emitter placed in a different location from the receiver) to communicate sensor data by means of acoustic reflections. In principle, underwater backscatter acoustic communication [2] is implemented with a switch (e.g., a single transistor) that alternates the termination load of a piezoelectric transducer between two (or more) loads. If the transducer load termination is alternated with frequency $f_{SW}$ while a continuous wave (CW) with frequency $f_c$ (produced by a distant emitter) is incident on the transducer, then two subcarriers will emerge at frequencies $f_c \pm f_{SW}$. We implement the front-end of an acoustic backscatter-enabled tag with minimal number of simple electronic circuit components, greatly reducing cost and complexity per tag, and thus, enabling large-scale deployments.

## 2. System Overview

The bistatic underwater acoustic backscatter communication system consists of a carrier emitter, a sensor tag and a software-defined underwater acoustic receiver, as depicted in Fig. 1. The emitter illuminates the tag with a CW carrier at frequency $f_c = 35.9$ kHz. To modulate sensor information, the tag terminates its piezoceramic transducer between two loads. Ideally, when the transistor is switched

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on, the transducer is short-circuited and the incident CW is scattered back with a negative reflection coefficient (phase change $\pi$). Respectively, when the transistor is switched off, the transducer is open-circuited and the incident wave is scattered intact (i.e., no phase change). Modulation on the tag is achieved by switching the transistor at two rates i.e., $f_1 - f_c$ and $f_0 - f_c$, thus changing between two reflection coefficients $\Gamma_0$, and $\Gamma_1$.

The reflection coefficient itself can be expressed as a function of the source impedance $Z_s$ (i.e., that of the piezo-transducer) and load impedance $Z_l$ (i.e., that of the electrical load) i.e., $\Gamma = \frac{Z_l - Z_s^*}{Z_l + Z_s^*}$. Since the source impedance $Z_s$ is constant for a given $f_c$, we modify the load impedance $Z_l$ to obtain different reflection coefficient values.

In binary frequency shift keying (B-FSK), the tag switches between two distinct reflection coefficient values $\Gamma_0, \Gamma_1$ with different rates $f_i$ for corresponding bits $i = 0, 1$ (also called subcarrier frequencies). To ensure orthogonality in noncoherent FSK, the spacing between the two subcarrier frequencies is $|f_1 - f_0| \geq 1/2T$, where $f_0 = 40\,\text{kHz}$, $f_1 = 44.5\,\text{kHz}$ and $T = 10\,\text{ms}$ is the $i$-th bit duration.

## 3. Battery-Free Modem/Tag Prototype

The battery-free tag prototype consists of a piezoelectric transducer, electric impedance matching, voltage multiplier circuitry, and a low-power microcontroller that can interface to a sensor unit. After potting the piezo-transducer with UV-resin, we match its electrical impedance to the piezo with an RLC network upon measuring the piezo's resonant and anti-resonant frequencies as depicted in Fig. 2. Harvested voltage is then multiplied by 4x and also rectified to DC to power-on the microcontroller. A small storage capacitor acts as a buffer for noise that is generated from transmission through the underwater environment. The tag stays in idle mode for approximately $5\,\text{s}$, while the capacitor charges to $3\,\text{V}$. Then, the microcontroller turns on, reads the sensor data and communicates them to the receiver by means of reflection. The modem wakes up when the capacitor has sufficient charge for transmission. Cold start times are between $5\,\text{s}$ and $10\,\text{s}$, and warm start is between $2\,\text{s}$ and $5\,\text{s}$. The modem/tag footprint is about $10\,\text{cm}^2$.

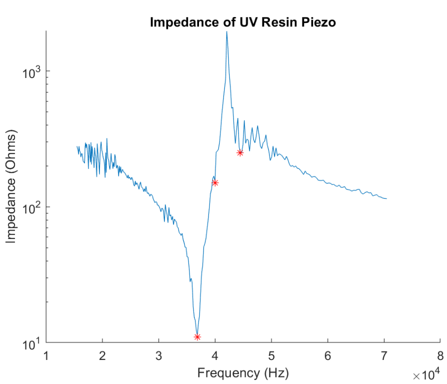


Figure 2. Impedance of a UV-resin potted piezoceramic cylinder.

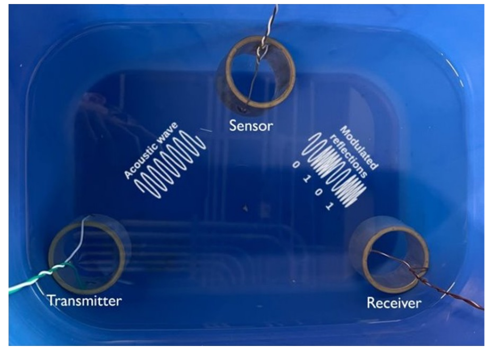


Figure 3. Experimental setup.

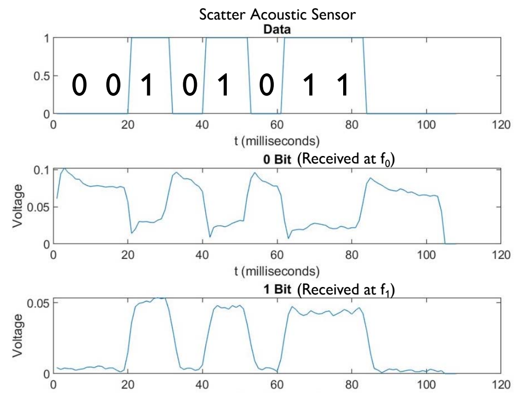


Figure 4. Data decoding results at the receiver.

## 4. Experiments

The carrier frequency for the CW is chosen as the resonant frequency with the lowest impedance. Figure 2 depicts the impedance of the piezo-transducers for $f_c$, $f_0$ and $f_1$ used by the transmitter and the tag. We used piezoceramic cylinders with resonant frequency of $17\,\text{kHz}$. The resonant frequency slightly changed when we potted the piezo with different materials and placed it underwater. Resonance also varied by the thickness of the material we used for potting. Subcarrier frequencies $f_0$ and $f_1$ were selected based on the impedance measurements in Fig. 2 and the minimum frequency separation criterion for non-coherent FSK. Experiments were carried out in a small fish tank at small distances between the transmitter, tag and receiver of approximately $15\,\text{cm}$. Figure 3 shows the experimental setup. Figure 4 demonstrates successful decoding at the receiver of a frame of 8-bits that is transmitted by the tag at $100\,\text{bps}$ and a receiver-estimated SNR of $48\,\text{dB}$.

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