



Oscillating Linear Wave Energy Converter to Support Autonomous Surface Vessels (ASVs)

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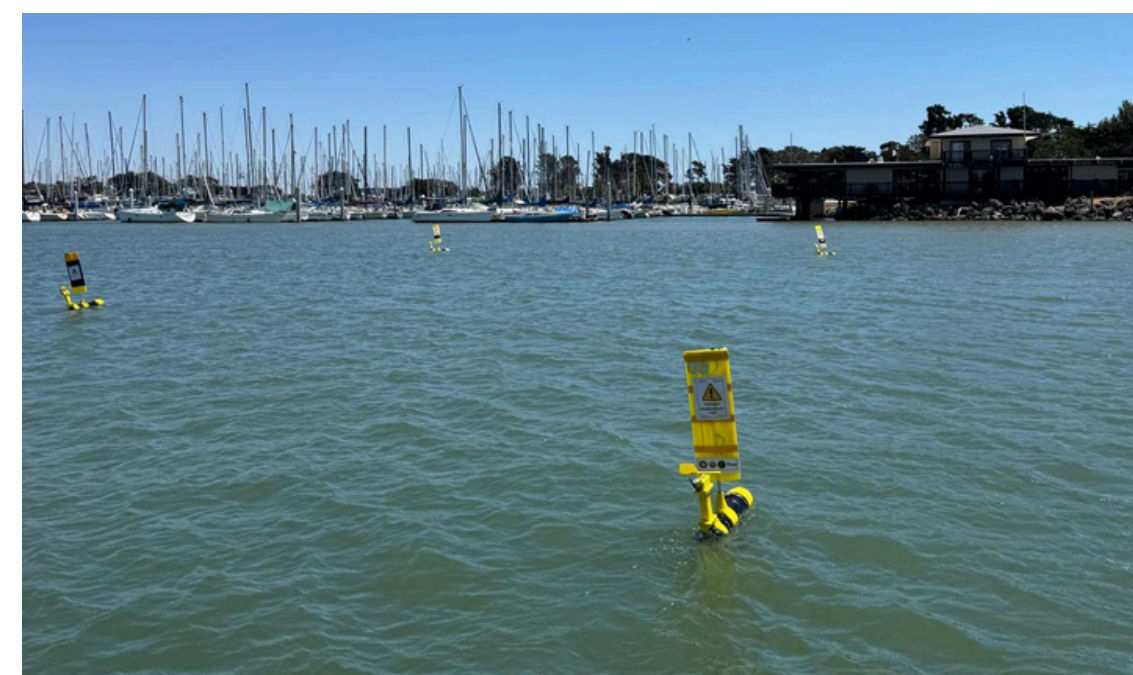
Introduction

Problem:
Autonomous Surface Vessels (like the CaptAI ocean drones) require continuous power (1–50 W) for persistent environmental monitoring. Solar and wind are intermittent (only 20–40% uptime), leaving vessels vulnerable to battery depletion during overcast nights.

Ocean waves provide a highly reliable third modality. Because waves persist long after winds die down, wave energy converters (WECs) can operate up to 90% of the time, bridging the gaps left by solar and wind. Long-term marine deployment requires fully encapsulated systems to prevent salt spray corrosion and biofouling. This necessitates an internal electromagnetic harvester with minimal external moving parts.

Research Goals

- Design and validate a kinetically resonant linear induction WEC optimized to generate continuous supplemental power at the ultra-low, aperiodic frequencies (0.1 – 1.0 Hz).
- Optimizing mechanical spring stiffness and dynamic electrical loads to maximize average active power.



Mechanical Design

- The sled houses 4 N52 Neodymium magnets arranged side-by-side with alternating polarities (N-S-N-S) to maximize the spatial magnetic flux gradient.
- 10 stationary copper coils (5 above, 5 below) are positioned along the track, comprised of 32 AWG enameled wire at 1200 turns each.
- 1.2 mm air gap across magnet tolerance and 1/32" polycarbonate panel minimizes decay of the magnetic field.
- 4.5 N/m Symmetric springs mounted on both ends of the track tuned to 0.7 Hz

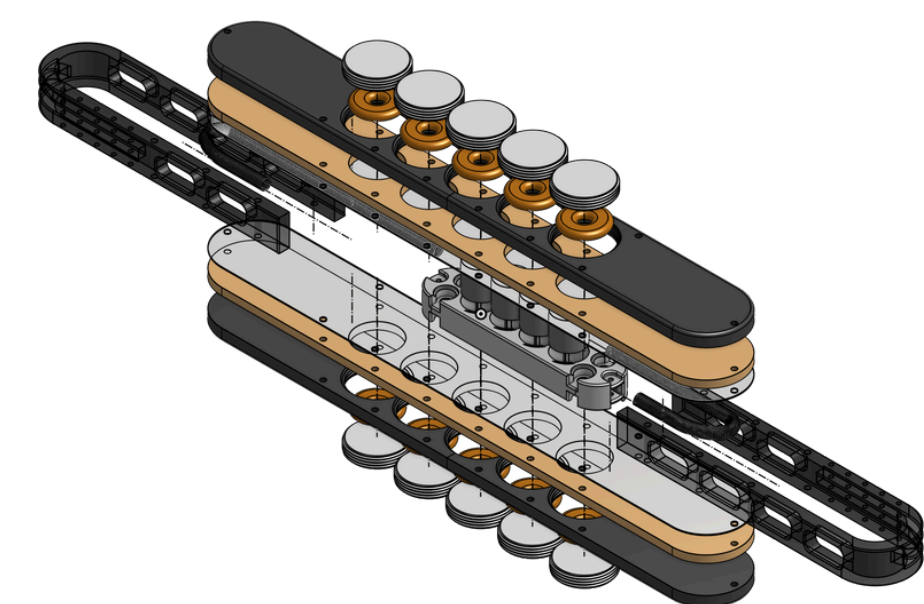


Figure 1. Exploded CAD assembly

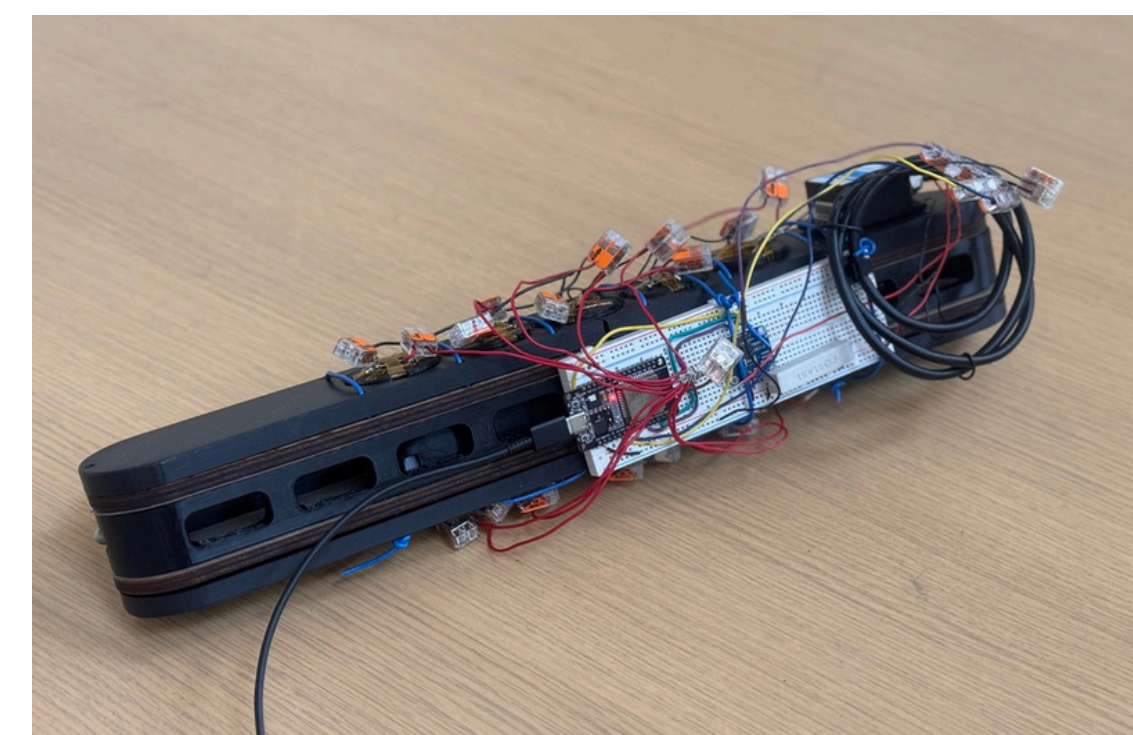
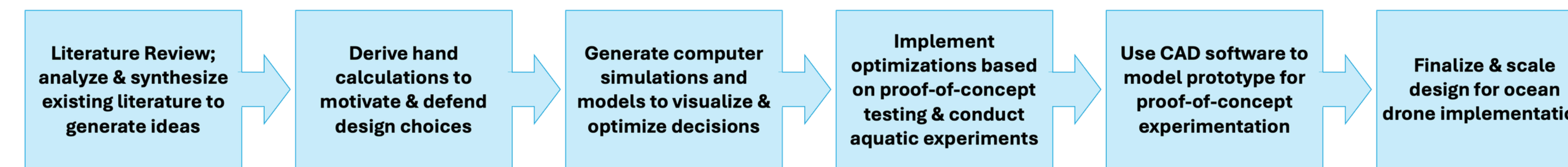


Figure 2. Proof-of-concept prototype equipped with current/voltage sensor and accelerometer

Analysis

Methodology



Electromagnetism

- Power generation is governed by Faraday's Law of electromagnetic induction and electrical power law
- Coil geometry is optimized to minimize resistance and maximize effective surface area to "capture" the emitted magnetic field
- Coil orientation is alternating (clockwise-counterclockwise) to ensure additive induction
- Iterative application of Kirchhoff's Current Law (KCL) at every time step based on powered coils that overcome diode drop

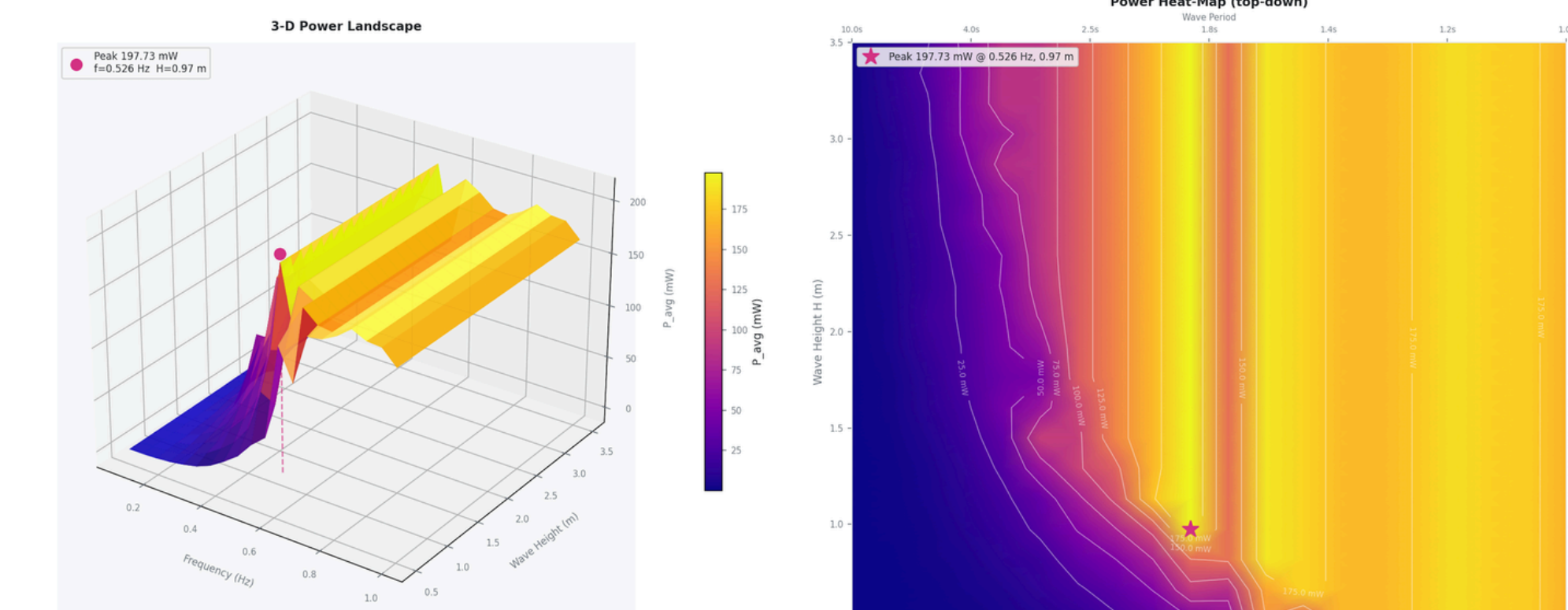
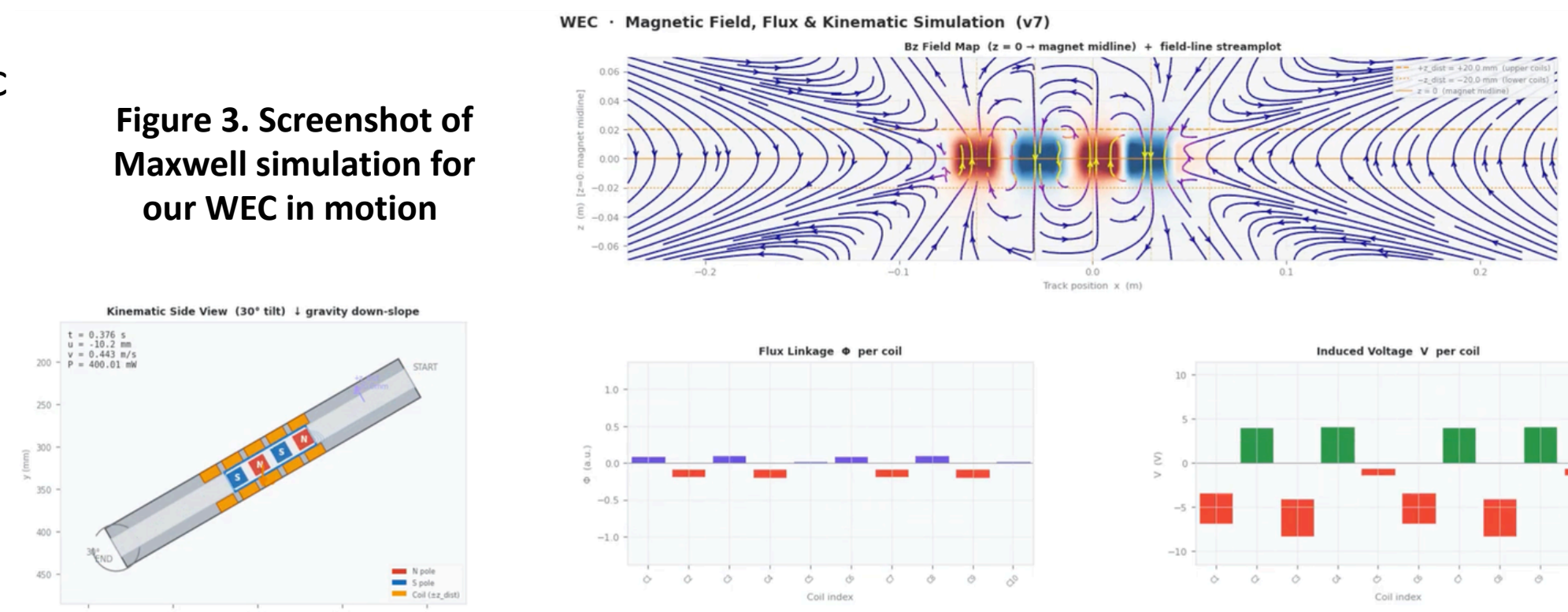


Figure 4. Frequency-Amplitude Plot

Frequency & Spring Stiffness

- Symmetric suspension architecture with springs anchored to both ends of the track, acting in parallel on the sliding mass
- Dynamics are solved with stiff LSODA method to step through the nonlinear ODEs, combining kinematics and accounting for electromagnetic drag
- Tuning accuracy is critical due to the finite 400 mm track length. If springs are under-stiffened for a given wave frequency, the mass overshoots and collides with the physical end-stops, stopping the simple harmonic motion and losing kinetic energy as impact heat rather than electrical power.

Circuitry

- The output voltage is first rectified by a full-wave rectifier to convert the alternating current output to direct current.
- The capacitor and resistor are placed in parallel to reduce the equivalent impedance of the circuit
- The INA219 is installed to measure experimental outputs and relay realtime data about the status of the WEC's generation and output
- Coils are wired in parallel so the total current magnitude is summed and the voltage at each node is equivalent to the source voltage

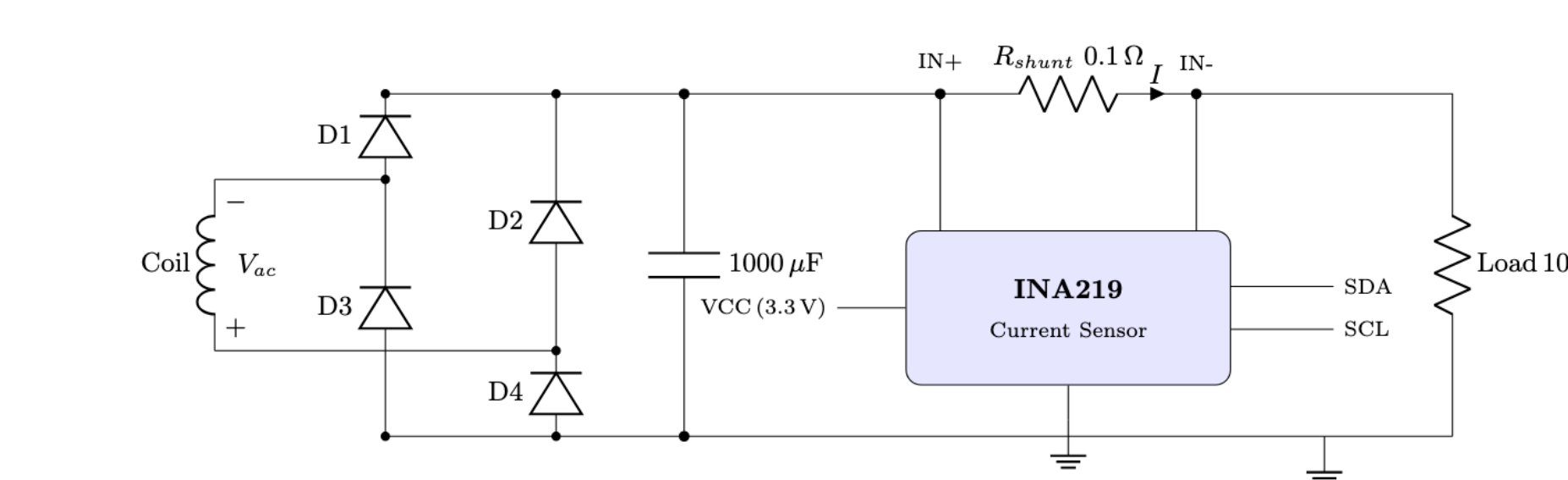


Figure 5. Circuit diagram

Results

- 170mW average active power @ 0.67 Hz frequency with 4 magnets (4.5 Percent Error)
- 265 mW average cycle power w/ 35mW standard error
- Achieved kinetic resonance at the target ocean swell frequency (0.67 Hz) by tuning the symmetric spring array
- Average of a 15% mean error when mapped against the theoretical power generation

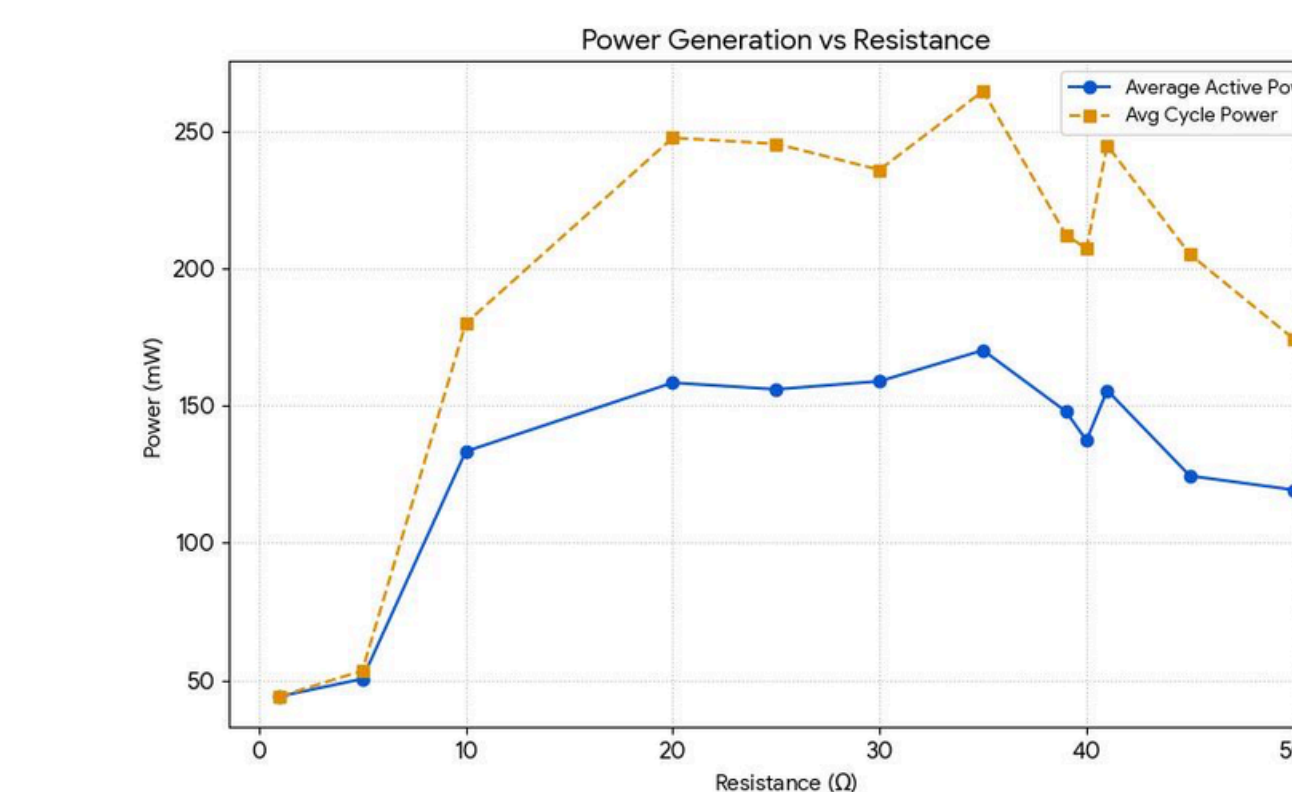


Figure 6. Load resistor testing data

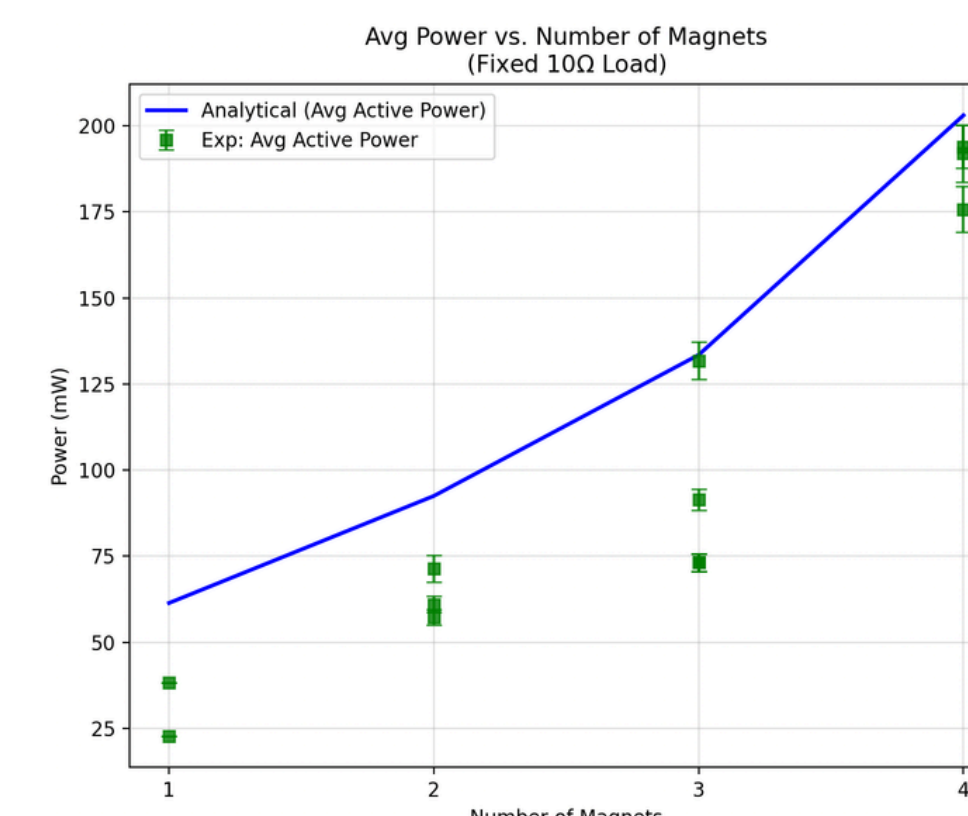


Figure 7. Average power as a function of number of magnets

Conclusion

This project validates a kinetically resonant linear WEC for ultra-low frequency ocean swells. By tuning the mechanical spring stiffness to the incoming wave period, the prototype achieved a peak average active power of 170 mW. We evaluated these empirical results against our fully coupled electromechanical digital twin, yielding a 15% mean error, largely explained by air gap tolerances and physical friction.

Ongoing validation includes variable frequency & amplitude jig trials and open-water deployments mounted on our lab's ASVs. Future iterations will scale the overall architecture and transition to a 2-DOF system to capture aperiodic, multi-directional swell energy.

References

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