Seismo-Tag

Seismic Sensing with Harmonic RFID Backscatter and AI

ELECOMP Capstone Design Project 2026-2027

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Project Motivation:

Seismic monitoring underpins our understanding of Earth's structure and dynamics and drives earthquake and volcano hazard assessment and early warning. Conventional seismic networks, however, rely on mechanical seismometers costing thousands of dollars per station, limiting network density and spatial coverage. This project explores a fundamentally different sensing paradigm: using radio frequency (RF) backscatter itself as the seismic sensor. A low-cost harmonic RFID tag on the ground is illuminated by a software-defined radio (SDR); ground vibration displaces the tag by micrometers to millimeters, imprinting a phase modulation on the backscattered signal, and signal processing and AI algorithms recover the seismic waveform. Because tags are nearly free and one reader serves many tags, the approach could enable dense, scalable seismic networks at a fraction of today's cost, with applications in earthquake early warning, volcano monitoring, structural health monitoring, and environmental sensing. This Capstone project is part of an active research program funded by the URI Institute for AI & Computational Research (IACR), conducted in the ARCAS Lab in collaboration with the URI Seismological Lab (Prof. Yang Shen, Graduate School of Oceanography).

Students will build and validate the complete sensing chain: an SDR transceiver (USRP B210) illuminating a passive harmonic RFID tag (900 MHz uplink, 1.8 GHz backscatter), an RF front end with power amplification and harmonic-rejection filtering, a coherent phase-demodulation pipeline, and supervised deep-learning models that convert RF measurements into calibrated seismic waveforms benchmarked against accelerometer ground truth. The team will not start from scratch: the ARCAS Lab has already developed an initial sensing-link prototype and a soil-filled seismic simulation chamber, which the team will advance to a fully characterized, AI-enabled sensing system. Through laboratory experiments, students will confront real-world debugging problems where the limiting factor may be physics, hardware, or algorithms, gaining hands-on experience across the full hardware-to-AI stack: RF systems, digital signal processing, and applied machine learning. Results will directly contribute to the sponsoring IACR project and provide preliminary data for planned external proposals; a working system serves as a prototype for next-generation low-cost geophysical and infrastructure monitoring.

Anticipated Best Outcome:

ABO1: Establishment of a reliable harmonic RFID backscatter sensing link using the USRP B210, and demonstration of wireless vibration detection through phase demodulation.

Students will be provided with materials on IQ modulation/demodulation and backscatter communication. Because the backscattered phase is highly sensitive to tag displacement, ground vibration appears as weak phase-modulation sidebands around the recovered tag tone. Starting from the existing prototype, students will operate the B210 with independently tuned Tx (900 MHz) and Rx (1.8 GHz) chains, integrate transmit amplification with harmonic-rejection filtering, and implement a phase-extraction pipeline. Detection will be validated in stages — first with the tag mounted directly on a controlled vibration source (large, known displacement), then with the tag on the soil surface with sensing vibrations propagated from the buried source — culminating in reliable detection in the 5–100 Hz seismic band.

ABO2: Characterization of sensing performance against accelerometer ground truth, and an initial AI-based demonstration of vibration waveform recovery from RF measurements.

Students will quantify the system: minimum detectable displacement versus vibration frequency (5–100 Hz) and reader–tag range, calibrated against collocated accelerometer measurements — including the actual displacement delivered to the soil surface by the buried source. From these

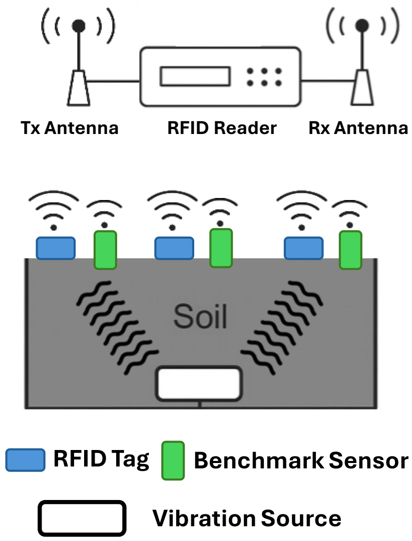

Fig. 1. Harmonic RFID backscatter sensing system and the laboratory seismic testbed.

synchronized RF/accelerometer recordings, students will assemble a first labeled dataset and train an initial supervised model that reconstructs the vibration waveform from RF phase measurements, evaluated against a classical-demodulation baseline. Together, ABO1 and ABO2 deliver a characterized, AI-assisted vibration sensor by the end of fall.

ABO3: Expanded experimental campaign and refined AI models on the seismic testbed, producing benchmark-quality results that support external research proposals.

In the spring, students will broaden the experimental campaign — varying source drive level and frequency content, soil conditions, and tag/antenna placements — to build a benchmark-quality dataset, and will refine the AI models, comparing architectures such as encoder–decoder LSTMs and transformer-based sequence models for seismic waveform reconstruction and event detection. All outputs will be benchmarked against reference sensors, yielding publication- and proposal-grade results. (Bonus) Multi-tag operation — several tags read by a single reader — enabling differential-phase strain estimation as a first step toward a distributed sensing network.

Project Details:

The Universal Software Radio Peripheral (USRP) B210 is a software-defined radio platform from Ettus Research (Austin, TX). Built around the Analog Devices AD9361 RFIC, it provides continuous RF coverage from 70 MHz to 6 GHz, two transmit and two receive channels, and up to 56 MHz of instantaneous bandwidth, streamed over USB 3.0 and controlled through the UHD driver from Python or GNU Radio. In this project the B210 serves as both illuminating transmitter and coherent receiver, with its two local oscillators tuned independently — Tx at 900 MHz, Rx at 1.8 GHz — a configuration well suited to harmonic backscatter sensing.

The sensing node is a passive harmonic RFID tag: a nonlinear transmission line (NLTL) based harmonic generator that absorbs the 900 MHz signal and re-radiates its second harmonic around 1.8 GHz, cleanly separating the tag return from environmental clutter. A tag vibrating along the line of sight imposes phase-modulation sidebands whose level directly encodes the displacement amplitude.

The laboratory testbed, already constructed in the ARCAS Lab, comprises (1) the harmonic RFID sensing link described above; (2) a seismic-wave simulator — a soil-filled chamber of approximately 40’’ × 21’’ × 18’’ with a commercial vibration source buried in the soil, generating 10–100 Hz ground motion characteristic of local earthquakes, sensed by RFID tags on the soil surface; and (3) reference sensors — accelerometer modules collocated with the tags, providing ground truth for calibration and AI training. A Tx power amplifier with post-amplifier low-pass filtering and receiver band-select filtering maintains harmonic hygiene, ensuring the observed 1.8 GHz signal originates from the tag rather than the transmitter chain's own harmonics. The system block diagram is shown in Fig. 1.

Phase I (Fall Semester): ABO 1 and 2

The team will begin from the existing ARCAS Lab prototype and focus on reliable vibration detection, sensing-performance characterization, and initial AI-based waveform recovery. Fall results directly support the final report of the sponsoring IACR seed project, so vibration detection, measured sensitivity curves, and an initial trained model are required by early December.

[Algorithm/Software/Computer Tasks:]

1. Reproduce the existing baseline: establish control of the B210, transmit the single-sideband probe tone, and verify recovery of the frequency-doubled tag tone and of large manual tag motion through phase demodulation.

2. Execute the displacement ladder — the tag mounted directly on the vibration source, at low frequency first and then across the 10–100 Hz band (large, accelerometer-verified displacement), followed by the tag on the soil surface with the buried source — and benchmark measured phase modulation against accelerometer-derived displacement to produce calibration curves.

3. Assemble a labeled bench-vibration dataset and train an initial supervised model that reconstructs the vibration waveform from RF phase data; evaluate against classical demodulation.

4. (Bonus) Develop a real-time phase-spectrogram display for live monitoring and debugging.

[Hardware/Electrical Tasks:]

1. Characterize the harmonic tag (conversion behavior versus input power) and antennas; align the sensing line of sight with the dominant surface motion direction (largely vertical above a buried source).

2. Integrate the Tx power amplifier; characterize its gain and harmonic output with a spectrum analyzer; add post-amplifier low-pass filtering and receiver band-select filtering; verify that transmitter-chain 1.8 GHz leakage remains below the tag return.

3. Rig both measurement configurations (tag on the source; tag on the soil surface); measure the true displacement at the tag with the collocated accelerometer in each, quantifying the attenuation from the buried source to the surface.

4. Debug hardware throughout algorithm development and validation.

Phase II (Spring Semester): ABO 3

The team will broaden the experimental campaign on the seismic testbed and refine the AI models, producing benchmark-quality datasets and results that support external research proposals.

[Algorithm/Software/Computer Tasks:]

1. Expand the training corpus: synchronized RF and accelerometer recordings across source amplitudes, frequencies, soil conditions, and tag/antenna placements, with a documented preprocessing pipeline.

2. Refine and compare model architectures (encoder–decoder LSTM; transformer-based sequence-to-sequence) for seismic waveform reconstruction; evaluate fidelity against classical baselines.

3. Implement and evaluate seismic event detection on reconstructed waveforms (classical STA/LTA and/or learned detectors).

4. (Bonus) Explore multi-tag differential-phase processing for relative displacement and strain estimation between tag pairs.

[Hardware/Electrical Tasks:]

1. Map the chamber's surface vibration field with an accelerometer survey across varied soil conditions (e.g., moisture, compaction), source drive levels, and tag/antenna placements to broaden the dataset.

2. Stress-test the system under these varied conditions and iterate hardware improvements (antenna placement, filtering, gain staging) driven by model error analysis.

3. (Bonus) Conduct an outdoor proof-of-concept using vehicle traffic or sledgehammer strikes as seismic sources.

Composition of Team:

2 Electrical Engineers & 1 Computer Engineer

Skills Required:

Electrical Engineering Skills Required:

- Strong digital signal processing background, especially Fourier transforms, sampling theory, and digital filtering.
- Understanding of basic circuit theory and RF fundamentals (antennas, amplifiers, filters, link budget).
- Familiarity with communication systems, e.g., up-conversion/down-conversion, I/Q modulation/demodulation, nonlinearity (harmonics and intermodulation).
- RF module and spectrum measurement using laboratory instruments (spectrum analyzer, signal generator, oscilloscope); network analyzer experience is a plus.
- Interest in software-defined radios (USRP/UHD, GNU Radio); prior SDR experience preferred but not required.

Computer Engineering Skills Required:

- Proficiency in MATLAB/Python. C/C++ is a plus.
- Foundations in machine learning (supervised learning, training/validation/test methodology); hands-on experience with PyTorch or TensorFlow preferred.

- Familiarity with Linux OS and basic command-line workflows is a plus.
- (Preferred, not required) Deep learning for time series (RNN/LSTM, transformer models), Git version control.

AI Usage:

The AI Use Policy for this project is defined in Appendix A at the end of this proposal. Technical Directors: complete the checklist in Appendix A to indicate which AI uses are permitted on this project. Any item left unchecked is not allowed.

Appendix A: AI Use Policy – Seismo-Tag

Allowed

- Students may use AI tools for
  - ✓ brainstorming support
  - ✓ concept development
  - ✓ literature and publicly available documentation review
  - ✓ software development
  - ✓ debugging
  - ✓ data analysis
  - ✓ test development
  - ✓ non-proprietary paragraph editing
  - ✓ non-proprietary single-slide formatting
  - ✓ preparation of project deliverables
  - ☐ note taking or transcription of meetings
  - ☐ Others: ______________________________

Not Allowed

- Using AI in violation of university policies, applicable laws, or course-specific rules identified by capstone instruction team and project-specific rules identified by the technical directors.
- Entering proprietary, confidential, personally identifiable, security-sensitive, or otherwise restricted information into an AI system without authorization.
- Submitting AI-assisted work without understanding, reviewing, verifying, and appropriately disclosing its use.

- Submitting entire documents or presentations to an AI system for editing or formatting.
- Any unchecked items from the allowed list above.

Requirements

- If any use is allowed, AI tools may only be used to enhance, but not replace, students' technical reasoning, engineering judgment, and understanding. Students must be able to explain, justify, and defend all submitted designs, code, analyses, test results, documentation, and conclusions.
- During the first two weeks of the project, the student team shall work with the Technical Directors to: identify any proprietary or confidential information that may be involved in the project; determine what information may or may not be shared with AI systems; identify the AI tools, models, accounts, and configurations approved for project use; and document any project-specific restrictions or approval requirements.
- Students shall transparently document the uses of AI using the URI CYPHER AI Usage Marking guidelines (https://web.uri.edu/cypher/ai-marking/). A workshop is planned for September to familiarize students with these guidelines.
- Students retain full professional responsibility for all design decisions, analyses, implementations, testing, documentation, presentations, and final deliverables, regardless of whether AI tools contributed to the work.