Application Use cases and Design Implementation of a Portable Potentiostat system

Zachary Thornton, Dr. Masudul Imtiaz

Abstract

System Design & Implementation
We present the design and preliminary performance results of a highly miniaturized, low-cost wireless electrochemical sensing system. The platform is engineered to serve as a portable and reliable alternative to bulky, expensive, lab-grade benchtop equipment without sacrificing measurement accuracy.
At the core of our hardware architecture, we integrate:

- **Analog Front-End (AFE):** The Texas Instruments **LMP91000** potentiostat for precise chemical interface control.
- **Microcontroller (MCU):** The Silicon Labs **EFR32BG24** to manage data processing and system execution.
- **Wireless Connectivity:** Built-in **Bluetooth 5.3** to enable seamless, real-time data streaming to mobile devices.

Supported Experimental Methods
To ensure versatility across different research needs, the system is programmed to perform a complete suite of standard electrochemical experiments:

- **Cyclic Voltammetry (CV)** and **Square-Wave Voltammetry (SWV)** for characterization.
- **Differential Pulse Voltammetry (DPV)** for high-sensitivity detection.
- **Chronoamperometry (CA)** for time-dependent current measurements.

Applications & Performance Validation
This work covers both the practical design implementation and real-world application use cases. By successfully demonstrating stable chemical measurements outside of standard laboratory environments, we show that this pocket-sized platform works as a dependable, real-time sensing tool ready for a wide range of demanding field applications.

Approach

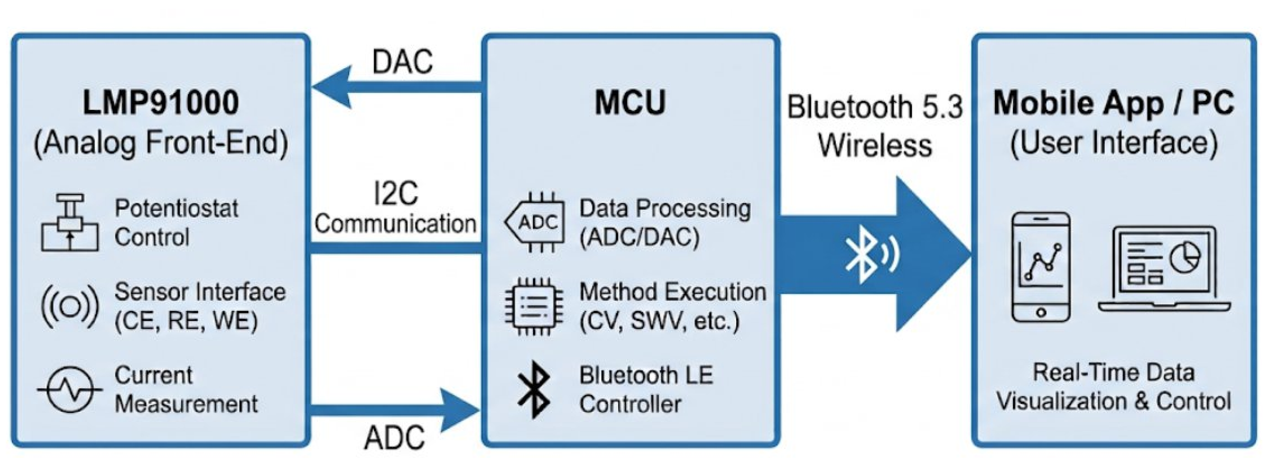

Fig 1. System Design Diagram

Hardware Integration:

- **Analog Front-End (AFE):** Texas Instruments **LMP91000** for precise potentiostat control.
- **Microcontroller (MCU):** Silicon Labs **EFR32BG24** for processing and Bluetooth 5.3 wireless transmission.
- **Multi-Method Support:** Programmed to perform key electrochemical techniques:
  - Cyclic Voltammetry (CV)
  - Square-Wave Voltammetry (SWV)
  - Differential Pulse Voltammetry (DPV)
  - Chronoamperometry (CA)

Design Improvements with OTA DFU

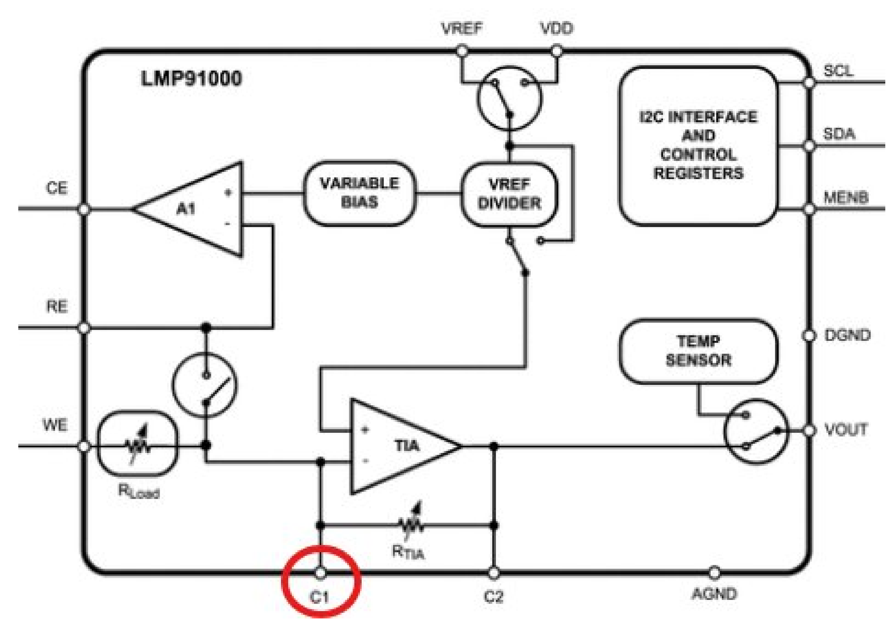

Fig 2. LMP91000 Internal Schematic

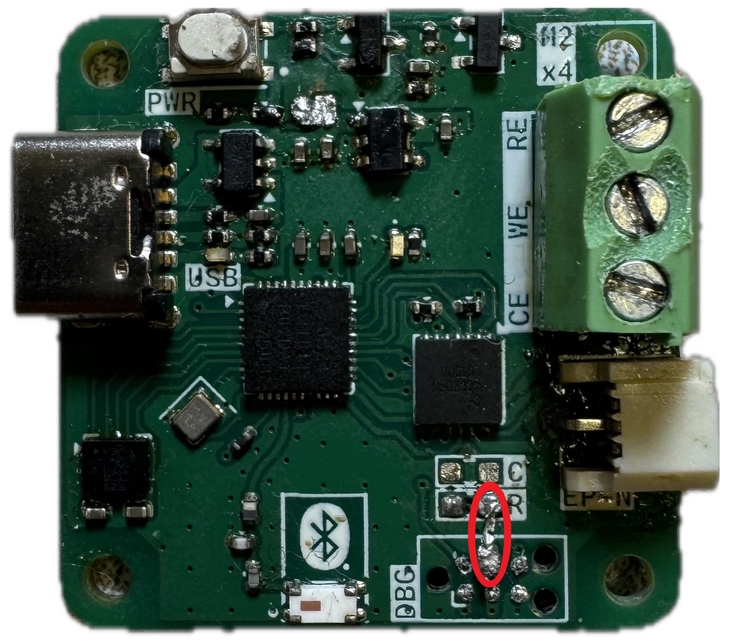

Fig 3. Front view of board with solder joint indication

Differential Sensing & Firmware Flexibility

- **Hardware Rework:** To enable true differential mode measurements relative to the virtual ground, we soldered a flying lead directly from the LMP91000's C1 pad to an exposed debug header on the board.
- **Over-the-Air (OTA) DFU:** Because this physical rework repurposed debug pins normally used for standard flashing, we implemented Over-the-Air Device Firmware Updates (OTA DFU). This guaranteed seamless wireless firmware upgrades without requiring direct hardware access.
- **Custom Bluetooth Debug Logger:** To replace traditional serial logging, we developed a custom Bluetooth GATT service that streams live debug messages to a host computer. A custom Python script intercepts and parses this data stream in real time, allowing full system visibility and automated measurement logging during active testing.

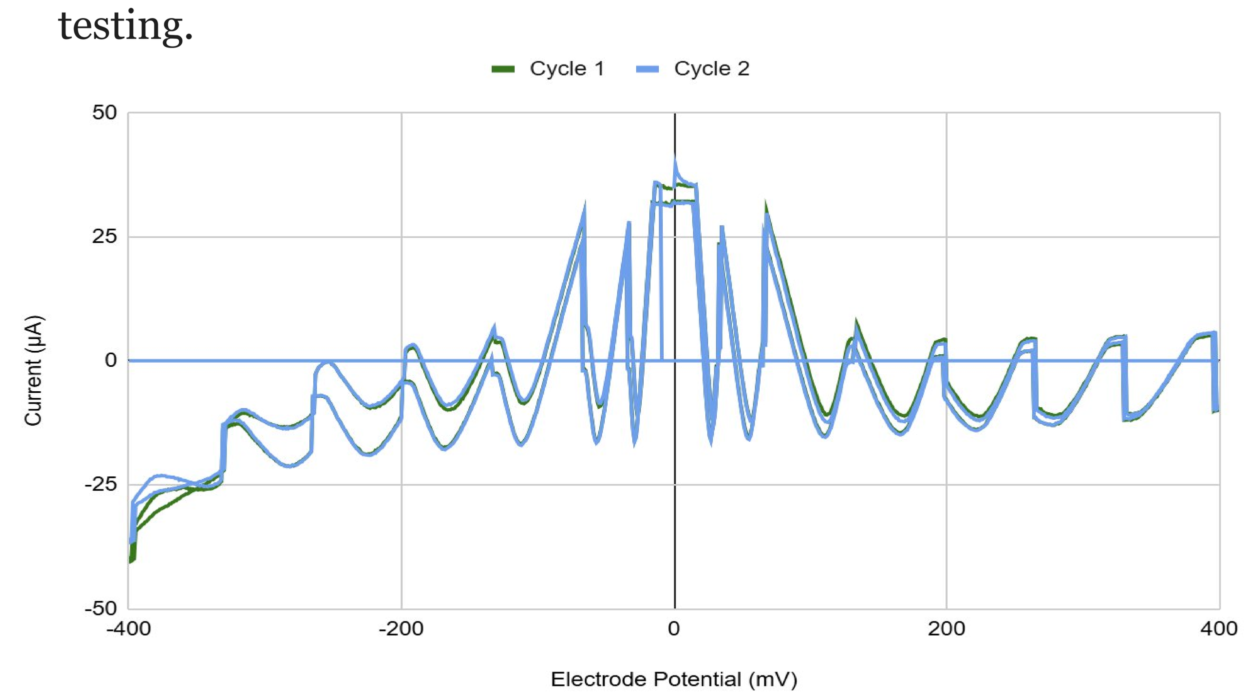

Figure 4. CV Experiment with Calculated Virtual Ground

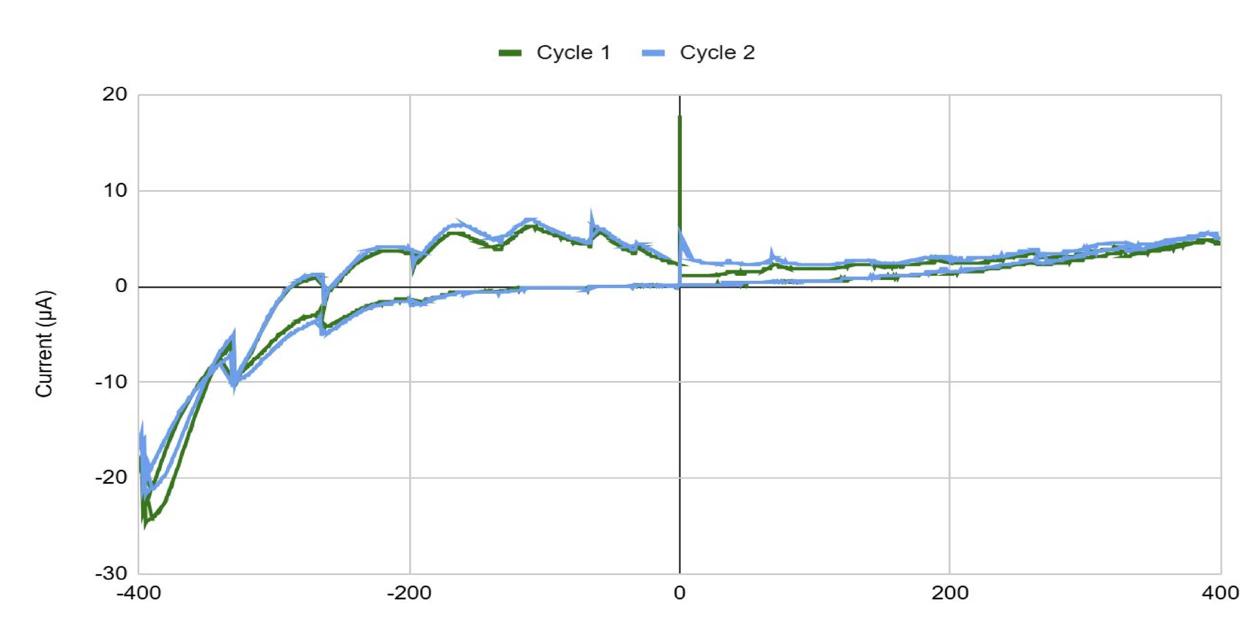

Figure 5. CV Experiment with Measured Virtual Ground

Experimental Results

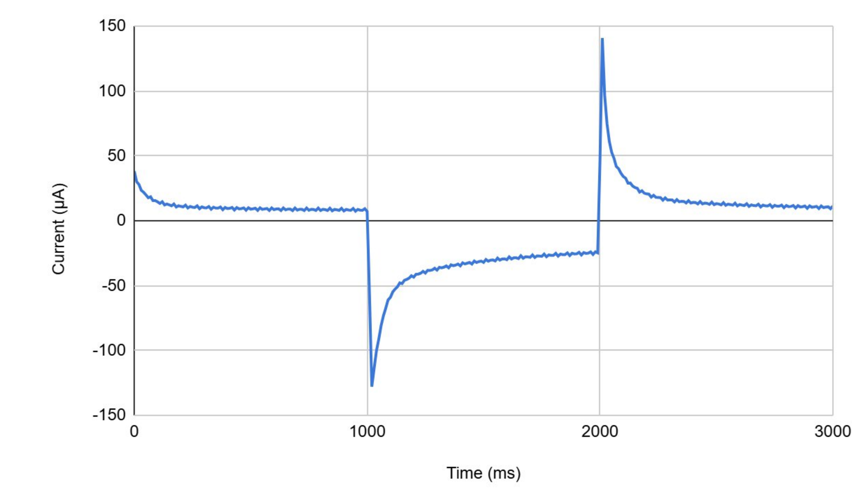

Fig 6. Laboratory 3 Level CA in Ferro Ferri

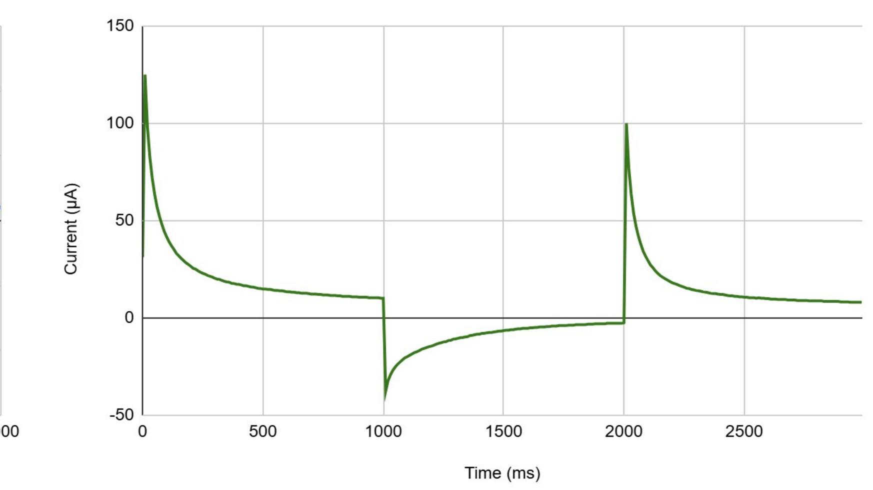

Fig 7. 3 Level CA With Custom Board in Ferro Ferri

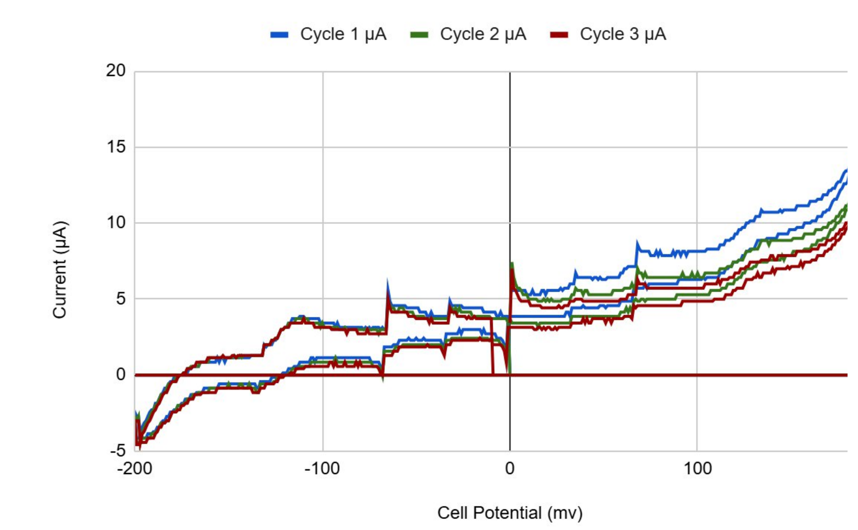

Fig 8. 3 Cycle CV With Custom Board in Ferro Ferri

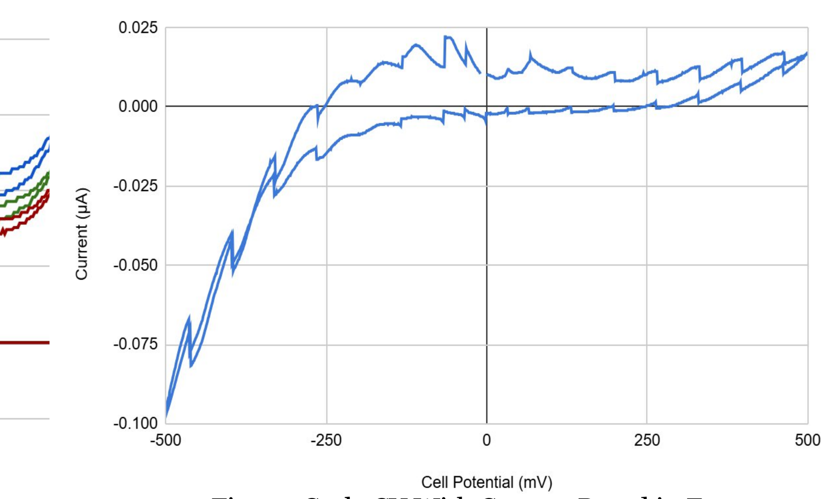

Fig 9. 1 Cycle CV With Custom Board in Ferro Ferri

Future Applications

The portable, high-precision nature of this system enables reliable electrochemical analysis across diverse field-use and clinical environments:

- **PFAS Detection:** Enables rapid, on-site screening of "forever chemicals" in water supplies, bypassing lengthy laboratory processing times to accelerate environmental remediation efforts.
- **Pesticide Field Testing:** Provides agricultural workers with a portable, point-of-use diagnostic tool to identify toxic chemical runoff and pesticide residues directly on crops before harvesting.
- **Sweat Biomarker Monitoring:** Integrates into wearable health electronics for continuous, non-invasive tracking of biomarkers (such as glucose, lactate, or electrolytes) to assess athletic performance and patient health in real time.

Acknowledgments

This material is based upon work supported by the National Science Foundation under Grant No. 2349238. This work was supported in part by the Semiconductor Research Corporation (SRC)

Kukla, Sigmond, et al. “Lessons learned from designing a wireless universal electrochemical sensing system.” 2025 IEEE 16th Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON), 22 Oct. 2025, pp. 0143–0149, https://doi.org/10.1109/uemcon67449.2025.11267680.

Hoilett, Orlando S., et al. “Kickstat: A coin-sized potentiostat for high-resolution electrochemical analysis.” Sensors, vol. 20, no. 8, 23 Apr. 2020, p. 2407, https://doi.org/10.3390/s20082407.