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Autonomous Reconfigurable Event Sensor (ARES) System

by Sean Heintzelman

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Sean Heintzelman
DEVCOM Army Research Laboratory

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14. ABSTRACT
ARL's Electric-/Magnetic-field sensing team has successfully demonstrated three different prototype low size, weight, and power sensor systems for measuring and analyzing ultra-low-frequency (30–300 Hz) electric and magnetic fields. These Autonomous Reconfigurable Event Sensor (ARES) systems exhibit low size, weight, power, and cost characteristics; volume and weight on the order of a deck of playing cards (75–150 cm^3, 50–100 g), low active power consumption (10–30 mW) to permit over 10 days of continuous operation on a cell-phone-sized battery (5–20 Wh), and a total system cost of under $1000. The size and power consumption also permits indefinite operation in a sunny environment with a 50–100 cm^2 integrated solar panel.
This report provides an overview for one of the three prototype ARES-class sensor systems: ARL-ARES. This system was designed and built in-house at ARL. It is a novel sensor system that includes a custom-designed 2.125- × 3.125-inch printed circuit board, a small 5-Wh LiPo battery, and a custom 3D-printed enclosure. Power consumption less than 25 mW, frequency bandwidth of 0 Hz – 2 kHz, and wireless communication using standard Bluetooth low-energy protocols have been demonstrated. ARL-ARES additionally has a modular interface to permit other communications options (e.g., inter-integrated circuit, serial peripheral interface, or universal asynchronous receiver–transmitter). This ARES form factor has one integrated D-dot (electric-field) sensor and two integrated Hall-effect (magnetic-field) sensors to measure 0–2 kHz local electric and magnetic fields but can also accept up to six external analog sensors for alternative applications with similar bandwidth.

15. SUBJECT TERMS
Electromagnetic Spectrum Sciences, Autonomous Reconfigurable Event Sensor, ARES, Hall effect, magnetic field, sensor system

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Sean Heintzelman	(520) 714-2525

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1. Introduction

The emergence of Internet of Things (IoT) technologies in private industry has resulted in rapid development and widespread availability of low size, weight, and power–cost (SWaP-C) embedded system technologies. The private sector alone has more than 16 billion IoT endpoints with an expected increase in the following years.[1] The ability to perform edge processing at lower cost and power is advantageous for applications that require small size, portability, long battery life, etc. Additionally, new standard protocols such as Bluetooth Low-Energy (BLE)[2] and radio-frequency identification (RFID)[3] have greatly reduced the power consumption of "low-bandwidth" wireless communications. By combining edge processing with low-power wireless communications and various sensors, commercial IoT sensor systems[4,5] have been realized and used across the world.

Low-frequency (LF) Electric-/Magnetic-field (E-/H-field) has not generally been implemented in these commercial IoT sensor systems. However, several government programs have requirements for sensing capabilities—e.g., the Defense Advanced Research Projects Agency's (DARPA's) Imaging Through Almost Anything Anywhere (ITAAAA) research program[6] and the U.S. Army's noncontact power sensing program.[7] Many of these programs would greatly benefit from incorporating sensing capabilities into an IoT-compatible architecture.

To meet the need of low-SWaP, LF electromagnetic edge processing, the U.S. Army Combat Capabilities Development Command (DEVCOM) Army Research Laboratory (ARL) E-/H-field sensing team developed an approximately 40-cm^2, 20-mW class Autonomous Reconfigurable Event Sensor (ARES) platform. This platform is powered via 3.7-V battery and recharged via solar panel or USB-C cable, has an interface for measuring and processing analog sensor outputs in real time, and has several communication interfaces for reading from the ARES platform via serial peripheral interface (SPI), inter-integrated circuit (I2C), or BLE. The ARES platform contains two commercial microcontrollers for various applications that require a combination of data acquisition (DAQ) and low-power processing. The SWaP of the ARES platform makes it compatible with IOT-class (typically 1–5 Ah) lithium-polymer (Li-Po) or lithium-ion (Li-Ion) batteries, which gives the entire system an approximately 100-cm^3 form factor and continuous lifetime of more than 1 week.

The remainder of this technical report is organized as follows. Section 2 describes how current state of the art for IoT-class, LF E-/H-field sensing provides motivation for the ARL-ARES sensor. Section 3 describes the system design in more detail, focusing on the low-power aspects of each major system component. Section 4 outlines the experimental results obtained in the laboratory on raw data accuracy and power consumption. Sections 5 and 6 summarize our conclusions, next steps, and references.

2. Background

ARL Autonomous Real-Time Electric and Magnetic Integrated Sensor (ARTEMIS)[8] is a modular printed circuit board (PCB) that uses external sensors to function as a high-performance IoT node. The PCB provides 8–16 channels of 24-bit analog-to-digital converters (ADCs), up to 2 TB of raw data storage with removeable MicroSD cards, GPS for Institute of Electrical and Electronics Engineers (IEEE) compliance as a phasor measurement unit (PMU),[9] Wi-Fi and Ethernet options for communication, and a processor running a Linux Ubuntu operating system. Two sensor systems utilizing the ARTEMIS PCB at ARL are the mobile power meter (MPM) and the mobile unattended ground sensor (MUGS), shown in Figure 1. The MPM reads analog voltages of six differential H-effect sensors and two differential D-dot[10] sensors. MUGS uses either 1–8 analog sensors with Bayonet Neill–Concelman (BNC) outputs or 4 or 8 sensors through a LEMO interface.

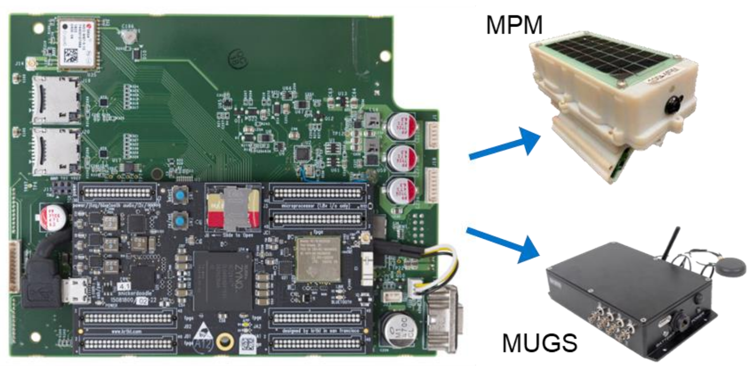


Figure 1. Top-down view of ARTEMIS PCB. The two ARL-developed primary sensor systems are shown: MPM (top right) and MUGS (bottom right).

Full operation of the MPM or MUGS systems consumes roughly 3 W, which is not practical for many applications; thus, ARL has developed a lower-power mode[11] where most ARTEMIS microcontroller units (MCUs) and integrated circuits implement an approximately 3% duty cycle to bring the average power consumption below 200 mW. Both systems also have an approximately 500-cm^3 form factors, and cost between $6000–$10,000.

The MPM includes two cable sensor PCBs, each with one "D-dot" (electric-field) and three Hall-effect (magnetic-field) sensors. Each cable sensor PCB also includes an MSP430 microcontroller[12] to provide sensor processing and minimal storage capability in low-power mode. The MSP430 class of microcontroller was chosen for the embedded cable sensor since it has several useful peripherals in ultra-low-power form factors:

differential 16-bit ADCs, 16-MHz processing speed, several low-power timers, and more than 50 general-purpose input-output pins. See Figure 2.

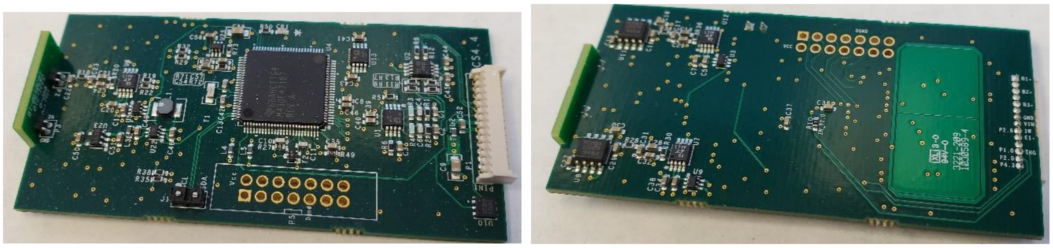


Figure 2. Top (left) and bottom (right) view of the embedded cable sensor PCB used in the ARTEMIS-class MPM.

While these embedded cable sensors offer 1–2 orders of magnitude power savings over the ARTEMIS in a much smaller form factor, there are several limitations preventing it from being a reliable low-SWaP standalone sensor node:

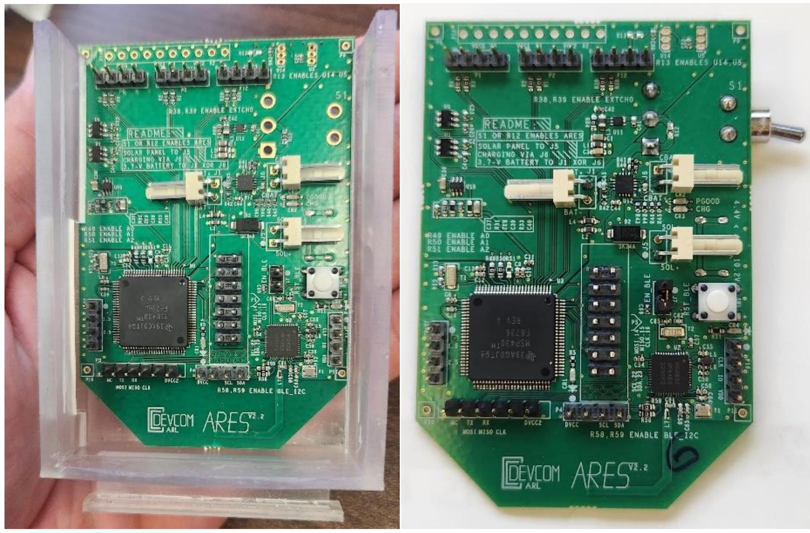
1) The three Melexis Hall effect sensors and one D-Dot sensor consume more than 150 mW to provide the proper bandwidth and transducer sensitivities for the MPM.

2) There is no hardware to synchronize measurements (within 1 ms) between several cable sensors.

3) There are no wireless data communication options.

4) The firmware is inadequate for storing data in a nonvolatile manner or in quantities larger than 4 kB.

These limitations mean the embedded cable sensor cannot operate as a wireless, low-SWaP, high-quality 0–2 kHz electromagnetic sensor. Therefore, ARES was designed and tested to improve on these limitations. The standard ARL-ARES form factor has one integrated D-dot sensor and two integrated H-effect sensors to measure local electric and magnetic fields, and is designed to operate unattended for more than 1 week off a 5-Wh Li-Po battery. The electric-field sensor and two Hall-effect sensors located on the bottom PCB layer were designed to measure sources near the top of the PCB. See Figure 3.



(a) (b)

Figure 3. (a) The ARES PCB inside a 3D-printed case. The case measures approximately 2.5 × 3.5 × 0.5 inches. (b) Top-down view of the 2023 ARES PCB with a power switch soldered.

3. ARL-ARES System Design

A summary of the ARES architecture is provided in Figure 4 as a block diagram, which highlights the major components and shows how they are linked to each other. The architecture includes both DC and AC sensing, up to six channels of DAQ, four communication options, up to 256-kb off-chip electrically erasable programmable read-only memory (EEPROM) storage, the ability to power ARES via solar panel and/or Li-Ion battery, and two embedded processors for system control and algorithm development. Details on several of these architecture components are covered in the following subsections.

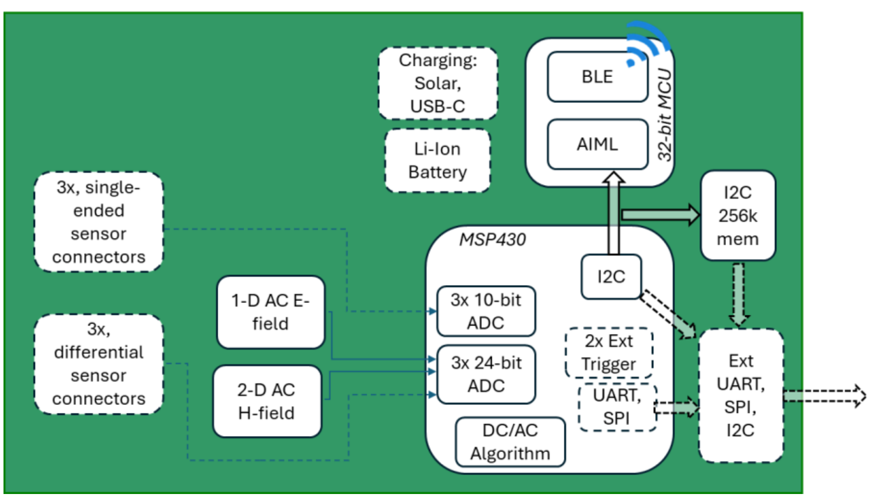


Figure 4. High-level diagram of the ARL-ARES architecture. The "blocks" internal to the PCB have solid outlines, while the blocks that physically connect to external components have dashed outlines.

3.1 Sensing

The ARES PCB has two onboard magnetic fields sensors. Two DRV5053 Hall-effect sensors[13] in the TO-92 package are used to measure the local magnetic field in two directions parallel to the PCB surface. These sensors have a nominal sensitivity of –90 V/T, a noise floor of 110 uV/rtHz, a rated current consumption of 2.7 mA, and a frequency bandwidth of DC –20 kHz. The DRV5053 sensors are connected to a passive low-pass filter, then connect to differential inputs of the 24-bit ADC Channel 0.

In addition to the magnetic field sensors, an integrated D-dot sensor[14] is designed and used to measure electric fields normal to the PCB surface. Two bottom layers of the PCB have 22- × 10-mm copper fills to function as D-dot electrodes, with the bottommost layer getting most of the induced electric-field current. This induced current travels through a trans-impedance amplifier, then to passive filtering and a differential amplifier for differential ADCs.

There are times when a user or application requires sensors other than those on the ARES PCB. Three channels of both the 10-bit ADC and 24-bit differential ADC are routed to external 100-mil header pins, which can be enabled/disabled via 0-Ω resistors. This allows the ARES board to read analog signals from novel LF sensors like the multidimensional electric- and magnetic-field sensor,[15] E-field cube,[16] H-cube,[17] etc. Commercial acoustic, magnetic, or seismic sensors are also generally compatible with these onboard ADCs.

3.2 Digital Interfacing

ARES has two physical connectors to support three different common low-power communication protocols: SPI, universal asynchronous receiver-transmitter (UART), and I2C. The two onboard processors, which will be discussed later, can both communicate in real time through these interfaces as required for a given application. The ARES PCB has silkscreen labels to aid the user in making these connections correctly (Figure 5).

Figure 5. The six-pin header for SPI or UART communication and four-pin connector for I2C communication are shown. Both can be used to send or receive data from either onboard processor.

For I2C communications, both processors on the ARES PCB support standard 100-kHz and fast-mode 400-kHz speeds. Both processors can be configured for client or server operation based on the specific application. The P4 connector gives the user access to this communication method with four-pin connections: (left to right) power "DVcc," ground, serial clock "SCL," and serial data "SDA."

For SPI communications, the MSP430 MCU supports speeds up to 17 MHz. The nRF52 system on a chip can support speeds of 8 MHz. As with the I2C communication method, both MCUs can be configured to be a client or server. The P3 connector gives the user access to this communication method with five-pins connections: (left to right) master out slave in "MOSI," master in slave out "MISO," clock "CLK," ground, and power "DVCC2." Pin 1 "NC" can optionally be used as trigger reset, but it is not typically used.

For UART communication, the MSP430 MCU supports clock speeds up to 25 MHz and data rates up to 5 MBaud. The nRF52832 supports clock speeds of 10 MHz and a BAUD rate of 1000 kBaud. As with the I2C and SPI communication methods, both processors are configurable to be a client or server. The P3 connector gives the user access to this communication method with four-pins connections: (left to right) transmit data "TX," receive data "RX," ground, and power "DVCC2." Pin 1 "NC" and Pin 3 (unlabeled) are not needed for most UART applications.

3.3 Front-End 16-bit Reduced Instruction Set Computer (RISC) Processor

ARES has a MSP430F6736 microcontroller[18] that contains an ultra-low-power 16-bit RISC processor. This microcontroller has three channels of differential 24-bit sigma-delta ADCs, six channels of single-ended 10-bit ADCs, 8 kB of on-chip RAM, 128-kB of on-chip FLASH, and the CPU clock can readily be adjusted between 32 kHz and 25 MHz based on low-power versus higher-performance applications.

The MSP430 is used as the "front-end" processor in the ARES architecture. It acquires all data from ADC inputs, performs basic signal processing algorithms like low-pass filtering, high-pass filtering, phasor estimation algorithms, or noise-suppression averaging, then sends the raw or processed data off chip for storage and/or high-end processing.

The MSP430 uses a common low-power, I2C interface to offload processed ADC measurements to an onboard 256-kB EEPROM to overcome the lack of nonvolatile memory of the MSP430. The MSP430 can also offload the processed ADC measurements to a host/server via I2C, SPI, or UART digital communications.

3.4 Back-End 32-bit Advanced RISC Machine (ARM) Processor

ARES also has a nRF52832 microprocessor[19] that contains a low-power 32-bit ARM core. The nRF52 has eight channels of single-ended 12-bit ADCs, 64 kB of on-chip RAM, 512 kB of on-chip FLASH, and the CPU clock can readily be adjusted between 1 and 64 MHz based on low-power versus higher-performance applications.

The nRF52 is used as the "back-end" processor in the ARES architecture. It acquires all data from the MSP430 via I2C or SPI and can perform advanced signal processing algorithms like Discrete Fourier Transform (DFT), floating-point mathematics, or machine learning with TensorFlow Lite. Then, it sends the raw or processed data off-chip trough wired connectors (P3 and P4) or wirelessly via Bluetooth.

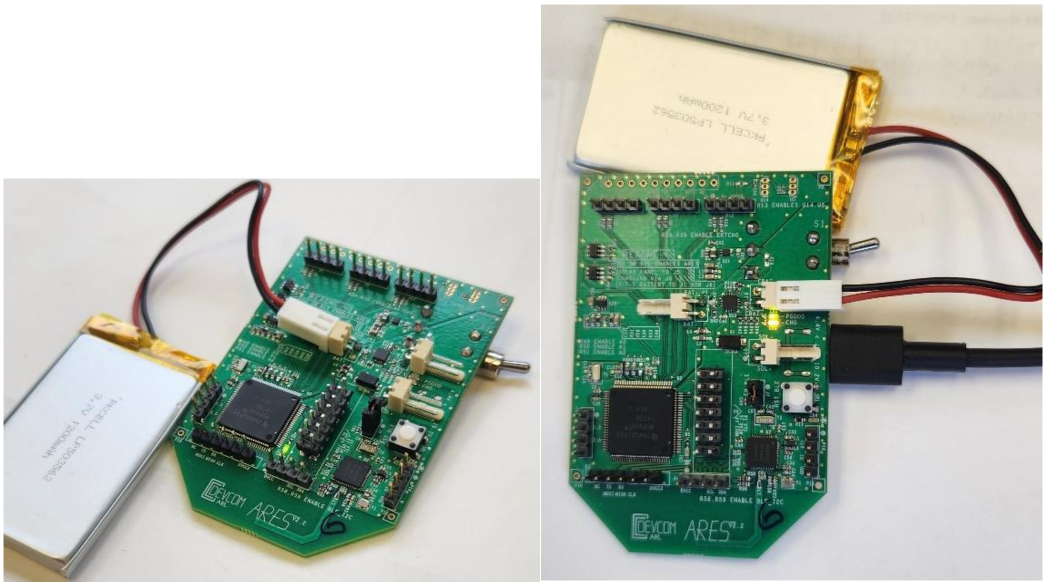
ARES achieves wireless communications via BLE protocols, which are implemented with the nRF52832 BLE Stack.[*20] This wireless communication method gives ARES a 1-Mb bandwidth for raw data, while also allowing for low-bandwidth IoT notifications so the end user is only alerted when "an event" is detected by ARES. ARES has a 2.45-GHz quarter-wave monopole antenna[21] on the PCB with a custom nRF52 layout for wireless data transfer (Figure 6).

Figure 6. Back-end processing section. It includes nRF52 to read data via SPI or I2C, a 2.45-GHz PCB antenna to transmit processed data over BLE, a reset button, and a four-wire programming interface.

[*] BLE Stack is an open-source soft device provided by Nordic Semiconductor, which provides the user both standard BLE applications and the framework for custom BLE applications.

3.5 Power and Battery Charging

ARES is typically powered by a single 3.7-V rechargeable battery and turned on/off with an IP-68 rated toggle switch. It is also equipped with a battery-charging circuit to increase lifetime when an IoT-class power/recharging source is available. Two typical battery configurations for the ARES are pictured in Figure 7.



(a) (b)

Figure 7. (a) ARES PCB is powered directly with the left-facing battery connector J1 for stand-alone applications. (b) ARES is connected to a USB-C power source, which charges a battery powered by the right-facing battery connector J6.

ARES can operate off a 3.0-V button-cell battery connected directly to a Vdd or Vcc pin, 3.3-V LiFePO4 battery connected to J1 or a Vdd or Vcc pin, or 3.7-V Li-based battery connected to J1 (used in Figure 7a). However, only 3.7-V class batteries are compatible with charging circuitry via connector J6 (used in Figure 7b).

The charging circuit can simultaneously power ARES onboard electronics and recharge a 3.7-V battery with a 4.4–10.2 V power source. In IoT, arguably the most common method fitting such criteria is standard USB-C charging[22]; therefore, the ARES has been designed with a power-only USB-C female connector. For wireless sensing applications, a third 100-mil friction-lock connector J5 and USB-C female connector are both available to directly connect IoT-class solar panels[23] or other wireless chargers.

4. Sample ARES Application

A simple test setup is created to demonstrate the "raw data" configuration of ARES. An Agilent 33500-B[24] arbitrary waveform generator (AWG) is used to generate known sinusoidal voltages and provide a ground reference voltage. The AWG output is configured for the second output channel to be an inverted duplicate (same voltage, same frequency, same offset, 180-phase shifted) of the first output channel. We will generate a 60-Hz 1-V_{pp} signal with a 0-V offset on the first two output channels and use the grounded-BNC shield as the third analog voltage output.

The outputs of the Agilent AWG are wired to ARL-ARES connectors P1, P2, and P12: AWG channel 0 output to 24-bit ADC Channel 0 input via P12, AWG channel 1 output to 24-bit ADC channel 1 input via P2, and AWG reference ground to 24-bit ADC Channel 0 input via P1. The MSP430 24-bit ADCs are configured to measure at 4-kHz/s sample rate on all three channels. Then, they are configured to push all the data over the SPI channel to the nRF52. The Nordic S132 soft device was downloaded to the NRF52 and a peripheral customer service template[25] was used with sleep time removed and the Two-Wire Interface (TWI) SPI driver enabled to maximize data throughput to a Bluetooth server.

The raw data was sent off-chip to a Dell computer with an Ubuntu operating system and Bluetooth capability. The computer has a Python script leveraging the MATPLOTLIB library to graphically display ARES data as it comes in. The ARES board was powered through a MSP430-FET cable running Texas Instruments (TI) EnergyTrace[26] software to measure power usage of the entire ARES PCB. A 1-s plot of the ARES raw data is shown in Figure 8, as well as a 10-snapshot of the power consumption measured by the EnergyTrace software.

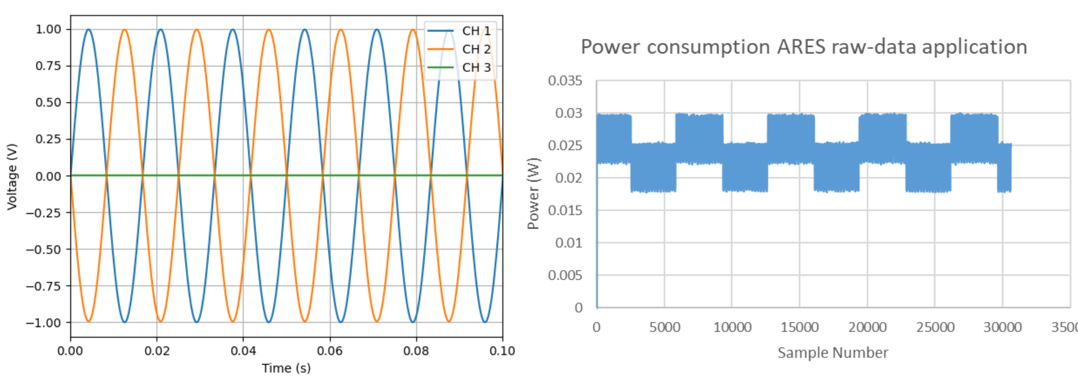


Figure 8. (Left) Python library MATPLOTLIB is used to graph ARES raw data in real time and display data in 1-s intervals. (Right) TI EnergyTrace software was set to record 10 s of power-usage data at a 3-kHz sample rate.

The MSP430 ADC voltage measurement for all three channels is shown to be within 1% of the voltage output set on the AWG front panel. The power consumption of the 10-s power measurements was 30-mW peak and 23-mW average, which could be lowered to 25-mW peak and 21-mW average with the indicator LED duty cycle reduced from 50% to 0%. With the small battery included in Figure 7, this setup can run for more than 1 week without any recharging or battery swapping.

5. Conclusion and Future Work

This technical report describes the design, operation, and performance of the ARL-ARES. This novel sensor system was shown to perform 24-bit data acquisition processing, storage, and wireless communications of 4-kHz raw data for an average power consumption of 23 mW. We demonstrated that ARES ADCs can measure calibrated 60-Hz sinusoids within 1% accuracy. The complete form factor of the design is approximately 80 cm^3 without external sensors.

ARES architecture is the basis for a variety of custom applications related to power/energy, machine learning, anomaly detection, etc. Those applications typically require custom sensors, electronics, and algorithms that will be detailed in future reports.

6. References

1. IoT Analytics. Number of connected IoT devices growing 13% to 18.8 billion. State of IoT Summer 2024 report; 2024.
2. Woolley M. Bluetooth Core Specification Version 5.0 Feature Enhancements. Bluetooth; 2021 Sep 9.
3. ISO/IEC 18000. Information technology — radio frequency identification for item management. International Organization for Standardization; 2008.
4. Apple Watch Ultra 2. Apple Inc; c2024 [accessed 2024 Sep]. https://www.apple.com/apple-watch-ultra-2/
5. Nordic thingy:52 IoT sensor kit. Nordic Semiconductor; c2024 [accessed 2024 Sep]. https://www.nordicsemi.com/Products/Development-hardware/Nordic-Thingy-52/GetStarted
6. Imaging through almost anything anywhere. Defense Advanced Research Projects Agency; [date unknown], [accessed 2024 Sep]. https://www.darpa.mil/program/imaging-through-almost-anything-anywhere
7. Mobile Power Meter (MPM). TechLink; c2022 [accessed 2024 Sep]. https://techlinkcenter.org/technologies/mobile-power-meter-mpm/4ba5be3f-2f19-4694-a6d5-ff79fe26b9a2
8. Hull D. ARL-ARTEMIS, Revision 3.5 [poster presentation]. DEVCOM Army Research Laboratory (US); 2021 Nov 22.
9. IEEE C37118.1-2011. IEEE standard for synchrophasor measurements for power systems. IEEE; 2011.
10. Heintzelman S. Self-adjusting quasi-static electric-field Sensor. Proceedings of the 2016 Electrostatics Joint Conference; 2016.
11. Snellman A et al. Continuous, non-intrusive electric field & electric power monitoring using smart low power mode switching for ARTEMIS MPM. Proceedings of the Military Sensing Symposium; 2022.
12. MSP430F471×3, MSP430F471×6, MSP430F471×7 mixed signal microcontrollers. Texas Instruments; 2011 Oct.
13. DRV5053 analog-bipolar hall effect sensor. Texas Instruments; 2015 Dec.
14. Heintzelman SM, Ghionea SJ, Hull DM, inventors; US Department of Army, assignee. Non-contact multi-phase cable sensor. United States patent US 10,775,420. 2020 Sep 15.

15. Heintzelman S, Hull D, George A. Multi-dimensional electric- and magnetic-field sensor for low-frequency applications. Proceedings of IEEE Industrial Applications Society Annual Meeting; 2019; Baltimore, MD.

16. Ghionea SJ, Hull DM, inventors; US Department of Army, assignee. Electric field sensor. United States patent US 9,829,524. 2015.

17. Hull D. ARL-MUGS, Revision 3.3 [poster presentation]. DEVCOM Army Research Laboratory (US); 2021 Nov 22.

18. MSP430F673x, MSP430F672x mixed-signal microcontrollers. Texas Instruments Inc; 2018.

19. Multiprotocol Bluetooth smart, ANT/ANT+and 2.4GHz proprietary system-on-chip. Nordic Semiconductor Inc; c2024 [accessed 2024 Sep].

20. Bluetooth Stack Architecture. Nordic Semiconductor Inc; c2024 [accessed 2024 Sep]. https://docs.nordicsemi.com/bundle/ncs-2.2.0/page/zephyr/connectivity/bluetooth/bluetooth-arch.html

21. λ/4 printed monopole antenna for 2.45GHz [white paper]. Nordic Semiconductor Inc; 2005.

22. Universal serial bus type-C cable and connector specification. USB 3.0 Promoter Group; 2019.

23. Anker. PowerPort Solar Lite 2. Fantasia Trading LLC; 2022, [accessed 2024 Sep]. https://www.anker.com/products/a2422?variant=37437269672086

24. 33500B and 33600A series true waveform generators. Keysight Technologies; 2023.

25. Haakonsh. nRF Connect SDK Bluetooth Low Energy tutorial. Nordic Semiconductor Inc, DevZone; 2020 Feb 11 [accessed 2024 Feb]. https://devzone.nordicsemi.com/guides/nrf-connect-sdk-guides/b/getting-started/posts/ncs-ble-tutorial-part-1-custom-service-in-peripheral-role

26. EnergyTrace. Texas Instruments Inc; c2024 [accessed 2024 Feb]. https://www.ti.com/tool/ENERGYTRACE

List of Symbols, Abbreviations, and Acronyms

3D	three-dimensional
AC	alternating current
ADC	analog-to-digital converter
ARES	Autonomous Reconfigurable Event Sensor
ARL	Army Research Laboratory
ARM	Advanced RISC Machine
ARTEMIS	Autonomous Real-Time Electric and Magnetic Integrated Sensor
AWG	arbitrary waveform generator
BLE	Bluetooth Low-Energy
BNC	Bayonet Neill–Concelman
CLK	clock
CPU	central processing unit
DAQ	data acquisition
DARPA	Defense Advanced Research Projects Agency
DC	direct current
DEVCOM	U.S. Army Combat Capabilities Development Command
DFT	Discrete Fourier Transform
EEPROM	electrically erasable programmable read-only memory
GPS	global positioning system
I2C	inter-integrated circuit
IoT	Internet of Things
ITAAAA	Imaging Through Almost Anything Anywhere
LED	light-emitting diode
Li-Ion	lithium-ion
Li-Po	lithium-polymer
MCU	microcontroller unit

MISO	master in slave out
MOSI	master out slave in
MPM	mobile power meter
MUGS	mobile unattended ground sensor
PCB	printed circuit board
PMU	phasor measurement unit
RAM	random access memory
RFID	radio-frequency identification
RISC	reduced instruction set computer
RX	receive data
SCL	serial clock
SDA	serial data
SPI	serial peripheral interface
SWaP	size, weight, and power
SWaP-C	size, weight, and power–cost
TI	Texas Instruments
TX	transmit data
UART	universal asynchronous receiver-transmitter
USB	Universal Serial Bus

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