Demo: Design and Implementation of a Low-cost Arduino-based High-Frequency AC Waveform Meter Board for the Raspberry Pi

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ABSTRACT

This paper introduces a low-cost AC meter designed to continuously measure voltage and current waveforms at up to 14 kHz. The AC power meter, provided as open hardware, is designed using the same micro controller as the Arduino UNO[1] with an In-system Programming (ISP) interface, thus allowing the user to change the firmware to match their particular use case using Arduino libraries or standard C language. The suggested design is compatible with the Raspberry Pi 3[2], making it a suitable real-time measurement accessory for the single board computer. The platform features an 8 channel simultaneous sampling Analog-to-Digital Converter (ADC) which allows a high fidelity sampling without time offsets. Depending on how the user decides to combine current transformers (CTs) and AC-AC voltage adapters for the input channels, circuit breakers or appliances can be measured in either one phase or three phases.

CCS CONCEPTS

• **Computer systems organization → Embedded hardware**; *Sensors and actuators*; *Real-time system specification*;

KEYWORDS

AC waveform, High frequency, Power meter, Open source, Open hardware, Low-cost

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1 INTRODUCTION

Smart meters, electronic devices with the capability of recording electrical consumption in regular intervals are key participants in a fully smart grid. From households to businesses a collection of connected and controlled devices able to report and track electricty consumption will potentially reduce points of failure as well as track demand and overall performance. These devices are also valuable tools to collect data for further analysis with Non-Intrusive Load Monitoring (NILM) techniques for appliance-specific identification [3] or real-time feedback towards energy savings [4].

Our team has been working on energy disaggregation approaches [2] and, in terms of hardware selection, we have already used the open source Open Energy Monitor[3] for experiments [2] and decided we wanted to look for more options, especially with higher sampling frequencies and more input channels. Commercial alternatives such as Fluke Power Quality Analyzers[4] offer high fidelity sampling at high frequencies but at thousands of U.S. Dollars. At similar costs, companies such as Verdigris[5] offer a complete solution from sensor deployment to data collection and analytics, which are robust and attractive candidate solutions to our problem. However, for many applications a simpler and lower-cost hardware solution is preferables. Thus, we decided to look for an open source smart meter board with similar characteristics to commercial solutions such as multi input channels and high sampling frequency, but at a lower cost.

Among the different open source platforms for prototyping, Arduino has been widely used in different power metering projects [1][6]. In some cases, the device might not have the open source development board but will make use of its libraries and Integrated Development Environment (IDE) for its simplicity and already available support [5]. Yet, these open source alternatives are more focused towards in-hardware power calculation at low frequencies with expandability of only up to a couple of channels.

In this demo, we present a low-cost AC waveform power meter based on an Arduino UNO in a shield form factor, i.e. extension board, compatible with single board PCs like the Raspberry Pi 3 (RPi3). The core idea behind this device is to acquire data simultaneously on multiples channels at relatively high frequencies for multiple or single circuit branches, i.e. circuit breakers or appliances, in either one phase or three phases. The proposed device could also potentially be used as another data collection alternative for high-resolution datasets such as PLAID[6].

2 HARDWARE DESIGN

The Arduino UNO is an open source development board with an ATmega328p as the main micro controller. It is easy to use and configure with different available libraries if the user decides to use the Arduino bootloader, or with standard C language. For these reasons, we decided to use this micro-controller to interact directly with the selected ADC, AD7808. This ADC from Analog Devices is

[1]http://www.arduino.cc
[2]https://www.raspberrypi.org
[3]http://openenergymonitor.org
[4]http://en-us.fluke.com/products/power-quality-analyzers/
[5]https://verdigris.co
[6]http://plaidplug.com

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Table 1: Sampling frequencies using different number of channels

Num. of Channels	Frequency (kHz)	Use Case Example
2	14	Voltage, Current
3	11.8	Voltage, 2 CTs Current
4	10	Voltage, 3 phase Current
8	6.7	Full use of ADC

an 8-channel simultaneous sampling integrated circuit with inputs of up to ±10V, and a resolution of 16 bits, which is able to communicate with the micro-controller using the Serial Peripheral Interface (SPI). By sending start commands from the micro-controller, the AD7808 is able to sample and convert its 8 inputs in approximately 50 μs. The micro-controller is then in charge of sending the data using the Universal Asynchronous Receiver/Transmitter (UART) at 2Mbps to the RPi3. Though the ATmega328p can achieve a UART speed of 2.5Mbps with a 20MHz external oscillator, we decided to use the same 16MHz external oscillator that the Arduino UNO board uses, mainly to maintain compatibility.

Since the suggested design is provided as a shield, it can be stacked on top of the RPi3, use its general-purpose input/output pins to power itself, and work as a plug and play device allowing the RPi3 to start reading the data at any moment. The software component on the power meter board allows the user to change the number of channels to be used. Fewer channels will allow a higher sampling frequency since one full cycle consist of sampling, converting, and transmitting the data. Table 1 shows the obtained measurements for a different number of channels. The sampling frequency can also be modified by changing the communication speed between the meter board and the RPi3. The meter board suggested design has ISP pin headers so that the user can change the firmware with a regular AVR programmer, or directly from the RPi3 using the appropriate libraries.

3 SET UP AND REQUERIMENTS

Our proposed design of an AC waveform power meter can be deployed at the appliance level, measuring one or three phases just by adding more CTs or AC-AC voltage adapters. Before connecting the CTs and the AC-AC voltage adapter or powering the RPi3, the meter should be stacked on top of the RPi3. Once the single board PC is powered, the power meter will start acquiring data. On the RPi3, the UART speed has to match the speed on the meter board in order to correctly receive the data. After the stream is synchronized, data is ready to either be stored or processed locally or remotely, thanks to the wireless local area network (WLAN) capabilities of the RPi3. Figure 1 shows the computer-aided design (CAD) done with EAGLE[7]. In our suggested design, 7 of the 8 channels have connectors for CTs, with the option to use shunt resistors, while the remaining one has a barrel connector jack for AC-AC voltage adapters.

[7]https://www.autodesk.com/products/eagle/overview

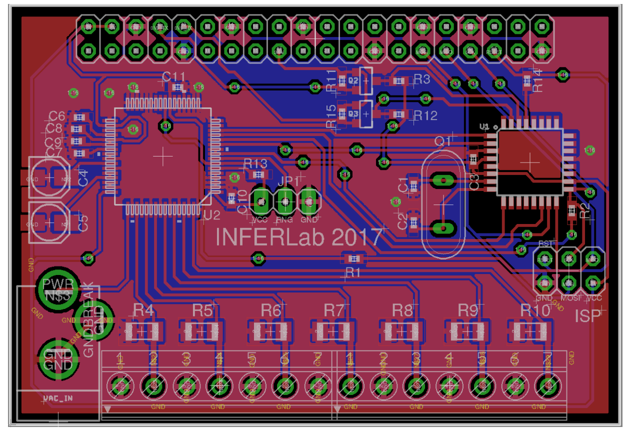

Figure 1: Metering shield board CAD.

4 CONCLUSION

This demo presents a low-cost (less than U.S. Dollars 50 excluding the RPi3) open source AC power meter with the main focus on waveforms and relatively high frequencies. In contrast to other open source meters, it relies on up to 8 simultaneous sampling channels, allowing it to successfully measure voltage and three phase current of one appliance at 10kHz. This device can be used to perform NILM techniques such as load disaggregation and identification with a live stream of data. The design files and source code is available at `https://github.com/INFERLab/AC_Waveform_Meter`.

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