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Design and Initial Performance of the HARDWARE.astronomy Housekeeping (H.aHk) Box

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Abstract

An often unglamourous, yet critical, part of most millimeter/submillimeter astronomical instruments is cryogenic temperature monitoring and control. Depending on the operating wavelength of the instrument and detector technology, this could be stable temperatures in the Kelvin range for millimeter heterodyne systems to 100mK temperatures at sub-microKelvin stability as for many submillimeter bolometer systems. Here we describe a project of the HARDWARE.astronomy initiative to build a low-cost open-source temperature monitoring and control system. The HARDWARE.astronomy Housekeeping Box, or H.aHk Box (pronounced "hack box") is developed primarily by undergraduates and employs existing open-source devices (e.g Arduino, RaspberryPi) to reduce costs while also limiting the complexity of the development. The H.aHk Box features a chassis with a control computer and 10 expansion slots that can be filled with a variety of expansion cards. These cards include initially an AC 4-wire temperature monitor and PID control cards. Future work will develop 2-wire temperature monitors, stepper motor controller, and high-power supply. The base-system will also be able to interface with other house-keeping systems over USB, serial port and ethernet. The first deployment of the H.aHk Box will be for the 2nd gen. z(Redshift) and Early Universe Spectrometer (ZEUS-2), a submillimeter grating spectrometer. All designs, firmware, software, and parts list will be published online allowing for other projects to adopt the system and create custom expansion cards as needed. Here we describe the design (including mechanical, electrical, firmware, and software components) and initial performance of the H.aHk Box system with initial AC/DC 4-wire and PID cards.

Figure 1: Zeus-2 submillimeter grating Spectrometer (Top Left), APEX telescope in Chile (Top Right), current housekeeping instrumentation for Zeus-2 (Bottom).

I. Background/Requirements

Goal: Design and implement the H.aHk Box [1], an open-source platform for monitoring and controlling internal temperatures of the Zeus-2 [2][3][4] Spectrometer.

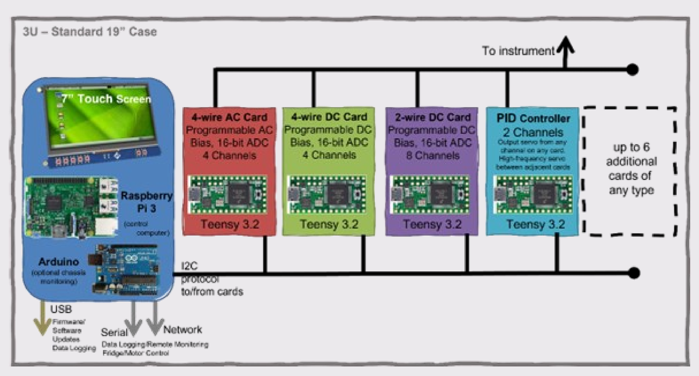


Figure 2: System block diagram including provisions for user interface (touch screen), central processing unit (RPI 3), communication and signal routing device (Arduino), and various planned expansion cards.

Design Requirements:

- ~$3000 in hardware costs.
- Adhere to opensource standards.
- Flexible platform for future adaptation
- Interface with various exterior hardware.
- Temperature accuracy and stability comparable to a Lakeshore Model 350 Temperature controller.
- ≥3x times the readout channels than Model 350.

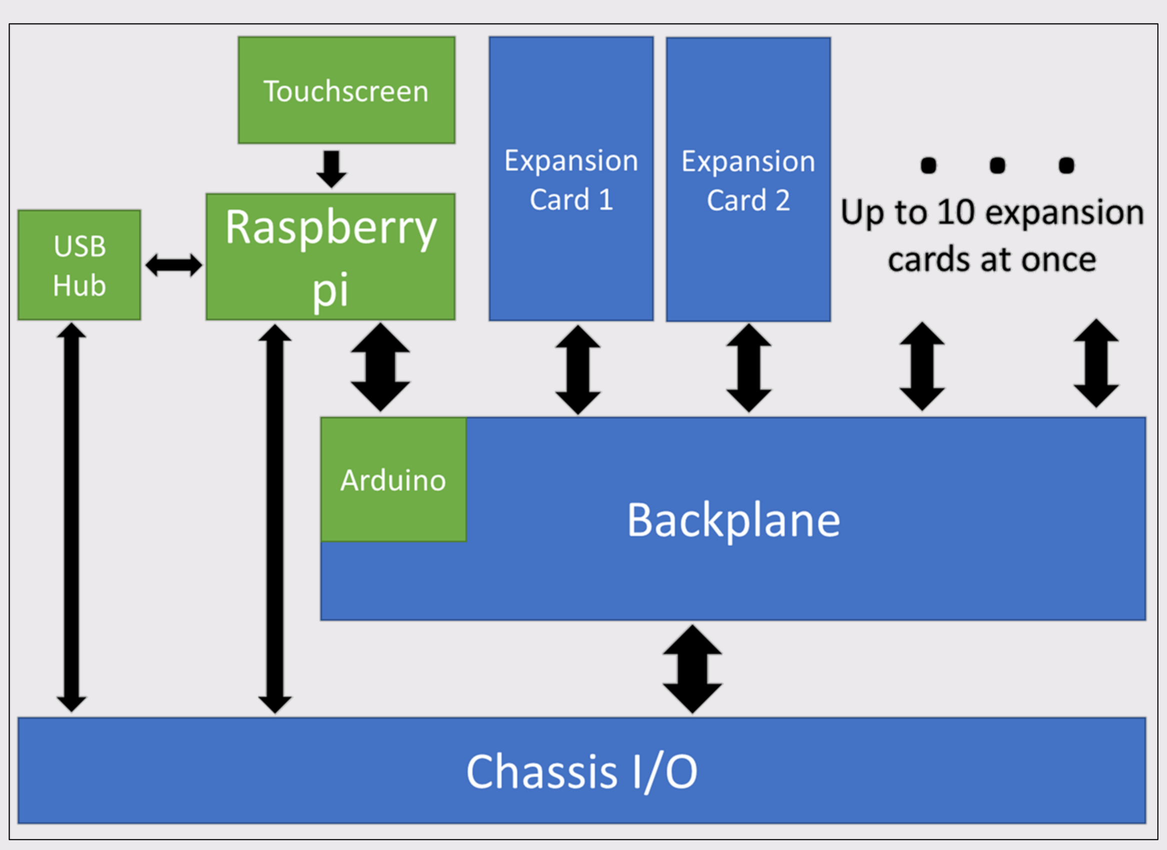


Figure 3: H.aHk Box system block diagram including all primary system components and their respective relationships.

II. Chassis

- 3U unit with 10 expansion cards and a touch screen
- Dedicated DC power supplies @ +5V and +24V
- 2 high power pins per slot
- 36 GPIO pins per slot
- 8 custom parts

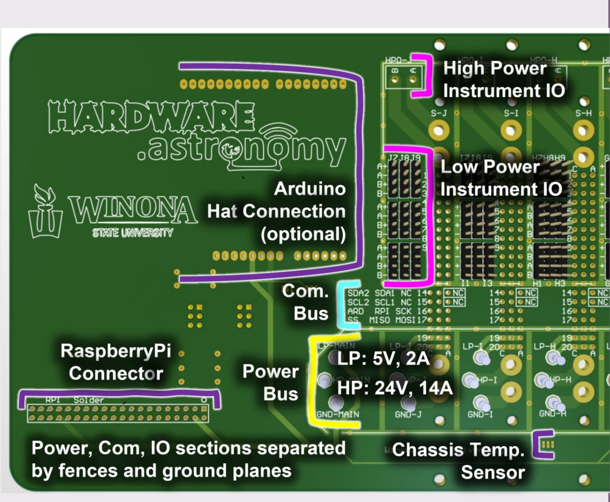
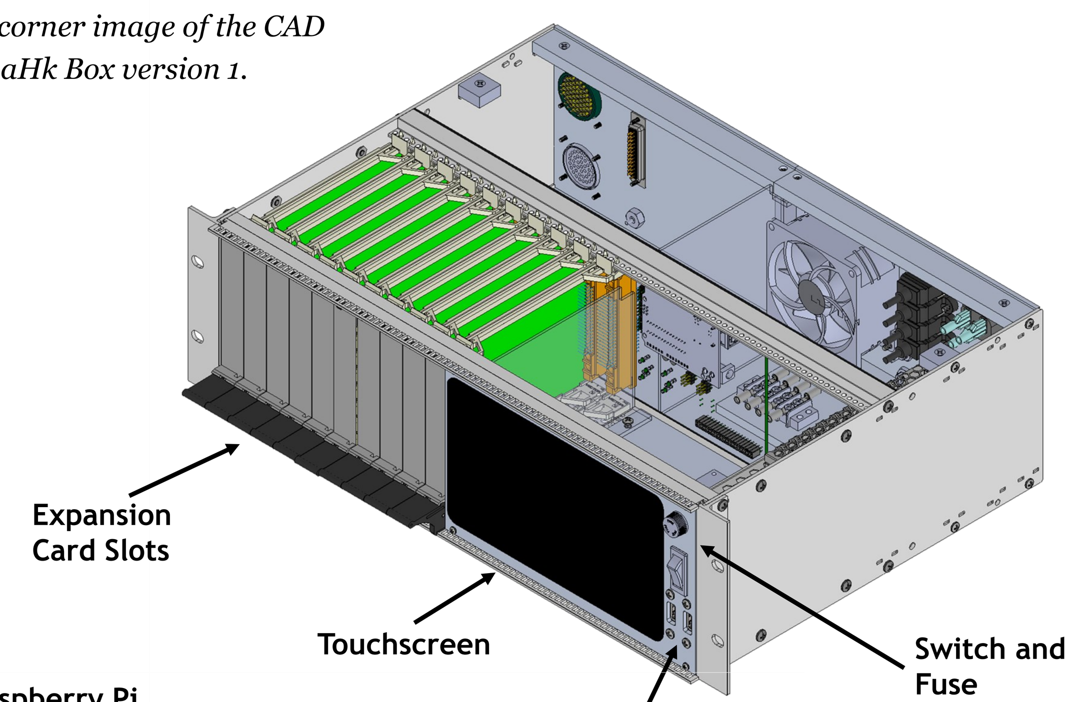


Figure 4: Chassis Backplane that expansion cards plug into providing 5V & 24v power, I²C communication to RaspberryPi, SPI communication between card pairs for high speed PID control, and both High-Power (20A max) and Low Power Instrument IO. The later are general purpose for various card types but are grouped into 4-wire pairs.

Figure 5: Front corner image of the CAD model for the H.aHk Box version 1.



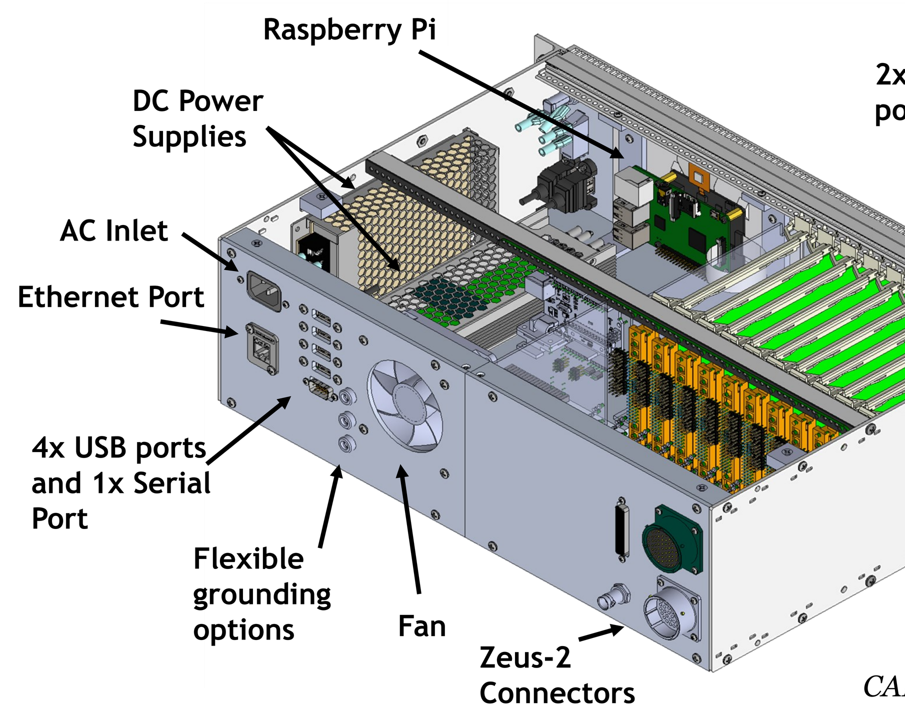


Figure 6: Back corner image of the CAD model for the H.aHk Box version 1.

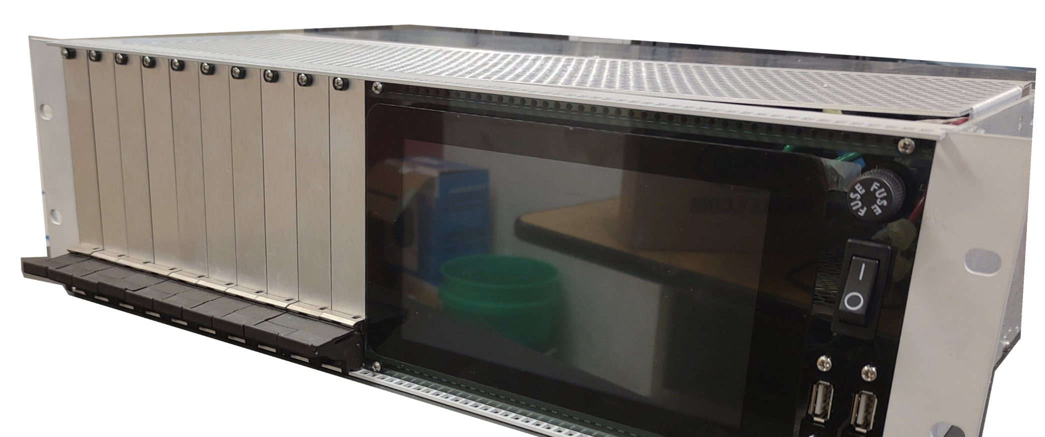


Figure 7: The physical implementation of the H.aHk Box version 1.

III. Software

Communication API:

- Python (RaspberryPI) and Arduino (Expansion Cards)
- I²C between Raspberry Pi & Expansion Cards
- SPI between card pairs

Graphical User Interface:

- Built on Plot.ly & DashDAQ
- Touch screen or remotely
- Runs in Webserver

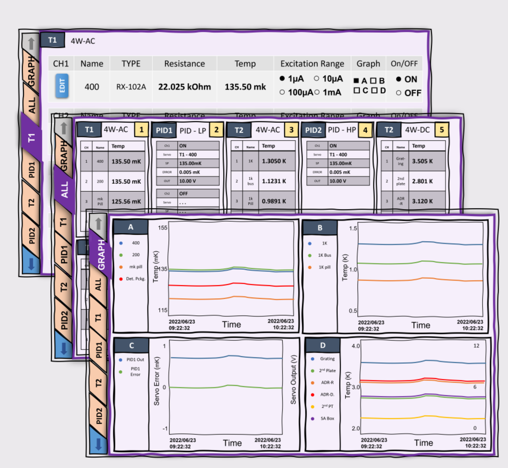


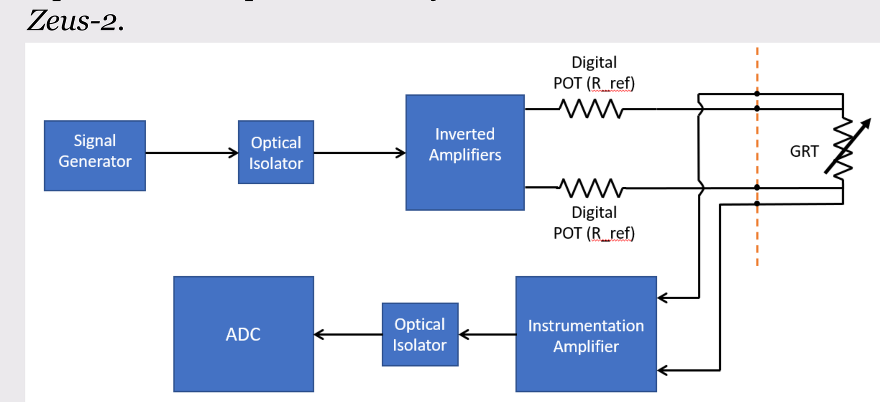
Figure 8: Mock-up of H.aHk box GUI showing (bottom to top) tabs of graphs, a summary of each card, and card configuration.

IV. 4-Wire AC Expansion Card

Methods of Operation:

- 4 wire measurement
- AC coupled signal
- RMS algorithm
- Measurement averaging
- Multiple sensitivity ranges
- Calibrated look-up tables

Figure 10: Analog circuit block diagram. The orange dashed line separates the expansion card from the GRT that resides within Zeus-2.



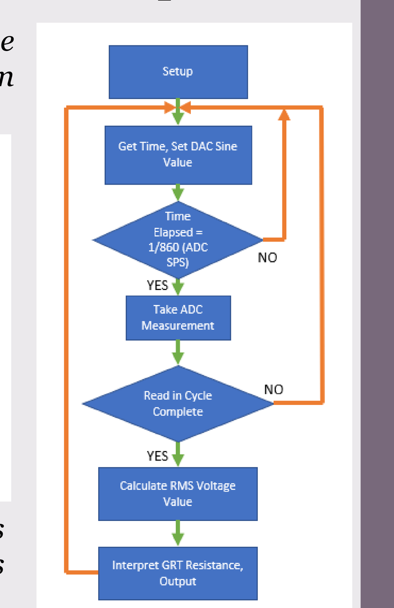


Figure 9: Firmware block diagram. Firmware initializes hardware, continuously pulls ADC measurements, calculates RMS, and averages across multiple sinusoidal cycles.

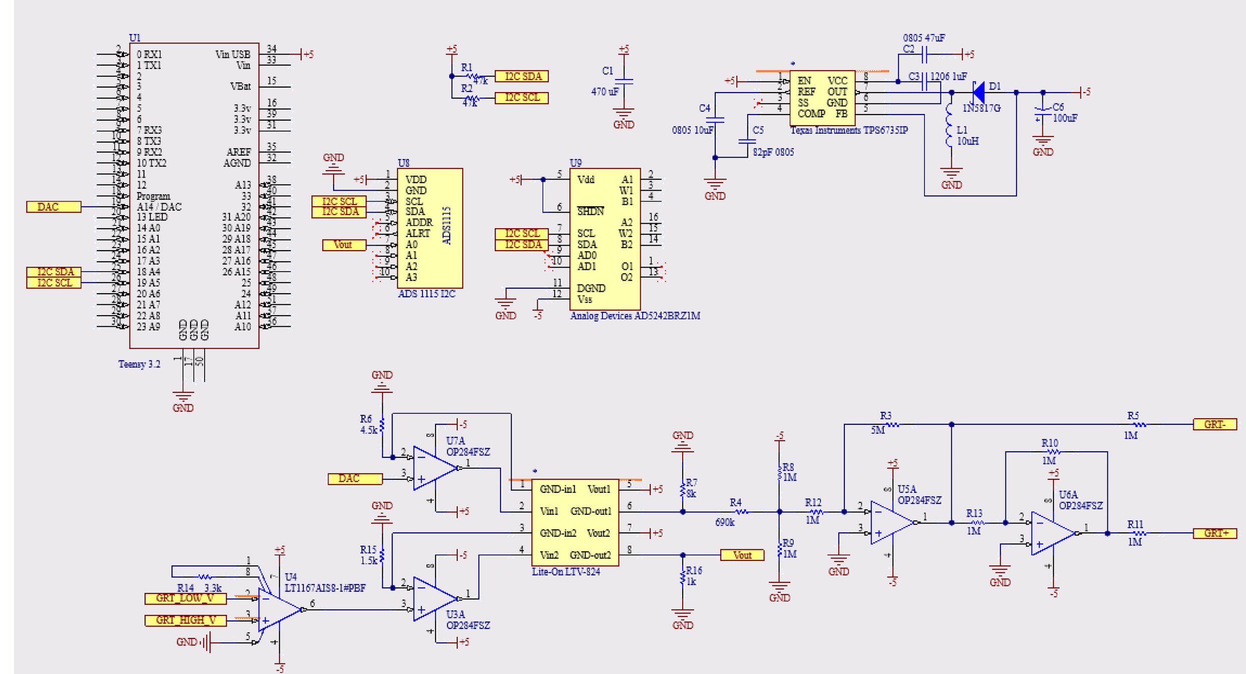


Figure 11: Current prototype circuit schematic. Critical components include the Teensy 3.2, the ADS1115 ADC for digitizing the signal, the ADS5242 digital potentiometer, the LTV-824 optical isolator, 4 OP284 op-amps, and an LT1167 instrumentation amplifier for amplifying and converting the signal from differential to single ended.

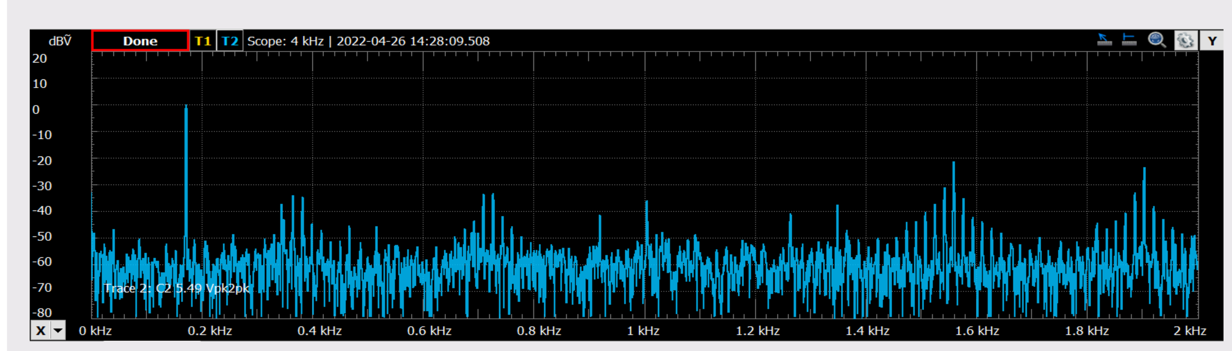


Figure 12: FFT spectrum of 4-wire AC analog circuit output. A clear spike at the modulation frequency of about 172 Hz was observed with only small amounts of other noise noted.

V. Next Steps

- Complete PCB design of 4-wire AC card
- Validate and test 4-wire AC card
- Refine and test system software
- Design 4-wire DC expansion card
- Design PID expansion card
- Design 2-wire DC expansion card

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[1] Ferkinhoff, Carl. (2014). Hacking for astronomy: can 3D printers and open-hardware enable low-cost sub-/millimeter instrumentation?. 915329. 10.1117/12.2056627.
[2] Ferkinhoff, Carl & Nikola, Thomas & Parshley, Stephen & Stacey, Gordon & Irwin, Kent & Cho, Hsiao-Mei & Halpern, Mark. (2010). ZEUS-2: A second generation submillimeter grating spectrometer for exploring distant galaxies. 7741. 10.1117/12.857018.
[3] Parshley, Stephen & Ferkinhoff, Carl & Nikola, Thomas & Stacey, Gordon & Ade, Peter & Tucker, Carole. (2012). The Optical, Mechanical, and Thermal Design and Performance of the 2nd Generation Redshift (z) and Early Universe Spectrometer, ZEUS-2. 8452. 10.1117/12.927238.
[4] Ferkinhoff, Carl & Nikola, Thomas & Parshley, Stephen & Stacey, Gordon & Irwin, Kent & Cho, Hsiao-Mei & Niemack, Mike & Halpern, Mark & Hasselfield, Matthew & Amiri, M.. (2012). Design and first-light performance of TES bolometer arrays for submillimeter spectroscopy with ZEUS-2. 8452. 07-. 10.1117/12.927237.

Learn more about the project at https://osf.io/yktem/