Antarctica Ross Ice-Shelf Antenna Neutrino Array (ARIANNA) Microcontroller Conversion

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***Abstract*—The goal of this project was to analyze and rework current schematics of the ARIANNA base motherboard. This included updating the current microcontroller (Mbed 1768) with a Raspberry Pi, adding a USB hub, updating the microSD reader, removing the ethernet device, and ensuring proper analog and digital connections to the board's FPGA. All of this had to be accomplished while maintaining a 3.3 V standard. Additionally, group members had to gain familiarity with current tools and software that the ARIANNA project utilizes such as EasyEDA and PCB Artist. To accomplish these objectives, the ARIANNA circuit board schematics were analyzed along with the schematics of the Raspberry Pi Computer Module 4 and its respective input-output board. The analysis included research into each device's datasheet and basic circuit analysis to determine the appropriate connections to run the ARIANNA board with the Raspberry Pi. New useful components such as a USB hub and microSD card reader were selected and designed in EasyEDA to be compatible with the Raspberry Pi. Scrupulous attention to detail was adhered to in order to ensure proper labelling of ports, pins, and wires within the schematic. Ultimately, a final schematic was successfully designed with plans of integrating it into the ARIANNA's next printed circuit board design.**

***Index Terms*—Raspberry Pi, neutrino, microcontroller, printed circuit board, Mbed**

I. Introduction

THE ARIANNA project was first deployed back in 2016, with the intention to detect and gather information on high-energy neutrinos–sub-atomic particles which travel near light speed [1]. Since neutrinos do not interact with matter, they can travel across the universe and reach the Earth while traveling on a completely unaffected path. However, their high energy allows them to be detected via radio transmission, which allows physicists and cosmologists the ability to track their vectors. In essence, this detection allows for a telescopic observation of cosmic activity using neutrinos rather than photons [2], [3]. However, as time goes on, so does the power of technology and the flow of information. With this in mind, the ARIANNA project has tasked us with upgrading ARIANNA to keep up with the ever evolving technology.

We, Chaoyi Wang, Gail Manlapaz, Thomas Steven Trombino, and William Malpica, have been tasked with updating the current Mbed microcontroller (LPC1768) to a component that is relatively more efficient and financially cheaper. This component is the Raspberry Pi Computer Module 4. At a high level view, the Raspberry Pi CM4 is half the cost of the mbed, and boasts a quad-core processor running at 1.5 GHz along with SDRAM at 1GB [4].

Before we could begin to implement the Raspberry Pi CM4 for ARIANNA, we first had to draft and complete the schematics and PCB design for the transition. This required learning tools such as PCB Artist and Easy EDA, all while being able to comprehend and dissect the current schematics of ARIANNA. Up until this point, no other candidates were being considered to be an upgrade to the ARIANNA board. This means that this will be the first upgrade it gets in a little over 5 years.

We achieved a desired goal by collaborating with the ARIANNA team on a weekly basis to reassure that we were on the right track on what it was that needed to succeed. The constant and consistent back and forth helped get the ARIANNA project to the next potential step. This step will allow for faster and more efficient information being stored for better and more concise data.

II. Materials Used

Developing the new design for the PCB required the review of vast amounts of literature and reference documents. The datasheets of the Mbed 1768, the CM4 and the CM4 IO Board had to be referenced. These datasheets provided functional specifications for each component directly from the manufacturers. Such specifications include: pin voltage, analog input-output capabilities, analog to digital converter locations, device measurements, and power thresholds.

Referring to the standard documentation of USB 2.0 (as well as other interfaces that were eliminated from our project later such as Ethernet)

III. Hardware and Software

The project has used four main pieces of hardware thus far. These include the ARIANNA PCB, the Mbed 1768, the Raspberry Pi Compute Module 4, and the Raspberry Pi CM4 IO Board.

- The ARIANNA PCB is the central device that allows each piece of the antenna to work with one another. It integrates the antenna amplifiers, with the microcontroller and the FPGA. All of these components and several others must be arranged properly so as to maximize efficiency and reduce the cost of these boards.
- The Mbed 1768, shown in Fig. 1, is the microcontroller currently operating the ARIANNA PCB. It acts to convert the analog signals retrieved from the antennas by the FPGA into digital information that can be stored and analyzed. Currently, data is written to the SD card contained in the reader on the PCB.
- The Raspberry Pi Compute Module 4 is the device that will replace the Mbed 1768. Not only is the CM4 cheaper than the Mbed, it is more energy efficient, and has much

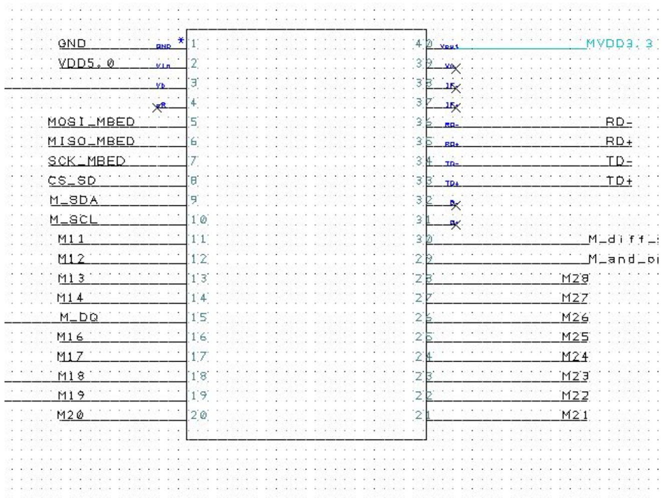

Fig. 1. The schematic of the Mbed 1768 as it is connected to the ARIANNA PCB. The device offers 40 pins for various input-output functionality.

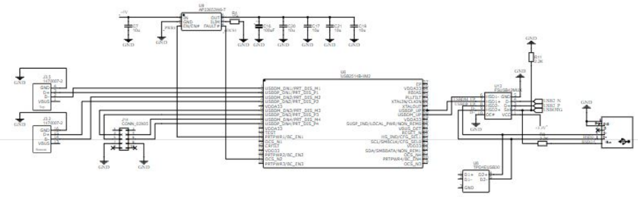

Fig. 2. The schematic of the USB hub designed to be retrofitted onto the ARIANNA PCB. The hub contains a USB IC controller, 2 USB 2.0 connectors, 2 IC switches, and a capacitor bank for voltage regulation.

more computing power. Since the USB hub has been added to the ARIANNA board, data retrieval can be accomplished by USB connection rather than ejection and handling of the small microSD card.

- The CM4 IO Board allows the CM4 to be connected to various devices. This board was used as a reference to see which components are compatible with the Raspberry Pi as well as how they are connected to its pins. This allowed for the proper selection of such components for the ARIANNA PCB.

The design required 2 important software programs – PCB Artist and EasyEDA. PCB Artist is a PCB design software that was used by the team that developed the original ARIANNA PCB. All of the components' schematics were included in PCB Artist files and were referenced scrupulously to identify circuit characteristics. However, since PCB Artist is a limited and outdated software, all of the new components were designed using EasyEDA, which is the ARIANNA team's preferred schematic and PCB design software.

IV. Methods

Accomplishing the design was done by subdividing tasks and responsibilities:

1) Materials such as datasheets, pinout diagrams, and schematics were retrieved and analyzed.
2) The new schematic files were created and templated in EasyEDA.
3) Pins on the CM4 were marked on the schematic as usable, grounded, or floating based on the information provided in the datasheets and by which components were required on the PCB (e.g. the USB hub).
4) The schematics and datasheets were thoroughly reviewed to determine the necessary pins used on the CM4 for both new and existing PCB components.
5) Individual schematics were designed for the new USB hub (shown in Fig. 2) and SD card reader (shown in Fig. 3). Group members were designated specific responsibilities in order to modularize the design.
6) All ports, wires, and components were scrupulously connected and labeled, as shown in Fig. 4, so as to integrate the CM4 and the new components with the existing ARIANNA PCB.

V. Results and Performance

The schematic design for the RPCM4 and the USB hub, and microSD card reader were successfully completed. All necessary ports and wires were connected with high confidence. However, the PCB must now be designed and synthesized so that it may be tested for accuracy and functionality. At this time, there is no certainty that this novel design will integrate with the ARIANNA PCB. Nevertheless, the design is mathematically and technically sound.

VI. Conclusions

The designing of the schematic was an iterative process founded on research and execution. The datasheets and prior schematics were researched and analyzed to determine power, voltages, and correct input/output setup. Then, two group members connected and labeled wires and ports to existing components on the PCB such as the FPGA. Simultaneously,

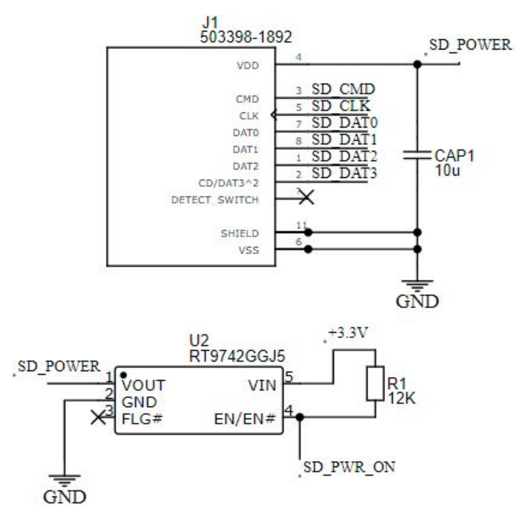

Fig. 3. The schematic of the microSD card reader designed to operate with the Raspberry Pi.

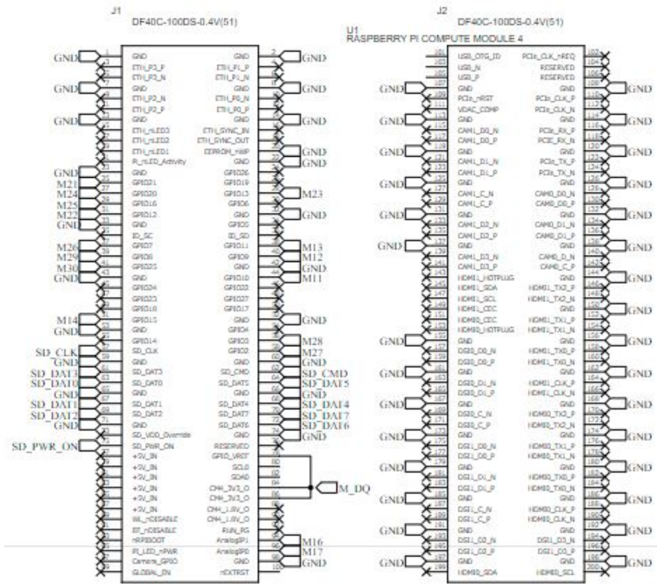

Fig. 4. The schematic of the Raspberry Pi Compute Module 4 with all ports and pins labeled for the ARIANNA board. This device allows for 200 input-output connections compared to the 40 of the Mbed

the other two members designed the schematics for the new USB hub and SD card reader.

The design was ultimately a success. However, rigorous testing of the schematics and its respective PCB design needs to be performed in order to ensure the functionality of the new components with the existing ones.

During the next quarter we intend on completing two major design contributions. The first is to integrate the Iridium satellite communications module into the schematic we have designed and the ARIANNA PCB schematic as well. This will allow for the board to have internet via satellite at all times. The second contribution will be to create an updated master PCB design that includes the CM4, its new components, and the Iridium module as well.

Appendix A
Standards

We are expected to follow IEEE standards such as software and systems engineering standards and antennas and propagation standards. Government standards conjointly come into play in the broader scope of our project, as the ARIANNA project collaborates with the German research foundation, Taiwan Ministry of Science and Technology, the Swedish Government, European Research Council, etc [2]. Therefore government regulations are considered, serving as the Environmental Protection Agency, Occupational Safety and Health Organization. A few general sets of standards we follow are: the safety standards of the engineering lab we work in, and cost/price point standards with the materials we purchase because we use commercial, off-the-shelf components, Raspberry Pi CM4, to control production costs of the ARIANNA circuit boards. We choose to follow these standards to promote organization in the workplace and marketplace, allowing maintainability while preserving public health and safety. Another example of an IEEE standard we follow IEEE 1801-2015 - IEEE Standard for Design and Verification of Low-Power, Energy-Aware Electronic Systems, as we specify power intent on our Raspberry Pi CM4 [4]. Furthermore, we follow these standards to ensure our circuit functions as intended, keeping public safety and regulations in mind. Our design is compliant to all of these standards as we mainly focused on schematic and PCB design this quarter, giving us little flexibility with not following these standards as they must be realized to ensure our project's accurate performance.

Appendix B
Challenges

Undertaking an existing and active research project overseen by the University of California Irvine, Henry Samueli School of Engineering, inherently comes with its own challenges. To begin with, on a limited timeline to produce results during the ten week quarter, our group members were faced with the difficulty of quickly familiarizing ourselves with the tools and hardware ARIANNA utilized. We could not simply jump into software and hardware adaptation without reading ARIANNA documentation and research reports, and with having no experience with the utilized software programs. To overcome this, we promptly studied the ARIANNA white paper, the design and performance of the antenna deployed in Antarctica, and downloaded PCB Artist and Easy EDA. In scheduling frequent meetings with our advisor, we reduced the learning curve granted by these programs as our advisor would demonstrate the basic functions we would be performing.

Through implementing the components of the ARIANNA circuit board, we were also faced with the challenge of seamlessly converting the inputs and outputs of the previously used Mbed 1768 to the Raspberry Pi Compute Module 4. The pin outs were not a simple one-to-one conversion, and initially we were unaware of the Mbed pin functionalities, as we were not provided with the source code associated with the Mbed. After trying our best to match the pins used by the Mbed to the Raspberry Pi, we requested the Mbed pin operations to accurately match them to our Raspberry Pi pins. This required diligent study of both processors' data sheets and research of our own on their pinout purposes.

Also, we encountered the challenge of integrating standardized components into our schematics that were not deployed through academic careers. These include Thermistors, USB/SD slots, Ethernet connections, HDMI, and the concept of decoupling capacitors.

Appendix C
Security Issues

The idea of a telescope made for neutrino detection is relatively novel but there are many that exist in the world. While the University of California is a public institution, it is still the owner of all of its respective intellectual property. Therefore, it is possible for bad actors to find the schematics developed by the ARIANNA group as well as this EECS 159 team and use it to their advantage. The design of this is novel especially given that it has been made to cheaply operate in the extreme temperatures of Antarctica. Therefore, it is important to consider the threat of intellectual theft. To deal with these issues, the hardware is kept on the 4th floor of the Engineering building in a locked lab room. Similarly, the schematic files used by PCB Artist and EasyEDA are only granted access to select individuals. Additionally, these files are subject to version control to ensure publishing accuracy.

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