1. Hello everyone, I’m Claire Hopfensperger, and I am studying computer engineering and electrical engineering at Miami University. This past year, I have been researching ”Reliable Power Conversion for Space Applications” under Dr. Mark Scott. <click>

2. Today I’m going to be talking about relevant background concepts, what exactly I did for my research, and potential future work. <click.

3. To start, I want to first explore some important background to this research. <click>

4. Power electronics are used in many aspects of our lives, but the reliability of these systems is crucial for safety and correct functionality in many space applications such as satellites and solar panels, rockets, and aircraft. <click>

5. Power electronics do have some weak points that challenge reliability <click>, and the two main weak points are semiconductor switching devices and capacitors. (NOTE TO SELF: “semiconductor switching devices” examples are transistors (BJTs), MOSFETS, and diodes).

A study done in 2007 revealed that the three components most responsible for failure in power electronics were printed circuit boards (PCBs), semiconductors, and capacitors.

<click> About a decade later, another study revealed that semiconductors and capacitors were still responsible for the majority of component failure in power electronics.

For this research, we will be focusing on capacitors. <click>

6. Specifically, the aluminum electrolytic capacitor.

This type of capacitor is used often in power electronics because it has a high energy capacitor per size, and it is low cost.

Despite these advantages, electrolytic capacitors fail more than its capacitor counterparts because they are prone to thermal stress which can cause the electrolyte to vaporize or leak out of the capacitor.

The reason we care so much about failing capacitors is because if a capacitor fails, the whole system can fail, which can be dangerous. Currently, there is no perfectly reliable way to predict when a capacitor will fail, so they are often replaced much before their claimed lifetime in order to avoid failures, which can become expensive. But, this research strives to be a basis for health monitoring and failure prediction systems. <click>

<click> Before we move on, it is important to understand how all capacitors function. Capacitors can charge and discharge electrons, similar to this water tank analogy. As the tank fills up, there is less room to fill, so the water flow into the tank slows, similar to how a capacitor charges up. When the input water is turned off, the water tank empties, with the speed decreasing as the water in the tank gets lower, similar to how a capacitor discharges. <click>

7. In order to understand how to monitor the health of capacitors, it is important to understand the parameters that play into capacitor aging. A non-ideal capacitor has 3 main characteristics: its capacitance, equivalent series resistance (or ESR), and equivalent series inductance.

<click> For this research, we are going to focus on the shape of the capacitor’s ripple voltage for health monitoring. The ripple voltage is the process of the capacitor charging and discharging electrons. As seen in this graph, the degraded capacitor ripple voltage in blue has a higher amplitude than the ideal ripple voltage in red. This change in shape indicates that there has been an increase in ESR or a decrease in capacitance. ESR doubling or capacitance decreasing by 10% are often used to define if a capacitor has failed. <click>

8. To implement health monitoring by comparing ripple voltage shapes, this research uses a virtual-twinning approach. Virtual twinning is method in which a physical system is simulated digitally. To identify or predict failure, we must first know how a circuit would operate in its ideal conditions. The digital twin of the physical system provides a baseline of correct functionality to compare the failing circuit results to. The distinct benefit of this approach over others is that there is a less hardware utilized such as sensors which have their own rates of failure. <click>

9. Now that we have explored the background, we can explore the research I’ve conducted! <click>

10. A previous Miami University capstone group developed a digital twin model of a capacitor in a buck converter and a virtual twin-based health-monitoring system that plots the ripple voltage of a capacitor in the buck converter and the simulated ideal version of the capacitor’s ripple voltage from the digital twin together for visual comparison.

My research objectives:

-Develop next version of health monitoring prototype

-Condense system to one board to make system more compact, accessible, and scalable

-Compact: increases ease of use of system

-Accessible: creating a model for a raspberry pi hat that could be publicly available makes the system more accessible (?? – REVISIT)

-Scalable: by including the microcontroller, potentiomenters, and raspberry pi, the system could be adjusted to be used for more than just buck converter cap health monitoring

11. This is the whole test setup, but the health monitoring system I am focusing on is in the <click> top right corner here.

To develop the next prototype of this system, I first needed to understand how the system is built and functions. The system is made of four main components: <click>

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16. These graphs show the system output that I would be looking to reproduce with my new system would develop. On the left is an oscilloscope capture showing the filtered signal in blue, and the amplified filtered signal in red, which is sampled by the Blue Pill. On the right is the graph that the Raspberry Pi creates with the digital twin ideal capacitor ripple voltage in blue and the sampled ripple voltage overlaid in orange. <click>

17. So, now that we know how the system works, we can focus on turning <click> the original system into <click> a consolidated board. <click>

18. I created my raspberry pi HAT with Altium designer, and I first had to design the schematic before I could do board layout. The main parts of the schematic design were breaking down the amplifier board and connecting the high-pass filter, amplifier, Blue Pill, and Raspberry Pi together. Once I finished that, I could move on to board layout! <click>

19. After schematic design was board layout. On the left is the raspberry pi HAT with the top level components and traces, and on the right is the virtual 3D view of the PCB. After completing the layout, I ordered my board for production, and <click> it turned out just as expected, looking nearly identical to the 3D PCB view! <click>

20. After soldering on the header pins for the Blue Pill and Raspberry Pi, I was finally ready for integration, and luckily everything fit together first try! <click>

21. By creating the raspberry pi hat, I was able to make the system more efficient in two specific ways. First, I removed the need for the additional power supply that powered the amplifier and microcontroller by powering those two sub systems with the power pins from the raspberry pi itself. Second, removed the need for the UART to USB connector by reconfiguring the raspberry PI for UART communication and routing the Blue Pill UART pins directly to the raspberry pi transmit/receive pins.

22. My new system appeared to function properly, and on the first attempt of connecting everything too! The oscilloscope capture on the left shows the filtered and amplified signals, and the plot on the right shows the sampled ripple voltage over the ideal ripple voltage again. There is one difference I saw, though. <click>

23. Signal dips could be caused by:

-System sampling signal more accurately than breadboard setup (more secure connections)

-Imperfect wires sending signal to hat, introducing noise

-Otherwise, we are unsure of exact cause, but just determined that new system comes with artifact that could further be investigated

24. The last thing I did for this research was implementing pseudo-live sampling. By adjusting the python script on the raspberry pi, I could repeatedly trigger the blue pill to sample the ripple voltage and send the data to the raspberry pi to be plotted. As seen, the sampling is nowhere near live-sampling, but I believe this step could be an interesting basis for further system improvement.