Development of MonARCH Payload

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Introduction

- The MonARCH mission is a technology demonstration CubeSat designed to validate advanced, space-ready multimode propulsion capabilities in orbit.
- The payload integrates a unique dual-system architecture, utilizing both high-thrust chemical and high-efficiency electrospray microthrusters.
- To conserve mass and volume, both thruster systems are fed by a single, shared "green" multi-mode propellant.
- Complex payload operations, fluid management, and kilovolt-level power regulation are orchestrated by custom-built avionics, namely the Payload Interface Board (PIB) and Power Processing Unit (PPU).

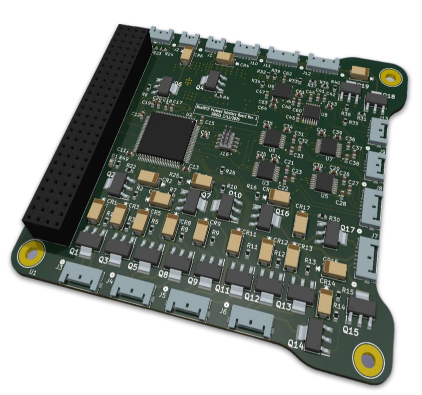

Figure 1: 1st Revision 3-D Model of the Payload Interface Board (PIB)

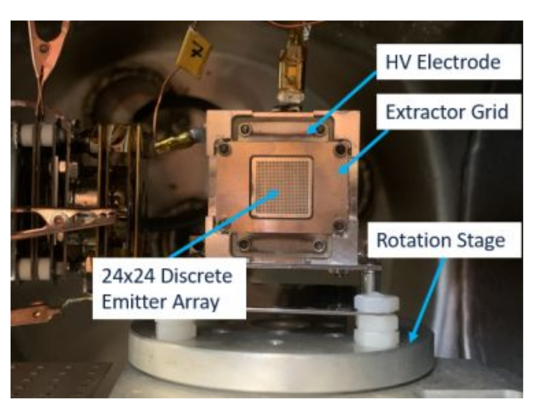

Figure 2: Depiction of MonARCH thruster featuring a 24x24 discrete emitter array and extractor grid[1]

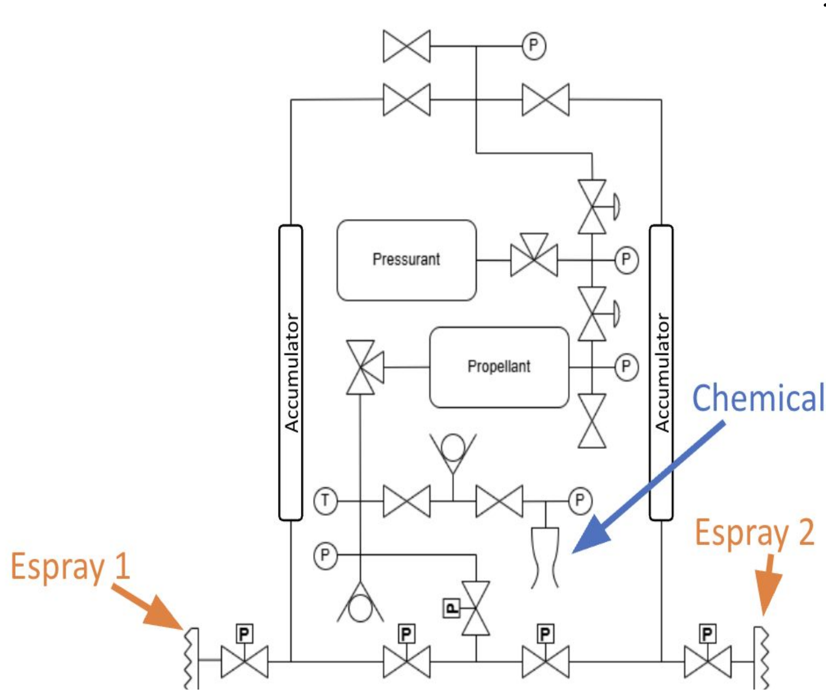

Figure 3: A diagram of the Feed System which will be supplying our propellant

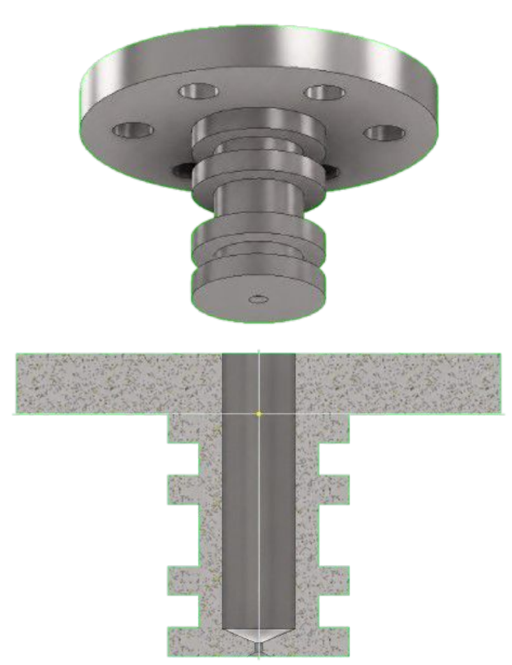

Figure 4: Redesigned chemical thruster model

Research Objective

To comprehensively redesign and integrate the MonARCH payload's custom avionics and dual-propulsion architectures, transitioning the system from laboratory prototypes to a fully autonomous, flight-ready state.

Overview of the Payload Interface Board

- Acts as the primary communication and control bridge between the spacecraft bus and the MonARCH payload.
- The PIB directly controls chemical thruster firing via heat tape, drives solenoid valves for the propellant feed system, and commands the PPU.

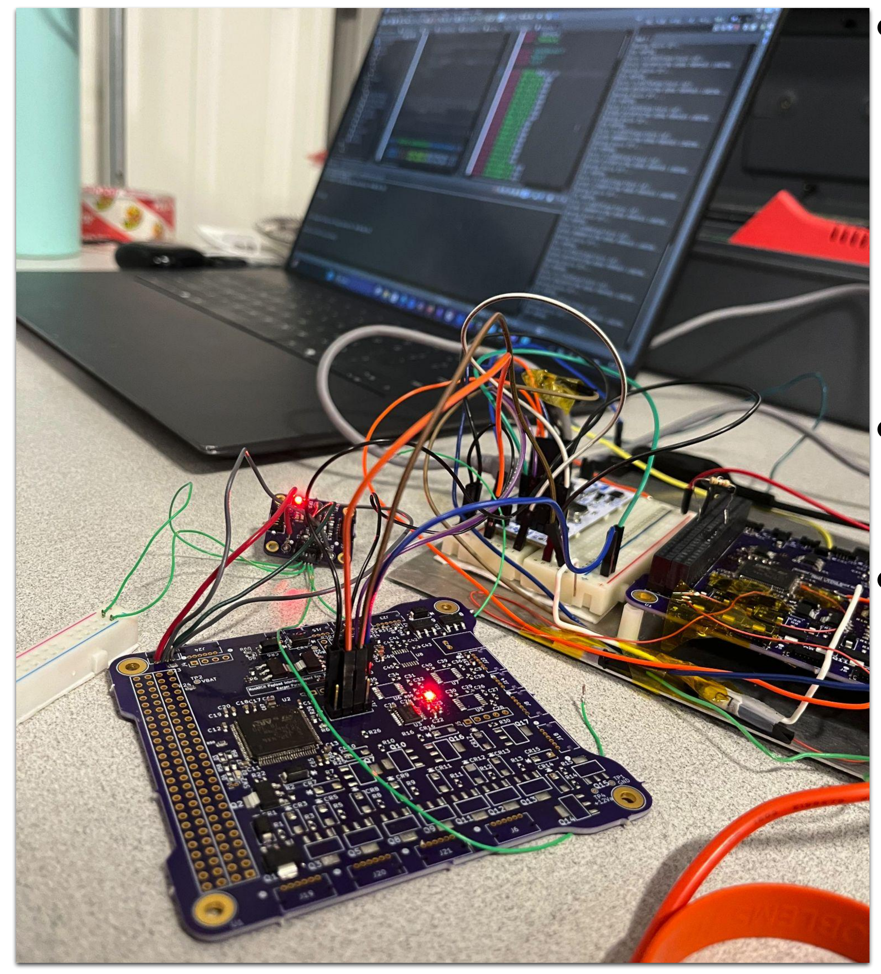

Figure 5: New PIB Revision Testing

- The PIB monitors pressure, temperature, voltage, and fuel levels, and then provides data packets to the Onboard Flight Computer (OBC) through UART communication
- Monitors payload current draw and detects electrospray plume.
- The summer 2026 development cycle brought an initial spring prototype to a heavily revised architecture following an intensive campaign of testing, debugging, and redesign.

Overview on the Electrospray Thruster

- Serves as the high-efficiency, low-thrust propulsion mode for the MonARCH dual-system architecture.
- Utilizes strong electrostatic fields (up to ~3 kV) to extract and accelerate charged particles directly from the shared green ionic liquid propellant.
- Generates micro-Newton thrust with specific impulse (Isp) compared to traditional chemical modes.
- Operates at µL/sec flow rates and necessitates a highly precise propellant feed system to prevent overfilling of the thruster which can lead to catastrophic spacecraft failure due to high voltage breakdowns.

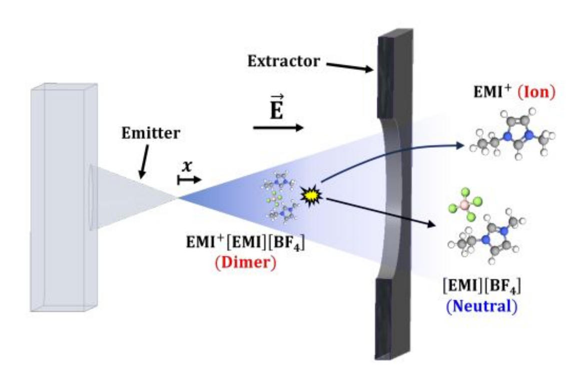

Figure 6: Illustration of emitter-extraction assembly accelerating ions, dimers, and neutral species via strong electric fields[1]

Electrospray Thruster Redesign

- Adapted from the Air Force Electrospray Thruster Series 2 (AFET-2).
- In order to make the spacecraft more robust for the launch environment, we improved the high voltage connection by making small changes to the existing electrospray thruster.
- Iterated on previous propellant filling procedures by creating a new filling apparatus that guaranteed safer and more efficient propellant reservoir saturation.
- Working to upgrade the thruster housing to include a built-in charge collecting probe.

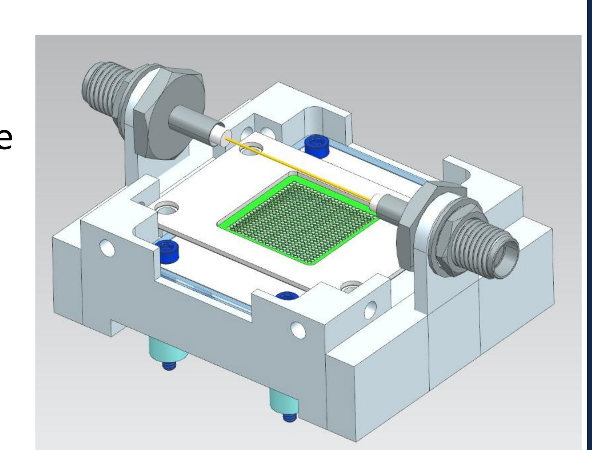

Figure 7: A model of the redesigned electrospray with the mounted charge probe

PIB Debugging & Redesign Process

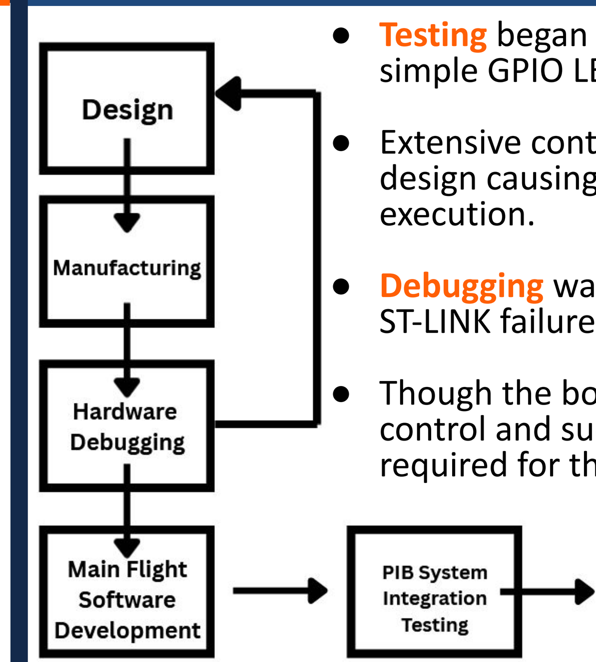

Figure 8: PIB Development Process

- Testing began with the primary MCU (STM32L4A6) failing basic code execution, such as a simple GPIO LED toggle.
- Extensive continuity checks, pin probing, and datasheet analysis revealed errors in PCB design causing memory placement errors and constant board resets that prohibited code execution.
- Debugging was severely bottlenecked by improper connectors, fragile "bodged" wires, and ST-LINK failures caused by wire noise and bit flips.
- Though the board ultimately succumbed to hardware issues, achieving brief solenoid control and successfully reading device IDs provided the critical baseline knowledge required for the next PIB revision.

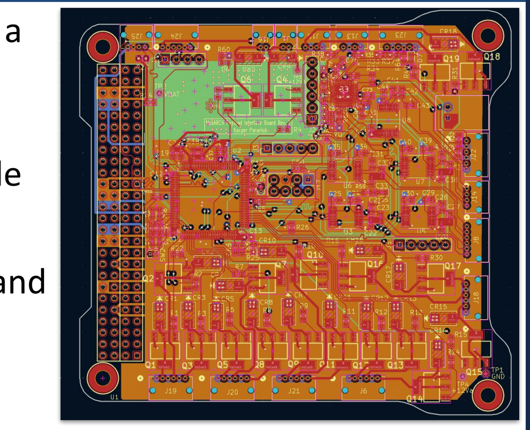

Figure 9: PIB Rev 2 Layout

With all mistakes documented the hardware redesign was simple and quick. Next, the new revision was built and software drivers were corrected. As a result, temperature, pressure, voltage, and capacitance measurements were all successfully read from sensors. Additionally, a command line interface was implemented for easy commanding. This enabled easy solenoid valve control and will be used for integrating all MonARCH components together, testing feed systems, and propulsion elements in the fall semester.

Overview of the PPU

The PPU converts the spacecraft's 12V supply into approximately 3.4kV. This high voltage creates the electric field needed to extract and accelerate the charged droplets from the electrospray thruster.

The design uses a coupled-inductor boost stage followed by a Cockcroft-Walton voltage multiplier.

- The boost stage creates a high-amplitude switching waveform, alternating positive and negative pulses.

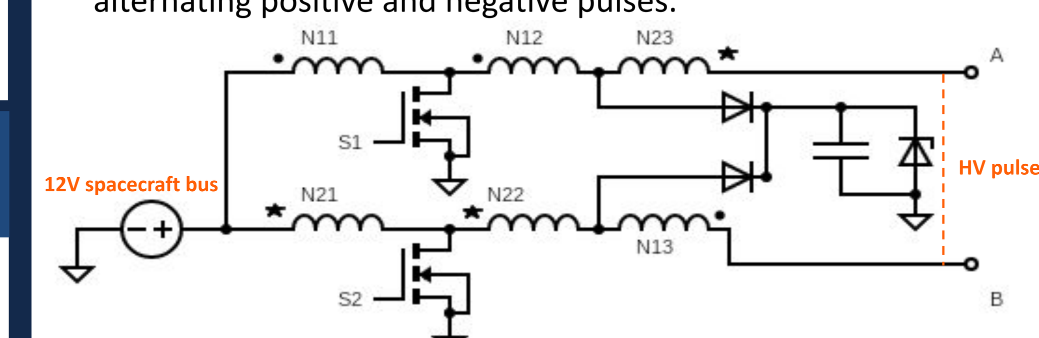

Figure 10: Stage 1: Create higher voltage pulses.

- The switching waveform drives the voltage multiplier ladder, which uses diodes and capacitors to repeatedly store and add these voltage pulses until the output reaches 3.4 kV DC.

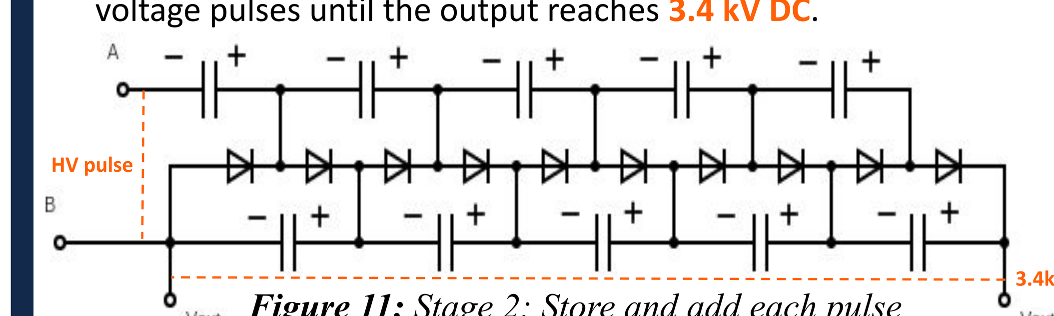

Figure 11: Stage 2: Store and add each pulse

High Voltage Hardware Design

- Instead of asking one component to withstand the entire 3.4 kV, the circuit divides the voltage increase across several transformers, diodes, and capacitors. This allows the converter to produce a large output voltage using smaller, PCB-mounted components.
- At several thousand volts, electricity can arc through air or travel across the PCB surface. Components and copper traces were therefore separated using high-voltage spacing guidelines from IPC-2221B and NASA-HDBK-4007A. High-CTI circuit-board material was also selected to resist surface electrical damage.
- The magnetic components were wound in the laboratory using a drill-driven fixture. The three windings contained 50, 150 and 150 turns, giving a 1:3:3 turns ratio. Kapton tape electrically insulated the windings from the core and from one another.

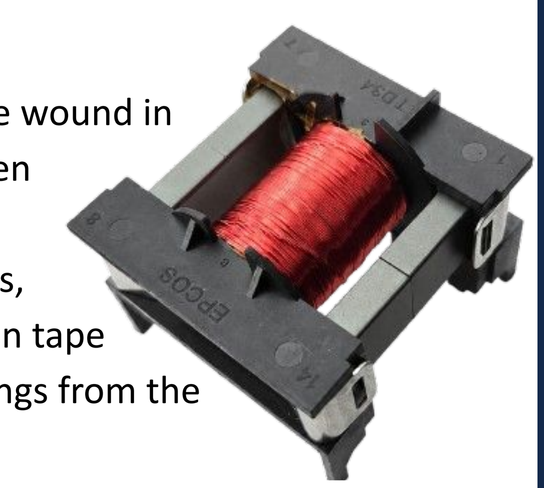

Figure 12: Hand-wound transformer assembled on a ferrite core.

Conclusion

During the summer of 2026, we developed a commandable PIB with a full suite of sensors, generated thrust from a redesigned electrospray thruster, prototyped multiple feed systems to downselect to a robust architecture, and prototyped and validated elements of the PPU which allowed us to converge on a full design. The next steps are to build a flight ready feed system, test the PIB with full payload integration, and conduct more testing to validate all thrusters. These systems will be critical to test electrospray and chemical propulsion in space with the novel FAM-142 monopropellant, supplied by one shared feed system. All of this work contributes to creating a payload to further prove multi-mode propulsion viability. As we transition from conceptual design to system integration, we will continue preparing for our critical design review and demo-day going into the 2026 fall semester.

Acknowledgements

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References

- [1] Lyne, C. T., Liu, M. F., & Rovey, J. L. *A brief review of electrospray propulsion diagnostics*. University of Illinois Urbana-Champaign.
- [2] Baddipadiga, B. P., Strathman, S., Ferdowsi, M., & Kimball, J. W. *A high-voltage-gain DC–DC converter for powering a multi-mode monopropellant-electrospray propulsion system in satellites.*