

Space Environmental Effects on Electronic Components

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CubeSats are a low-cost platform transforming access to space. Their standardized design allows universities, researchers, and private organizations to rapidly develop and conduct missions, enabling scientific and technological advancements within a compact form factor. In any CubeSat mission, electronics are critical for data acquisition, system control, and communication but are exposed to potentially damaging space environments. The purpose of this research is to design and construct a reliable, radiation-tolerant electrical system for payload control and instrumentation using commercial-off-the-shelf (COTS) components not inherently designed or qualified for the space environment. The use of such electrical components is an active area of research because, while they offer significant cost and performance advantages compared to radiation-tolerant alternatives, they risk insufficient protection against space environments. This presentation focuses on custom-designed printed circuit boards (PCBs) researched, designed, and constructed by researchers in the Electric Propulsion Lab in collaboration with The Laboratory of Advanced Space Systems at Illinois. This analysis highlights the critical factors researchers must consider when integrating electronics onboard CubeSats, including radiation types, temperature extremes, and vacuum-related effects. Finally, the effects of Total Ionizing Dose (TID), Single Event Latch-Up (SEL), and Single Event Upsets (SEU) on semiconductor devices used in critical PCBs are discussed.

I. Nomenclature

dE = electric field change
 dx = position step
 ρ = density of the absorbing material

II. Introduction

This paper documents the development of the payload electrical system of the Mono Propellant Multi-mode Propulsion CubeSat Mission (MonARCH) during the UIUC Spring 2026 semester. MonARCH is a collaborative project between the Electric Propulsion Lab (EPL) and the Laboratory for Advanced Space Systems at Illinois (LASSI). The mission features a multi-mode propulsion system that utilizes a novel mono-propellant. This design aims to demonstrate efficient propulsion in a compact form factor to support future small satellite applications. The hand-based propellant FAM-142 is a highly ionic liquid that fuels the propulsion system consisting of two electrospray thrusters and one chemical thruster. The electrospray thrusters are custom and based on the Air Force Electrospray Thruster (AFET 2). They are primarily used for attitude control by producing a continuous low-thrust plume of charged particles, operating on 3kV AC from the power processing unit (PPU). The chemical thruster is a micro thruster designed at UIUC and undergoes catalytic decomposition with the addition of heat ($\sim 120^{\circ}\text{C}$). This thruster is used for orbit phasing. The EPL is in charge of the thrusters and the payload onboard MonARCH. The electrical sub-team of EPL is in charge of creating the payload electrical system which interfaces with the instrumentation and controls of the MonARCH payload. This includes solenoid valve control for the feed system, and electrospray, chemical thruster ignition. During the spring semester, the payload electrical system went from an initial research phase to a first prototype which consisted of the payload interface and breakout board (PIBs). The paper details the 5-step development process of the MonARCH payload electrical system and the influence of space environment effects on the PCB design process. First, in January the MonARCH system requirements were assessed to establish what functions the PIBs needed to perform and the components that would be necessary to fulfill them. Second, the effects of the space environment on

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electronic components were evaluated to guide component selection and risk mitigation in the design process. Third, electronic components were chosen based on their reliability and accuracy. Fourth, February through April the PIBs were designed and built using KiCad, with supporting software developed in STM32CubeIDE. Finally, the prototype electrical system was tested and debugged in collaboration with LASSI during the final days of the spring semester. The following sections detail each phase of this process, documenting the development of the PIBs from initial concept to prototype testing. This paper aims to document development of PCBs for space applications using commercial off the shelf (COTS) components.

III. Background

Earth's atmosphere and magnetic field shield electronic systems from many of the environmental hazards present in space. A PCB that performs reliably on Earth can fail catastrophically in orbit, where radiation, vacuum, and extreme thermal cycling can trigger mission-ending failures. As a result, the demands of the space environment introduce additional constraints into the design of spacecraft electrical systems. In the past 50 years, electronics have evolved tremendously from bulky vacuum tubes (2-3 inches tall) to 2-3 nanometer CMOS transistor gates which both serve as high-speed electronic switches and make up all electronics. Although electronics are more efficient and powerful than they were for Apollo missions they are more prone to radiation as one charged particle has a greater effect on the CMOS structure of an integrated circuit (IC). Designing PCBs for space applications therefore requires careful cost-risk analysis. While modern radiation-tolerant components provide increased reliability, they are often expensive and exceed the requirements of short-duration CubeSat missions. Consequently, some COTS components are frequently considered as lower-cost alternatives, though they are generally more susceptible to single event effects (SEEs). MonARCH is estimated to have a ~ 400 km altitude, around where the Van Allen Belts begin. Van Allen Belts are trapped energetic particle belts in orbit where electrons and protons group due to Earth's magnetic field. Luckily, MonARCH does not have to worry about extreme cases of radiation doses. Thus, decreasing the chances of SEE's. In LEO (160-2000km), spacecrafts are bombarded by a constant transfer of energy through particles and waves coming from the sun (solar energetic particles) and from outside the solar system (galactic cosmic rays). Galactic Cosmic Rays (GCRs) are high energy particles/waves believed to be produced by accelerated magnetic fields of supernova remnant events such as supernovae explosions. While solar energetic particles (SEPs), originate from Solar flares, coronal mass ejections, and solar winds (continuous streams of charged particles (plasma)). As shown in Figure 1, radiation comes in many energies and penetrations. Although some of the ionizing particles are deflected and dissipated as a result of the Earth's magnetic field, much of the energetic particles still come through. The continuous exposure to radiation is the most important factor to consider when designing a PCB. The constant transfer of energy from radiation is the primary factor that can cause memory corruption and short circuit latch-ups. These effects are primarily inside of CMOS substrates. Because electronics in space are exposed to dangerous environments such as high-energy particles, engineers study the fatal effects such as radiation-induced failures to understand the limits of COTS components and how to build space environment tolerant electronics and systems. Therefore, documenting design processes and flight successes such as [10] and [13] are essential to making space flight more affordable and accessible.

IV. Methodology

The development of the payload interface boards began with the analysis of the MonARCH payload system requirements provided by EPL and LASSI. The first step in developing the payload electrical system was to become familiar with the payload needs. The electrical system was required to interface with the electrospray and chemical propulsion systems, including chemical thruster ignition through heat tape actuation, solenoid valve control within the feed system, and PPU control. Additional functionality included communication with the onboard flight computer (OBC); monitoring of pressure and temperature sensors, electrospray plume detection, payload current measurements, and catalyst level sensing. Once requirements were understood a functional block diagram was created, as seen in Figure 15, to identify subsystem interactions and determine required voltage rails, communication protocols, and required functions throughout the payload and bus of MonARCH. Environmental analyzes were performed on the STM32 series to evaluate the radiation effects on the STM32 micro-controller unit using resources such as [10] and [11]. Additional environmental effects were evaluated using [6]. Electronics were selected based on reliability, availability, operating temperature range, and existing aerospace usage. Components from STMicroelectronics, Texas Instruments, and Analog Devices were used due to their established reputation and broad availability within the COTS market. In the design phase, PCB schematics and layouts were developed using KiCad. The process included schematic capture,

footprint verification, PCB routing, computing passive electronic values, design rule checking, and ensuring equal length of communication traces. Firmware for the PIBs was developed in STM32CubeIDE using embedded C. Initial firmware functionality included GPIO control for solenoid valve drivers; integrating, and building IC drivers for electronic chips on the PIBs. Lastly, a bill of materials (BOMS) was created to order, assemble, and build prototype PIBs in the final weeks of the Spring 2026 semester in collaboration with LASSI.

V. Evaluating Space Environmental Effects on Electronic Components

The second step in developing the payload electrical system, was to understand the design process related to building of electrical systems in space. In general, when building a spacecraft, there are many environmental factors to consider according to [6]. However, when examining electrical systems specifically, we have characterized the following five main environmental factors that are of greatest concern.

A. Radiation

MonARCH's space environment will be in Low Earth Orbit (LEO) with an expected altitude of 400km with unknown beta angle and inclination. MonARCH is dependent on the service provider for what type of orbit it will be in. If MonARCH experiences a sun synchronous orbit there will be significant differences in the kRad dosages. Lastly, exposure to radiation peaks intensely in the South Atlantic Anomaly where the radiation belt dips closer to the Earth's surface.

1. Types of Radiation

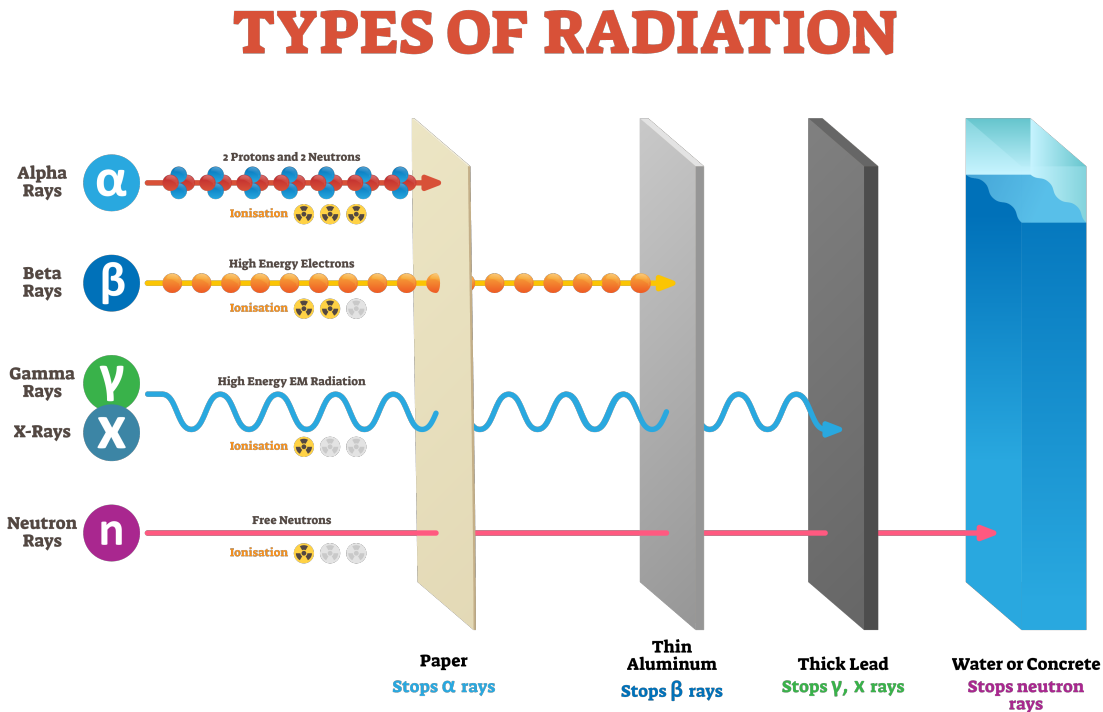


Fig. 1 Types of Radiation and Penetrations [7]

A complex mixture of ionizing radiation is present in LEO and the different types can be seen in Figure1, along with their penetrations. No matter what type of radiation, it still has the same general effects on electronics which are the

SEEs. The primary source of radiation in our solar system is the sun. The “Sun continuously emits a low-energy stream

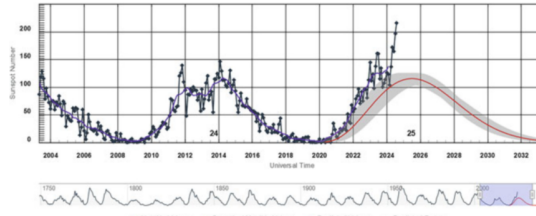


Fig. 2 Solar Activity Measurements and Predictions [1]

of particles primarily consisting of protons and electrons” [1] Another critical factor to look at when launching COTS electronics is the solar activity. The sun follows an 11-year pattern of rising and falling magnetic and explosive activity. These maximum periods directly effect the number of SEEs as the amount of radiation is directly associated to solar activity. “In LEO and in low inclination (<28 degrees) typical dose rates include 100-1000 rad(Si)/year [9]. In higher inclinations there’s an increase in number of trapped electrons and typical dose rates include 1000-10,000 rad(Si)/year” [9]. These are important numbers when testing thresholds of electronics.

2. Particle Interactions

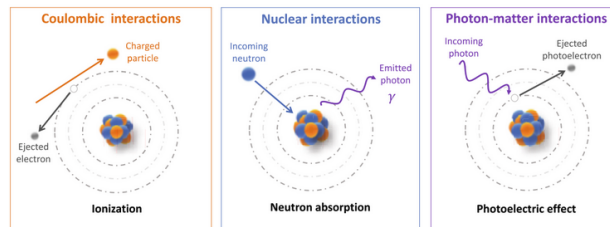


Fig. 3 Coulombic, Nuclear, and Photon Matter Interactions [1]

The harmful effects of radiation primarily arise from particle interaction, as shown in Figure 3. These interactions consist of Columbic interactions such as ionization, as well as nuclear and photon-matter interactions. With enough energy radiation can overcome the strong nuclear force in atoms breaking them apart and changing material properties. Additionally, ionization can generate electron-hole pairs within semiconductor substrates, altering electrical properties of electronic components.

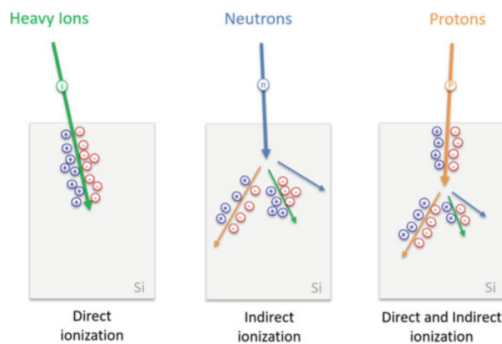


Fig. 4 Direct Ionization and Indirect Ionization [1]

Charged particles are not the only catalyst for ionization as neutrons can cause indirect ionization as shown in Figure3 . The ionized electrons are classified as Delta rays which then causes secondary electrons to become ionized causing a chain reaction.

3. Linear Energy Transfer

$$LET(X) = \frac{1}{\rho} \frac{dE}{dx}(x) \text{ (units of MeV/mg.cm}^2\text{)} \quad (1)$$

Linear Energy Transfer (LET) is a measure of much radiation energy is transferred into sensitive components. [2] This equation can be used to analyze radiation effects on electronics and also make models of them as seen in [2].

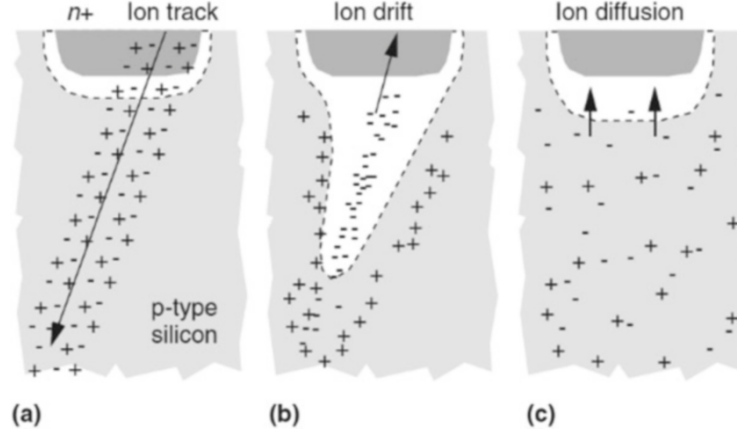


Fig. 5 Charge Collection [1]

Figure 5 presents the three step process when an ion strike occurs in a PN junction. In the first stage (a), a charged particle creates a trail of electron-hole pairs which can be modeled with equation LET equation. Next, ion drift occurs due to the electric field between N and P junctions. Lastly, Ion diffusion spreads the holes and electrons throughout the substrate. The ion strike is bad for electronics as these ions create conductive paths, increasing leakage currents and dielectric degradation. These are called semiconductor lattice defects. An example of an macroscopic effect is memory corruption in flash/DRAM because of unwanted ion migration causing stored-charge to leak away.

4. Total Ionizing Dose

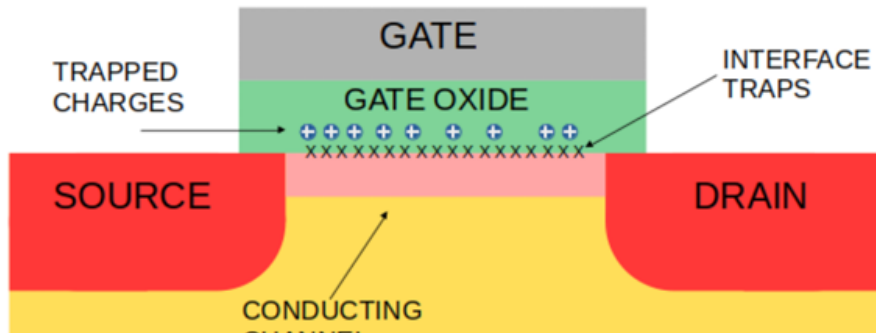


Fig. 6 Trapped Charges in Gate Oxide [3]

As shown in Figure 6, charge trapping occurs in the gate oxide. This leads to an induced electric field which decreases the operating voltage in Bi-Polar Junction Transistors (BJTs).

5. Single Event Effects

SEEs are the primary choke point for electronic systems in orbit and they are all caused by ion strikes. SEE effects on integrated circuits span from non-destructive to destructive, as shown in Figure 6. Presented is an exhaustive list of SEE and their corresponding effects space electronics can come by.

Table 1 Nondestructive SEEs		
Single Event Upset – SEU	Corruption of the information stored in a memory element	Memories, latches in logic devices
Multiple Bit Upset – MBU	Several memory elements corrupted by a single strike	Memories, latches in logic devices
Single Event Functional Interrupt – SEFI	Loss of normal operation	Complex devices with built-in state and control circuitry
Single Event Transient – SET	Impulse response of certain amplitude and duration	Analog/mixed signal circuits, photonics
Single Event Disturb – SED	Momentary corruption of the information stored in a bit	Combinational logic, latches in logic dev.
Single Hard Error – SHE	Unalterable change of state in a memory element	Memories, latches in logic devices
Table 2 Destructive SEEs		
Single Event Latchup – SEL	High current conditions	CMOS & BiCMOS devices
Single Event Singleburn – SESB	High current conditions	N-channel MOSFET, SOI devices
Single Event Burnout – SEB	Destructive burnout	BJT, N-channel Power MOSFET
Single Event Gate Rupture – SEGR	Rupture of gate dielectric	Power MOSFET
Single Event Dielectric Rupture – SEDR	Rupture of gate dielectric	Non-volatile NMOS struct., FPGA, linear devices
Table 3 List of typical anomalies due to SEE (non-exhaustive)		
Function	Potential anomalies	Origin of the anomalies
Acquisition channel	Switch to auto-calibration Conversion errors	SET in operation amplifier, comparators or ADC SEU in DAC/ADC
Processing unit	Program or data corruption Calculation errors, time-out, bus errors	SEU in memories SEU in microprocessor
Power unit	Power drops Self switch-off	SET in voltage regulators or switch SEB in DC/DC converters

Fig. 7 Single Event Effects [2]

The primary SEEs are the single event upset (SEU), single event transient (SET), and single event latchup (SEL). SEU are bit flips, changes in the state of SRAM (memory cells) and registers. These occur in sequential logic which circuitry latches onto some state. Alternatively, “A SET is a transient voltage pulse generated by a charge injected into the device from a high energy particle.” [5] The SET occurs in combinational logic where latching does not occur and is the most common occurrence. Lastly, “A SEL is where the formation of parasitic bipolar action (Parasitic Thyristors) in CMOS wells induces a low impedance path between power and ground, producing a high current condition.” [5] SEL arises when the charge builds up in the gate oxide and substrate as shown in Figure 6 SEL has a feedback loop as shown in 8.

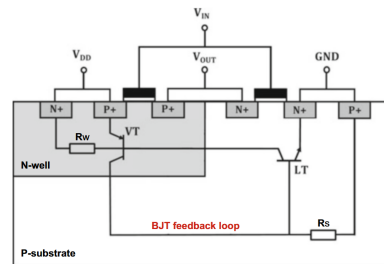


Fig. 8 CMOS-based inverter design [1]

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The BJTs (parasitic thyristors) in 8 model the feedback loop.

6. Leakage Current

Figure 9 presents the leakage current in an SRAM cell as mentioned before. Every electronic has some kind of resistance to radiation according to Table 2 . Listed in table 2 presents the typical radiation ratings for commercial components and depending on the type of orbit can alter the number of SEEs. ICs can be easily reset when an SEE occurs through its reset pin, and thus we do not worry as much about the radiation effects on ICs as we do on the MCU. Although shielding is one way to mitigate the probability of SEEs it is never going to be the perfect solution. Radiation is unavoidable in space and thus with a COTS component we need to find ways to be able to not only mitigate the amount of radiation exposure but apply software tricks to eliminate the problems of SEEs.

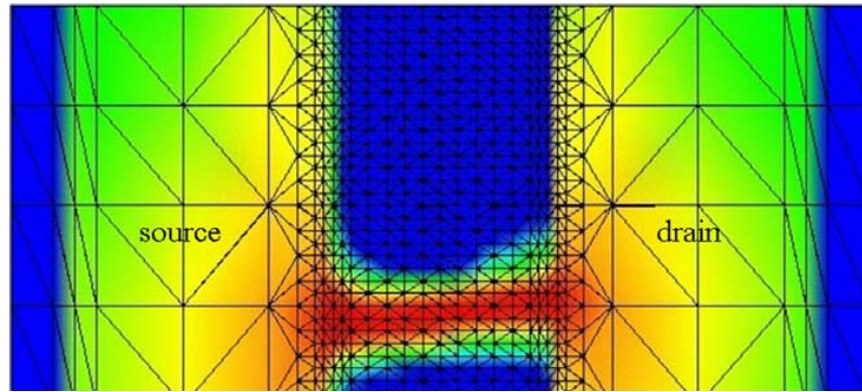


Fig. 9 Leakage Current in a 4-T SRAM cell [2]

Table 2 Typical Radiation Ratings for Commercial Components [9]

Parameter	Typical Rating
Total Ionizing Dose (TID)	2–10 krad
SEU Threshold LET	5 MeV·cm ² /mg
SEU Error Rate	10 ⁻⁵ errors/bit-day

B. Vacuum Environment

The primary concern for electronics in space is tin whiskers, which can cause electrical shorts and outgassing. A simple fix for tin-whiskers is to use lead-based solder.

1. Outgassing

Components on the PIB and the PCB itself may have little outgassing, but were not evaluated during the semester. This will be accessed in further detail.

C. Thermal Conditions

Thermal cycling may hinder key electrical properties and characteristics if electronics are not rated for such temperatures. Ensuring each component is rated to -55 °C - 125 °C and angling electronic payload away from the sun while in orbit are the key strategies to eliminating these effects.

D. Atomic Oxygen

LEO is "comprised of about 96% atomic oxygen," [5] and MonARCH is not sealed thus only a small amount of atomic oxygen will get into the spacecraft and thus potentially be able to degrade the material on the PIB. The electronics on-board MonARCH

E. Plasma

MonARCH's ground is floating as the physical spacecraft frame is the GND for the entire CubeSat and the electrospray thruster is using the electrons on the spacecraft. This means we need to pay careful attention to the charge balance of MonARCH and the low-density plasma around the spacecraft at all times. This does not directly effect the PIB but can be mission ending and is a major space environment concern. The goal we are still looking for is to get IIN = IOUT. As the electrospray ejects a plume of ions and LEO consists mostly of positive charges, there can be charge imbalances that can cause sparks.

The space environment is often overlooked when designing electronics for space. Nonetheless, it is the most important factor to consider when building such systems as electronics are the determining factor of proper mission

operation and reliable data acquisition.

VI. Deciding on the Micro-Controller Unit

The micro-controller unit (MCU) is the most critical component of the payload interface system and is similarly vulnerable to the space environment. Therefore, MCU selection required careful evaluation of the tradeoff between the risks posed by radiation exposure and the increased cost of radiation-hardened MCUs.

A. STM32 Selection

There are lots of commercial off the shelf (COTS) components available on the market that are not inherently designed for space flight nonetheless designed for radiation tolerance. Thus, the driving factors of selecting an MCU from the ST-Microelectronics (STM) series was the documentation behind these MCUs surviving and thriving in the LEO environment. Not only, STMs are very powerful, reliable, and accurate MCUs that we evaluated can perform every task the payload interface system needs to accomplish.

1. Reliability Heritage

The SONATE (Solutus NAno satellITE) CubeSat mission is an example used to evaluate the STM32L4A6 capabilities. During their mission, "the main software runs on a STM32 L4 microprocessor and implements attitude determination and control algorithms, as well as communication protocols with connected sensors and the satellite bus for telemetry/telecommand purposes." [10] After launching the cubesat into orbit, "the project has received more than 5000 telemetry frames from SONATE." [10] After a year of testing, "[Sonate] has achieved extraordinary things. However, the Würzburg space mission was designed for only one year." [10] Additionally, the STM32H7 series is backed by a report seen in [11]. Although not identical to the STM32L4 series, the H7s are more powerful and complex to the L4s and thus more prone to the space environment. Additionally, the Open Source Satellite (OSSAT) team performed a research project to test COTS resilience to the harsh space environment. They did this in the Realistic Electron Environment Facility (REEF), located at the University of Surrey, UK. by exposing samples in a vacuum to a 2.5 GBq Sr-90 source. According to [11], "Strontium-90 provides an excellent practical option for the provision of long-duration, low-intensity exposures as it allows uninterrupted irradiations over the required long periods with an electron spectrum that is appropriately representative of the real space environment." The REEF is used to test the vulnerability of the component to both internal charging and total ionizing dose phenomena. OSSAT had found the "[STM] is also capable of withstanding significant TID without failure. Through analysis, a 10 year 800km sun synchronous orbit would equate to approximately 10 kRads of radiation dose. Under the destruction test, the chip [STM32H7] only began to fail at 47 kRads." [11]

CubeSat	Type	Developer	Launch Year	MCU
EstCube-1	1U	University of Tartu	2013	STM32F1
SNUSAT-1/1b	2U	Seoul National University	2017	STM32F4
FOX-1C	1U	AMSAT	2018	STM32L1
PW-Sat2	2U	Warsaw University of Tech.	2018	STM32F1
SNUSAT-2	3U	Seoul National University	2018	STM32F4
PicSat	3U	Observatoire de Paris	2018	STM32F3
KrakSat	1U	AGH Uni. of Sci. and Tech., SatRevolution S.A.	2019	STM32xx
M6P	6U	Nanoavionics	2019	STM32H7

Fig. 10 CubeSats that have used ARM Cortex M STM32 MCUs in their system design [13]

The STM32 MCU Series has flown multiple times as seen in Figure 10. Figure 10 was used in [13] to validate the choice of the STM MCU for Convolutional Neural Network Designed for On-orbit Binary Image Classification 1U CubeSat Mission. Although not designed to be radiation tolerant, STM32 backed documentation validates that an STM32 MCU is the best COTS MCU on the market that balances power and reliability for space applications.

2. Specific Device Selection and Specifications of the STM32L4A6

The STM32L4A6 consists of four I2Cs, three SPIs, three USARTs, and two UARTs which are essential communication protocols for interfacing with sensors, onboard computer (OBC), and PPU. The STM32L4A6 is an ultra-low-power processor and thus consumes exponentially less power than an STM32H7 series. Also, it is important to note this MCU has an explicitly defined low power UART which is needed to communicate with the OBC. There are two 16-bit PWM timers which are needed for IEP valve pressure regulation. For power, LASSI has allocated 1 watt for the entire payload interface system. H7s consume around 264 μ /MHz typical value at VDD = 3.3 V and 25 °C in Run mode (peripherals off) almost 3x the amount compared to the L4s which have around a power consumption of 91 μ A/MHz run mode (LDO mode).

- 1) Sufficient flash and RAM to support basic software implementations
- 2) Hardware floating-point unit (FPU) for onboard computation
- 3) Availability of SPI, I²C, and UART peripherals required by the payload
- 4) Radiation characterization data confirming 10 krad(Si) TID tolerance
- 5) Flight history of STM32 devices in CubeSats

Therefore, the STM32L4A6 was chosen for our mission.

B. Software Framework

Initially, a suggestion was made to run F-prime. A software developed by NASA that streamlines a lot of flight critical software processes. However, through deep research it was concluded the software would be overkill for both a small MCU chip but also for the PIB software. Instead, C was the chosen language for software as it easily integrates with the STM32CubeMX and STM32CubeIDE softwares. Additionally, most pre-built drivers for the ICs were drag and drop with minor changes. Choosing C as the main language allowed for fast initial development time for testing the functionality of the PIB.

VII. Choosing Electronic Components

Once we knew what the PIB needed to execute, identified how the space environment affects electronics, and the MCU was chosen we were able to move onto choosing compatible external ICs with the MCU. Each electronic component is ensured to have an automotive rating to prepare the system for the immense shaking and conditions of launch. Additionally, electronics were picked to have temperature ratings ranging from -55 °C - 125 °C to mitigate the effects of thermal cycling on electronics.

A. FDC2214 Capacitance-to-Digital Converter

The FDC2214 is a special Texas Instruments IC to convert a capacitance reading directly to a catalyst level reading through software. The FDC2214 uses an inductance-capacitance (LC) resonant circuit to measure capacitance indirectly through frequency. The FDC2214 does not measure capacitance directly. Instead, the IC measures the oscillation frequency of an LC tank circuit then runs on an LC Tank which waves? These frequencies are modeled by the following equation.

$$f_{sensor} = \frac{1}{2\pi\sqrt{L \cdot C_{sensor}}} \quad (2)$$

An internal clock acts as a reference to the capacitance induced frequency reading and converts that into a level reading. The expected capacitance measurement range is 5-60pF. The driver was developed by adapting an incomplete driver implementation to achieve compatibility with the STM32 Hardware Abstraction Layer (HAL).

B. MAX31856 Thermocouple-to-Digital Converter

The MAX31856 is an Analog Devices chip used to take a thermocouple reading and convert it into a temperature reading. This converter communicates over 4-wire SPI and can interface with any K, J, N, R, S, T, E, or B type thermocouple. The chip primarily is created for K-type thermocouples and that is what MonARCH will be using it for. The chip does a lot for us. For example, the MAX31856 solves the cold-junction problem of needing a cold-compensation reference from another sensor by using an internal temperature reading. The estimated range is -210°C to +1800°C output in 0.0078125° resolution.

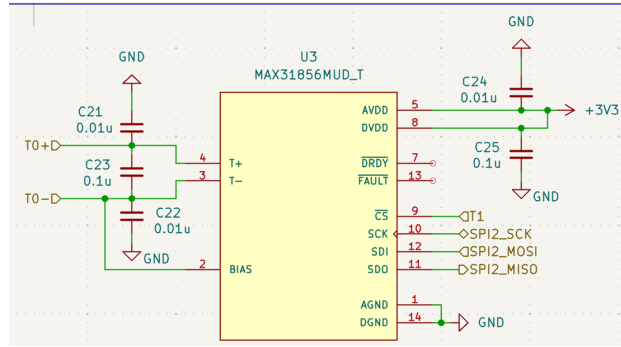


Fig. 11 KiCad Schematic: MAX31856

C. ADC7124 Analog-to-Digital Converter

The ADC7124-8 is a low noise, low power analog to digital converter used for high precision measurement applications. The PIB uses the ADC7124 to convert 4-20mA pressure transducers measurements into a pressure reading. This is done through a resistor voltage divider with the ADC7124 measuring the voltage on its input pin. We chose this IC because it is an 8-channel IC which in turn saves a lot of space on the PIB. The ADC7124 can be configured to have 8 differential inputs or 15 single-ended or pseudo differential inputs. On the PIB we use a unipolar setup which measures a voltage at its terminal with reference to the AVDD which is 3.3 volts (3V3).

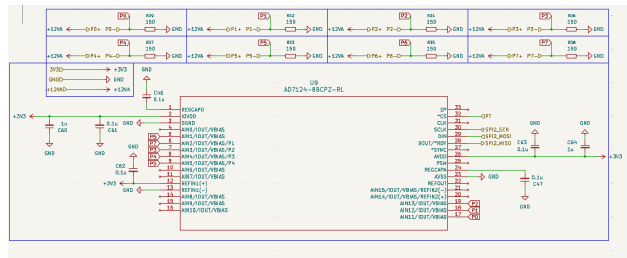


Fig. 12 KiCad Schematic: ADC7124

1. MOSFET Selection and BJT Trade Study

According to [9] Bi-Polar technologies with a TTL/STTL package have a total dose hardness of $1e6$ Rads(Si). Significantly bigger compared to MOS technologies, for example, NMOS with a TDH of $7e2$. Data can be seen in Figure 13.

TECHNOLOGY	TOTAL DOSE HARDNESS - Rads (Si)
BIPOLAR:	
TTL/STTL	1×10^6
ECL	1×10^7
IIL	1×10^6
Linear	1×10^4
MOS:	
NMOS	7×10^2
CMOS (Bulk)	3×10^3
CMOS/RH	1×10^7
CMOS-SOS	1×10^6

Source: See Ref. 1.

Fig. 13 BJT vs Mosfet [9]

The reason we chose to implement a BJT is that it is voltage controlled and less susceptible to radiation. The BJTs on the PIB control critical elements. This includes the heat tape which turns on the chemical thruster and all the

solenoid valves which control the catalyst movement. In these cases a SEE cannot happen and if it does it must be fixed immediately. Shown in Figure 14 is the circuit diagram to control IEP and LFN solenoid valves. A diode is placed for back emf protection induced by the solenoid.

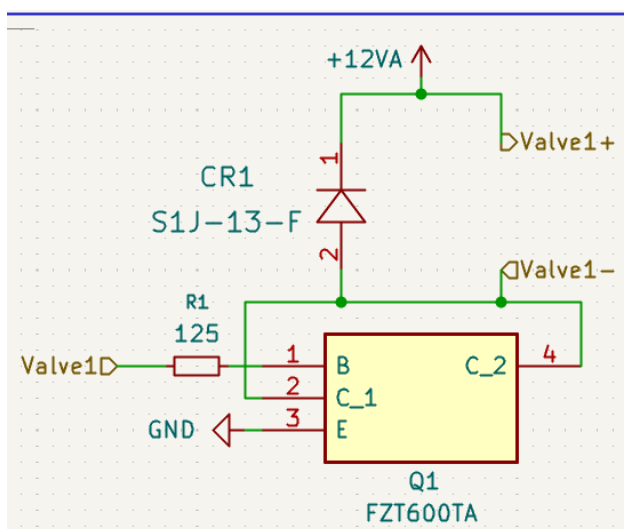


Fig. 14 KiCad Schematic: Solenoid Valve Control

2. Elimination of Electrospray Plume Measurement

Initially, the INA226-Q1 an ultra-precise current/voltage/power monitor was going to be used to measure the voltage drop across a resistor which is connected to an electrode above the electrospray. The electrode was going to catch the charges coming off the electrospray plume and the wire being grounded the charge would rush to ground across the voltage divider. The estimated max collected current is on the order of 20pA. However, complications were discovered when computing induced AC current produced by the electrospray.

VIII. Designing the Electrical System

While choosing electronics the initial diagram as seen in Figure 15 was created. The diagram was especially useful for understanding the flow of the PIBs and the interface between each element of MonARCH.

Additionally, the diagram clearly demonstrated the functionality of the payload interface board and was perfect for presenting. Once all components were agreed upon EPL and LASSI decided to split the work up with LASSI creating the PIB and EPL creating the breakout board and software for PIBs. For both the PIB and breakout board a schematic was created. During schematic design pin connections, footprints, and passives were determined. The schematic design for the STM32L4A6 on the PIB is shown in Figure 17 After the schematics were done we moved to routing the boards and tailoring the designs to specific dimensions fitted to MonARCH needs. The routing process for both the breakout board and PIB on KiCad software is portrayed in Figure 17 and Figure 18 This includes ensuring communication protocol same length traces, correct impedance paths between differential pairs, and correct passive values. The PIB is a four layer board and contains a 12 volt regulator for solenoid valve actuation. The routing of the board can be seen in 18.

A. Collaboration with LASSI for Payload Interface Board Design

Once schematic design and routing were finished the boards were ready to be reviewed and checked. They were sent to the leads of LASSI for thorough review.

B. Designing and Building the Breakout Board

The FDC2214 is contained on the breakout board. The breakout board was built for noise concerns as to bring the FDC2214 sensor closer to the electrodes as to minimize the distance the analog signals were being transmitted to.

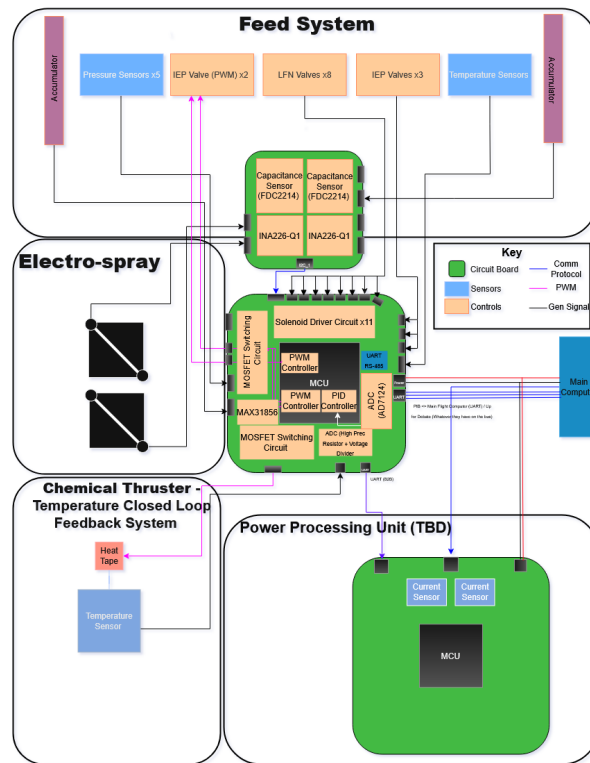


Fig. 15 Initial Diagram of Payload Interface System Layout

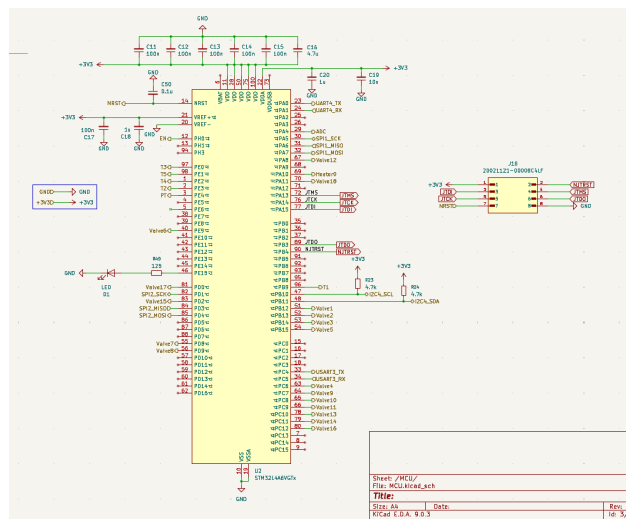


Fig. 16 MCU KiCad Schematic

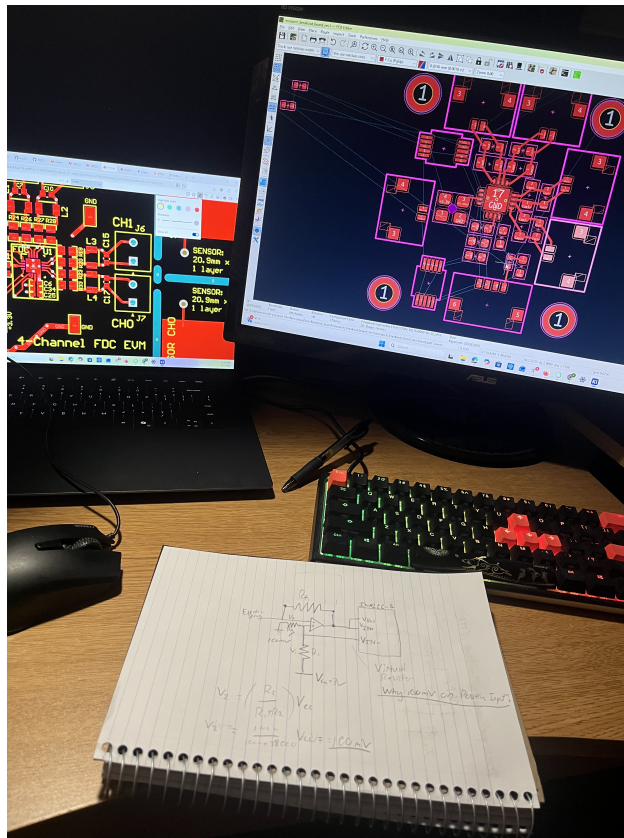


Fig. 17 Breakout Board KiCad Development

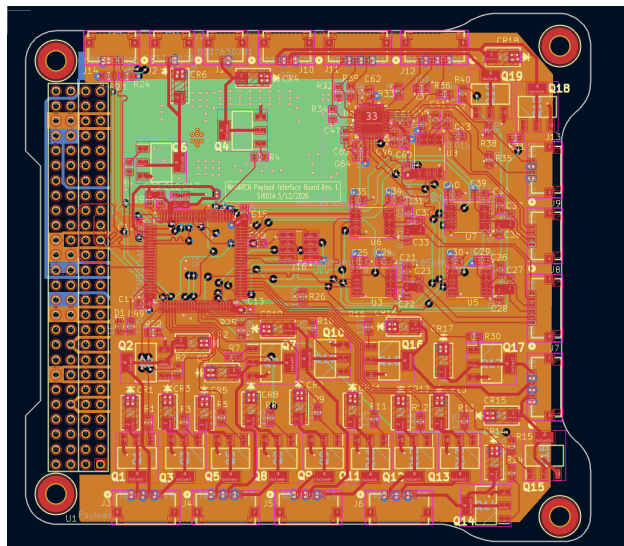


Fig. 18 Routing of PIB

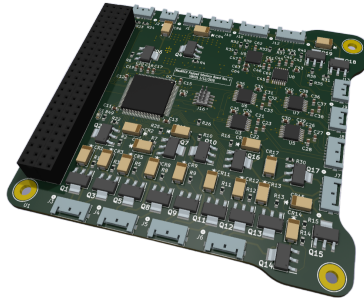


Fig. 19 Payload Interface Board

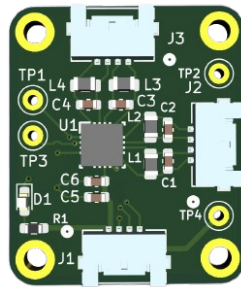


Fig. 20 Breakout Board Image

C. Software Design

STM32CubeMX alongside STM32CubeIDE were the main applications used to create the test programs for the STM32L4A6 on the PIB. All the programs have been built using C and the HAL library provided by STM. During the development process the following was accomplished: solenoid valve control, driver integration for each IC on PIB, and controls such as valve sequencing and electrospray chemical thruster ignition. The programs do build but they have not been tested physically on the PIB.

1. Control Flow and Finite State Machine

The PIB ultimately is a peripheral device controlled by the OBC through UART commands. The software is fairly simple. It contains an infinite loop continuously waiting for an assigned 8-bit command to execute. If no command the PIB continues waiting until a command is sent and then the PIB performs it.

2. Drivers

Drivers for each of the ICs were created by either adjusting online drivers to be compatible with the HAL STM32 library or built from scratch. When building drivers from scratch we followed a simple process of reading and writing to registers through I2C or SPI to configure and read from the ICs. An example of the software to convert a data reading from the FDC2214 to a level measurement reading is shown. Listing 1 .

Listing 1 FDC2214 Capacitance Read Function

```
uint8_t FDC2214_read_capacitance(uint8_t channel, float *cap_pf){

    uint32_t raw = FDC2214_read_data(channel);
    uint32_t f_sensor;

    // Convert raw data into sensor frequency
    f_sensor = (((float) raw) / ((float)(1UL << 28))) * FDC2214_F_REF;

    /* Step 2: Frequency to Total Capacitance */

    float omega = 2.0f * 3.14159265f * f_sensor;

    float total_c =
        (1.0f / (FDC2214_L_HENRY * omega * omega));

    /* Step 3: Subtract Parallel Capacitor */

    *cap_pf =
        (total_c - (FDC2214_C_PARALLEL)) * (1e12);

    return 1;
}
```

IX. Results and Discussion - Testing the Payload Interface Boards

After a review was done by leads at LASSI the board was ready to be ordered, soldered, and tested. Progress of soldering the breakout and PIB can be seen in 21 and 22. Lead solder was used for these prototypes and before flashing initial code, continuity was tested to ensure proper connections and to remove any shorts. During testing and debugging the boards we came upon a problem of not being able to identify the STM32L4A6. Through ensuring continuities, flashing development boards to ensure ST-LINK compatibility, checking for current readings it was determined the MCU was soldered in the wrong orientation. Once we replaced the MCU we were able to flash and identify the MCU. Shortly after a simple LED blink code was flashed. However, no LED blinked. Subsequently, it was identified the LED was on backwards. After re-soldering the LED we could no longer talk to the MCU and it is thus deemed we had shorted the MCU because we forget to turn off the power when re-soldering. The MCU was drawing half as much



Fig. 21 PIB in Development

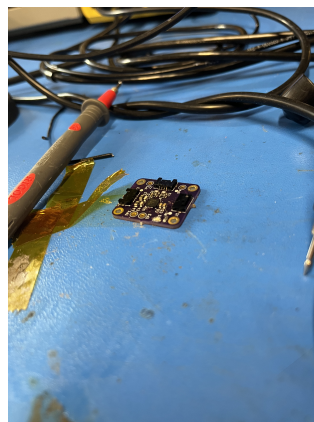


Fig. 22 Breakout Board

current compared to normal operation and we inferred we had fried the MCU. With no more MCU left to swap out the fried MCU we ended the semester ordering new MCUs leading into the summer.

X. Conclusion

The PIB prototype is currently in the testing phase and during the summer of 2026, testing the PIB for functionality is the main objective. This includes interfacing with K-type thermocouples and pressure transducers, measuring catalyst levels, and testing controls such as feed system sequencing events through UART commands from the OBC. Additionally, we will continue improving the payload electrical system and will be implementing techniques to protect the system and its data from the harsh space environment. Furthermore, testing will be done to evaluate the space effects on electronic systems discussed. This includes testing performance under harsh temperature conditions, re-designing prototype boards to reduce possible measurement drift due to EMI and parasitic capacitance replacing components for environmental stresses and out gassing potential. Our goal is to develop a robust and reliable instrumentation and control system capable of supporting accurate payload operation aboard MonARCH.

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