Document Title: Requirements Specifications		
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CHANGE HISTORY

Rev.	Date	Detailed change description (include rationale for change)	Affected Documents	Supporting Documents
01	02/28/2025	Initial Release		
02	3/5/2025	Updated Problem Statement, Table 01-3, Table 01-4, and added a “Conclusions/Next Steps” section at the end of the document The tables were updated to provide additional specifications for requirements and standards. Our conclusion was added to give insight on our plans for the remainder of the project. We updated our Problem Statement because our customer changed the sensor we were working with. It now mentions the new sensor.		
03	3/23/2025	Updated Requirements Table		

DOCUMENT REVIEW AND APPROVAL

Name	Title	Contributed Sections	Signature/Date
Cody Bullock	Project Lead	Table 01-3, Table 01-4, Table 02-1, Customer Needs, External Factors	Cody Bullock (03/07/2025)
Won Jae Chung	Technical Lead	Societal Factors, Next Steps / Conclusions	Won Jae Chung (02/28/2025)
Javier Torres	Programming Sub-Lead Testing Lead	Purpose, Key Stakeholders	Javier Torres (02/28/2025)
Yifu Yang	Programming Lead	Problem Statement, Ethical Factors	Yang Yifu (02/28/2025)
Todd Veach	Customer		
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Purpose

This document contains the initial requirements analysis for the small form factor imaging detector readout system intended for small satellite applications. It establishes the customers' needs incorporating them within the engineering requirements, functional specifications, and testing and verification approaches. The document includes a problem statement, engineering metrics, project specifications, and a high-level system diagram which all help make sure the design meets the project goals and technical limits. Serving as entry criteria to the Architecture Phase of the project, this document lays the groundwork for the project by identifying constraints that need resolution. This document is also a living reference as it will be evolving as the design is further refined and validated.

Definitions

Document Definitions

Table 01-1 Document Definitions

Term	Definition
Design History File	A compilation of records containing the complete design history of a finished device or service
Verification	Confirmation by examination and provision of objective evidence that specified requirements have been fulfilled
Validation	Establishing objective evidence that system specifications conform to user needs and intended uses
Component	One of the parts that make up a system. A component may be hardware or software and may be subdivided into components
Functional Testing	Testing that ignores the internal mechanism of a system or component and focuses on the outputs generated in response to selected inputs

Document Acronyms

Table 01-2 Document Acronyms

Acronym	Description
DHF	Design History File
IEEE	Institute of Electrical and Electronics Engineers
CR	Customer Requirement
FUN	Functional Requirement
SR	System Requirement
COM	Compliance Requirement
ENV	Environmental Requirement
REL	Reliability Requirement
POW	Power Requirement
ME	Mechanical Requirement
I/O	Input/Output Requirement
TEST	Testing Requirement
SCH	Scheduling Requirement
PER	Performance Requirement
CCD	Charge-Coupled Device
GPIO	General Purpose Input/Output
PCB	Printed Circuit Board
ADC	Analog-to-Digital Converter
U	Rack Unit

Customer Needs

Problem Statement

Todd Veach from Southwest Research Institute (SwRI) requires a small form factor CCD imaging sensor readout system designed specifically for small satellite applications in low orbit. The system must efficiently read data from a Teledyne-e2v CCD47-10 sensor while operating within strict constraints in terms of noise, size, weight, mass, and power consumption. Specifically, the system must exhibit less than 3 electrons read noise, and it must be able to operate within a temperature range of -55C to +35C with survival capability from -65C to +45C. The overall system's maximum power consumption is 5 watts.The solution we are providing should include essential functions such as clocking, preamplification, analog-to-digital conversion (12 or 16-bit ADC), and communication protocol via Ethernet. The final prototype will use commercial components. It will adhere to corresponding engineering and ethical standards. The project deadline is the end of Fall 2025 Semester.

Customer Needs Description

Our customer requires a driver circuit for the Teledyne-e2v CCD Sensor, with the goal of using it to take pictures of space from the satellite it's installed on. Because this system will be used inside of low-orbit satellites, it must be able to operate and survive under the harsh conditions of space. Our system is required to be able to operate fully between -55°C and 35°C, and survive between -65°C and 45°C. It must have radiation shielding, or at the very least radiation-safe parts, and have a readout noise of no more than three electrons. The system is compact and low-power. It must consume less than 5W, and be no larger than 1/2U. The entire system is driven by a 12 or 16-bit MCU, which clocks every aspect of the circuit. When an image is taken by the sensor, it goes through an ADC on the MCU, where the image data is digitized, then sent through ethernet to a separate computer on the satellite. A high-level diagram of the system is shown below in Figure 1, and an operation flow diagram is shown in Figure 2.

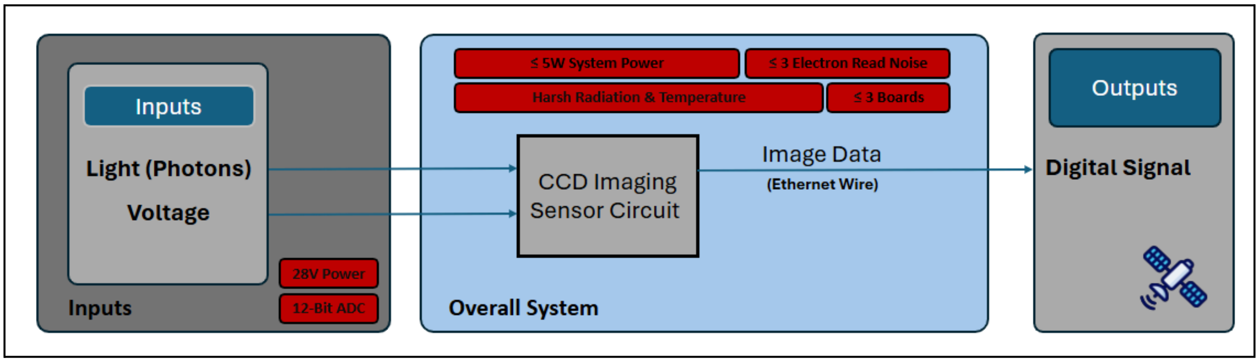

Figure 1 | High-Level Diagram

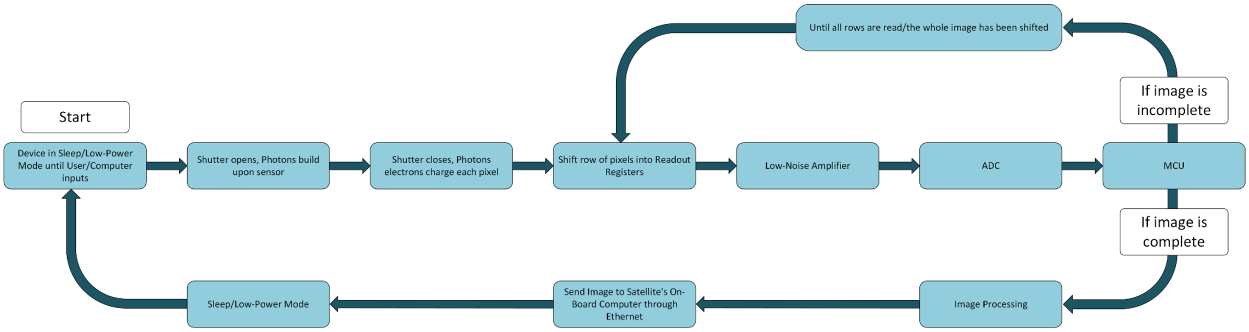

Figure 2 | Operation Flow Chart

Key Stakeholders

The key stakeholders for this project include Southwest Research Institute (SwRI), our primary customer, which will use the PCB for its suborbital and orbital applications. Todd Veach, as the representative for SwRI, who defines the system requirements, ensures that our PCB meets the needs of SWRI's applications, and provides us with expertise in spacecraft instrumentation and development. Internally, the VT ECE Department provides technical guidance and access to resources essential for the project so that the team is able to meet research and educational standards. Lastly, the F25-13 team who is responsible for designing, creating, and validating the PCB, ensuring it meets functionality standards while also managing constraints and different risks.

General Constraints

External Factors - Global, Cultural, and Environmental

The main constraint of this project is that it needs to be functional in a low-orbit environment. More specifically, it needs to be operational in a vacuum exposed to radiation and extreme temperatures. While there are no specifications for exactly how much radiation our product must be able to handle, it must remain fully operational between -55°C and 35°C, and it must be able to survive in environments that range between -65°C - 45°C. These two are the most important constraints, because if they're not met, our product will at best not function correctly, and at worst be destroyed if we actually tried to use it in space.

Another consideration is the power consumption. Our system must not consume more than 5W, which shouldn't be too difficult considering the relatively low voltage requirement. Our customer specified that our board will be powered by a DC 28V source that comes from the satellite that it's installed on. This 28V will get converted to 12V to power the sensor, then 3.3V to power both the MCU and Ethernet module.

The last few main requirements are much more lenient. Our total system must be no taller than 1/2U (0.875 inches), and must be clocked by an MCU. Considering that we're using PCBs to design the system, being shorter than 1/2U isn't that much of an issue, especially considering that there aren't strict length and width requirements. Other than making sure that no single part is too tall, our circuit can be relatively large, as long as the size stretches horizontally. Being clocked by an MCU is also easy because it'd be hard to clock it with anything else. There are no requirements for the speed at which it must be clocked, but the datasheet has suggestions for each pin that can be clocked. Most have some leeway, as the clocking speeds don't have a specific maximum clock speed, only a minimum. The general clock period recommended for taking the image itself is 30μs, or 33.333kHz.

Social Factors - Public Health, Safety, and Welfare

The design of a CCD small satellite readout system is influenced by external factors such as thermal extremes, radiation exposure, and power constraints. These space conditions degrade the circuit's performance overtime and the team needs to mitigate these effects.

For thermal management, the CCD needs to be operated at a stable temperature to minimize dark current noise and enhance image quality. With the use of thermal control mechanisms, thermoelectric coolers, and radiative heat dissipation techniques, the team aims to make the prototype operable in temperature fluctuating conditions. Moreover, based on Janesick's *"Radiation Effects on Spaceborne CCDs for spaceborne acquisition and tracking applications"* [1], the team is selecting space rated components and vacuum-compatible materials to prevent a degradation of optical and electronic performance.

For power, the readout system is operating in limited energy which efficiency is crucial. Efficient voltage regulations from the source and low power electronics are essential design considerations. Due to electromagnetic interference affecting the integrity of the signals, the customer requires a less than three electron read noise (PER -1). The team is aiming to resolve these issues by thoughtful PCB layout and shieldings on the design.

For space electronics, the engineering safety standards from NASA dictate best practices for component selection and fault tolerance. When testing the prototype, the team will follow precautions on electrostatic discharge to protect essential components. Lastly, the prototype will be tested in a thermal vacuum chamber to simulate space-like environments, ensuring the integrity and stability of the final design.

Ethical Factors - Global, Societal, Economic, and Environmental

Important parts of the IEEE Code of Ethics related to our CCD Small Satellite Readout System project include ensuring public safety, health, and welfare; maintaining accuracy, honesty, and transparency in data collection, reporting, and communication; and being responsible for our professional actions. According to IEEE Code of Ethics [2], we must avoid deceptive practices, openly disclose potential conflicts or risks, and ensure that the technology we develop contributes positively to society without harm.

The ethical issues in our project are related to global cooperation, cultural considerations, environmental concerns, and public health and safety. On a global level, accurate satellite data helps international research about climate and coordination in disaster situations, thus promoting trust among countries. From a cultural viewpoint, clearly communicating the system's strengths and limitations is important for keeping public trust and preventing misuse or misunderstanding of data. Regarding the environment, the project's low power usage and strong operational requirements address ethical duties to reduce negative impacts, such as space debris. Additionally, the reliability and accuracy of our system are very important for public health, safety, and welfare, as accurate monitoring data helps in making good decisions and responding quickly during emergencies.

We have an ethical responsibility to carefully make informed decisions during the design and development process. For example, we must openly identify and explain the risks involved in using commercial and non-space-rated components, such as potential failures or inaccuracies during space missions. Another example is to thoroughly test our system under realistic conditions, including extreme temperatures and radiation, to confirm its reliability and safety before actual deployment. Additionally, clearly documenting and communicating all findings from testing helps stakeholders and the customer understand potential limitations and ensures transparency. By carefully following these ethical practices, we contribute to responsible engineering and maintain professional integrity.

Based on our ethical analysis, specific customer requirements and target specifications have been initiated. These include strict adherence to temperature ranges for system operation and survival (FUN-1 and FUN-2), low electron read noise for accurate data capture (PER-1), and maintaining power consumption below 5 watts (POW-1). Additionally, standards for programming conventions (SR-2) and selecting space-rated components (SR-3) have been set to enhance the reliability and ethical compliance of the system in harsh space conditions.

Product Requirements

Table 01-3 Target Specifications

Category	REQ-#	Requirement	Version #	Notes	Verification Type
Functional	FUN-1	Shall be operational between -55C and 35C	v1		Test
	FUN-2	Shall survive between -65C and 45C	v1		Test
	FUN-3	Shall generate image	v1.2		Demonstration
	FUN-4	Shall be clocked my a microprocessor	v1	Microprocessor will provide the clocking essential to operate the CCD Sensor and all other components	Demonstration

Performance	PER-1	Shall not generate more than 3 electrons of read noise	v1		Analysis
	PER-2	Should use a 16-bit ADC	v1	A 12-bit ADC is the minimum requirement, but a 16-bit ADC is preferred	Analysis
Compliance	COM-1	All code shall be written in Python	v1		Demonstration
Environmental	ENV-1	Should use radiation-protected hardware	v1		Test
Reliability	REL-1	Shall stay operational in harsh conditions(temperatures and radiation)	v1		Test
Power	POW-2	Shall be powered by a 28V wired connection	v1		Demonstration
	POW-2	Shall not consume more than 5W	v1		Demonstration
	POW-3	Shall have DC voltage regulation	v1.2	Voltage biasing for 29V, 25V, 17V, 10V, 3.3V, 2V	Test
Mechanical	ME-1	Total system shall not be larger that 1/2U	v1		Inspection
	ME-2	Shall not be made of more that 3 boards	v1	Either 8-32 or 10-32 mounting holes	Inspection
	ME-3	Board must have mounting holes	v1.2		Inspection
	ME-4	Shall use the CCD sensor provided	v1		Inspection
Input/Output	I/O-1	Shall use either Ethernet or SpaceWire for data transfer	v1		Demonstration
	I/O-2	Shall have pre-amping for the digital signal produced from the CCD sensor	v1		Demonstration
	I/O-3	Shall develop a communication protocol	v1		Demonstration
Testing	TEST-1	Shall test the functionality of the prototype in a thermal vacuum chamber	v1		Test
Schedule	SCH-1	Shall finish prototype design by April 20th			Demonstration

Table 01-4 Standards and Statutory Requirements

Req. #	Requirement	Source Document (e.g., standard, regulatory requirements)	Details
SR-2	General Python programming conventions	PEP-8: Style Guide for Python Code	Coding conventions for the Python code comprising the standard library in the main Python distribution.
SR-3	Picking Space-Rated parts	NASA-STD-8739.10	4.1.1: General guidelines for selecting space-rated parts for different projects to ensure reliability in harsh space environments
SR-4	Ethernet Protocol	RFC-791	Specifies the DoD Standard Internet Protocol. This document addresses aspects of addressing, error handling, option codes, and the security, precedence, compartments, and handling restriction features of the internet protocol.

Benchmarking Information

Competitive benchmarking based on engineering metrics. This analysis can also be performed based on perceived satisfaction of customer requirements (i.e., user needs).

Table 02-1 Benchmarking Information

Spec. #	Req. #	Metric	Priority	Units	Hamamatsu CCD Driver Circuit	TI LM98555 CCD Driver	-
TEST-1	PER-1	Electron Readout Noise	5	e^{-} rms	10 e^{-}rms	-	-
TEST-2	FUN-1, FUN-2	Operating Temperature	4	°C	0°C - 50°C	0°C - 70°C	

Conclusions / Next Steps

The **small form factor CCD imaging detector readout system** outlined in this document establishes a strong foundation for meeting the customer's technical and operational requirements. By defining key constraints, engineering specifications, and external considerations, we have created a framework that ensures the system will function reliably in **low-orbit satellite environments** while maintaining efficiency in **power consumption, thermal management, and data acquisition**.

Moving forward, the next steps include:

1. **System Architecture Design** – Transitioning from requirements to detailed **hardware and software architecture**, ensuring alignment with performance specifications.
2. **Component Selection, Trade Studies, and Prototyping** – Choosing **space-rated** components and developing an initial prototype for testing.
3. **Simulation, Validation, and Verification** – Conducting simulations and **preliminary functional testing** to refine the design and mitigate risks.
4. **Integration and Final Testing** – Performing **thermal vacuum testing, radiation resistance assessments, and signal integrity verification** to ensure system reliability in space conditions.
5. **Final Review and Iteration** – Addressing test findings and making refinements before moving to the **manufacturing and deployment phase**.

This document will continue to evolve as we refine and validate the design, ensuring the project stays on track to meet the **end-of-Fall 2025** deadline

References

[1] "Radiation effects on commercial CCDs | Request PDF," in *ResearchGate*, Dec. 2024. doi: 10.1109/RADECS.2001.1159327.

[2] "IEEE Code of Ethics." Accessed: Feb. 28, 2025. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html