



**SwRI CCD Small Satellite  
Readout System  
(MDE F25-13)**

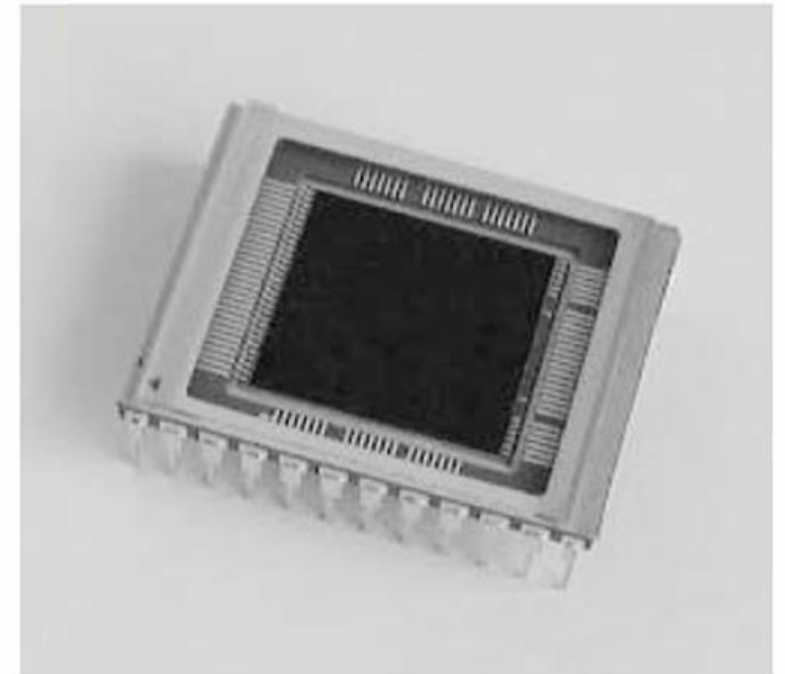
# Project Description

## Main Goal:

Our goal is to develop an imaging detector readout system using a CCD sensor for small orbital and suborbital satellites. The CCD captures a  $1024 \times 1024$  image, with its pins controlled by the MCU. The MCU processes the image data with its internal 12-bit ADC and transmits the image via an Ethernet chip to the host computer.

This system must have low noise and power consumption, must be compact, and must be able to operate in harsh space conditions such as extreme temperature and high radiation.

**CCD47-10 AIMO**  
**Back Illuminated Compact Pack High**  
**Performance CCD Sensor**



# Meet The Team



**Cody Bullock**

*Project Manager,  
Hardware Co-Lead*



**Jae Chung**

*Product Manager,  
Hardware Co-Lead*



**Yifu Yang**

*Cost Manager,  
Software Co-Lead*



**Javier Torres**

*Test and Configuration Manager,  
Software Co-Lead*

# Mentor, Customer, and Meeting Schedules



**Dr. Todd Veach**

*Customer*

**Meeting Times:**

*Times Decided on Availability  
Usually Once Every Two Weeks*



**Dr. Shelly Stover**

*Mentor*

**Meeting Times:**

*Every Sunday 7:45 PM – 8:45 PM*

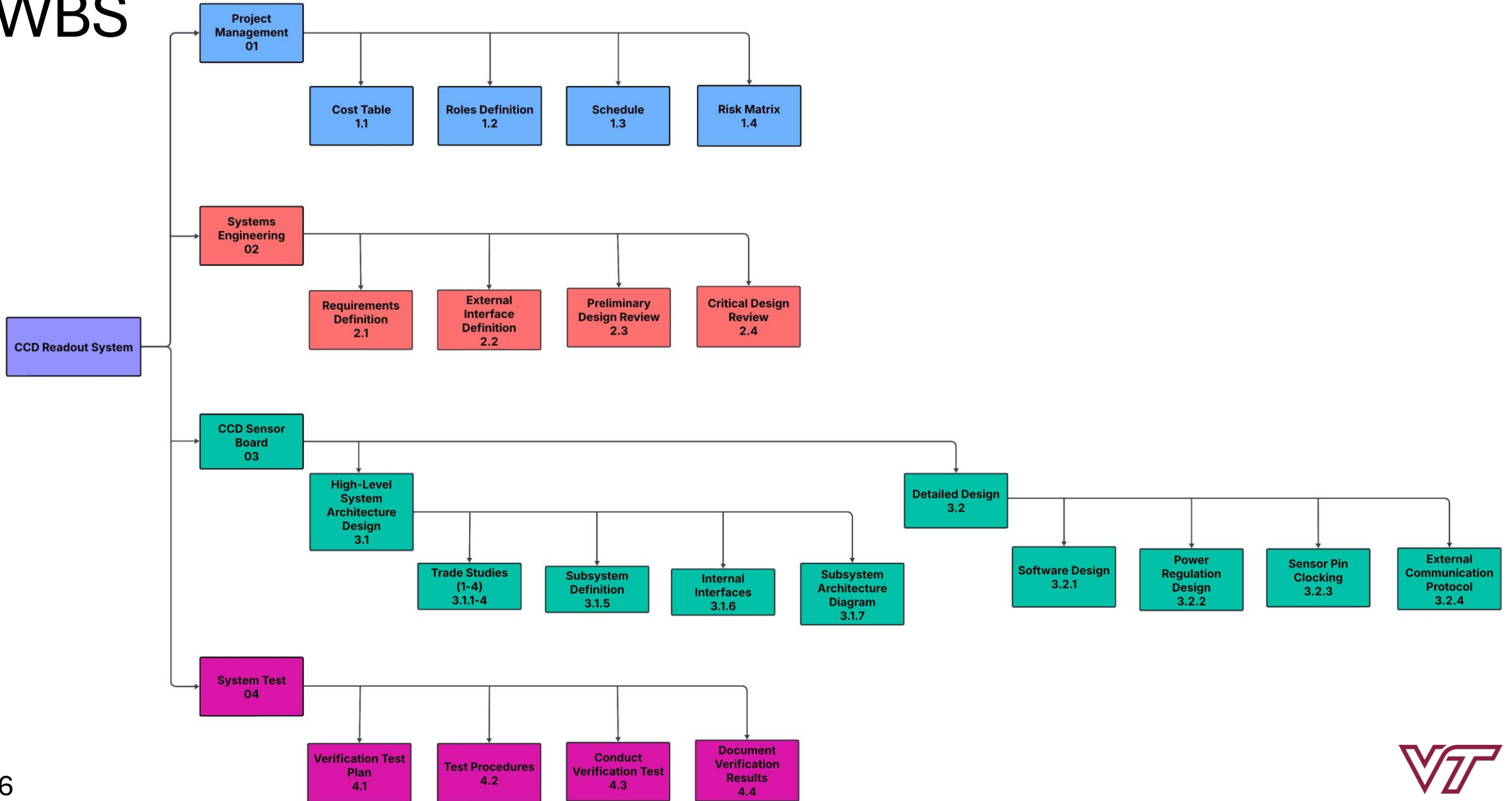
# Stakeholders

*Our Team (F25-13)*



COLLEGE OF ENGINEERING  
BRADLEY DEPARTMENT OF ELECTRICAL  
AND COMPUTER ENGINEERING  
VIRGINIA TECH™

# WBS



# Project Requirements

<p>Functional</p> <ol style="list-style-type: none"><li>1. Shall be operational between -55C and 35C</li><li>2. Shall survive between -65C and 45C</li><li>3. Shall generate image</li><li>4. Shall be clocked by a microprocessor</li><li>5. Must have at least a 12-bit ADC</li></ol>	<p>Verification Type</p> <p>Test</p> <p>Test</p> <p>Demonstration</p> <p>Demonstration</p> <p>Analysis</p>
<p>Performance</p> <ol style="list-style-type: none"><li>1. Shall not generate more than 3 electrons of read noise</li></ol>	<p>Analysis</p>
<p>Compliance</p> <ol style="list-style-type: none"><li>1. All code must be written in Python</li></ol>	<p>Demonstration</p>
<p>Environmental</p> <ol style="list-style-type: none"><li>1. Shall stay operational in harsh space conditions</li></ol>	<p>Test</p>

# Project Requirements cont.

<p>Power</p> <ol style="list-style-type: none"> <li>1. Shall be powered by a 28V wired connection</li> <li>2. Shall not consume more than 5W</li> <li>3. Shall have DC voltage regulation(i)</li> </ol>	<p>Verification Type</p> <p>Demonstration</p> <p>Demonstration</p> <p>Test</p>
<p>Mechanical</p> <ol style="list-style-type: none"> <li>1. Total system shall not be larger than 1/2U</li> <li>2. Shall not be made of more than 3 boards</li> <li>3. Boards must have mounting holes(ii)</li> <li>4. Shall use the CCD sensor provided</li> </ol>	<p>Inspection</p> <p>Inspection</p> <p>Inspection</p> <p>Inspection</p>
<p>Input/Output</p> <ol style="list-style-type: none"> <li>1. Shall have pre-amping for the analog signal produced from the CCD sensor</li> <li>2. Shall use Ethernet for data transfer</li> <li>3. Shall develop a communication protocol for interacting with the host computer</li> </ol>	<p>Demonstration</p> <p>Demonstration</p> <p>Demonstration</p>

i: Voltage biasing for 29V, 25V, 17V, 10V, 3.3V, 2V  
ii: Either 8-32 or 10-32 mounting holes

# Project Requirements cont.

Testing 1. Shall test the functionality of the prototype in a thermal vacuum chamber	Verification Type Test
Schedule 1. Shall finish prototype design by April 20th	Demonstration
Reliability 1. Shall use commercial/automotive hardware to build prototype	Demonstration

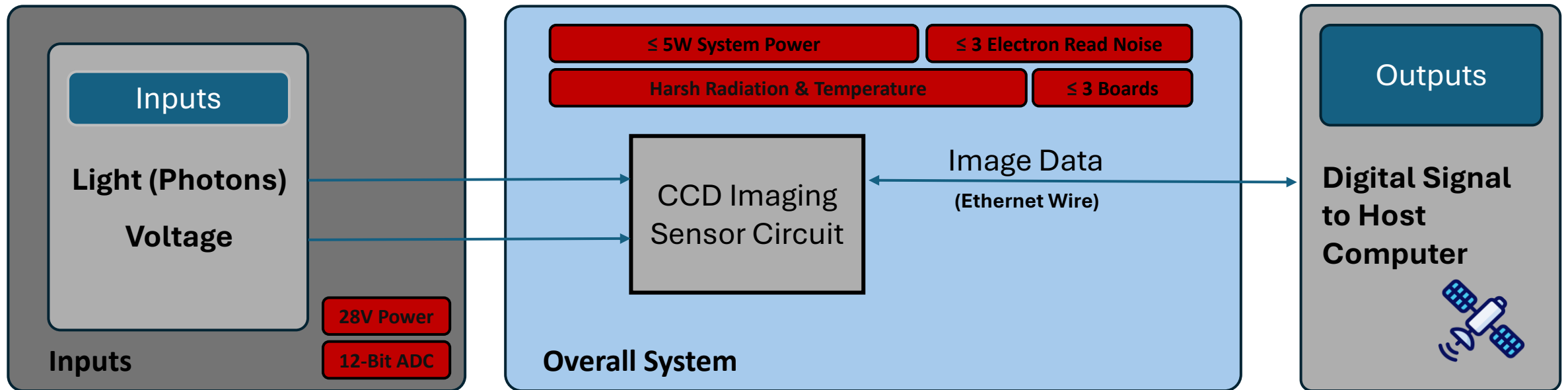
## Nice to Have

Design 1. Should use a 16-bit ADC (as opposed to 12-bit)	Demonstration
---	---------------

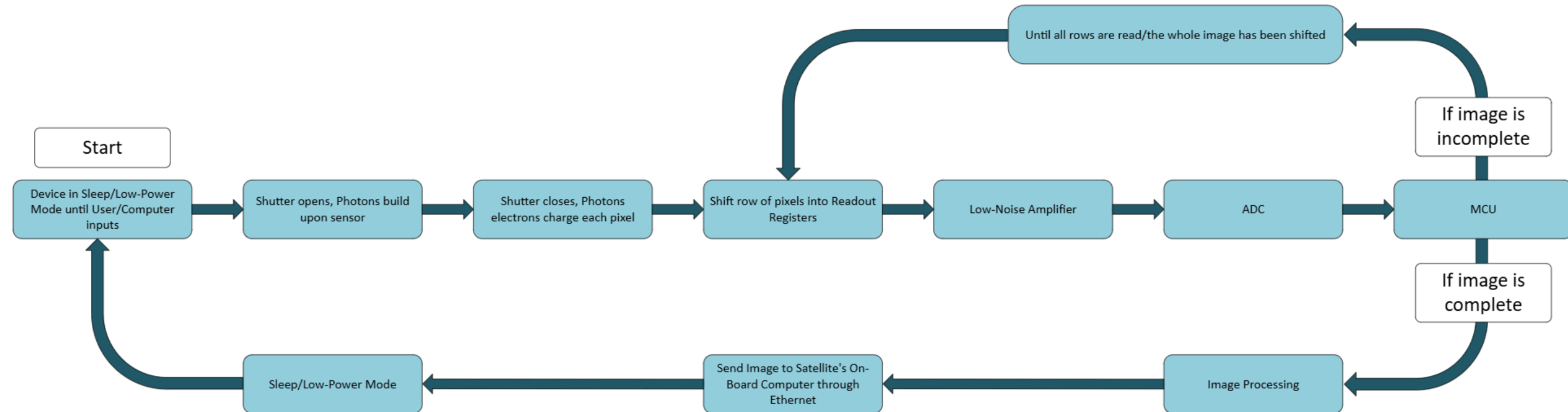
# CCD Sensor System Diagram

## Legend

- Constraints
- I/O



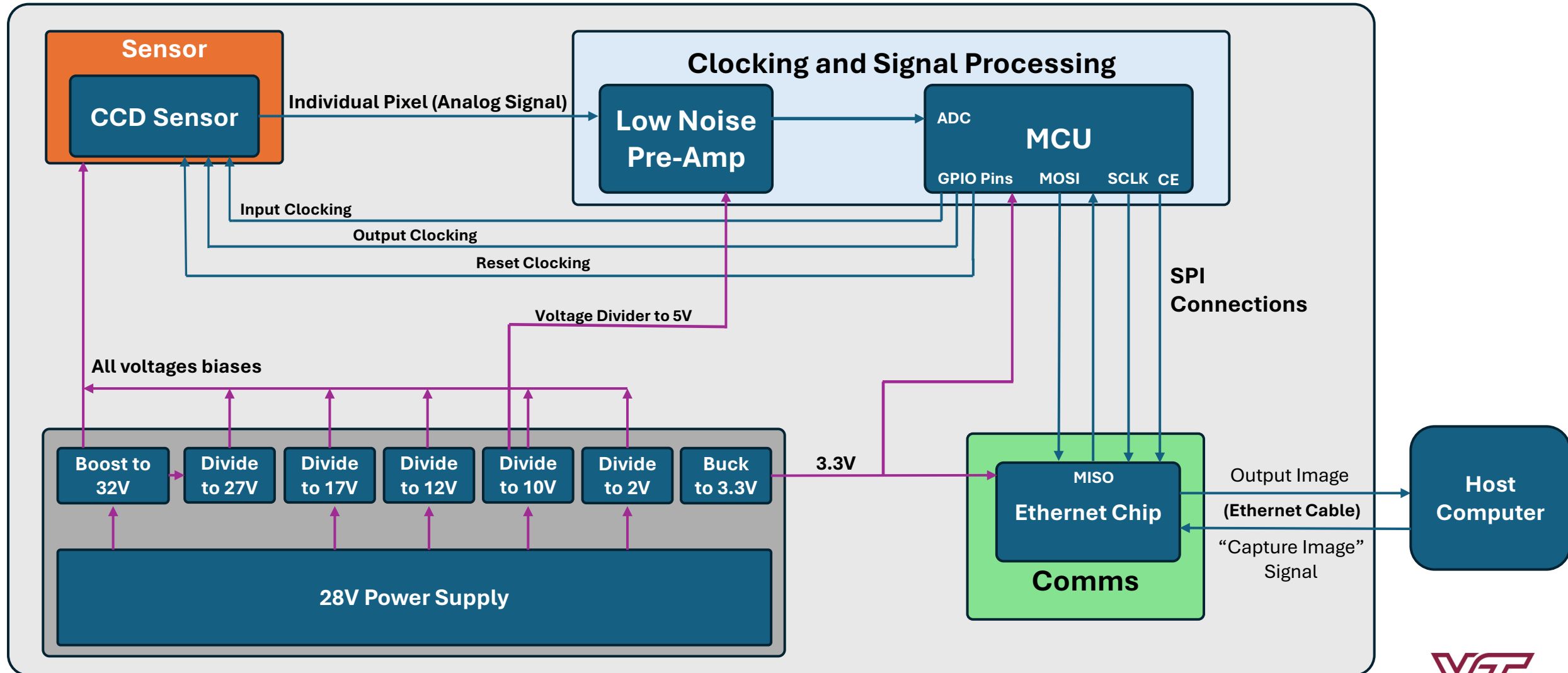
# Concepts of Operations



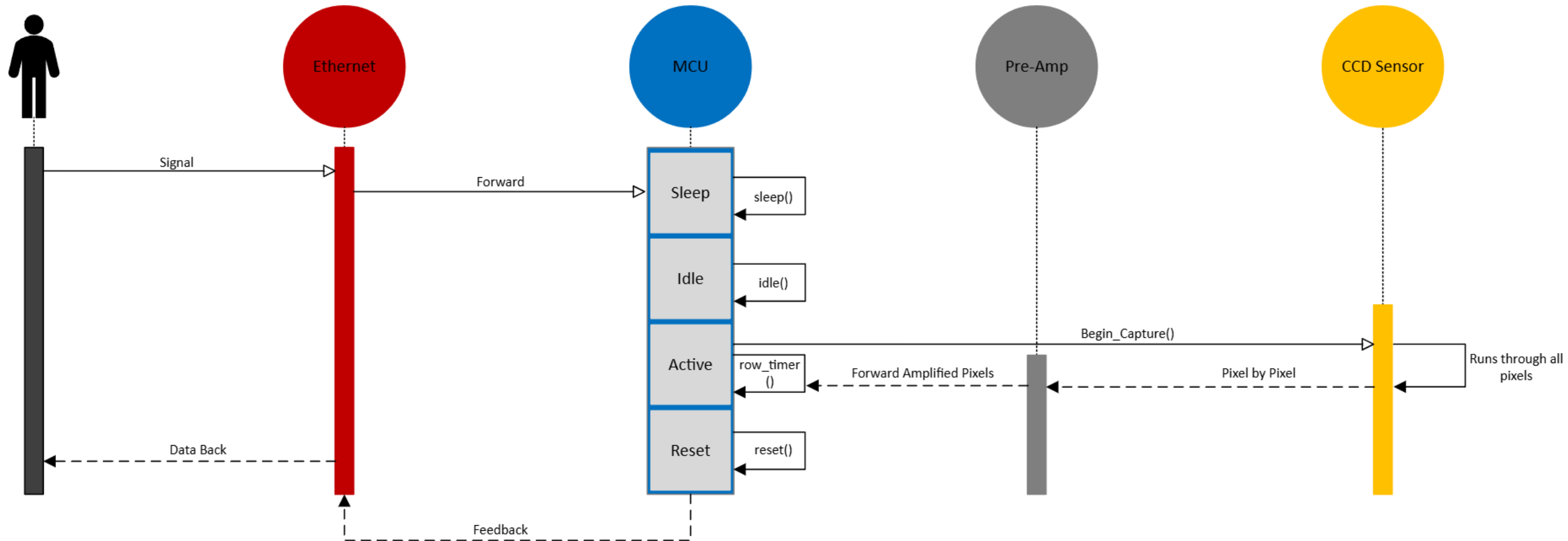
# CCD Subsystem Diagram

## Connections Legend

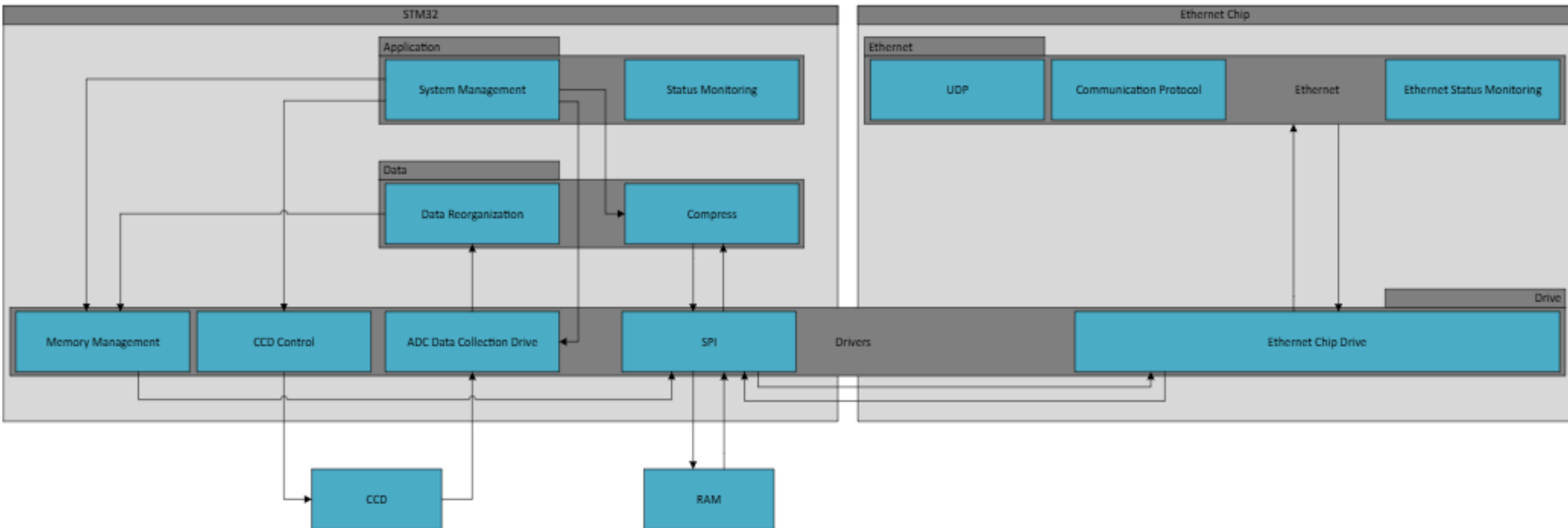
- Power
- Data



# System Sequencing Diagram

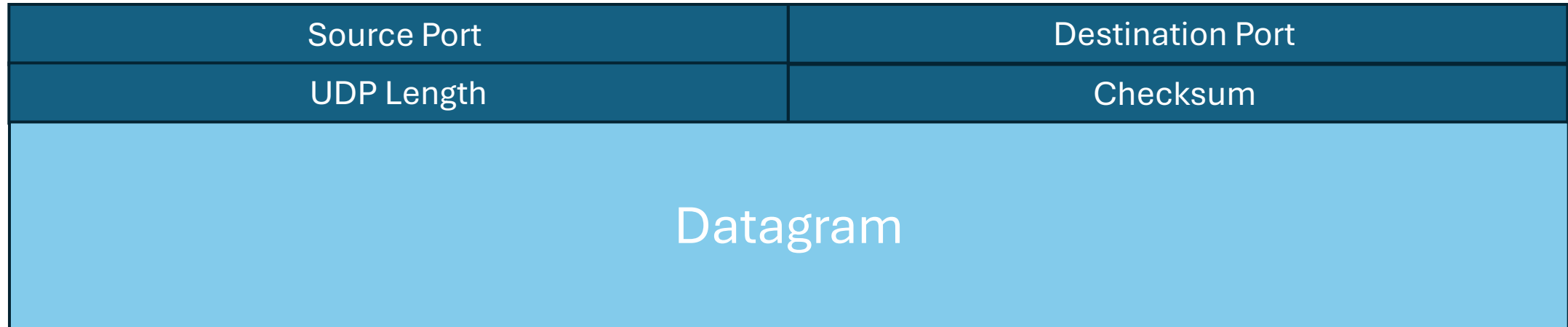


# Software Class Diagram



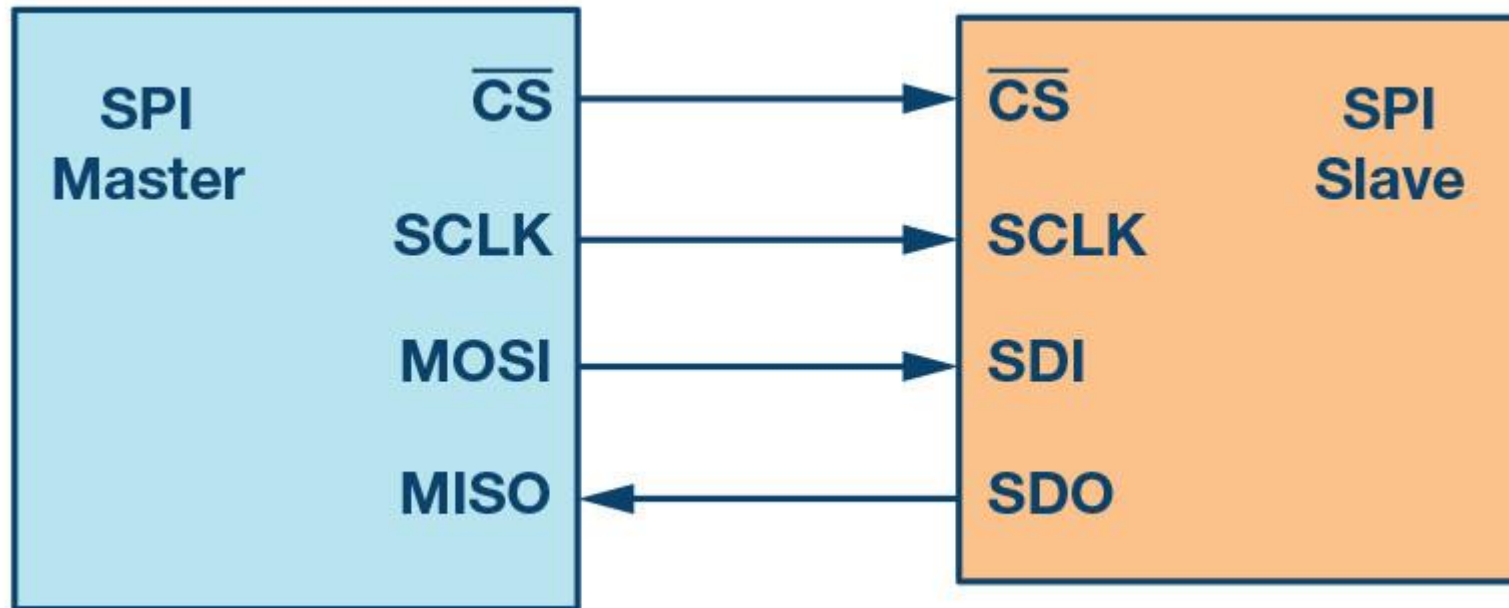
# System Transport Protocol- UDP

- Simple Encapsulation
- Best effort protocol
- Application layer handles data verification



# System Communication Protocol - SPI

- Full-Duplex
- Higher Speeds
- Synchronous
- Slaves: Ethernet Chip



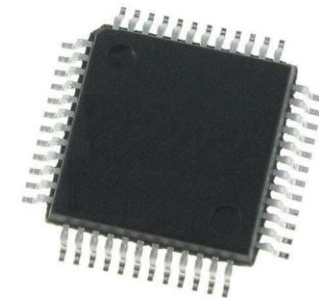
# *Trade Studies*

# Trade Study 1: MCU

Type	Input Voltage	Processing Power and Memory	Interface Protocols	ADC and DAC	Memory	Cost	Power Consumption	Timers
STM32L052C	1.65-3.6V	32-bit Cortex M0+ 32MHz	1xUSB 2xUSART 2xI2C 4xSPI	12-bit ADC  12-bit DAC	64KB Flash  8KB RAM  2KB EEPROM	\$2.70	0.27µA Standby  0.4µA Stop Mode  88µA/MHz Run Mode	5 x16-bit 1x SysTick 1x RTC 2 x WatchDog
MAX32675C	2.7-3.63V	12MHz ARM Cortex-M4 w/ FPU	3xUART 2xSPI 3xI2C 1x Low Power UART	16-/24 bit ADC  12-bit DAC	384KB Flash  160KB RAM  160KB SRAM	\$15.62	Active Current ≤ 2.1mA at 85°C	6x32-bit 2xWatchDog

## Best Option: STM32L052C

- The main criteria for the MCU is low power. The STM32 can operate at a lower voltage, meaning it can consume less power. The “Standby” and “Stop” mode currents are also very small. The more powerful ADC and higher amount of memory in the MAX are nice, but not necessary for our project.



# Trade Study 2: Ethernet Module

Type	Interface	Supported Protocols	Input Voltage	Power Down/ Sleep Mode	Cost	Speed
W5500	SPI at 80MHz	TCP, UDP, ICMP, IPv4, ARP, IGMP, PPPoE	3.3V	Yes	\$2.89	10Mbps 100Mbps
ENC28J90	SPI at 20MHz	IPv4, ARP, ICMP, UDP, TCP, ARP, DNS, UDP, DHCP	3.1-3.6V	Yes	\$2.84	10Mbps

## Best Option: W5500

- The main concerns for the ethernet chip are speed and reliability. The W5500 has the ability to transfer data much faster than the ENC.
- There's also much more support for the W5500 online, as it seems to be the go-to choice for general purpose Ethernet connectivity.



# Trade Study 3: Low Noise Preamplifier

Type	Low Noise Voltage	Slew Rate	Supply Range	Output Swing	Cost
AD797	0.9 nV/ $\sqrt{\text{Hz}}$	20 V/ $\mu\text{s}$	$\pm 5\text{ V}$ and $\pm 15\text{ V}$	$\pm 13\text{ V}$	\$18.12
OPA134	8nV/ $\sqrt{\text{Hz}}$	20 V/ $\mu\text{s}$	$\pm 2.5\text{ V}$ to $\pm 18\text{ V}$	$\pm 17\text{ V}$ (or within 1V of rails)	\$3.15
LM833	4.5 nV/ $\sqrt{\text{Hz}}$	7 V/ $\mu\text{s}$	-18V - 18V	-14.6 V to 14.1 V	\$0.86

## Best Option: AD797

- The AD797 has the lowest noise by a decent degree, and the high slew rate allows for more accurate readings in our high-speed system.
- The lower supply range is acceptable because the signal it's amplifying should be well within the  $\pm 5\text{ V}$  range.

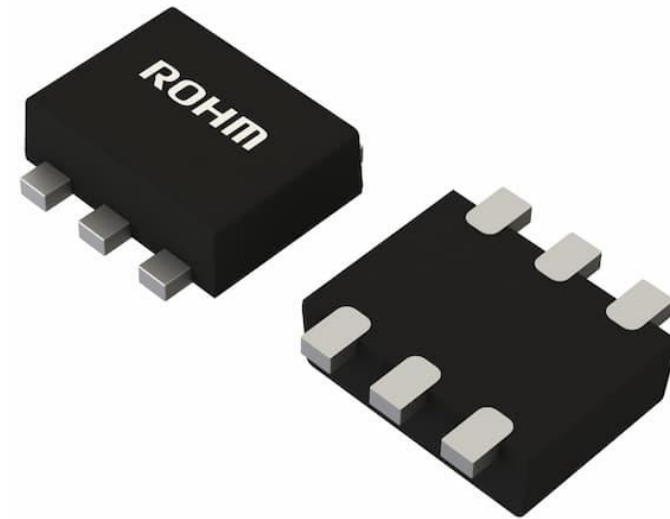


# Trade Study 4: Dual N-Channel MOSFETs

Type	Power Dissipation	Turn-On Delay Time (in ns)	Rise Time (in ns)	Turn-Off Delay Time (in ns)	Fall Time (in ns)	Cost
ROHM EM6K7	150mW	5	10	15	10	\$0.66
OptiMOS BSD235N	500mW	3.8	3.6	4.5	1.2	\$0.42
NTUD3174NZ	125mW	16.5	25.5	142	80	\$0.96

## Best Option: ROHM EM6K7

- The EM6K7 has the fastest switching times for the amount of power dissipation it has. We'll need at least 7 of these chips on our board for timing the sensor, so the power consumption will build up quick.



# Cost Table

Item	Purpose	Quantity	Total Price
STM32L052C	The system's main microcontroller	1	\$2.70
AD797	Low-Noise ADC Preamplifier	1	\$18.12
W5500 Ethernet Board	Used to transmit data from the MCU through SPI to an ethernet cable	1	\$2.89
Dual MOSFET Chip	Used for voltage switches on the sensor's pins	7	\$0.66
		Total	\$28.33

# *System Testing*

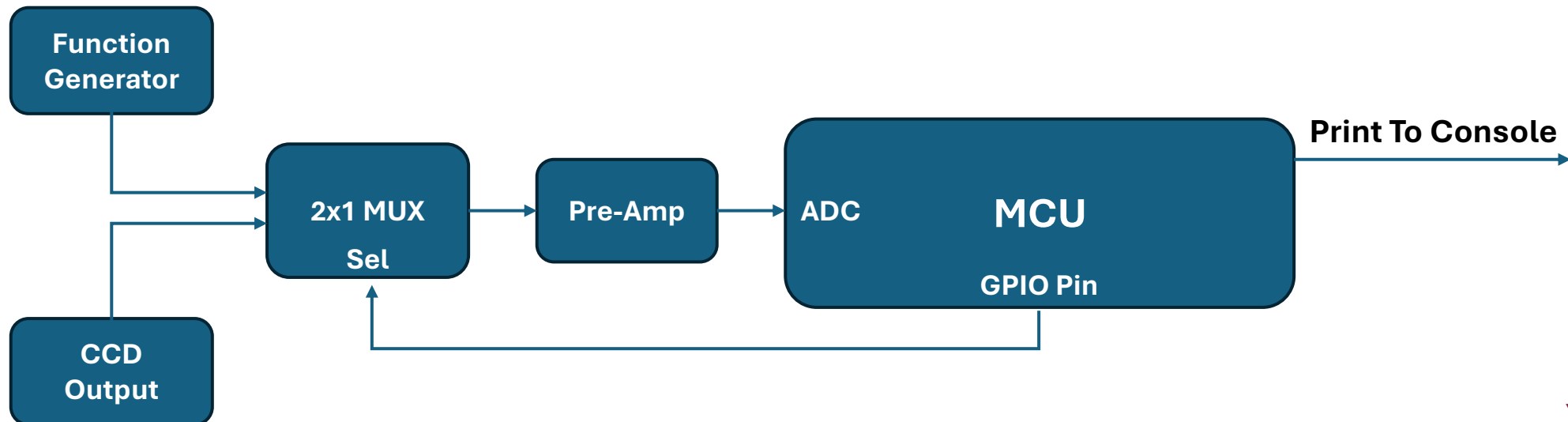
# ADC and Pre-Amp Testing

## Required Materials:

- 28V Board Power
- Function/Wave Generator
- Laptop to Program/Debug MCU
- IDE for Programming/Console Output

## Testing Procedure

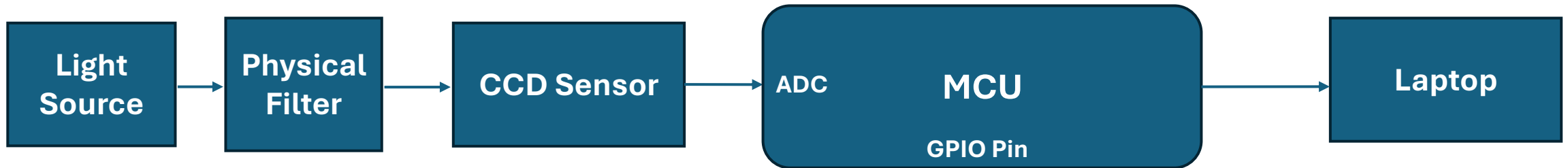
1. Apply voltage through function generator
2. Signal goes through MUX, to Pre-Amp, to ADC
3. Digital signal is printed to the console



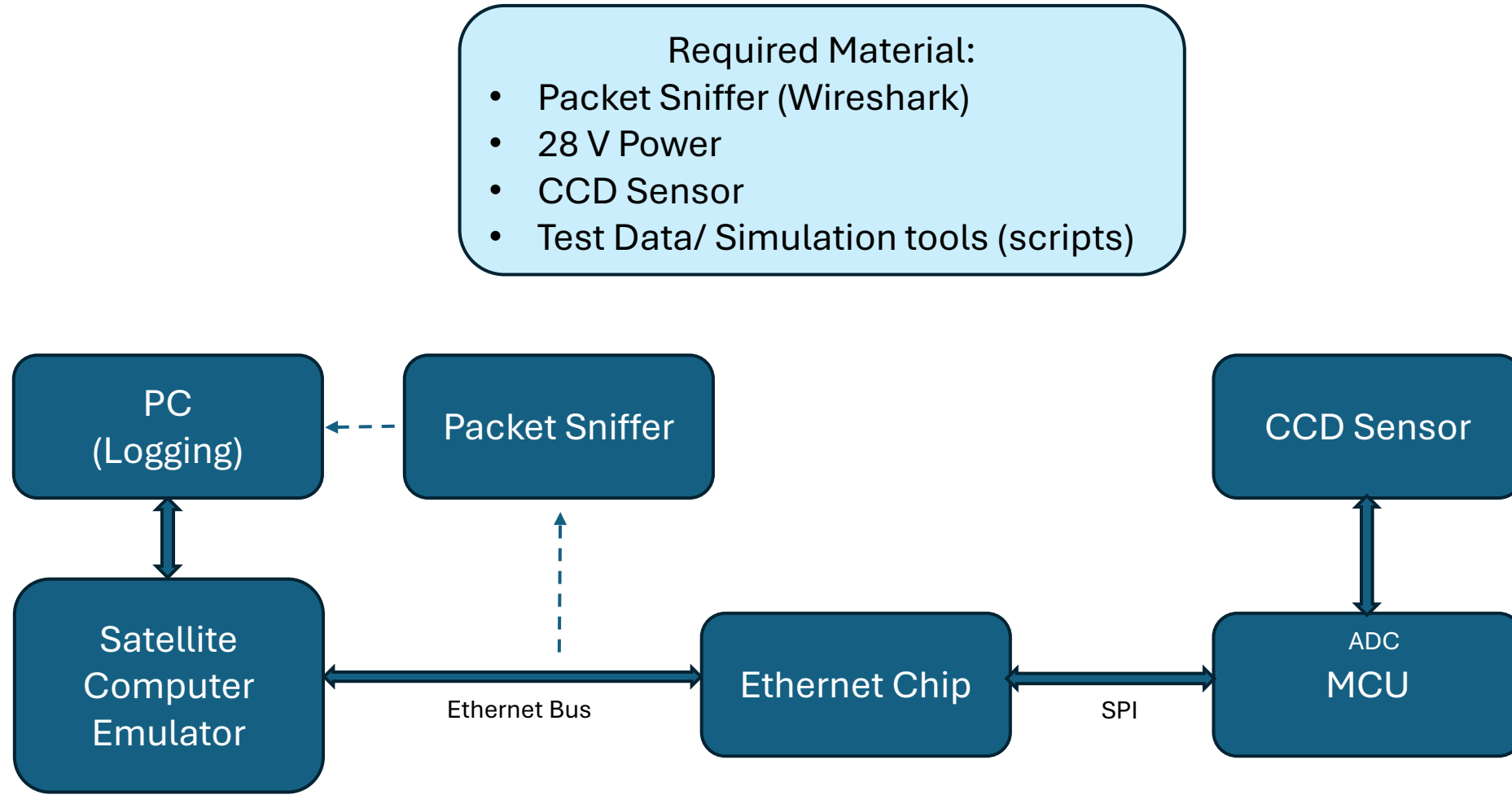
# Testing CCD Sensor

## Required Materials:

- Light Source
- Physical Filter for CCD
- CCD Sensor
- MCU
- Laptop
- IDE for Programming and Reading Output of CCD Sensor



# Communication and Protocol Testing Diagram



# Thermal and Noise level Testing Diagrams

## Thermal Survivability and Operability :

### Required Materials:

- Fully Assembled PCB
- Thermal Vacuum Chamber
- 28 V Power
- Testing Software/Simulation tools (scripts)

### Testing Procedure:

- Place PCB within Thermal Vacuum
- Operate vacuum at required temperatures
- Remove and validate survivability and operability



## Noise Level:

### Required Materials:

- 28 V Power
- Shorting Mechanism
- Testing Software/Simulation tools (scripts)

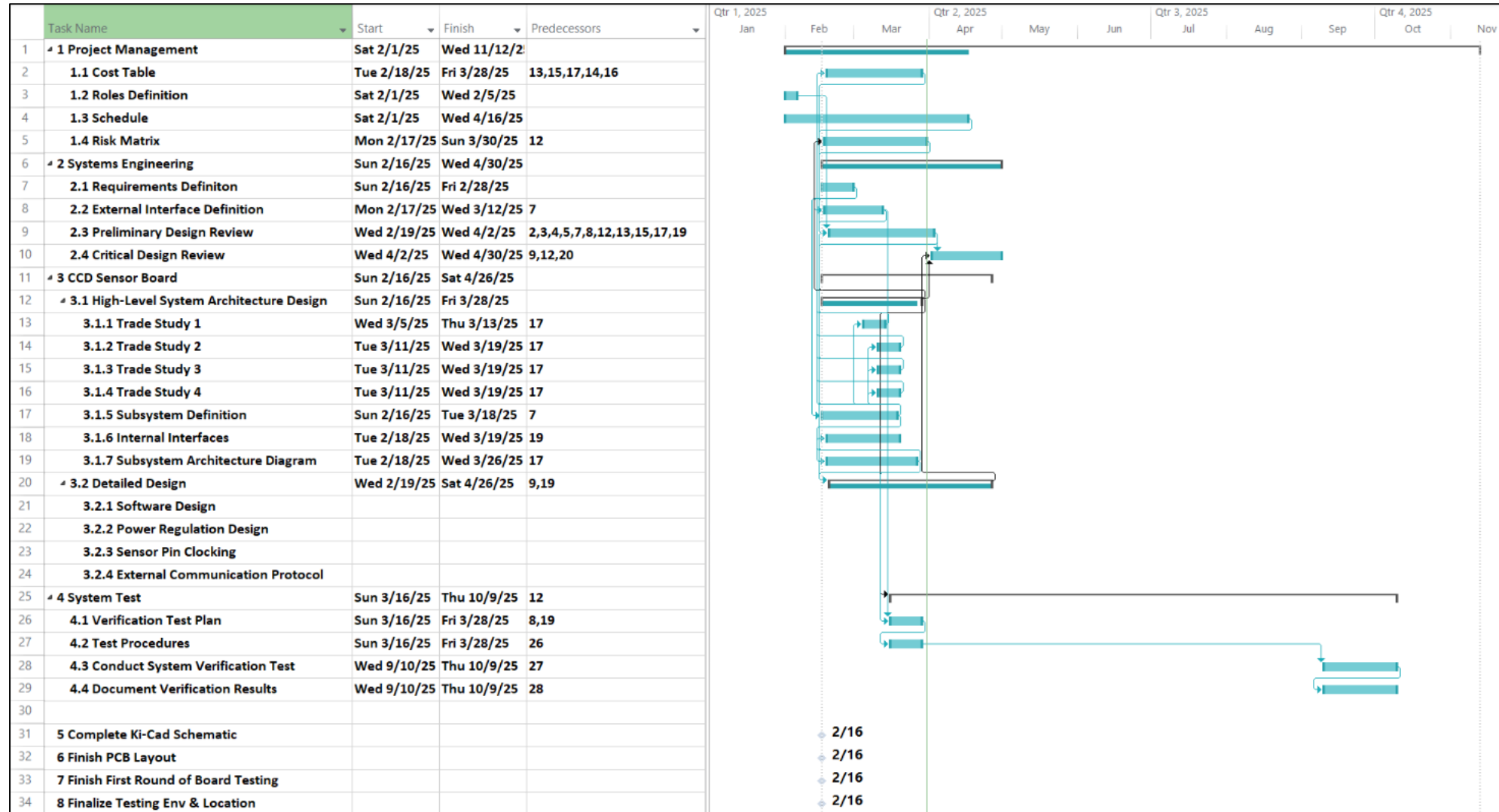
### Testing Procedure:

- Dark frame (zero exposure)
- Standard deviation (based on gain of system)
- < 3 Electrons



# *Project Schedule and Risks*

# Project Schedule and Milestones



# Risk Identification/Mitigation

Risk No	Related Risk	RISK	Severity	Probability	Mitigations
1	2	Damage the CCD sensor	High	Low	Handle the CCD sensor in a cleanroom environment, use ESD protection, and follow manufacturer handling guidelines.
2	1	Damage circuit componenets while testing in T-VAC	Medium	High	Perform pre-test functional checks, use appropriate thermal cycling procedures, and monitor temperature and pressure conditions closely.
3	1,2	Electrical damage due to incorrect power supply connections	High	Medium	Implement overvoltage and overcurrent protection, verify connections before powering up, and use proper grounding techniques.
4	1, 2, 3	Shipping delays	Medium	Medium	Finalize designs early and order as soon as we're confident. Our first prototype is most likely going to work exactly how we want it to, so we must redesign quickly to be able to order more parts/PCBs early.
5	N/A	Our circuit uses too much power	Low	Medium	Our spec requires that the circuit consume less than 5W. This can be ensured with more careful design choices and planning.

# Risk Matrix

		Impact				
Probability		Insignificant 1	Minor 2	Significant 3	Major 4	Severe 5
	5 Almost Certain			Damage in TVAC (Risk 2)		
	4 Likely					
	3 Moderate		Too Much Power (Risk 5)	Shipping (Risk 4)	Electrical Damage (Risk 3)	
	2 Unlikely					Damage to CCD (Risk 1)
	1 Rare					

# Actions

Task Name	Status	Assigned To	Date
Change various “Demonstration” verification types to “Test”. Whatever requires a quantifiable value is a “Test”	Incomplete	Jae	4/3/2025
Define the comms protocol we’re using in requirements (from ICD)	Incomplete	Javier	4/3/2025
Change “develop” to “utilize” for the comms requirement	Complete	Cody	4/3/2025
Update Slide 10 to current design (bidirectional communication, etc.)	Incomplete	Cody	4/3/2025
Remove anything from the blue box in slide 10 except for the name of our project	Complete	Cody	4/3/2025

# Actions

Task Name	Status	Assigned To	Date
<b>Update Concept of Operations:</b> remove shutter	Incomplete	Javier	4/3/2025
<b>Update Concept of Operations:</b> make “start” signal more explicit	Incomplete	Javier	4/3/2025
<b>Update Concept of Operations:</b> remove “image processing”	Incomplete	Javier	4/3/2025
<b>Update Concept of Operations:</b> don’t send signal (it’s requested async). Image is placed in a buffer	Incomplete	Javier	4/3/2025
Remove shutter from subsystem diagram	Complete	Cody	4/3/2025
Complete Soldering Training and Lab Swipe Access	Partially Complete	Team	4/3/2025

# Actions

Task Name	Status	Assigned To	Date
<b>CCD Subsystem Diagram:</b> add how the voltage dividers will go high and low using the MOSFETs	Incomplete	Cody	4/3/2025
<b>CCD Subsystem Diagram:</b> Complete subsystem layout for CDR	Incomplete	Cody	4/3/2025
<b>System Sequencing Diagram:</b> add commands found in ICD	Incomplete	Javier	4/3/2025
<b>System Sequencing Diagram:</b> add logic for “idle” and “sleep” functions	Incomplete	Javier	4/3/2025
<b>System Sequencing Diagram:</b> change “person” icon to “spacecraft”	Incomplete	Yifu	4/3/2025

# Actions

Task Name	Status	Assigned To	Date
<b>Class Diagram:</b> Show parameters for functions	Incomplete	Javier	4/3/2025
<b>Class Diagram:</b> remove compression and other unnecessary blocks	Incomplete	Yifu	4/3/2025
<b>Class Diagram:</b> expand each box with specifics for CDR	Incomplete	Javier	4/3/2025
<b>Class Diagram:</b> change “Data Reorganization” to “Data Storage”	Incomplete	Yifu	4/3/2025
<b>Trade Studies:</b> need to be made with later replacing with space-rated parts in mind	Incomplete	Cody	4/3/2025

# Actions

Task Name	Status	Assigned To	Date
<b>Cost Table:</b> add estimated PCB costs to the table	Incomplete	Cody	4/3/2025
<b>Cost Table:</b> use more of the available \$500-750 budget	Incomplete	Cody	4/3/2025
<b>System Testing:</b> choose a specific speed to test CCD at to make design easier	Incomplete	Jae	4/3/2025
<b>System Testing:</b> no need to test with a light filter, can test with LEDs on a bench	Incomplete	Jae	4/3/2025
<b>System Testing:</b> emulator for comms testing needs to be added to the WBS in “Testing Support”	Incomplete	Javier	4/3/2025

# Actions

Task Name	Status	Assigned To	Date
<b>System Testing:</b> add TVAC testing to our schedule. Have a bake out schedule	Incomplete	Team	4/3/2025
<b>System Testing:</b> make sure we know how to clean our board before entering the TVAC	Incomplete	Team	4/3/2025
<b>System Testing:</b> get to know how our specific chamber works (constraints, how to feed wires through). Get an actual tour and as much info as possible on the TVAC chamber	Incomplete	Team	4/3/2025
<b>System Testing:</b> add active temp readout through thermistors to the board	Incomplete	Cody	4/3/2025

# Actions

Task Name	Status	Assigned To	Date
<b>System Testing:</b> noise testing comes before putting it in the TVAC. Short CCD connections to board ground	Incomplete	Javier	4/3/2025
<b>Project Schedule:</b> detailed design needs to be built out for CDR	Incomplete	Cody	4/3/2025
<b>Risk Mitigation:</b> need to find a way to mitigate almost certain risks, nothing should be in the red in terms of probability. Re-Assess risks until we have good enough procedures to reduce their probability of occurring	Incomplete	Jae	4/3/2025

# Actions

Task Name	Status	Assigned To	Date
<b>Parts Ordering:</b> Start ordering parts that will take long shipping times.	Incomplete	Team	4/3/2025
<b>Documents for the customer:</b> prepare a document that the team and VT isn't responsible for breaking the CCD sensor	Incomplete	Cody	4/3/2025
<b>Soldering Training and Amp Lab Access</b>	Incomplete	Team	4/3/2025

**Thank You!**