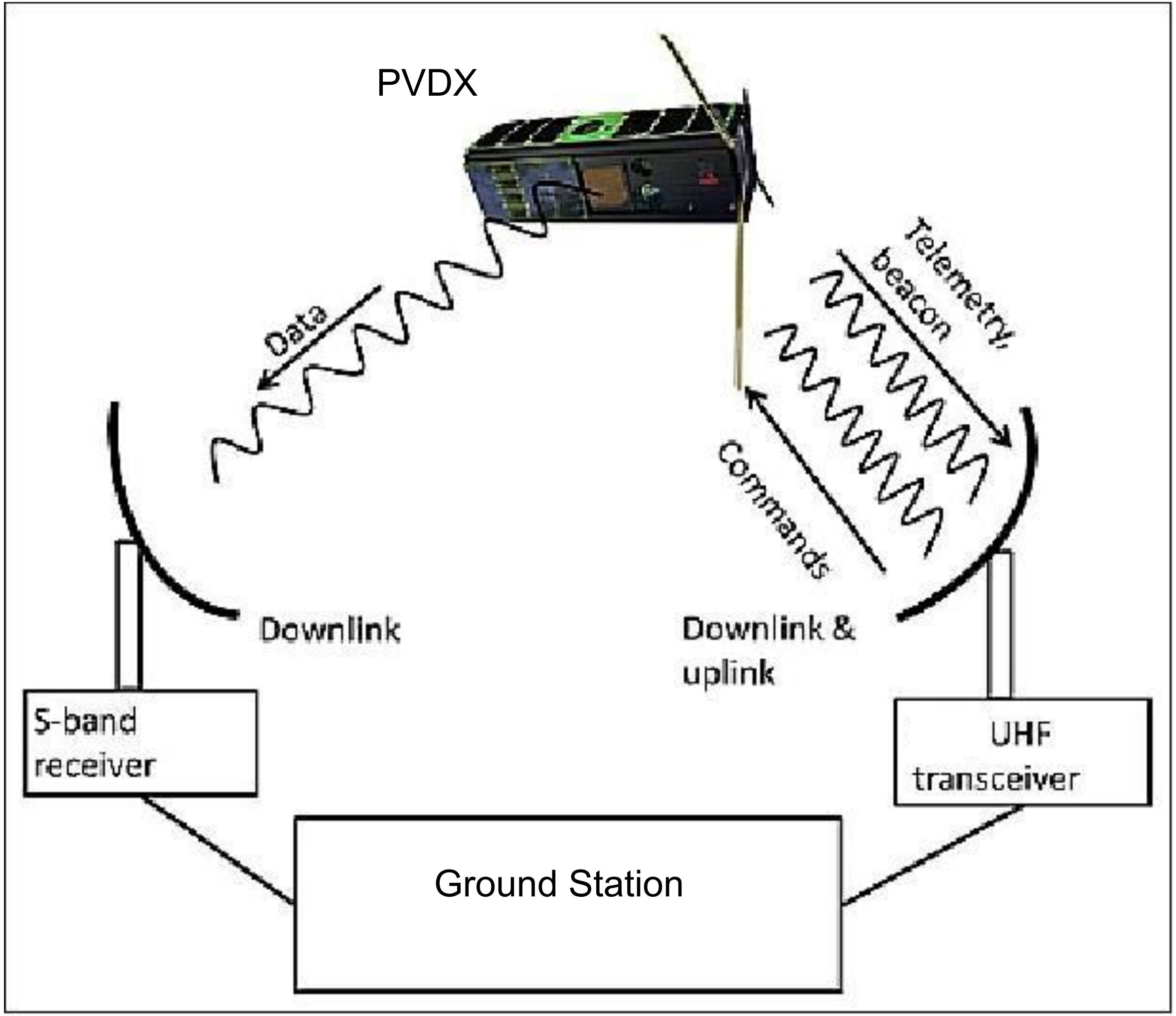
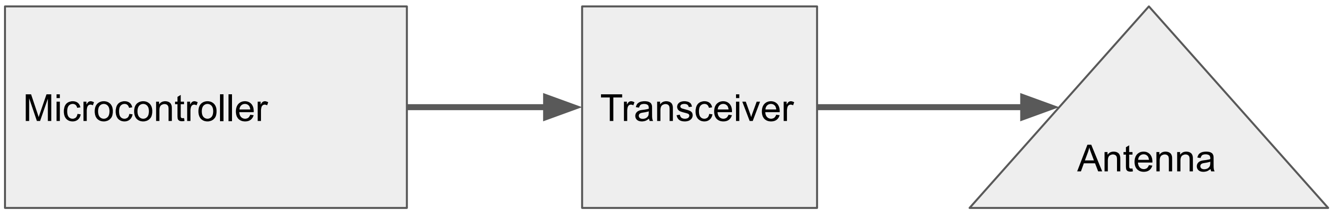
PVDX Systems Requirements Review: Communications System


BSE
Hello World


PVDX
Data
Telemetry,
beacon
Commands
Downlink
Downlink &
uplink
S-band
receiver
UHF
transceiver
Ground Station

UHF Radio Intro

Overall Block diagram



Technical Requirements

- The Communications subsystem has three primary tasks:
    a. Act as a beacon so that the position of the satellite can be tracked on Earth
    b. Downlink satellite health data and sensor data to ground stations
    c. Provide a means disabling the transmitter from a ground station via uplink

- Frequency: 436-437 MHz (~70cm band)
- Transmit Power: 0.5 Watt
- Data Downlink: GMSK modulation at 4800 bits-per-second
- Pointing: omnidirectional

- Will be the same system as used on EQUiSat

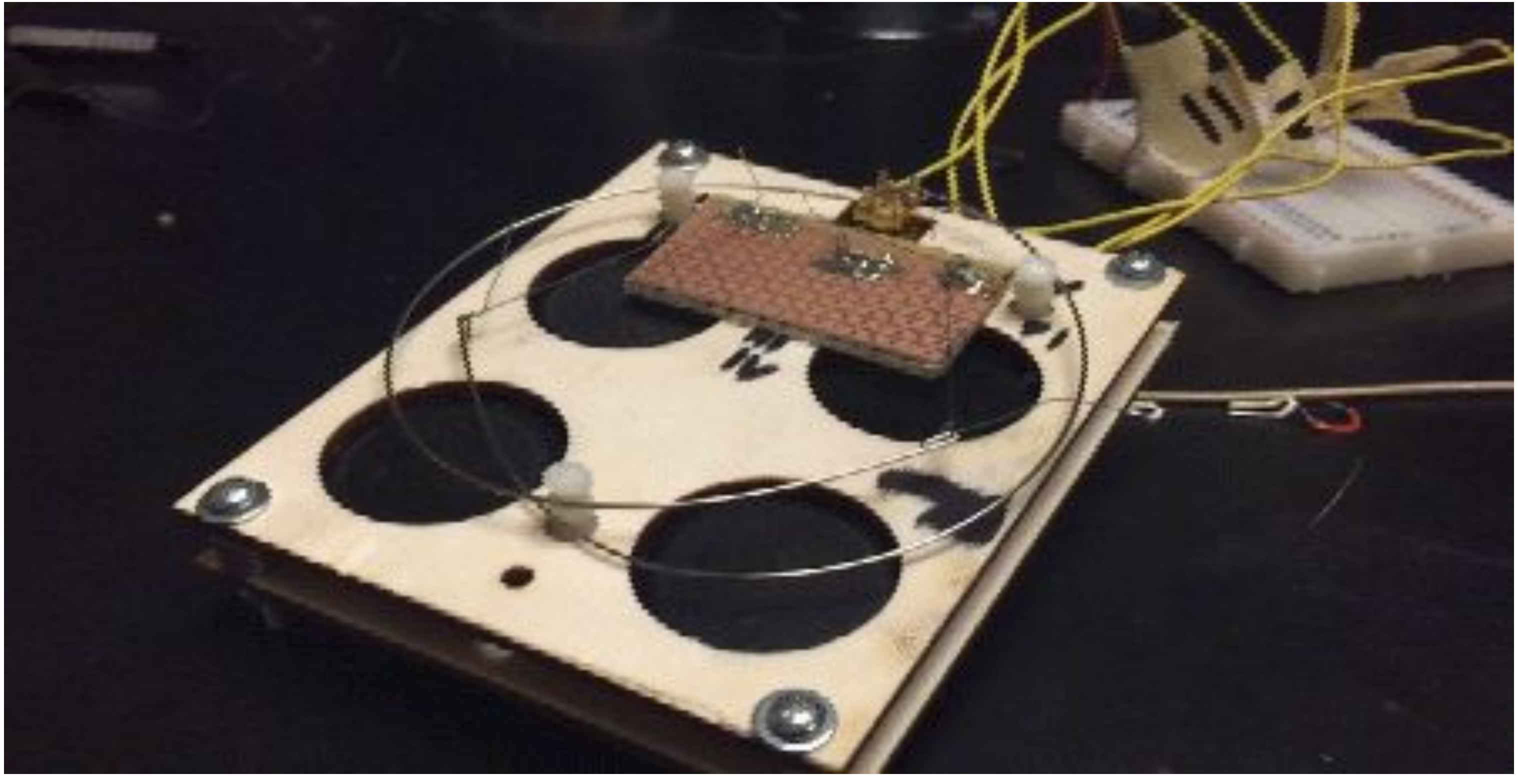
Transceiver

- XDL Micro Transceiver from Pacific Crest Communications
- Data Downlink: GMSK modulation at 4800 bits-per-second
- We have designed our communications subsystem to transmit and receive signals in the 435-438 MHz band. This 70cm band is ideal for accessibility to Amateur Radio operators
- Well documented and tested for thermal and vibration standards
- Transmission will include data automatically generated by the microprocessor to give updated reports of battery, solar panel, and sensor data that will help determine the attitude.

Antenna

- Type: Nitinol dipole antenna of 35cm (half wavelength)
- Directionality: omnidirectional transmissions
- Deployment mechanism:
  1) Will be coiled against protruding posts on a single face of the CubeSat and secured with nylon cord during launch (left figure).
  2) A small heating circuit consisting of three redundant nichrome loops holding down the nylon cord will be used as an electronic release for the antenna (right figure). The antenna poles themselves are made from nitinol wire, which has super-elastic properties to allow it to regain its straight shape after being coiled on the face of the CubeSat.

Antenna Deployment

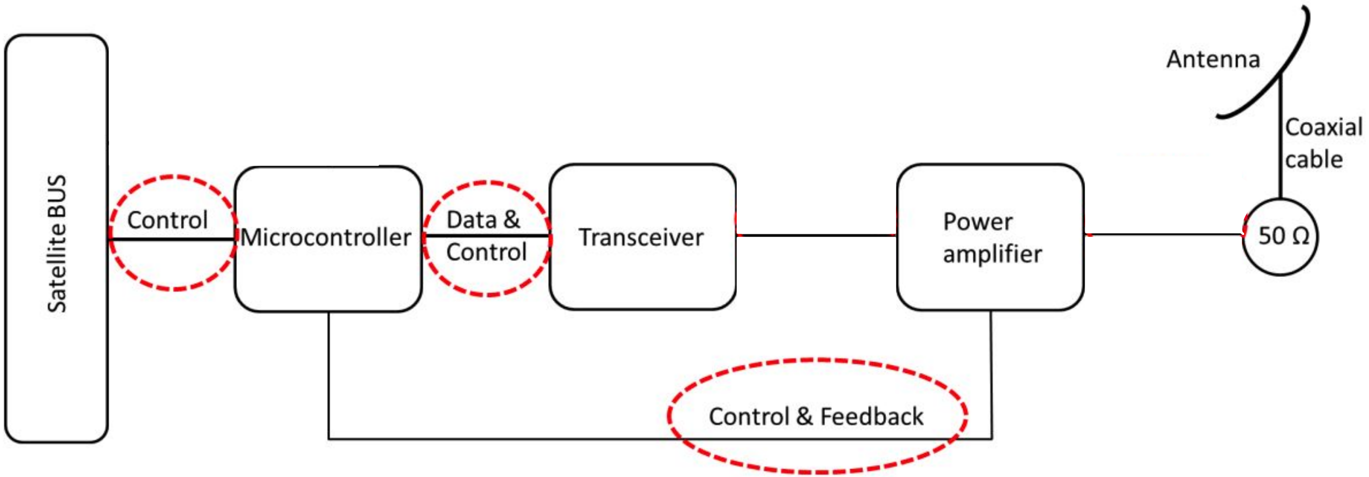


Link Budget

BROWN PVDX LINK BUDGET - UHF XDL Micro						
Constants						
earth radius (km)	6,370.00					
c (Gm/s)	0.30					
orbit altitude (km)	400.00					
K = 10log(Kb) (dB)	-228.60					
Transceiver Specs.						
carrier freq (GHz)	0.435	*435 MHz*				
wavelength (m)	0.69	*c/f*				
TX power (dBm)	27	*0.5 W power*				
data rate (bps)	9,600	*XDL's 4FSK 9k6 mode*				
antenna gain (dBi)	3.0	*based on EQUiSat dipole tests*				
Final EIRP (dBW)	0.0	*TX power + antenna gain*				
Groundstation						
system noise temp. (K)	300	*ground temp.*				
antenna gain (dBi)	13.30	*groundstation Yagi (436CP16)*				
low noise amplifier gain (dB)	14.00	*Mirage KP-2/440 LNA (minus 1dB noise figure)*				
antenna G/T fig. of merit (dB)	2.53	*Yagi gain + LNA gain + noise temp.*				
modulation BW (Hz)	12,500	*XDL RX filter bandwidth*				
Eb/No req. for 1e-5 BER (dB)	19.50	*Based on Eb/No vs. BER curve for noncoherent MFSK w/ M = 4*				
Losses (dB)						
RF losses on spacecraft	1.00					
atmospheric/fade loss	1.00					
polarization loss	0.50					
modulation loss	1.00					
demod loss	2.00					
pointing loss	2.75	*assuming unknown S/C orientation and +/-5deg G/S pointing precision w/ 42deg half-power beamwidth*				
sum	**8.25**					
Path Loss Calcs.						
elevation (degrees)	90.00	60.00	30.00	15.00	5.00	0.00
elevation (radians)	1.57	1.05	0.52	0.26	0.09	0.00
slant range (km)	400.00	457.42	739.31	1,175.17	1,803.68	2,292.60
space dispersion (dB)	137.25	138.42	142.59	146.61	150.33	152.42
margin (dB)	**25.15**	**23.98**	**19.81**	**15.78**	**12.06**	**9.98**

S-Band Radio Intro

Overall Block diagram



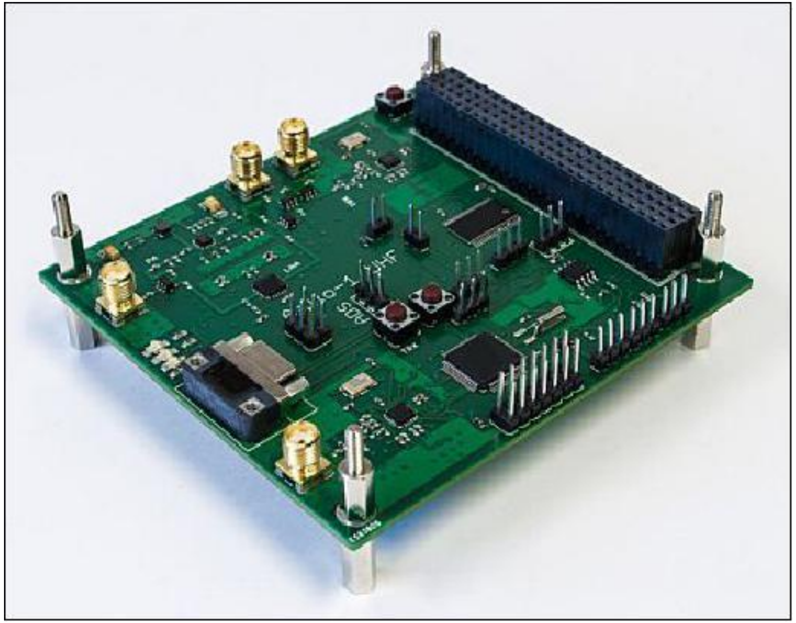
Technical Requirements

Mission Goal and Requirements:

1. Downlink images of satellite face (solar panels and LED display)
2. Send images within ~15min pass over time

S-Band Overall Features:

- Dedicated Microcontroller
- UHF can be used in case of failure



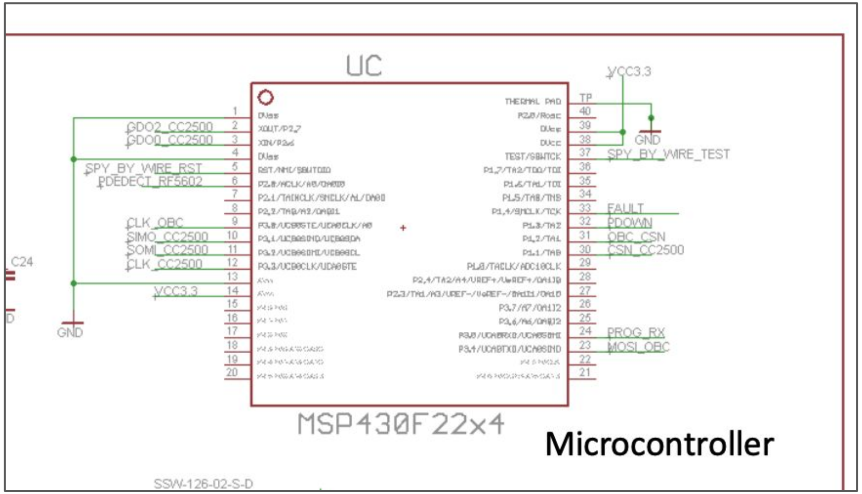
Microcontroller

TI MSP430F2274 Microcontroller Specs:

- Two serial interfaces, USCIA0 and ASCIB0, that can be programmed to either read or write independently
- Supply voltage: 1.8 to 3.6V
- Architecture: 16-bit RISC (reduced instruction set computer)
- CPU frequency: 16 MHz
- Flash Memory: 23 KB + 256 KB (?) (online: 32 KB flash)
- RAM: 512 KB (Online 1KB SRAM)
- Serial Interfaces: 2x SPI/I2C
- 2 Op-Amps

Programming:

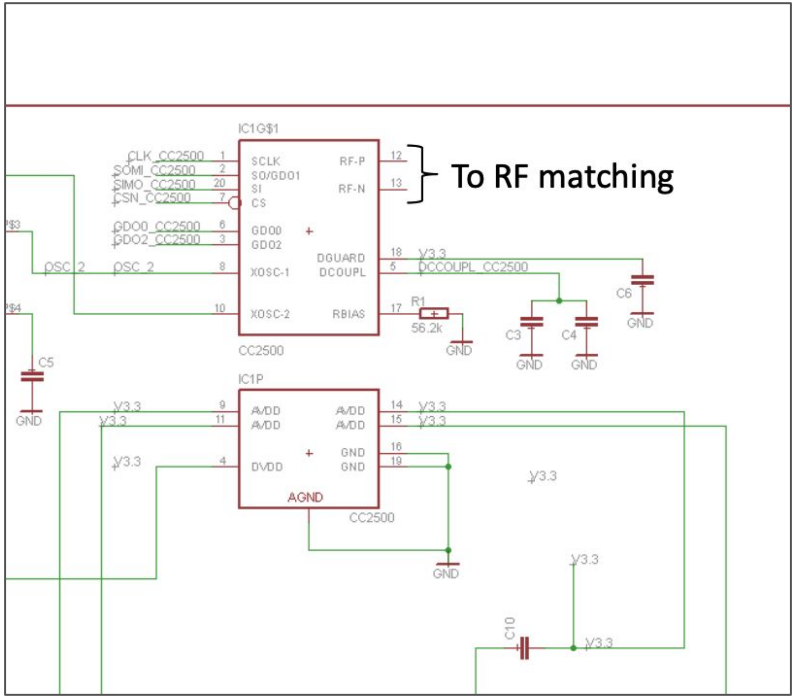
- Software is written and downloaded using TI MSP430 Launchpad (development board that has programming and debugging capabilities and pin connections to work with the microcontroller)
- TI has software examples available that can be immediately applied to controlling the transceiver
- To get the right register settings for the transceiver potentially use TI Smart RF Studio



Transceiver

TI CC2500

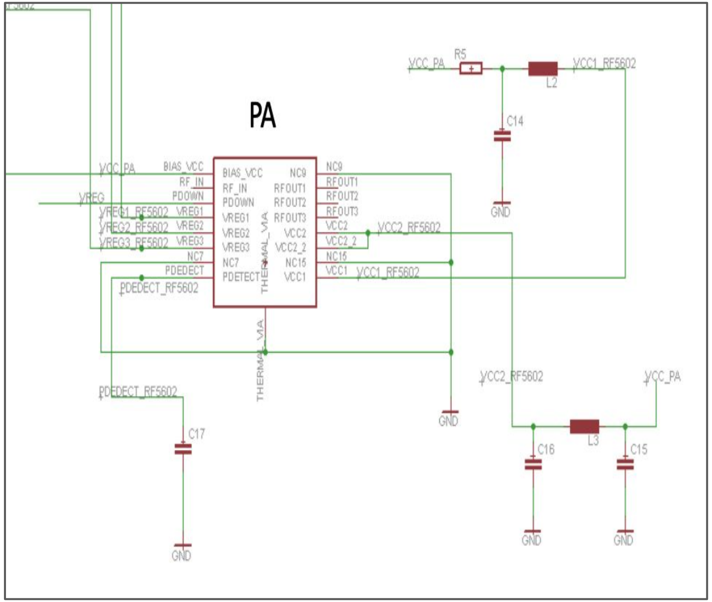
- ➢ Programmed and controlled via SPI which implements the microcontroller interface and also used for data transfer
- ➢ Packet handling capabilities: images as large as 10MB is divided into smaller packages to be transmitter
- ➢ Can implement FEC (forward error correction) to control errors in the data (for unreliable/noisy communication channels) - channel coding
- ➢ RF transmissions are organized
    1. Transceiver operation state is changed to transmitter
    2. Modulator sends programmed pre-ample bits
    3. First byte written into TXFIFO register
    4. Modulators sends synchronization word
    5. Modulator send data in TXFIFO register
- ➢ Overall, transmitter has adaptive RF features: data rate, RF power output level, modulation scheme, FEC, and packet format are programmable



Power Amplifier

Original Aalto-1 radio used a TI RF5602 Power Amplifier

- Gain of 32-34dBm
- Maximum output power 33dBm
- Optimized for linearity (accurate copying of input signal) at 27dBm
- Things to fix after their first prototype
    - Thermal venting was still not great in their design and more heat transfer pathways should be added
    - Power amplifier was reaching saturation too early because the RF matching circuit wasn't optimized enough



TI RF5200 Power Amplifier

- Similar characteristics as the RF5602, but handles internal and external impedance matching to 50Ω
- Gain of up to 38dBm, typical gain of 33dBm
- Supply voltage -0.5 to 5.5V
- Supply current of 1000mA
- Input to PA needs a 1:1 narrowband balun from the transceiver output

Impedance + RF Matching

Impedance: the effective resistance of an electric circuit or component to alternating current

Impedance matching is the designing of source and load impedances to minimize signal reflection or maximize power transfer.

RF matching is impedance matching through equalizing the source and load impedance for maximum power transfer.

<u>For the Aalto S-band radio:</u>

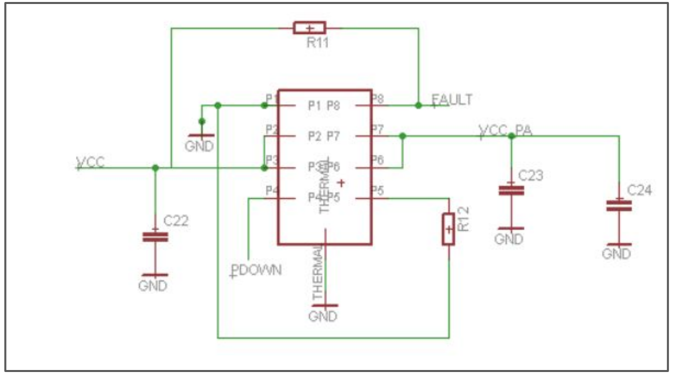
(1) **Original:** two external networks between transceiver and PA and then between PA and output

(2) **Optimized**: using a PA with integrated 50 ohm input and output matching network for simplification

Power Switch + Crystal Oscillator

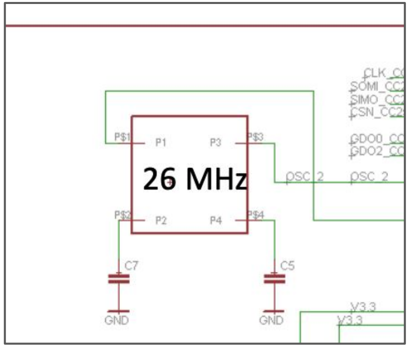
TI TPS2556 Power Switch

- ➢ Added to the supply line of the PA so the PA can be turned of when the transmitter is not used.
- ➢ Current-limited power switch, with the current limit threshold from 500 mA to 5.0 A, which is set with an external resistor



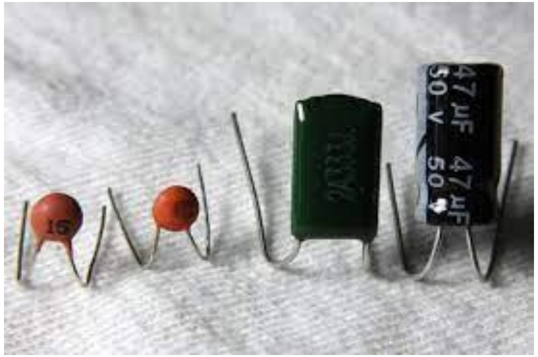
26mHz Crystal Oscillator

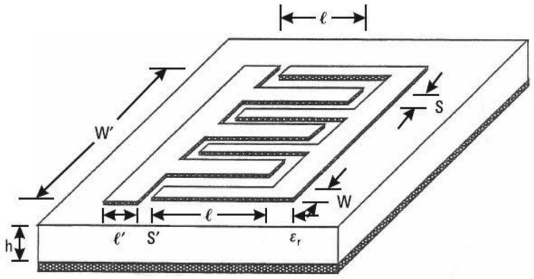
- ➢ Generates a clock frequency for the transceiver



Other Simplifications

1. LVDS convertor
   a. For Aalto, it converted the output of the camera from LVDS to SPI protocol
   b. For us, we are using a camera with SPI capabilities so this is not needed
2. Only using the TX function
   a. We are only sending and not receiving on PVDX, therefore only need the transmit function
3. Using discrete elements rather than microstrip elements
   a. Discrete components saves space but increases the amount of soldering required on RF matching circuit, which can lead to potential circuit failures
   b. BUT micrstrip elements are more complex to implement





Antenna

Quadrifilar Helix Antenna

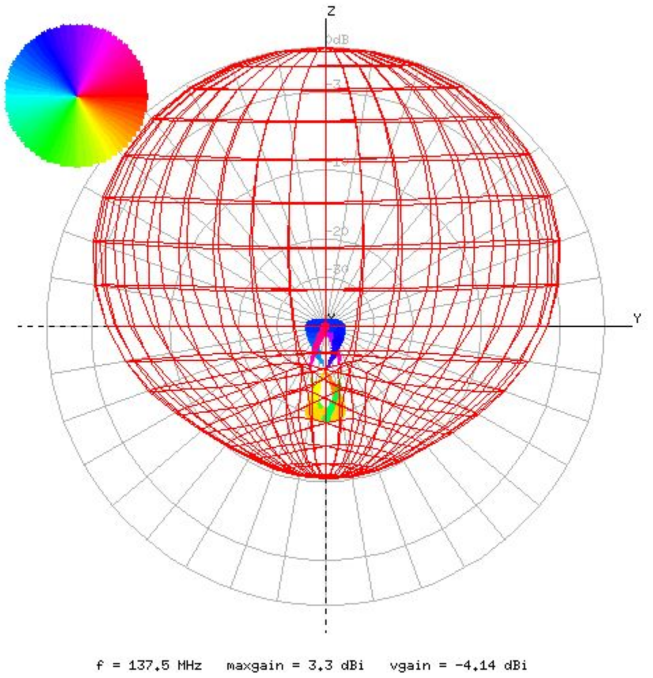
- 5-6dBi gain
- Placed on 1U face of the satellite, folded before launch
- Needs to be deployed λ/4 away from the body of the satellite (~6.8cm for 2.2GHz)
- Preliminary dimensions indicate largest leg size of 7.6cm (for 2.2GHz)

Big Loop

Height= 0.26 λ
Diameter=0.173 λ
Leg Size=0.560 λ

Small Loop

- Height=0.238 λ
- Diameter=0.156 λ
- Leg Size=0.508 λ



Sample QFH radiation pattern

Link Budget

S-band link budget								
Parameter	**Symbol**	**Units**	**Equation**	**Value**				
Frequency	f	GHz	Input param	2.40				
Transmitter Power	P	W	Input param	2.00				
Transmitter Power	P	dBW	10 log(P)	3.00				
Transmitter Line Loss	Ll	dB	Input param	*-1.00*				
Transmitter Antenna Beamwidth	θt	degrees	Input param	65.00				
Peak Transmit Antenna Gain	Gpt	dBi	For patch or	4.00				
Transmit Antenna Pointing Offset	et	degrees	Input param	24.00				
Transmit Antenna Pointing Loss	Lpt	dB	Eqn 13-21	-1.64				
Transmit Passive Splitter Loss	Lps	dB	Passive split	-3.90				
Transmit Antenna Gain (net)	Gt	dBi	Gpt + Lpt + L	-1.54				
Equiv. Isotropic Radiated Power	EIRP	dBW	P + Ll + Gt	0.46				
Propagation & Polarization Loss	La	dB	Fig 13-10	*-0.30*				
Receive Antenna Diameter	Dr	m	Input param	*1.00*				
Peak Receive Antenna Gain (net)	Grp	dBi	Eqn 13-18a	25.42				
Receive Antenna Beamwidth	θr	degrees	Eqn 13-19	8.75				
Receive Antenna Pointing Error	er	degrees	Input param	0.20				
Receive Antenna Pointing Loss	Lpr	dB	Eqn 13-21	-0.01				
Receive Antenna Gain	Grp	dBi	Grp + Lpr	25.41				
System Noise Temperature	Ts	K	Table 13-10	*135.00*				
Data Rate	R	bps	Input param	*500000.00*				
Orbit distance	H	km	Input param	400.00				
Elevation Angle	α	degrees	Input param	90.00	60	30	15	5
Propagation Path Length	S	km	Equation fro	400.00	457.42	739.32	1175.21	1803.78
Space Loss	Ls	dB	Eq 13-23b	-152.10	-153.26	-157.43	-161.46	-165.18
Eb/No	Eb/No	dB	Eqn 13-13	23.79	22.62	18.45	14.43	10.70
Carrier-to-Noise Density Ratio	C/No	dB*Hz	Eqn 13-15a	80.78				
Bit Error Rate	BER		Input parameter					
Required Eb/No	Req Rb/No	dB	Fig 13-9	10.40				
Implementation Loss		dB	Estimate	*-2.00*				
Margin		dB		**11.39**	**10.22**	**6.05**	**2.03**	**-1.70**

PVDX Systems Requirements Review: Power System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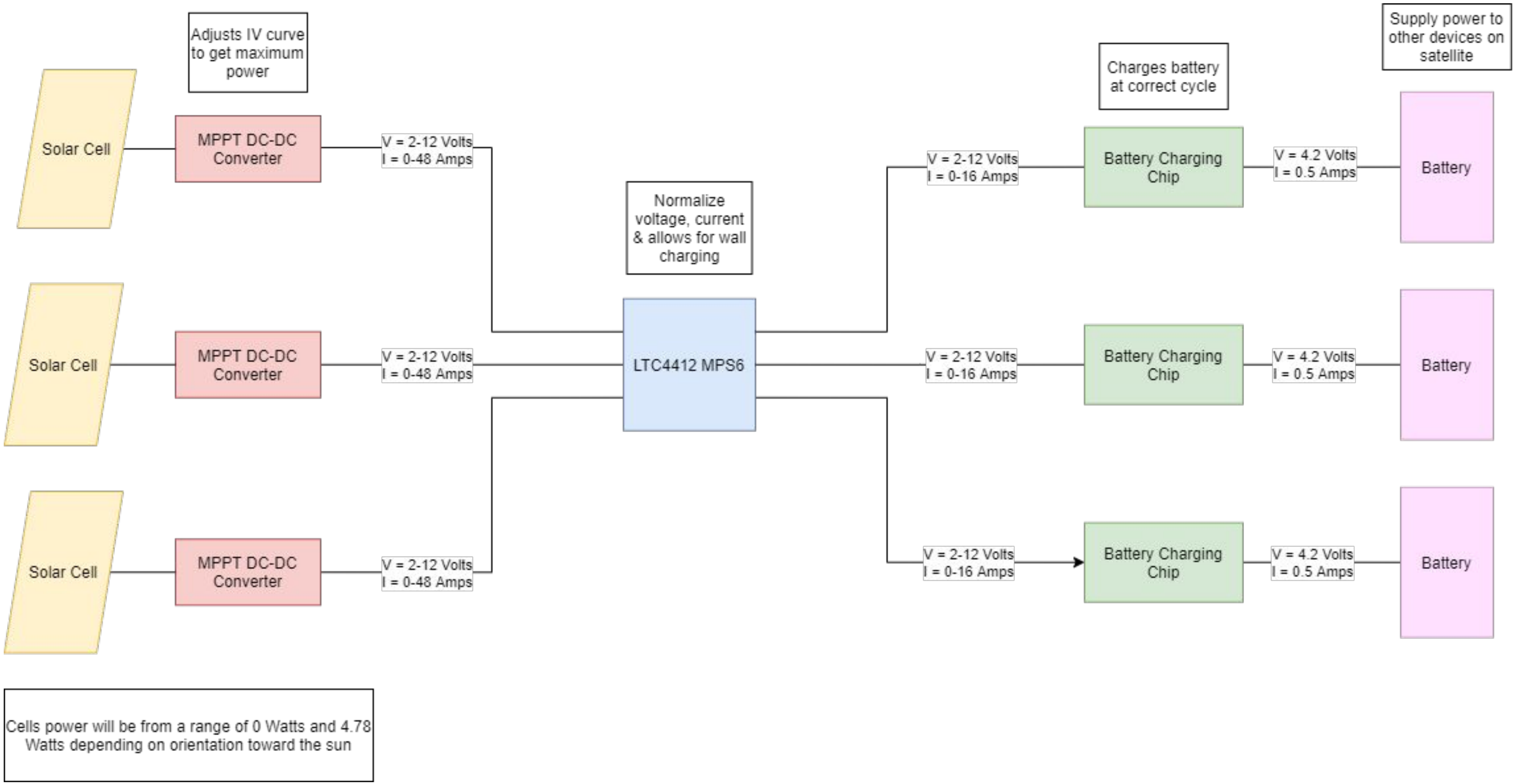
Design questions

- How can we maximize the voltage coming in from our solar cells by using MPPT (not present on EQUiSat)?
- How can we bring enough power to our batteries to power the satellite components?
- How can we make a design that includes redundancy?
- How can we integrate the power system with our main mission goal (Perovskite testing)?

Overall block diagram

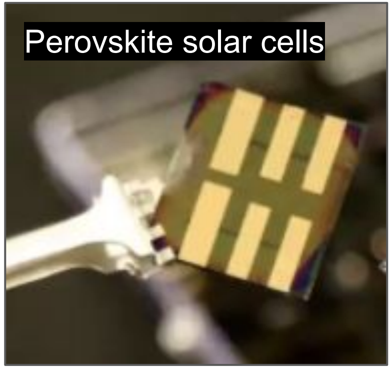


Overall System Design

1. Starts at solar cells
    a. Voltage goes from solar cells to MPPT chips (one chip per face, so 4 chips.)
        i. Purpose is to adjust variable resistance value → adjust IV curve → extract max power from sun/solar cells
2. Max power routes to LTC4412 MPS6 chip
    a. "Performs as neat ideal diode function between multiple power sources" - normalizes power
        i. Extends battery life, low self-heating, low voltage drop when conducting, auto disconnect load from battery when auxiliary wall power source is connected
3. Power routes from LTC4412 chip to an OR "chip" (circuit)
    a. Splits power between 3 batteries
4. Power routes from OR chip to separate battery charging chips for each battery
        i. Purpose: to charge batteries at correct cycle
    b. Likely: bypass system (1) sensing batteries are fully charged and (2) routing power from solar cells bypassing battery to rest of satellite
5. Power routes to rest of satellite (telemetry, sensors, camera, servos, etc.)

Main system components: Solar Panels

	Perovskite Cells	GaAs solar cells
Current	N/A	0.0146 A
Voltage	1 V	2.33 V
Power (at Max Power Point)	0.002	0.0340 W
Power budget in orbit	N/A	1.43 W avg. power → power margin 0.20 W (based on Equisat calculation methods)
Cell area	0.1 cm^2	1.30 cm^2
Efficiency	N/A	65%
Configuration on satellite		4 panels on 4 sides of PVDX (3 long sides, 1 short side) 4 cells per string - 27 strings in parallel (long) - 8 strings (short)

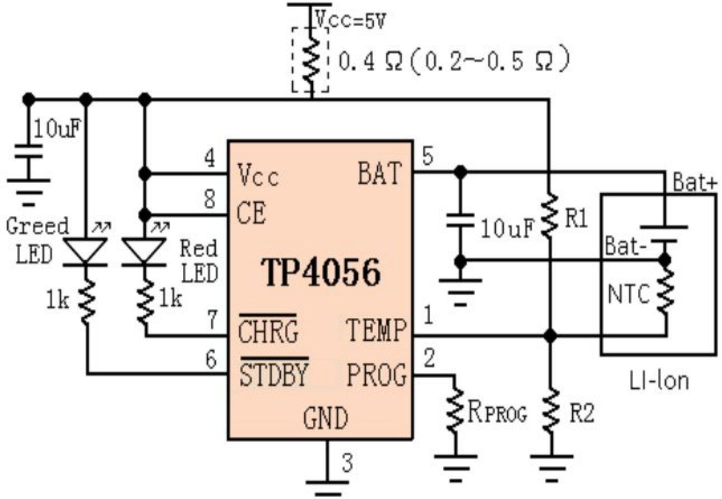


Perovskite solar cells

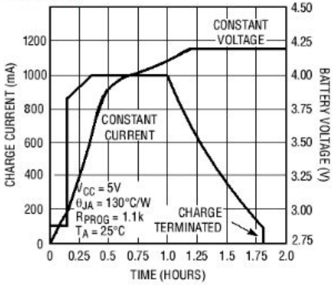
GaAs solar cells

Main system Components - Battery Charging circuit

- TP 4056
- 1A standalone Linear Battery Charger with Thermal Regulation
- Charge current: 1C
- Charge voltage: 4.2V
- Battery voltage: 3.7
- Operating temperatures -40ºC - 85ºC
- Estimated charge time = 2 hours from 0%
- Potential concern:
  - 500 μ C input supply current

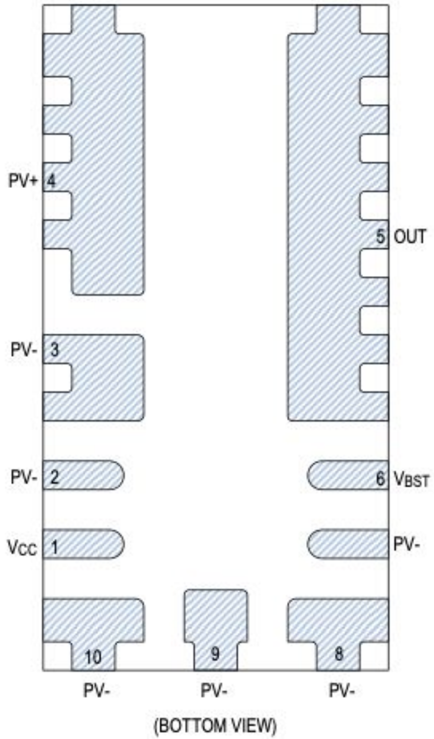


Complete Charge Cycle (1000mAh Battery)



Main system components: MPPT

- Maximum Power Point Tracking : MPPT
  - Based on Maximum Power Transfer Theorem
    - Attempts to match to the unknown source resistance of the cells
- Takes in power cell inputs, power for the chip itself, and outputs a new voltage
- Creates an internal IV curve to change the voltage such that it maximizes the power from a solar cell



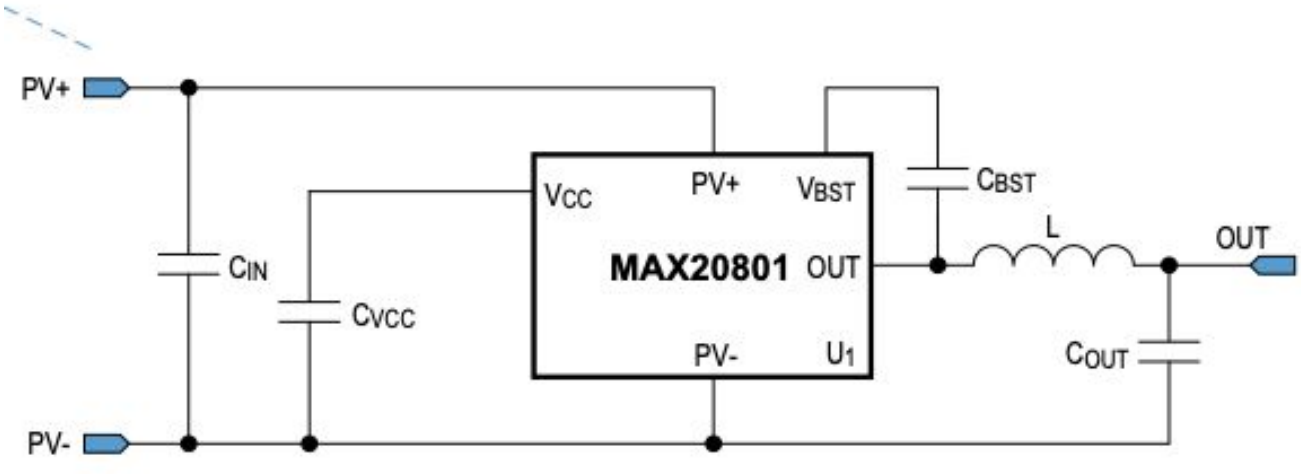
MAX20801 Chip

- Operating Voltage:
  - Input: -6.5V ~ 15.5V
  - Output: -0.3V ~ 21V
- Operating Current:
  - Input: N/A
  - Output: . -4A ~ 12A (Requires actual testing)
- Algorithm: Perturb and Observe
- Bypass feature

MPPT Features

- Considerations: Algorithm
  - “Perturb and Observe”
    - Used by the MAX20801 Chip
    - Changes the voltage by a small amount (perturb), and observe the power change as a result. Continue doing so with derivative of change until the power is maximized
  - Advantages:
    - Does not require other external sensors (like temperature)
  - Disadvantages:
    - No access to internal data, like a black box
- Bypass System
  - In the case that there is not enough power for the MAX20801 Chip to function it can send the voltage directly to the charging circuit instead, increases redundancy of satellite

Using the MPPT Chip



- Surrounding circuit of the MAX20801 (MPPT)
- Current plan: Creating a PCB to test basic functionality → integrate into whole PCB

Alternative to the MAX20801 Chip

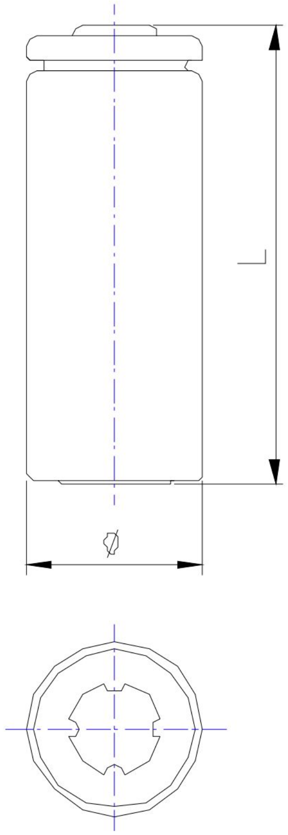
- In the case that during our testing we find that the MAX20801 Chip does not work for our use case we will consider other methods:

Use Perovskite Testing Circuit as MPPT	Find other MPPT Chips

• Advantages
  ○ Get more control over IV curves
• Disadvantages
  ○ Possibly less efficient without algorithm
	• During initial research out of around 4 other chips we could not find one that fit our voltage ranges and specifications

Main system components: Batteries

- 3 Lithium-Ion single cell batteries in parallel
  - Minimum capacity for each cell: 2.15Ah
  - Nominal voltage/cell: 3.7V
  - Temperature range: -20˚C to 60˚C
  - Capacity at different temperatures:
    - 60% at -20˚C
    - 80% at 0˚C
    - 95% at 55˚C
  - Power capacity at 20˚C: 7.955 Wh
- Power capacity at -20˚C: 4.733 Wh
- Charging current (std.): 0.5 CA
- Discharging current (std.): 0.2 CA



NO.	Name	Remarks
1	Diameter	ϕ 18.0 ±0.2mm
2	Length	64.8 ±0.5mm

Power budget

Supply						
Orbit Constants				**Solar Cell Constants**		
Orbital Period	5580	s	400km LEO orbit	Cell Current	0.0146	A
Sunlit Orbit Fraction	0.6	fraction	typical LEO orbit sun exposure	Cell Voltage	2.33	V
Maximum Eclipse Time	2180	s	Maximum amount of time without	Cell Power	0.034	W
				Silicon Cell Ineff. Comp.	-0.35	x100%
Solar Panels				Cell Area (for reference)	1.3	cm^2
Number of Cells (Top Panel)	32					
Number of Cells (Side Panel)	108			**Margin Calculation**		
Number of Side Panels	3			Energy Balance per Orbit		
Number of Top/Bottom Panels	1			Solar Energy In per Orbit, Total	7995	J
Total Number of Panels	4			Solar Power In (Average)	1.43	W
				SAMD51 Energy Out	362	J
Side Solar Panel				SAMD21 Energy Out	116	J
Cells in Series	4			XDL Micro Energy Out (Total)	3028	J
Strings in Parallel	27			S-band transmitter Energy Out (TX)	272.2	J
Power per String	0.14	W		S-Band Board Extra Consumption	272.2	J
Power per Side	3.67	W		Typical Payload Energy Out (Arm moving, Camera idle) per Orbit, Total	799	J
Total Power with Ineff. Comp.	2.39	W		Unaccounted-for Margin, including shading from arm	1000	J
				Attitude Control	1004	
Top Solar Panel				Energy Out per Orbit, Total	6854	J
Cells in Series	4			Watt Out Total	1.228	W
Strings in Parallel	8			Energy Balance per Orbit	1142	J
Power per String	0.14	W		Power Margin	0.2	W
Power per Side	1.09	W				
Total Power with Ineff. Comp.	0.71	W				
Solar Illumination Compensation						
Minimum illumination power	0	W	arm panel facing sun			
Typical illumination power	2.39	W	single side panel facing sun			
Maximum illumination power	4.78	W	pair of side panels facing sun			
Average illumination power	2.39	W				
Sunlit fraction compensated power	1.43	W				

Summary

- Power in: 1.43W
- Power used: 1.2W
- Power Margin: 0.2W

PVDX Systems Requirements Review: Electrical Testing System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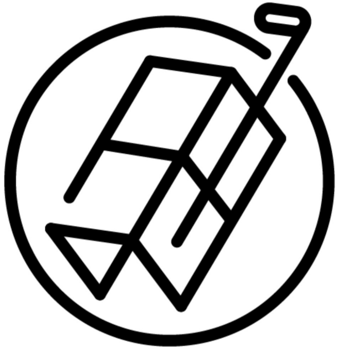
Background + Goals

Background: Perovskite Solar Cells (PSCs) are a new type of photovoltaic cell that has promising application for space.

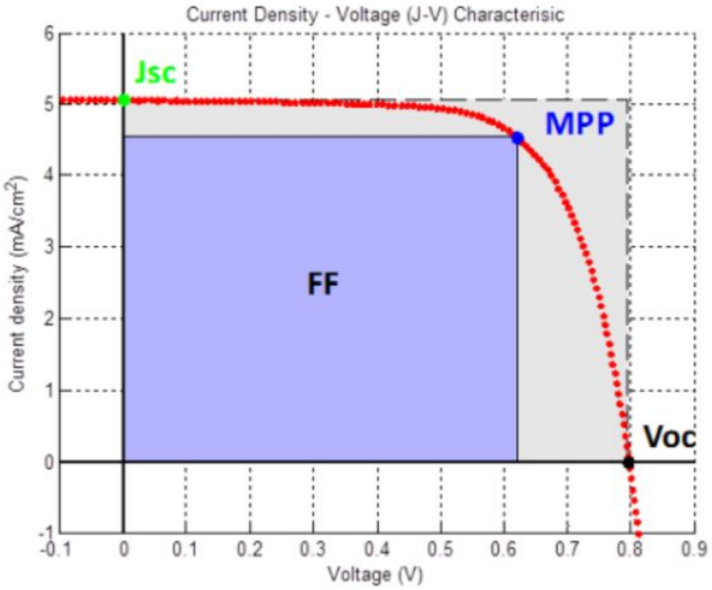
Overall System Goal: To record the degradation of PSCs over time using current-voltage curves (IV curves). This is especially significant because PSCs have not previously been tested in space, so this testing will help to establish the efficacy of these solar cells in space and for future missions.



Background: JV Curves

PSC current density vs. voltage plots (J-V curves) allow for the measurement of PSC performance and the diagnosis of causes of degradation within PVDX's low-orbit environment

- V_{OC} (open-circuit voltage) can tell us about temperature degradation to the PSCs. Increased thermal stress can cause recombination of electron and hole photocarriers.
- J_{SC} (short-circuit current) can tell us about cell absorption efficiency as well as degradation caused by glass corrosion and optical uncoupling of the layers
- MPP (maximum power point) is the point where the product of current and voltage is at its greatest value and thus directly measures the power a solar cell can provide.
- FF (fill factor) is an indicator of the health of the interface between the perovskite and other functional layers in the PSC

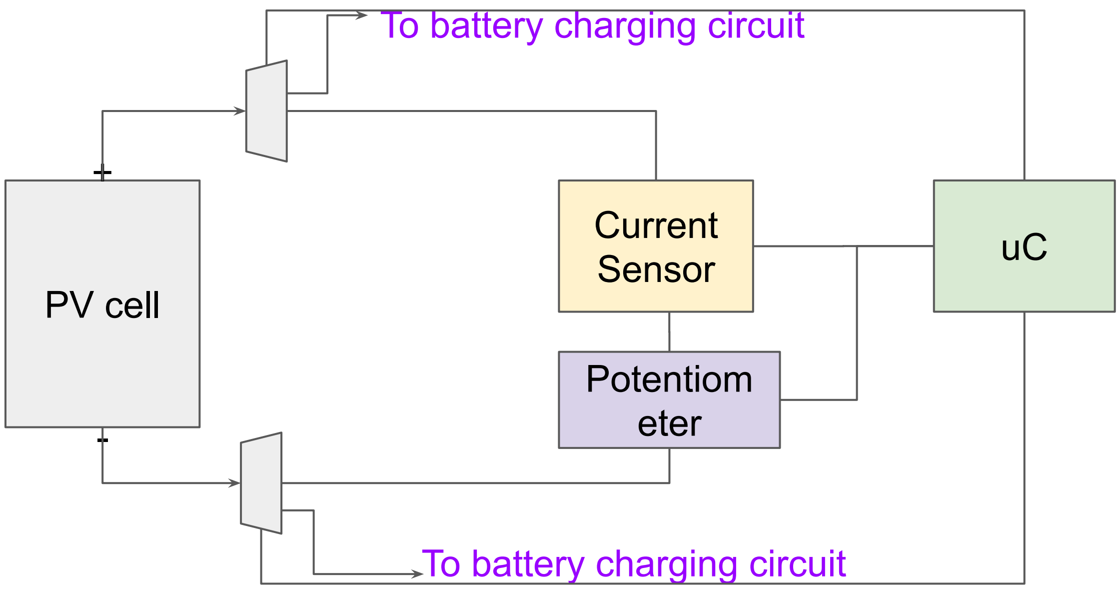


Technical Characteristics/Requirements

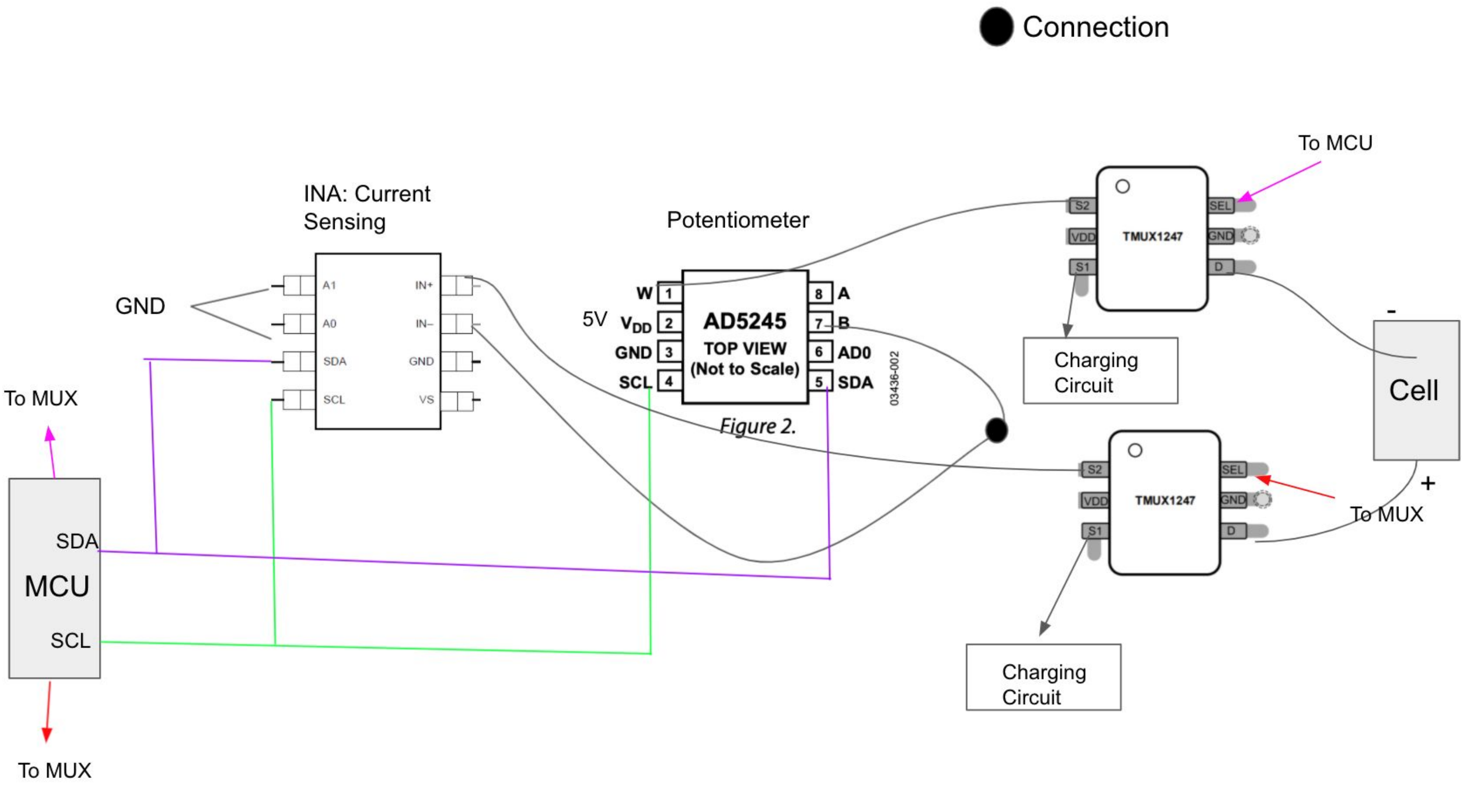
Our testing system needs to measure the voltage across an individual perovskite cell across a range of resistance values. The recorded voltage and known resistance will allow us to compute the current flowing out of the perovskite cell. These current and voltage values will be used to construct the JV curve for the particular perovskite cell.

- IV curves - set by data requirements to evaluate PSCs
  - How many data points?
    - 256/sweep
  - Sampling Period
    - A new data point on the JV curve should be taken every 130 microseconds
  - Sweep time
    - It will take about 33.280 ms to get one full sweep’s worth of data
  - How frequently
    - 2-12 times per day (up to us)
- Temperature
  - LEO limit: **-170 to 123C**
  - What we are spec-ing our parts to: **-40C to 125C**
- Sun sensors
  - Evaluate angle of incidence hitting solar panels
  - 10 degrees

Overall block diagram

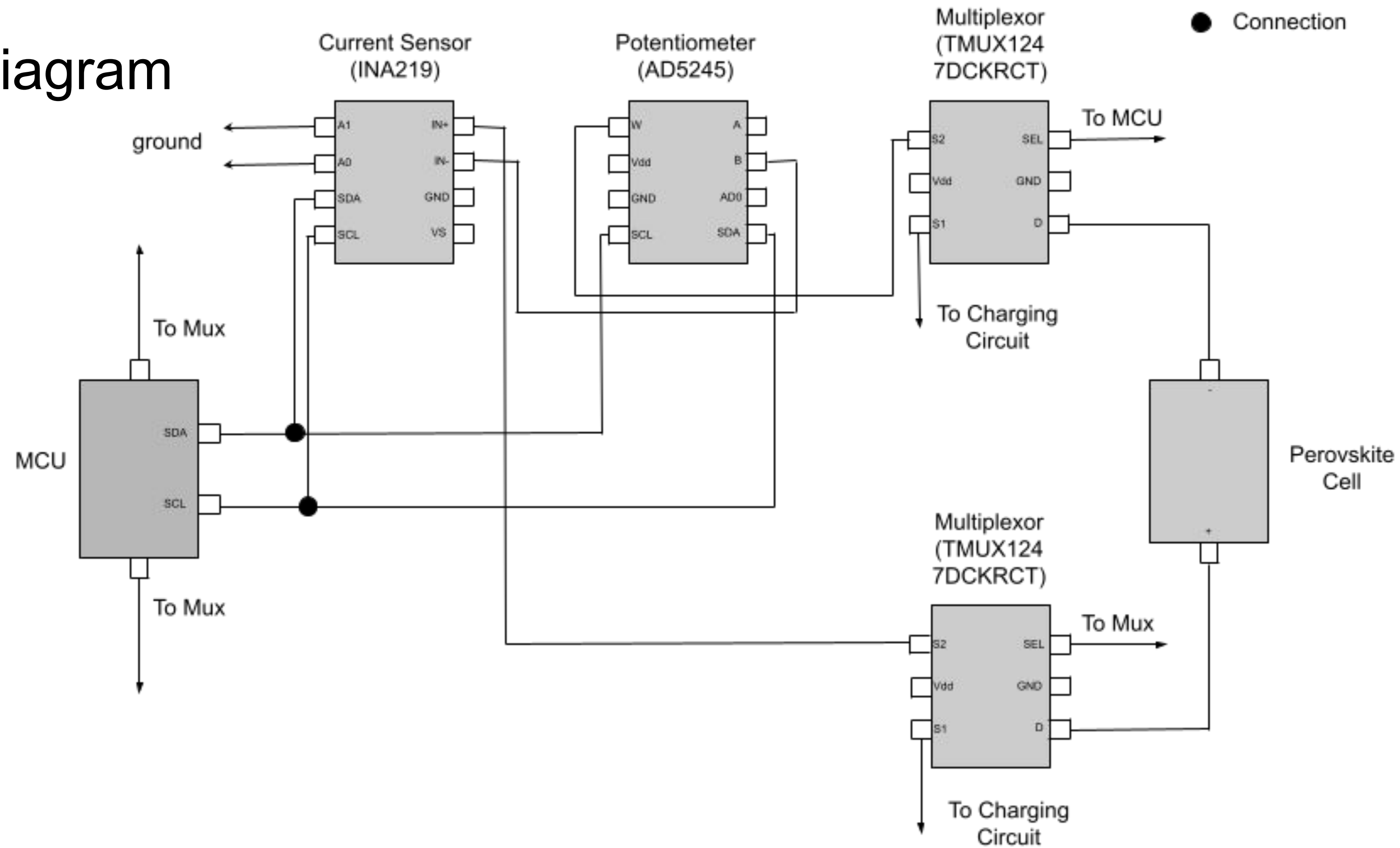


Diagram



Connection
To MCU
INA: Current
Sensing
Potentiometer
GND
A1
A0
SDA
SCL
IN+
IN−
GND
VS
W
5V
VDD
GND
SCL
AD5245
TOP VIEW
(Not to Scale)
A
B
AD0
SDA
03436-002
Figure 2.
S2
VDD
S1
TMUX1247
SEL
GND
D
Charging
Circuit
-
Cell
+
To MUX
To MUX
SDA
MCU
SCL
To MUX
Charging
Circuit

Diagram



Connection
Current Sensor
(INA219)
Potentiometer
(AD5245)
Multiplexor
(TMUX124
7DCKRCT)
ground
A1
A0
SDA
SCL
IN+
IN-
GND
VS
W
Vdd
GND
SCL
A
B
AD0
SDA
S2
Vdd
S1
SEL
GND
D
To MCU
To Charging
Circuit
To Mux
MCU
SDA
SCL
To Mux
Perovskite
Cell
-
+
Multiplexor
(TMUX124
7DCKRCT)
To Mux
S2
Vdd
S1
SEL
GND
D
To Charging
Circuit

Main system components: Overview

- Potentiometer (AD5245)
  - A digital potentiometer that is compatible with I2C communication so that we could interface it with our microcontroller.
  - 100 kOhm maximum resistance is large enough to simulate an open circuit.
  - 256 possible resistance values allows for enough resolution in the JV curve
- INA (INA219)
  - I2C communication compatibility allows for easy microcontroller interfacing.
  - Reads voltage over a shunt resistor, which in our system is our potentiometer
- Multiplexers (TMUX1247)
  - Must be analog multiplexers so that our voltage reading of the perovskite cells is accurate
- Batteries
- Perovskite Solar Cell

Main system components: Potentiometer

- AD5245 Digital Potentiometer used as variable resistor to sweep for the creation of IV curves
  - 100-100 kΩ
  - I2C protocol used
  - 256 possible resistance values
- Absolute Max Ratings
  - V_{DD} to Ground: -0.3V to +7V
  - Operating Temp: -40°C to +125°C

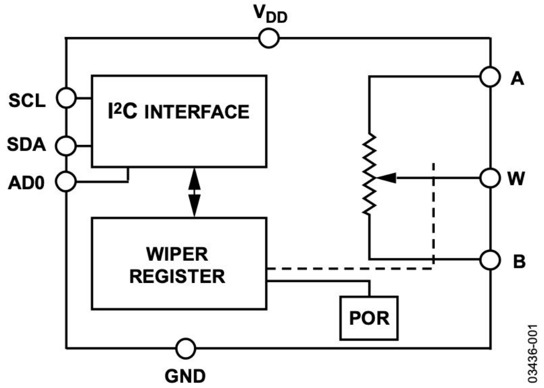
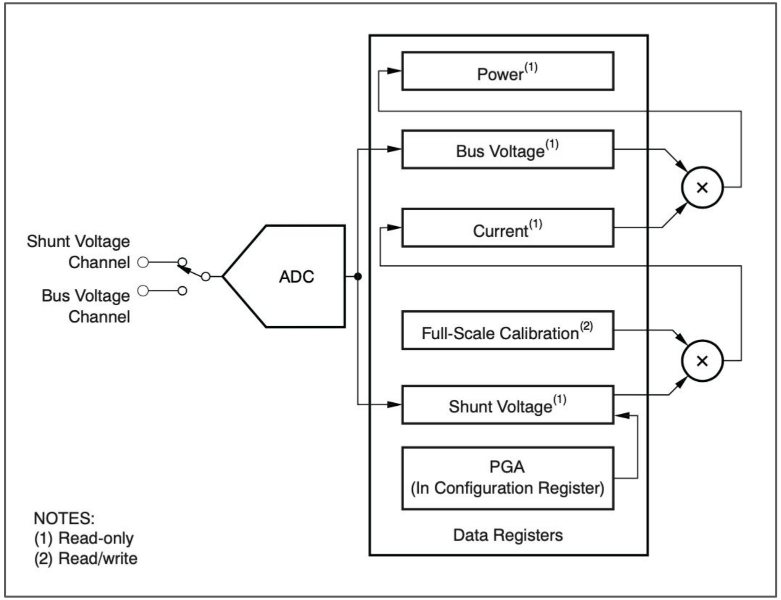


Figure 1.

Main system components: INA

- INA219 is a current-voltage sensor used to measure shunt voltage
    - I2C Communication
    - SOT23-8 Package
- Absolute Max Ratings
    - V_{IN+} to V_{OUT-}: 0V to 26V
    - Operating Temperature: -40C to 150C
    - Max I_{in} to any pin: 5 mA
- Electrical Characteristics
    - Shunt Voltage Range: ±40, ±80, ±160, or ±320 mV
    - Power Supply: 3 to 5.5 V
    - ADC conversion takes 532 microseconds



Main system components: Multiplexers

- TMUX12475-V Bidirectional multiplexer used to switch between perovskite cell testing and battery charging
  - I2C
  - 1.8V Logic Compatible
- Electrical Characteristics, V_{dd} = 5, Analogue Switch
  - On Resistance: 3 Ohm
  - Channel on Leakage Current: -500 to 500 nA
  - V_{high} = 1.42V to 5.5V
  - V_{low} = 0V to 0.87V
  - V_{DD} Supply Current: 0.007 μA (at 25 C) and 1.5 μA (from -40 C to 125 C)
- Absolute Max Ratings
  - Operating Temp: -40 to 125 C
  - Input Voltage V_{SEL} / V_{EN}: -0.5 V to 6 V
  - Input Current I_{SEL} / I_{EN}: -30 mA to 30 mA