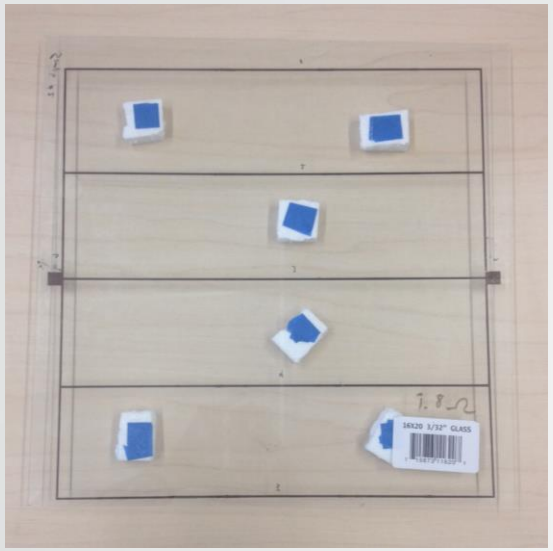

Smart PV Panel

P14421

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Project Description

- Advance Power Systems
  - Jasper Ball
  - Atlanta, GA
- Snow reduces power output of PV panels
- Develop method to prevent snow from accumulating in the first place
  - Apply current to conductive, heating ink
  - Keep temperature of panel surface above freezing
  - Sense presence of snow

Customer Needs

Customer Need #	Importance	Description	Comments
CN1	9	Prevent Snow Accumulation	Rather than remove the snow after accumulation, snow is prevented from doing so in the first place.
CN7	9	System require a minimum amount of power to operate	
CN6	6	Modular System	Each panel or group of panels will have a dedicated snow removal system
CN5	6	Manual System Shutdown	Method by which system can be manually overridden, allowing for safe maintenance,
CN8	6	Operation in extreme climate	System should be able to operate in low temperatures, high wind
CN9	6	Able to operate within desired range of mounting angles	
CN2	3	Snow detetection	System by which snow is detected is integrated, rather than an attachment.
CN4	3	Process can be put at front-end of existing manufacturing process.	
CN3	3	Minimize Expenses	

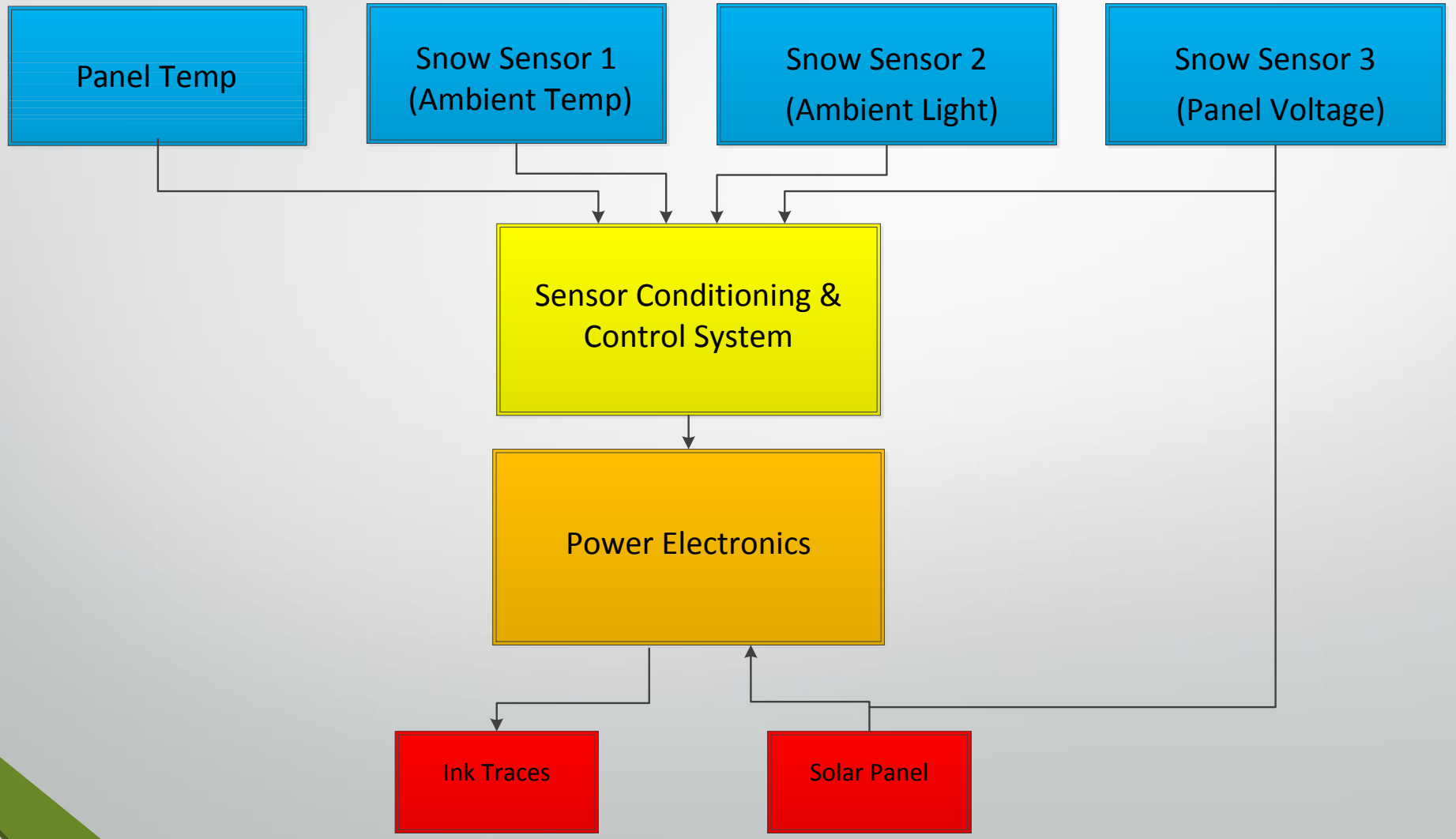
Engineering Requirements

Requirement	Source	Importanc	Function	Engr. Requirement (metric)	Unit of Measur	Marginal Valu	Ideal Value	Comments/Status
ER2	CN7	9	System Operation	Power Consumption	Wh/m^2-year		<29,111	Percentage of power consumption of solar panel. PRP says 10% power is lost due to snow, power consumption needs to be less then that
ER3	CN7	9	System Operation	Supply Voltage	Volts		12	
ER4	CN1	9	System Operation	Heat Output Rate	Watts		54	Based on the calculated power required to melt snow. Assumed snows 61 days/year, average 4 hours/day
ER6	CN1	9	System Operation	Temperature Output	°C	>0	20	PRP: had panel that could heat to 88°F, will aim for that
ER12	CN1	9	System Operation	Rate of Snowmelt	cm^3/hr		9600	Based on 54W ouput
ER10	CN8	9	System Robustness	Ink Lifetime	Years		25	Panel's lifetime
ER1	CN8	6	System Robustness	Climate Operational Temperature	°C		-40 to 85	Numbers based on record world high and low temps.
ER5	CN6	6	System Integration	Ink Trace Dimensions	mm		TBD	
ER8	CN3	6		Cost	USD		1000	Budget is flexible, given by Jasper
ER9	CN1, CN2	6	System Operation	System response time	Seconds	1	0.5	
ER11	CN5	6	System Operation	On/Off Mechanism	Binary		Yes	
ER13	CN7	6	System Operation	Heat Energy not transferred to snow	Watts	80	50	Percentage of heat output rate
ER7	CN1	3	System Operation	Heating Time of Ink	Seconds	300	120	

Concept Summary

- Snow causes loss in power production
- Want to remove snow from panels
  - Sense presence of snow
  - Heat resistive ink traces on panel
  - Melt snow
  - Increase power production of system

System Architecture



Design Summary

Ink Layout

- Trace widths determined by the bus bar width
- Spacing determined by bus bar location and spacing between cells
- Optimize number of traces per panel
  - With respect to total power dissipation and heat spread

Design Summary

Sensor System

- Monitor 3 environment variables
  - Ambient temperature
  - Ambient light
  - Panel voltage
- Optimal conditions to justify melting
  - Ambient temperature ~-15˚C-0 ˚C (it's cold enough to snow, but not too cold)
  - Ambient light great enough to produce power
  - Panel voltage < ~6V (i.e. snow covering panel, limiting output)
- If all 3 conditions are approximately optimal, drive interrupt to Arduino

Design Summary

Control System

- 2 modes
  - Sleep
  - Continuous melt
- Sleep
  - Arduino sits idle in low-power mode
  - Interrupt received from sensors
    - Arduino wakes up
    - Checks voltage levels output by sensor circuitry
    - If values are appropriate, drive PWM signal to SSR
    - Else, go back to sleep
- Continuous melt
  - While switch is turned on, system will constantly drive PWM signal to SSR

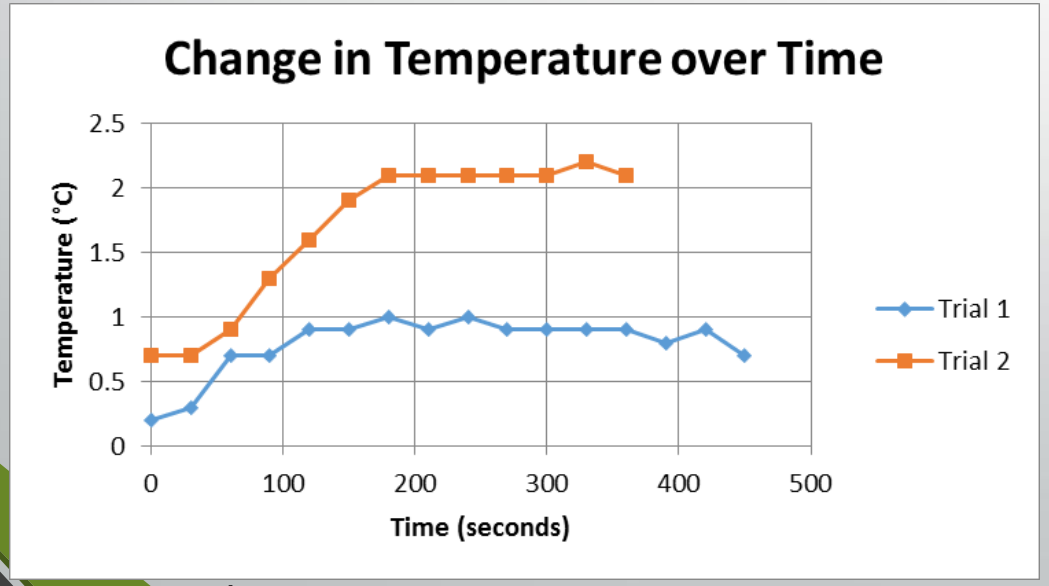
Design Summary

Power Electronics

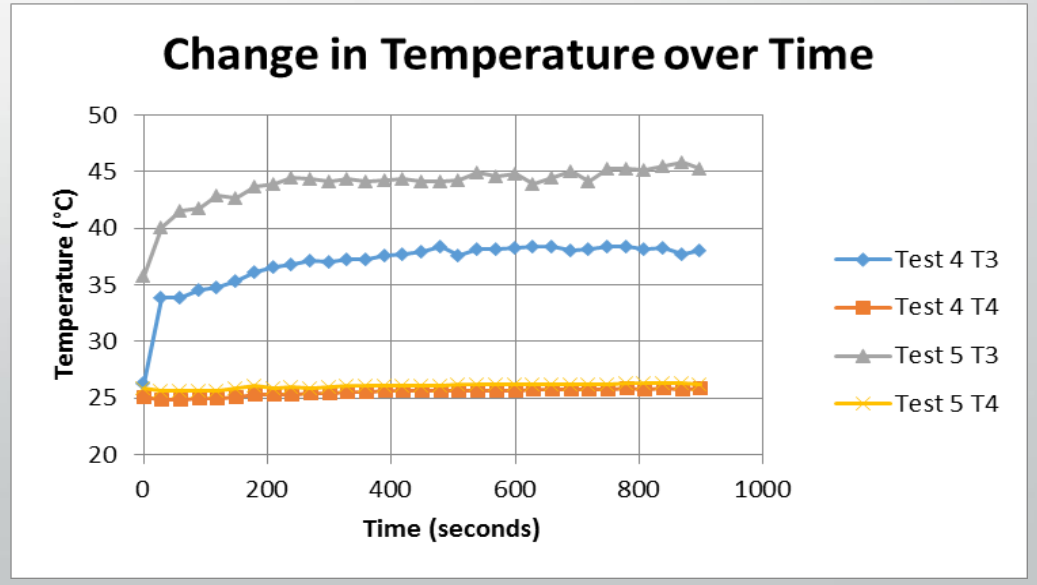
- Power distribution
  - 12VDC in from battery
  - 3 regulators supply 5V, -5V, and 3.3V to various sensors and components
- Solid State Relay (SSR)
  - Regulates voltage applied to resistive ink on panel
    - Based on PWM signal from Arduino
  - As the duty cycle of the PWM signal increases, so does the voltage applied to the ink
    - Panel gets to temperature faster

Ink Testing Results

- The current system doesn't perform well under freezing conditions.
- The current ink lacks required durability and may not survive the manufacturing process.
- Resistance and condition of ink is inconsistent because the traces were hand-printed and the laser-curing process was not uniform.
- Energy efficiency requirements not currently met.
- Future iterations of this project must work on finding a more durable, efficient ink, or look into alternative options for snow-removal.



Glass at Freezing Temperature



Glass at Room Temperature

System Testing Results

- Testing was accomplished in indoor ambient conditions and consisted of three main steps:
  1. **Modifying the set points**
  2. **Applying various artificial stimuli to simulate a "melt" condition**
  3. **Removing various stimuli to simulate a "no melt" condition**
- Individual stimuli were removed and then reapplied one at a time to check for system sleep and reawaken operation. Each functioned as intended. **Successful operation was observed indicating the system performs as intended**

Objective Project Evaluation: Success/Failure

Specification Number	Importance	Source	Function	Specification (Metric)	Unit of Measure	Marginal Value	Comments/Status	Test Plan	Concluded Condition
S1	9	System Operation	Power Consumption	Wh/m^2-year		<29,111	Percentage of power consumption of solar panel. PRP says 10% power is lost due to snow, power consumption needs to be less then that	Data Valid Test Plan	
S2	9	System Operation	Supply Voltage	Volts		12		System Test Plan	
S3	9	System Operation	Heat Output Rate	Watts		54	Based on the calculated power required to melt snow. Assumed snows 61 days/year, average 4 hours/day	System Test Plan	
S4	9	System Operation	Temperature Output	°C	>0	20	PRP: had panel that could heat to 88°F, will aim for that	Ink Test Plan	
S5	9	System Operation	Rate of Snowmelt	cm^3/hr		9600	Based on 54W ouput	System Test Plan	
S6	9	System Robustness	Ink Lifetime	Years		25	Panel's lifetime	N/A	
S7	6	System Robustness	Climate Operational Temperature	°C		-40 to 85	Numbers based on record world high and low temps.	N/A	
S8	6	System Integration	Ink Trace Dimensions	mm		TBD		Ink Test Plan	
S9	6		Cost	USD		1000	Budget is flexible, given by Jasper	N/A	
S10	6	System Operation	System response	Seconds	1	0.5		System Test Plan	
S11	6	System Operation	On/Off Mechanism	Binary		Yes		System Test Plan	
S12	6	System Operation	Heat Energy not transferred to snow	Watts	80	50	Percentage of heat output rate	Data Valid Test Plan	
S13	3	System Operation	Heating Time of Ink	Seconds	300	120		Ink Test Plan	
S14	9	System	Sense Snow	Binary		Yes	Make sure the sensors are able to accurately sense snc	SensorTest Plan	

Opportunities/Suggestions for Future Work

- Technical:
  - Do more research on how a car defroster works
  - Testing the situation where a small layer of snow is melted and the rest of the snow slides off.
  - Optimize power output vs. ink durability
  - Use cad program with DRC(Design Rule Check)/LVS (Layout versus Schematic)
  - Double and triple-check connections to avoid damaging parts
  - Too much current caused the ink to burn in some places
- Personal
  - If the project started spring semester for the design phase, there would be snow to test with outside for the fall semester
  - Seek more assistance from professors
  - Better organization early on aids later in projects
  - Expect unexpected problems to occur so start testing as soon possible
  - Agree on a clear goal with the customer before the project starts so there is no confusion
  - Make sure the test plans and subsystem tests are very detailed so there is no surprises when the full system is put together

Main Conclusions

- System is able to detect snow presence and apply power to ink
- The ink can be heated but quickly degrades
- More research has to be done to improve ink durability, **efficiency**, and performance