Solar Panel Protection System

ECE 445 - Team #3

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Problem

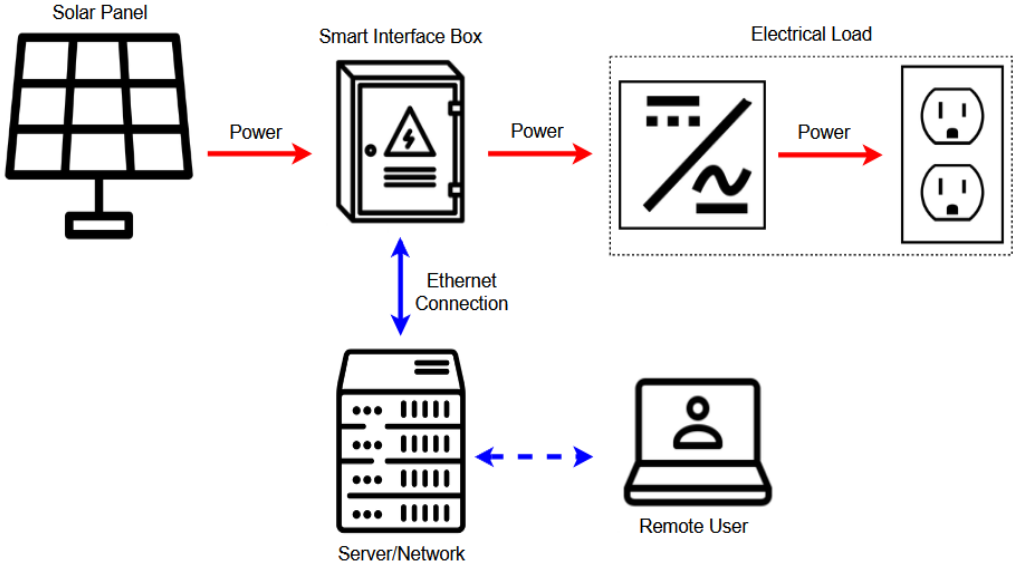
- 60 research solar panels
- None are in use
- They do not have **ANY** protection systems in place currently

Solar Panels Without Protection Systems

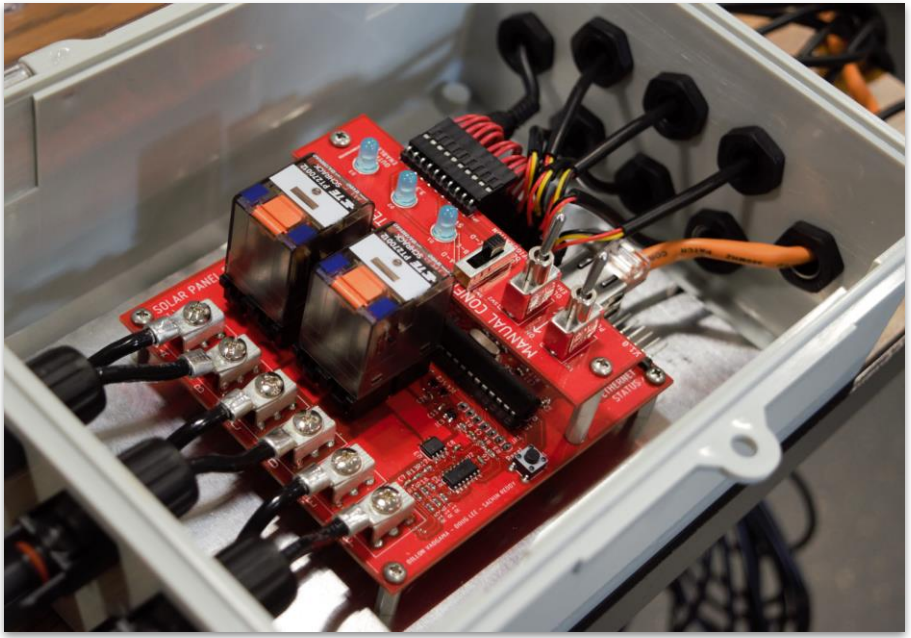
- Walmart sued Tesla due to solar panel failures.
  - Seven roof fires at different locations.
  - Detecting solar panel failures can help prevent catastrophes

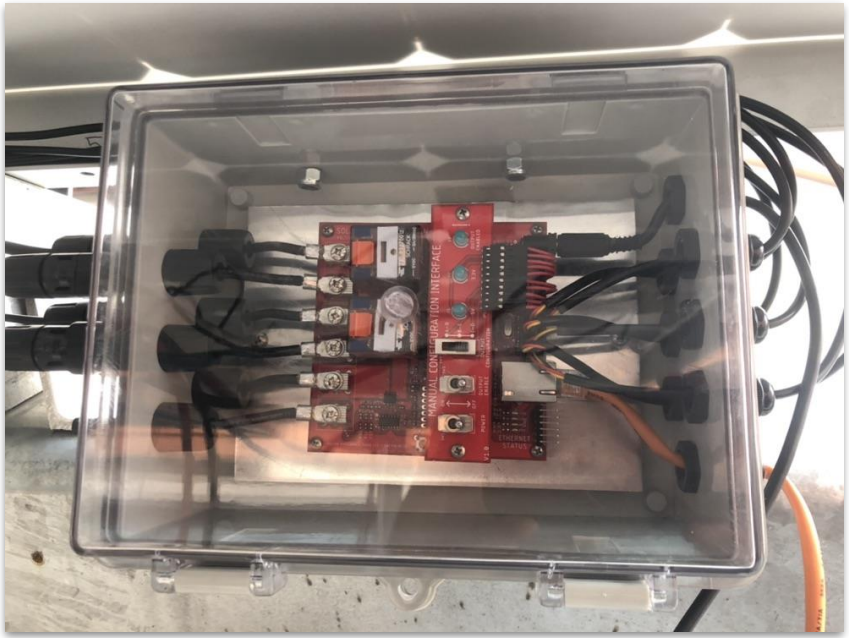
Photo Credit: https://arstechnica.com/tech-policy/2019/08/after-seven-roof-fires-walmart-sues-tesla-over-solar-panel-flaws/

Solution

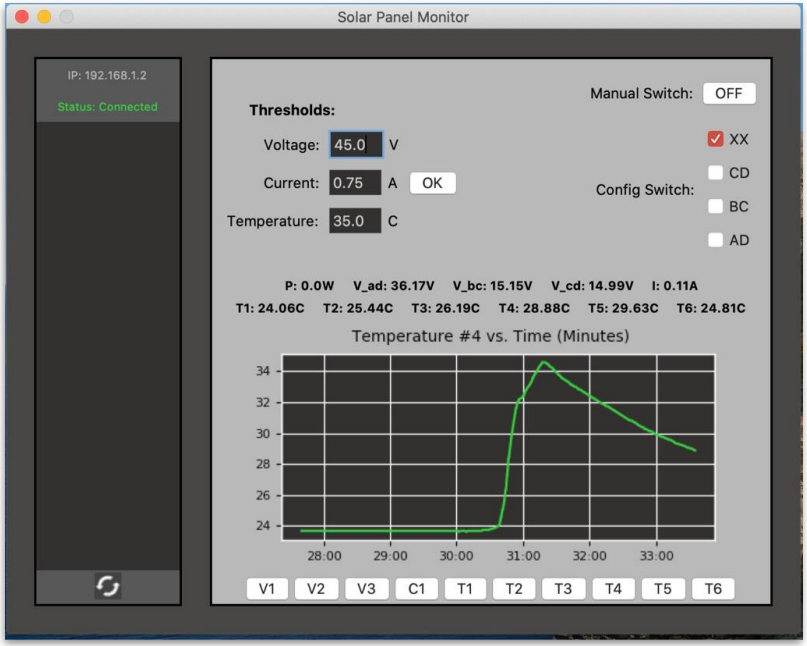

Solar Panel
Power
Smart Interface Box
Power
Electrical Load
Power
Ethernet
Connection
Server/Network
Remote User

Solution


SOLAR PANEL
MANUAL CONF
LINEMAN'S
STATUS


MANUAL CONFIGURATION INTERFACE
LINEMAN'S
STATUS

Solution


Solar Panel Monitor
IP: 192.168.1.2
Status: Connected
Thresholds:
Voltage: 45.0 V
Current: 0.75 A OK
Temperature: 35.0 C
Manual Switch: OFF
Config Switch:
XX
CD
BC
AD
P: 0.0W V_ad: 36.17V V_bc: 15.15V V_cd: 14.99V I: 0.11A
T1: 24.06C T2: 25.44C T3: 26.19C T4: 28.88C T5: 29.63C T6: 24.81C
Temperature #4 vs. Time (Minutes)
34
32
30
28
26
24
28:00
29:00
30:00
31:00
32:00
33:00
V1 V2 V3 C1 T1 T2 T3 T4 T5 T6

Objectives

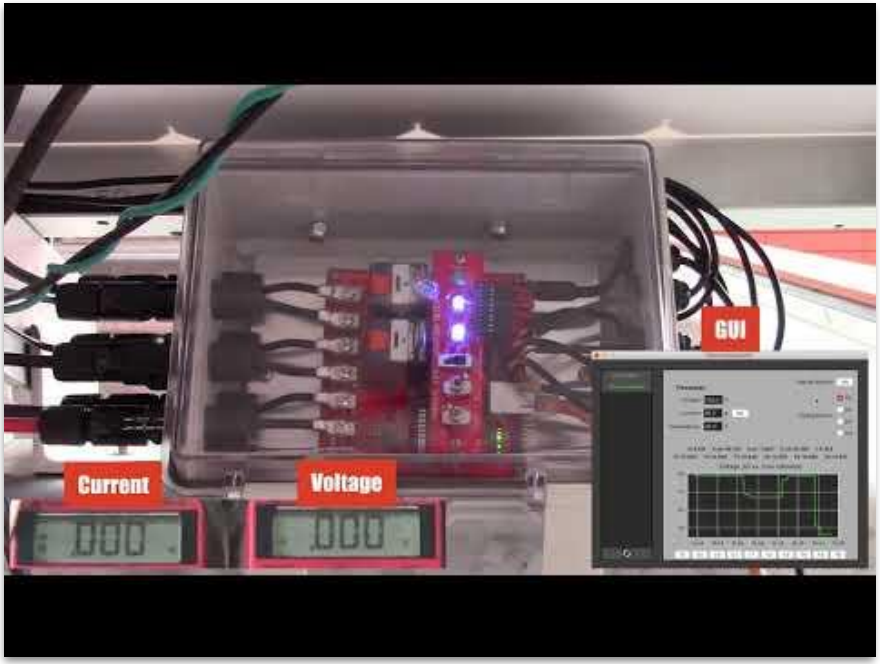
- Disconnect the solar panel if failure conditions occur
  - Over-current
  - Over-voltage
  - Over-heating

- Remote monitoring of system parameters over Ethernet
  - Voltages
  - Current
  - Power
  - Temperatures

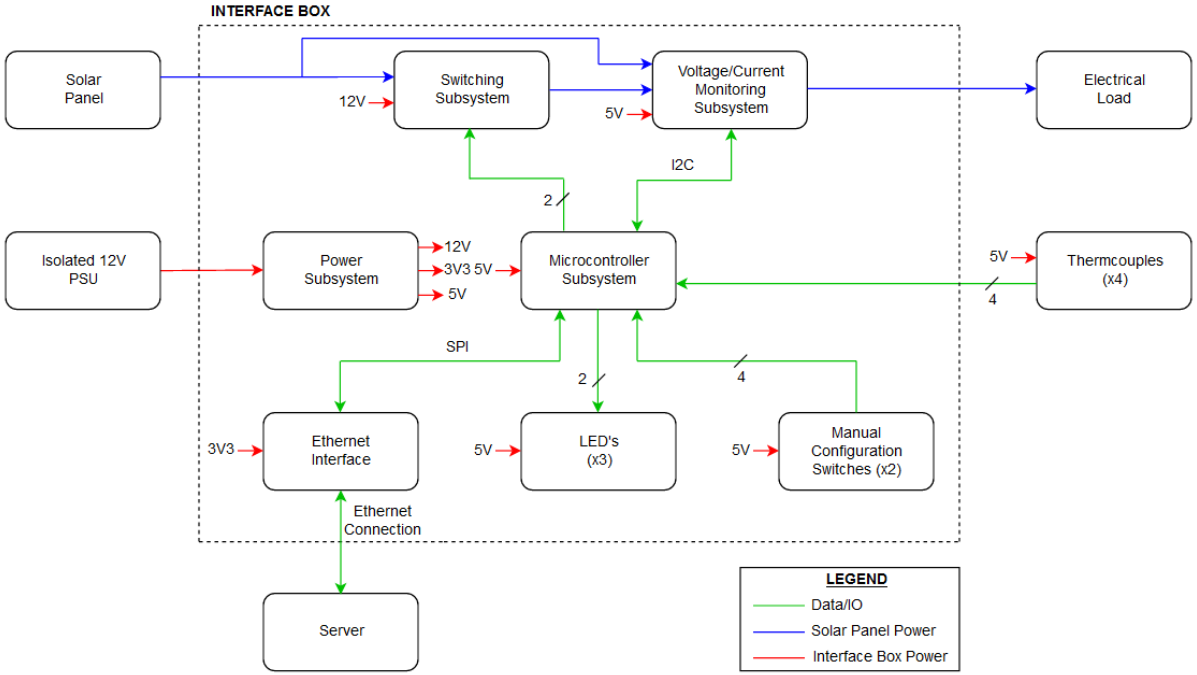
Objectives

- Remote configuration of the solar panel
  - Output voltage
  - Failure condition threshold values
- Manual configuration of the solar panel
- Turn off the system if the isolated 12V power supply fails.

Demonstration

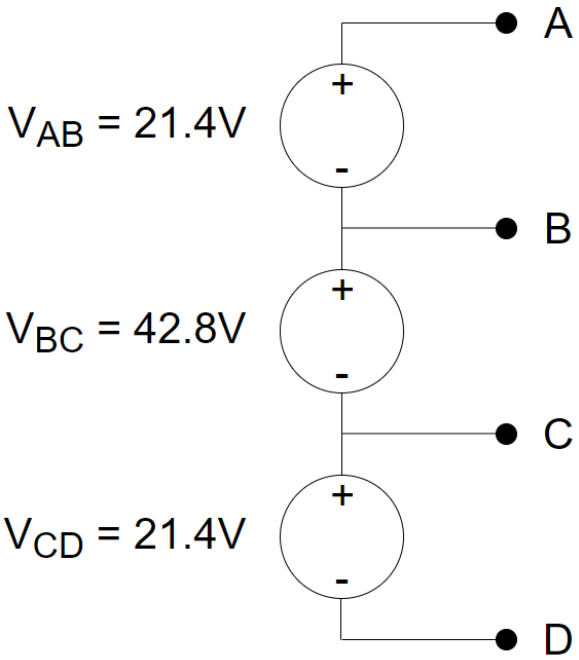


High Level Block Diagram

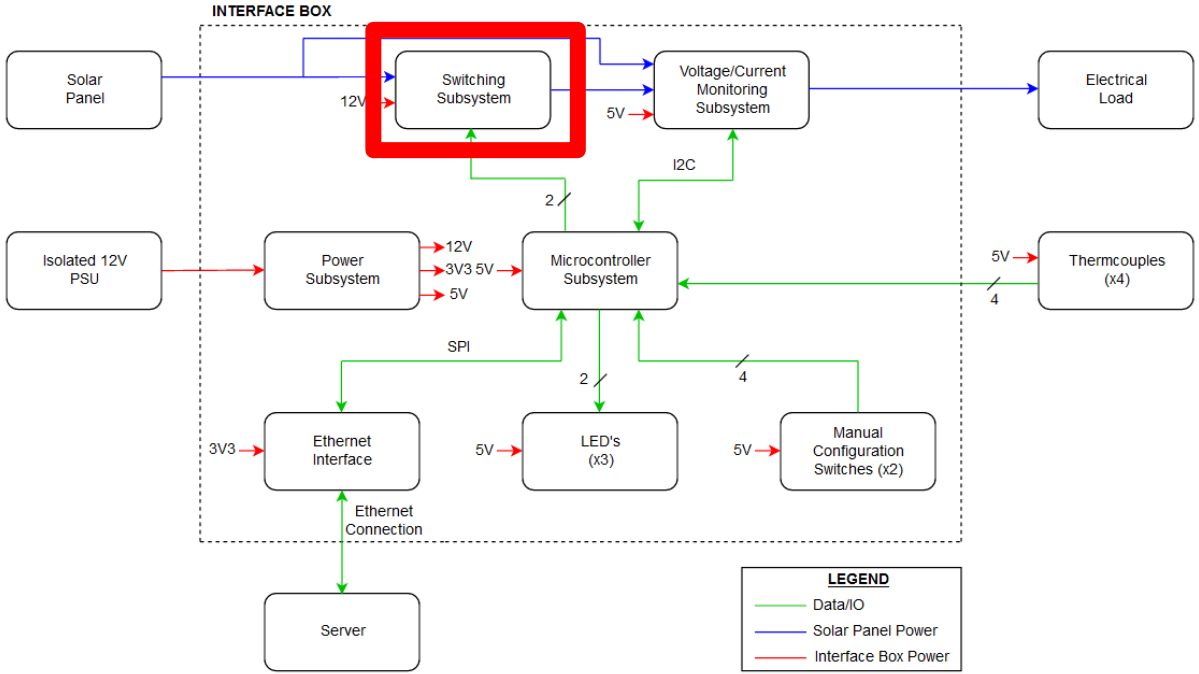


Solar Panel Structure

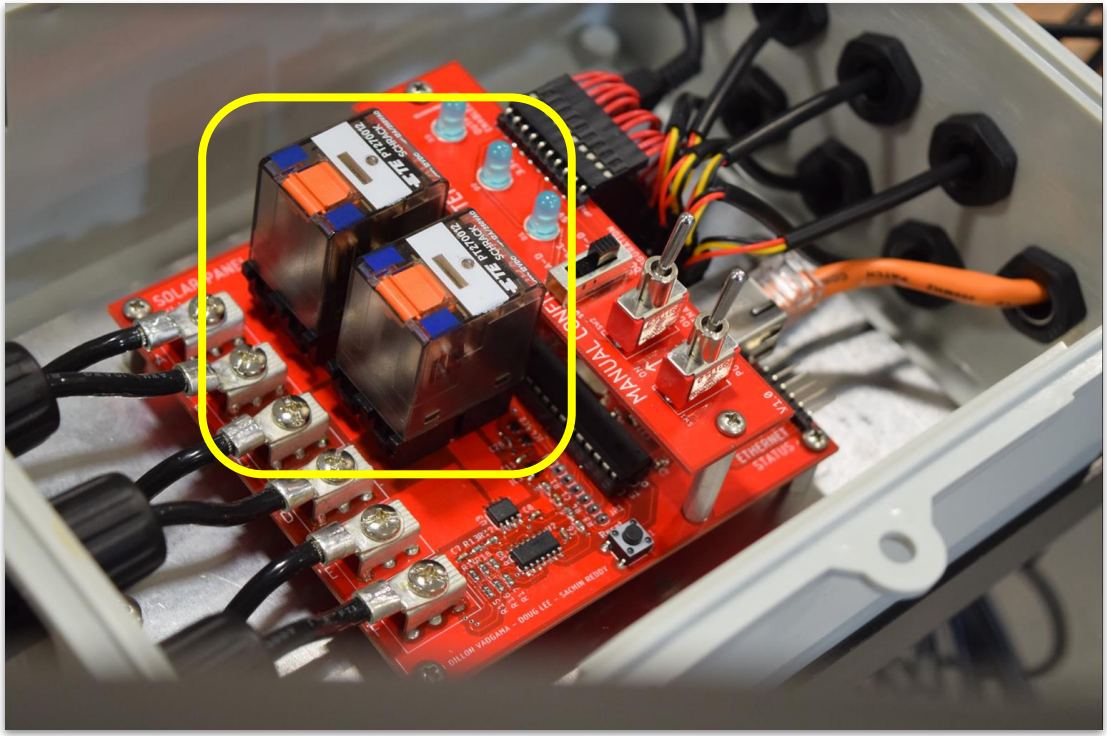
- 128 solar cells per panel
- Three partitions in series
  - 32 cells - 21.4V
  - 64 cells - 42.8V
  - 32 cells - 21.4V
- Four outputs - A, B, C, D
- Maximum Open Circuit Voltage - 85.6V
- Maximum Short Circuit Current - 6.21A



High Level Block Diagram - Switching Subsystem



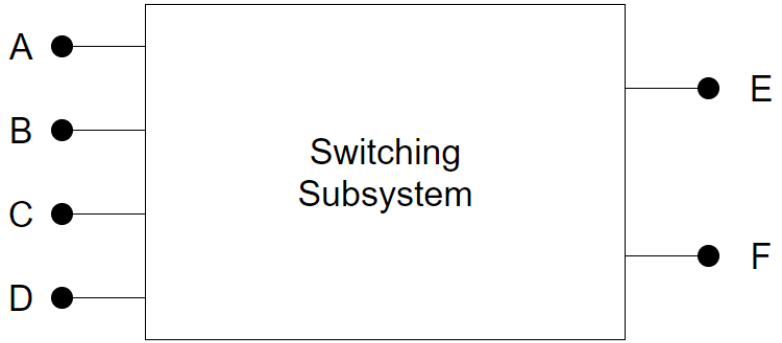
High Level Block Diagram - Switching Subsystem



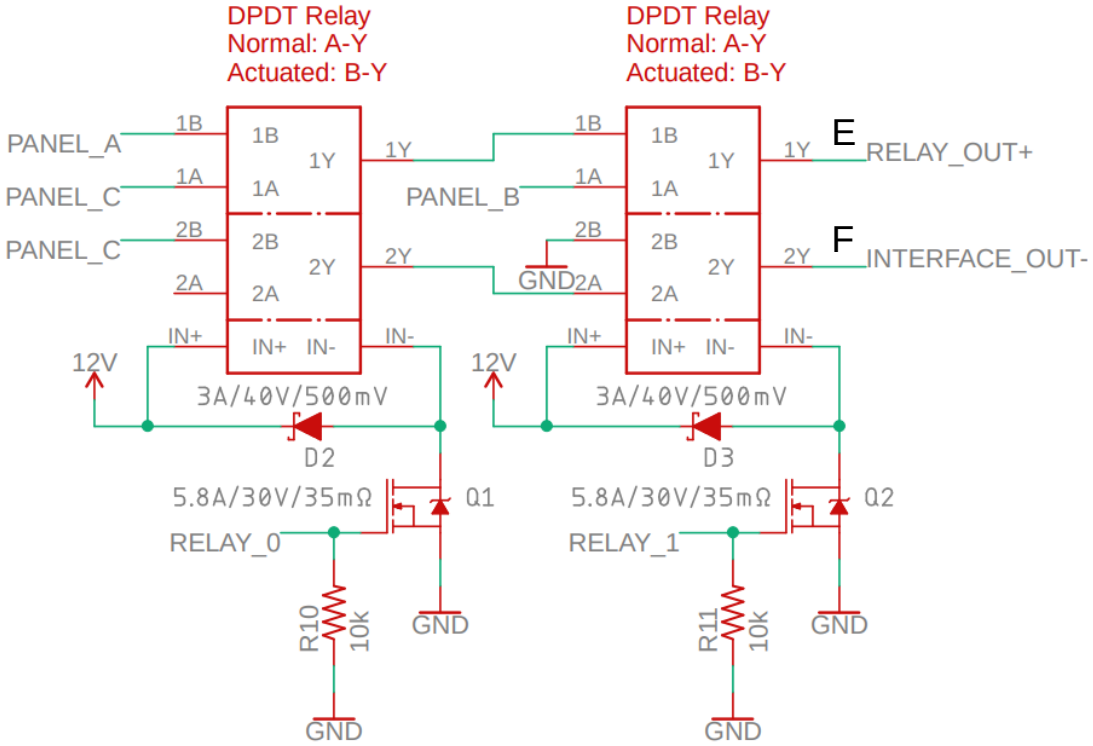
Design - Subsystem Requirements

- The switching subsystem must output the configurations shown below
- Default State - Not Connected
- Capable of delivering the maximum voltage and current of the solar panel.

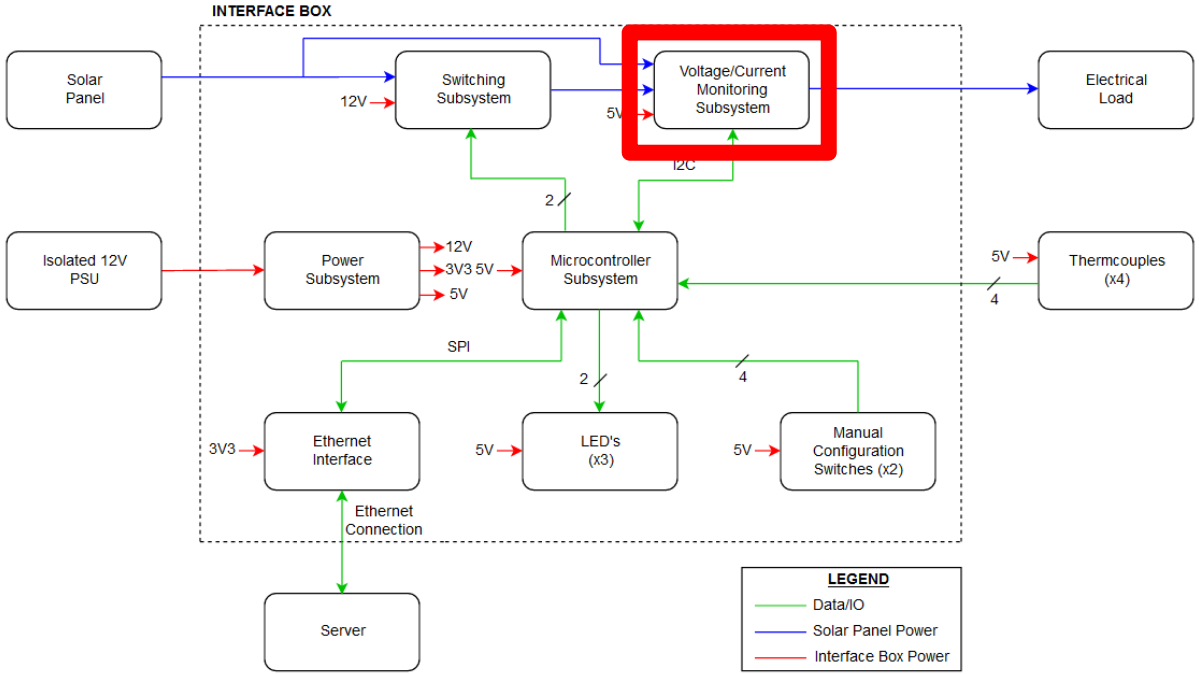
E	F
A	D
B	C
C	D
X	Not Connected



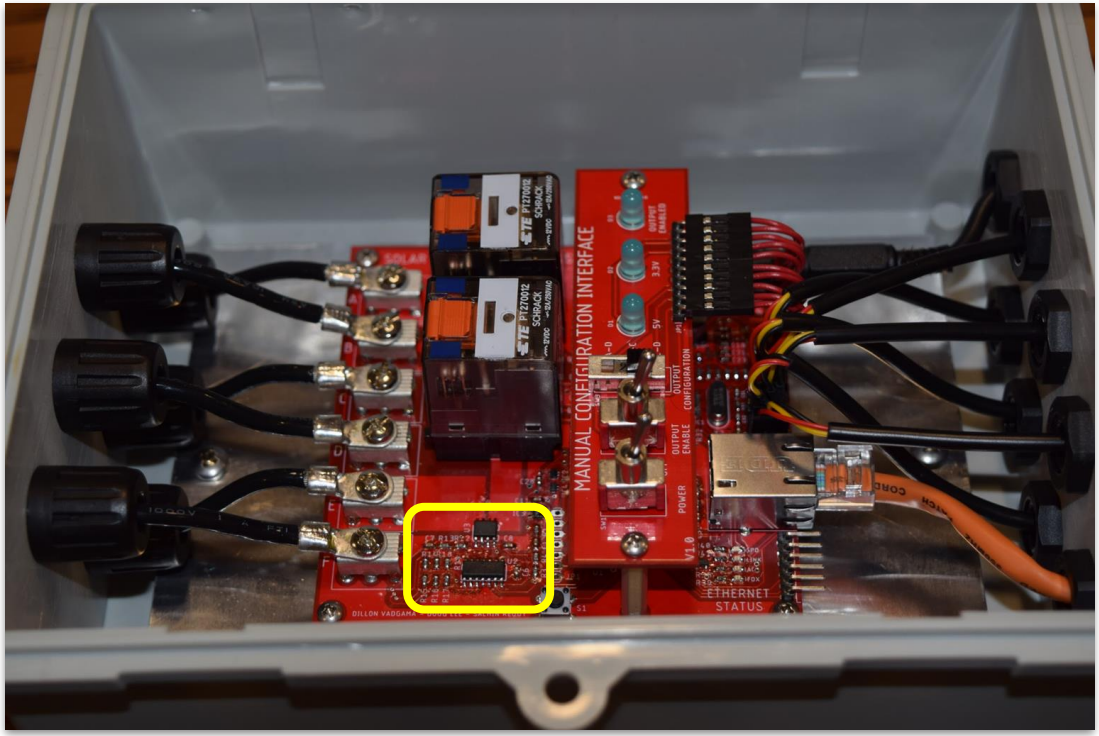
Design - Circuit Schematic



High Level Block Diagram - Voltage/Current Monitoring Subsystem



High Level Block Diagram - Voltage/Current Monitoring Subsystem



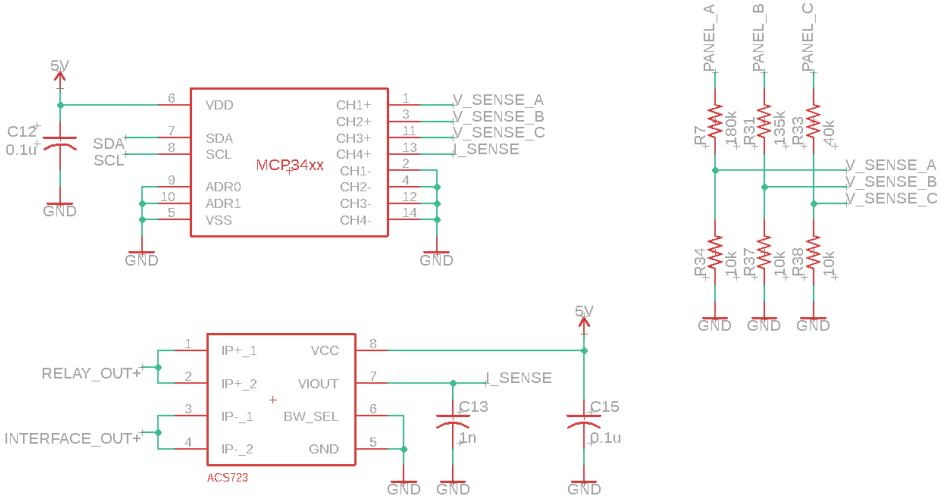
Voltage/Current Monitoring Subsystem

- Measurements:
  - Output current of the solar panel
  - Voltage across the three partitions of the solar panel

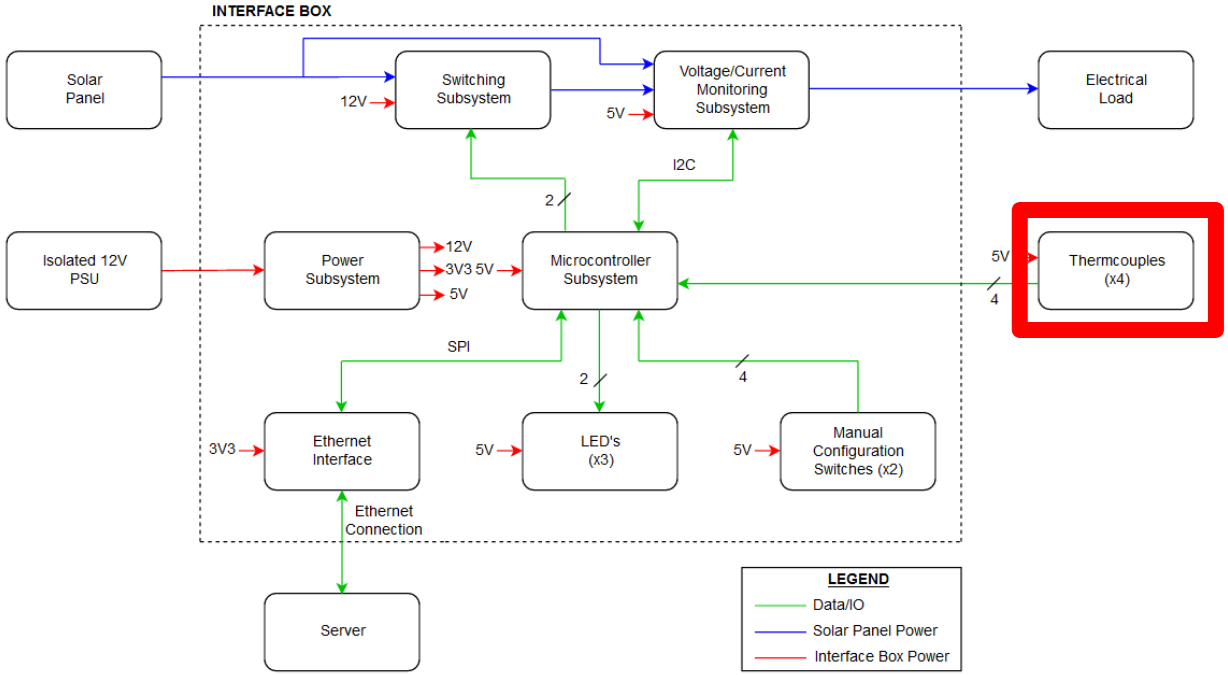
- Two subsystem outputs:
  1. Current/voltage data sent over I2C to the Microcontroller Subsystem
  2. Passes power from the Switching Subsystem to the interface box output

Voltage/Current Monitoring Subsystem

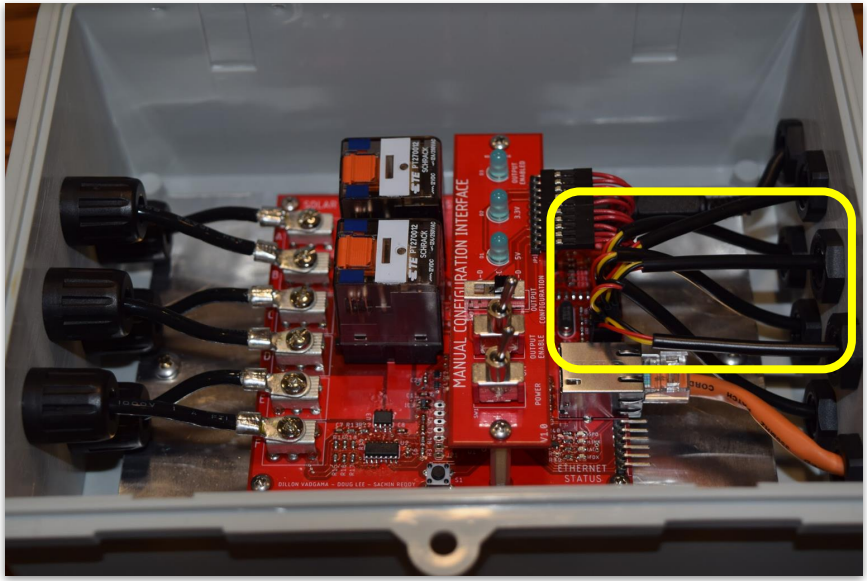
- High solar panel voltages are stepped down using voltage dividers
- Four channel 16-bit analog to digital converter (ADC) with an input range of 0-5V was utilized
  - Channels 1-3: Voltage Measurements
  - Channel 4: Current Measurements
- Accuracy prior to calibration
  - Voltages: ±100mV
  - Current: ±150mA



High Level Block Diagram - Thermocouples

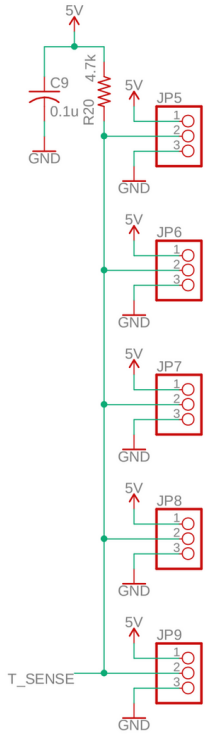


High Level Block Diagram - Thermocouples



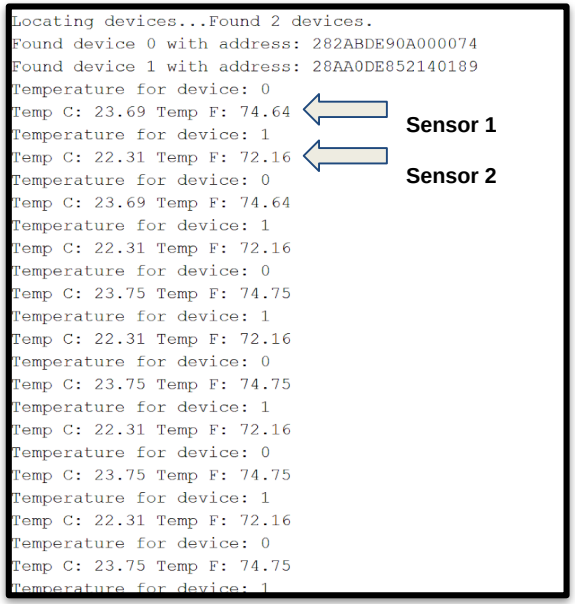
Temperature Monitoring Subsystem

- Used to measure the temperature of various areas of the solar panel
- Must be waterproof
- Powered by the 5V supply
- Only communicates with the Microcontroller Subsystem
- Problem: limited number of I/O ports on the microcontroller
  - Solution: 1-wire digital interface
- Accuracy of ±5°F would be sufficient to detect failure conditions



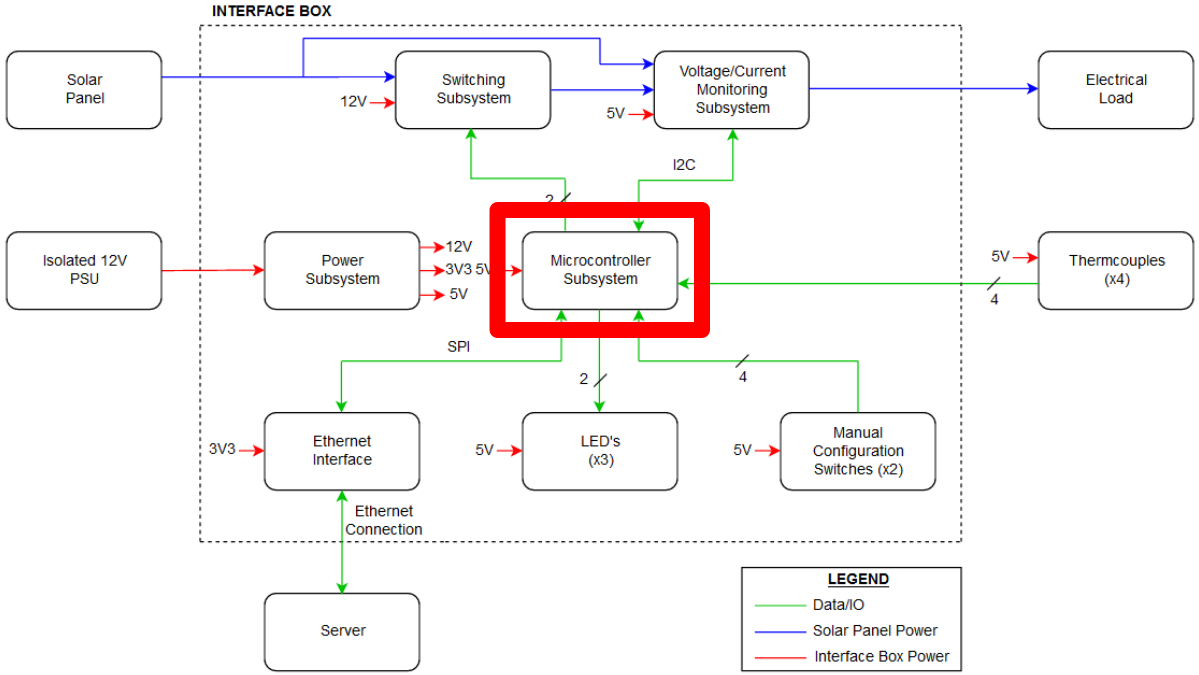
Temperature Monitoring Subsystem

- Six temperature sensors
- Temperature sensor chosen was the DS18B20
  - Operating range -67°F to +257°F
  - Accuracy of ±2.9°F within range 14°F to 185°F



Temperature Monitoring Subsystem

High Level Block Diagram - Microcontroller Subsystem



High Level Block Diagram - Microcontroller Subsystem

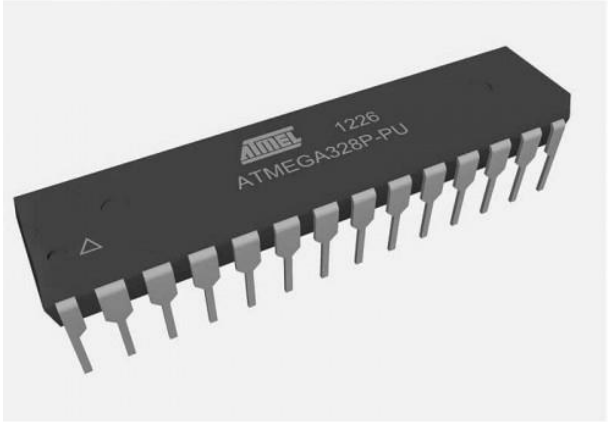
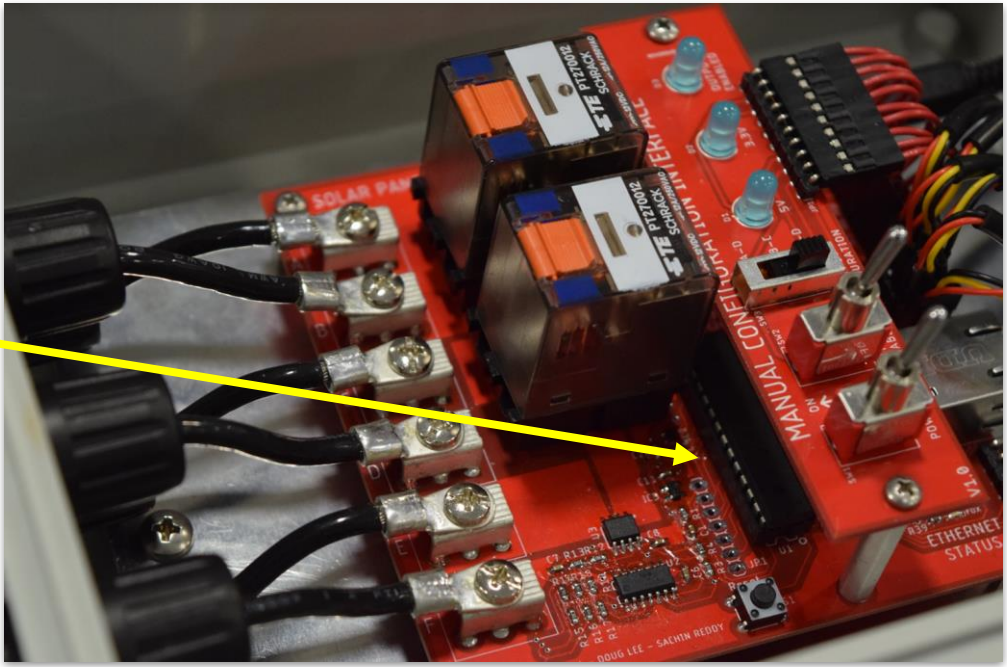
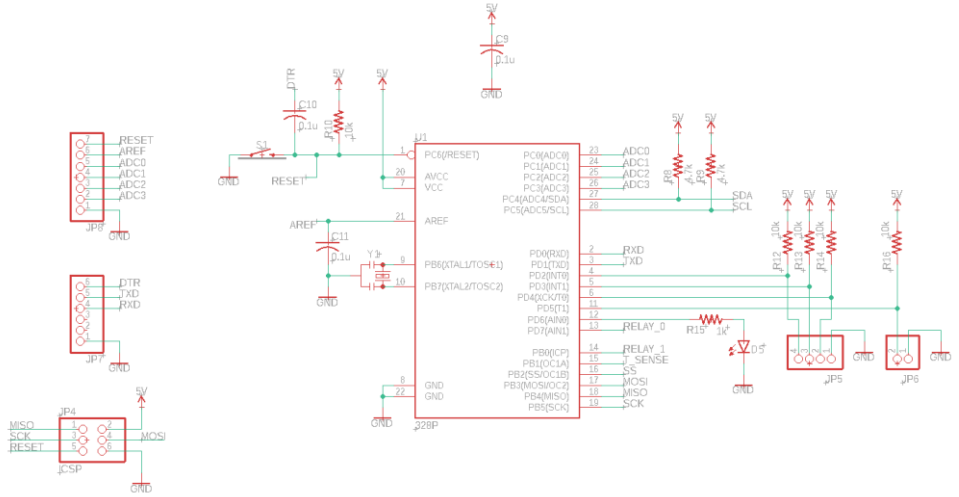


Photo Credit: https://www.component7.com/

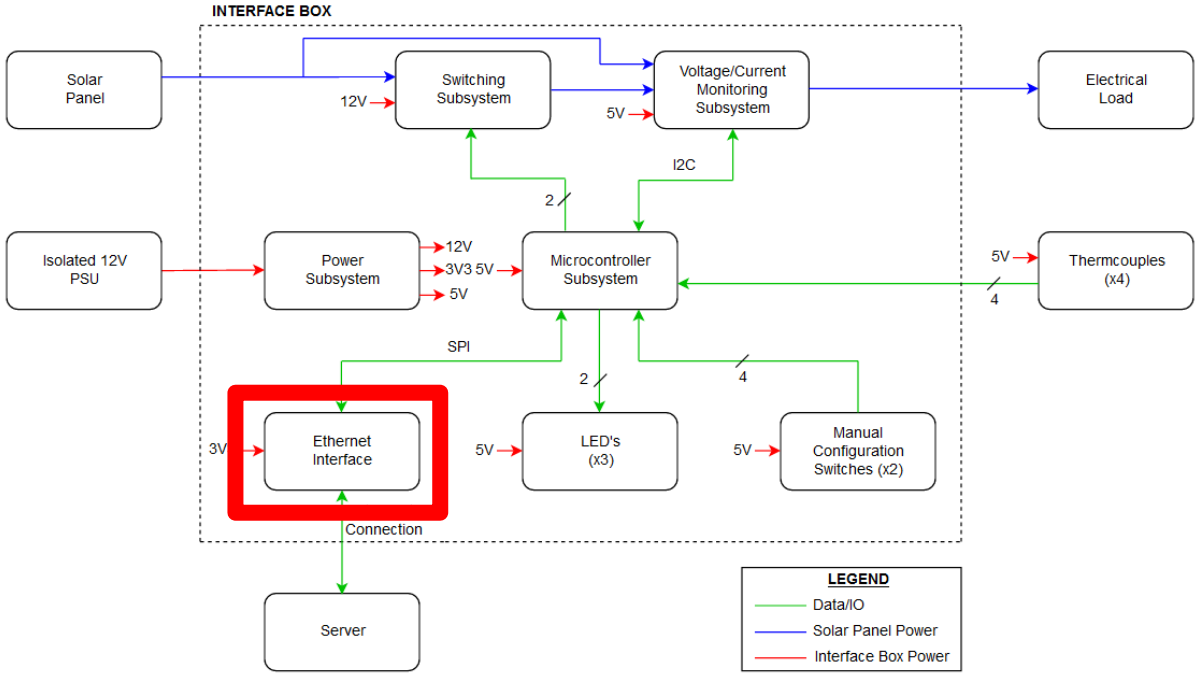


Microcontroller Subsystem

- Central processing unit of the interface box
- Powered by the 5V supply
- ATmega328P was chosen
- Operates at 16 MHz
- 6 pin programming header
  - Allows programming without removing the IC from the board



High Level Block Diagram - Ethernet Interface



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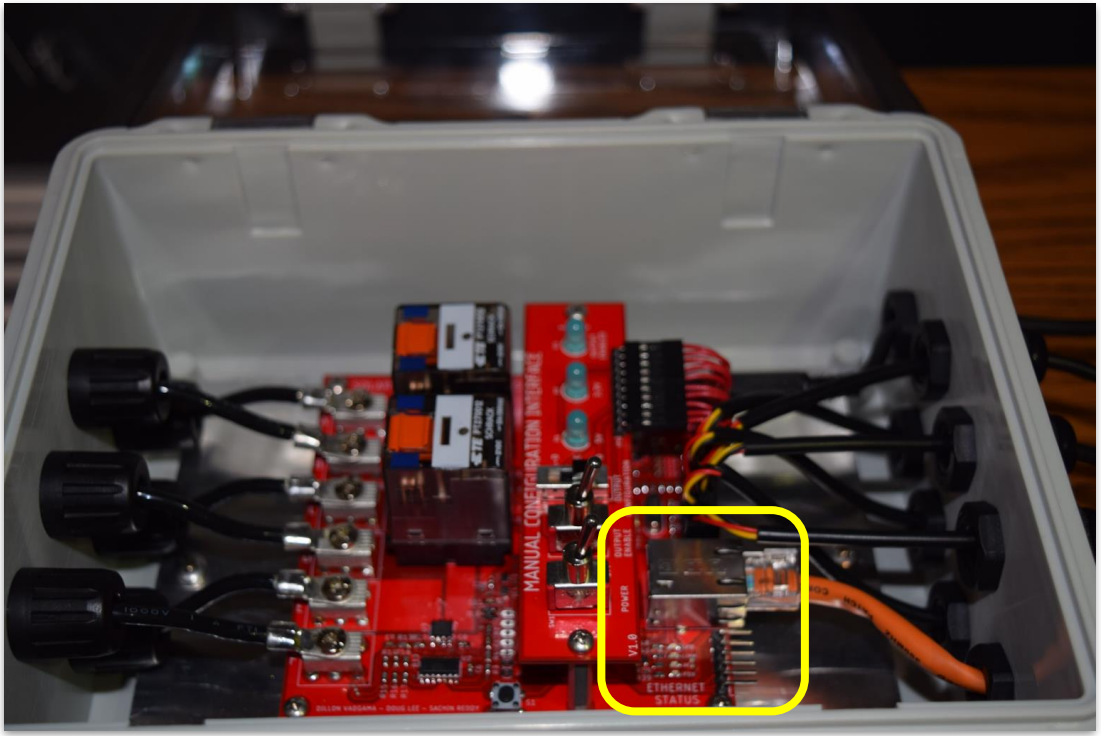
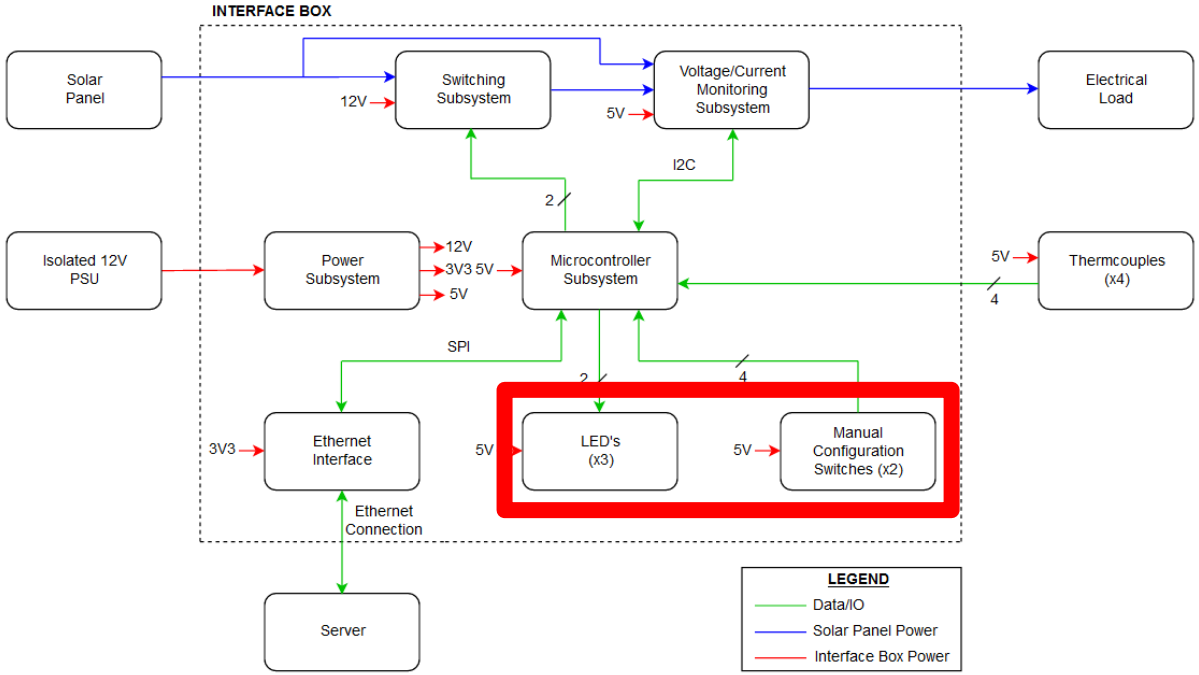


Ethernet Interface

- Communication between the Server/PC and the microcontroller
- Allows remote monitoring and control of the system
- Using the WizNet W5500 Ethernet Controller
  - Easily connect to a microcontroller SPI bus
  - Ethernet controller used in the Arduino Ethernet Shield 2
    - Libraries for Arduino are accessible

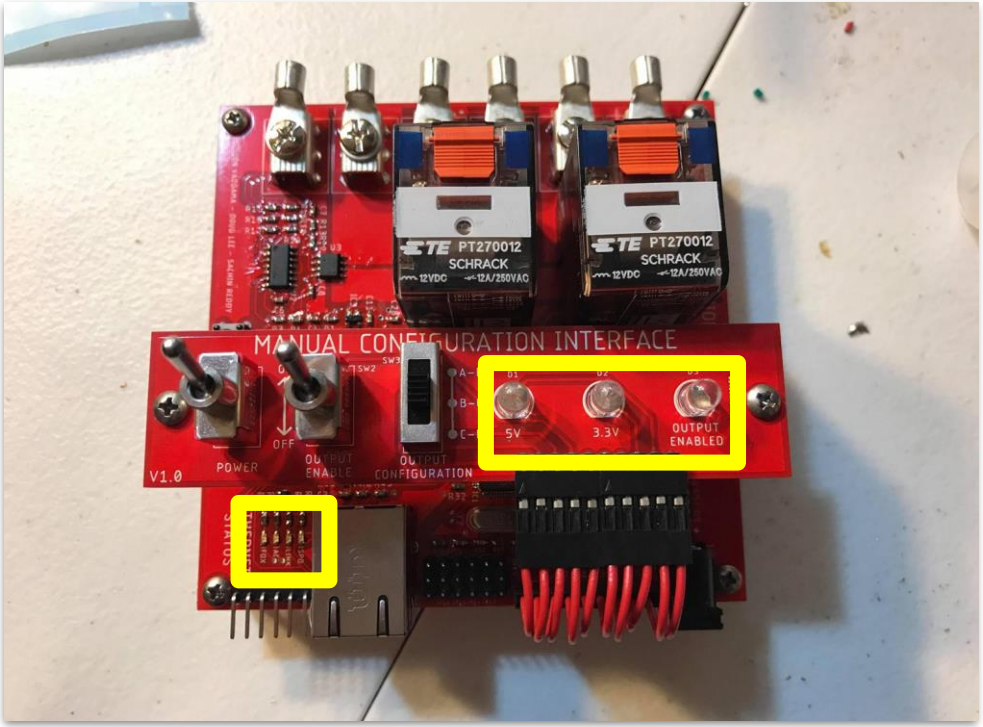
High Level Block Diagram - LED's and Manual Configuration Switches



Manual Configuration Interface - LEDs

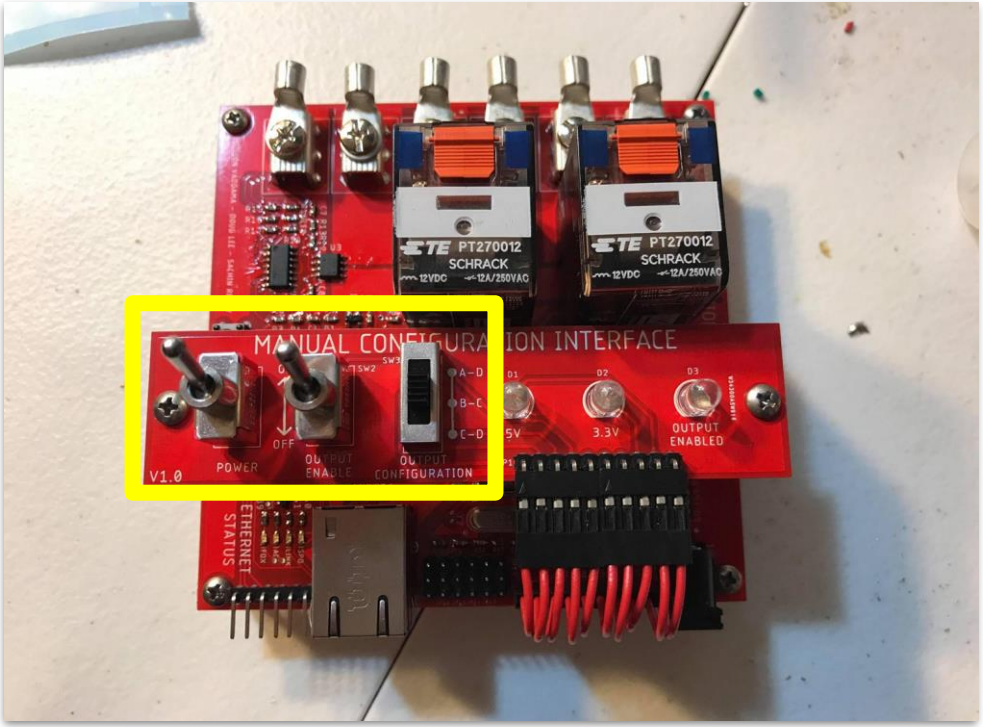
- LED’s show status of:
  - Ethernet connection
  - Output connection
  - Interface box power

- Controlled by the Microcontroller and Power Subsystems

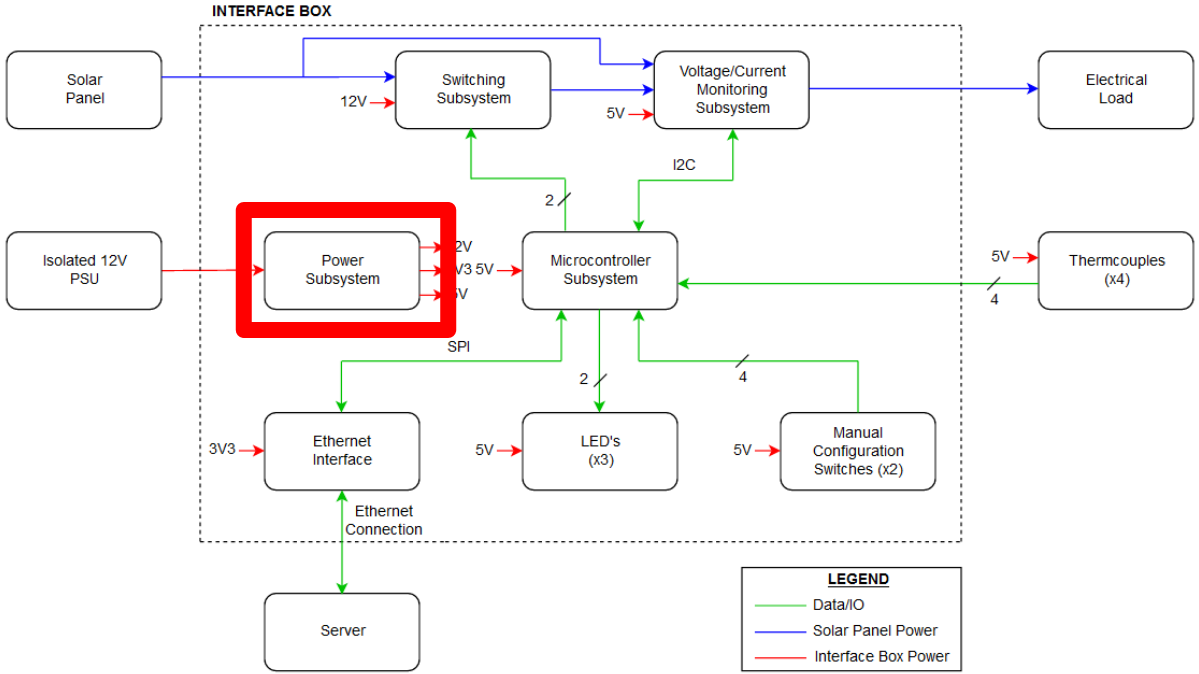


Manual Configuration Interface - Switches

- Controls the configuration of the solar panel and can shut off the system entirely
- Power Switch
  - Toggles the 12V supply to the box
- Output Configuration Slide Switch
  - Configures the output of the box
- Output Enable Switch
  - Enables the output of the box according to the Output Configuration Switch

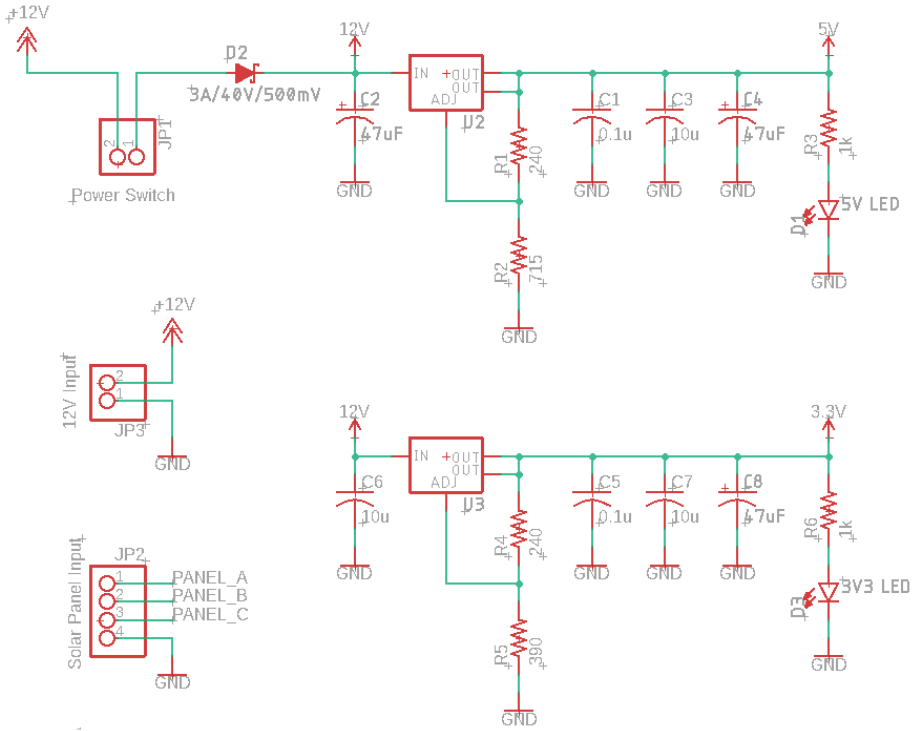


High Level Block Diagram - Power Subsystem



Power Subsystem

- Generates 5V and 3.3V supplies
- Supplied with an isolated 12V power supply
- Max System Current Draw ~ 0.150A.



Firmware

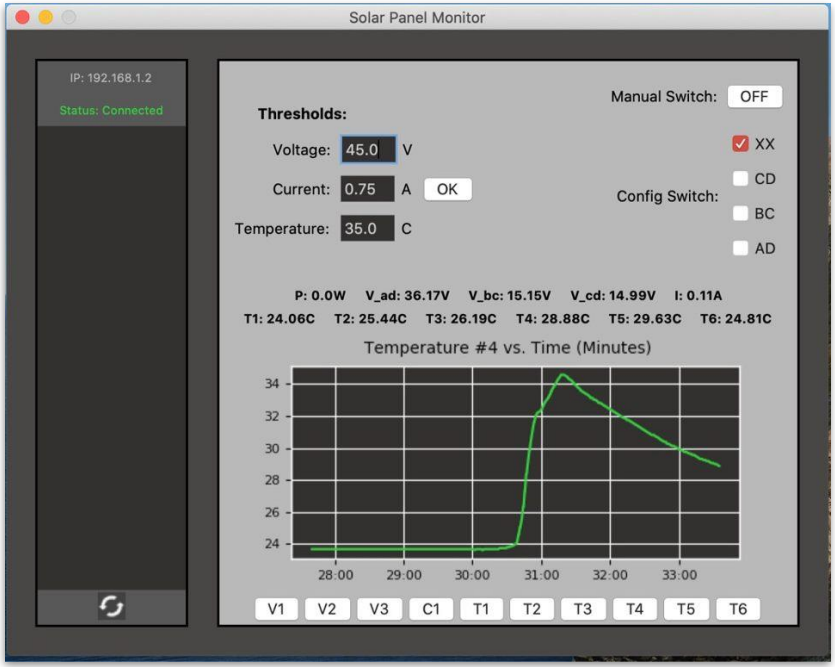
- Collects and computes sensor data
  - Voltage
  - Current
  - Temperature

- Autonomous
  - Disconnects output when threshold is breached

- Sends and receives data over Ethernet
  - Packet of JSON objects

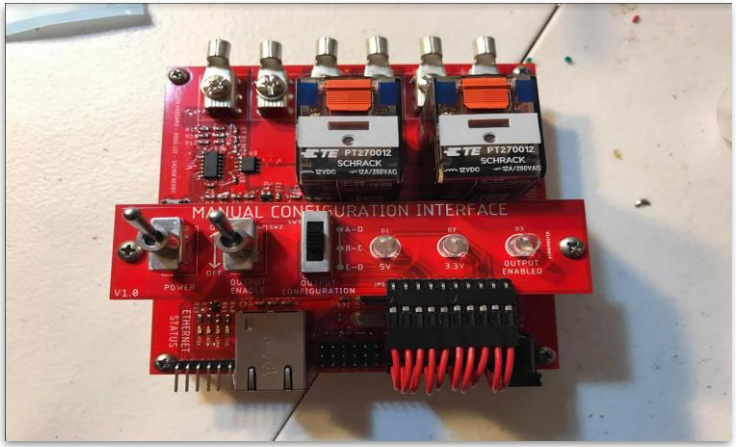
Software - Graphical User Interface (GUI)

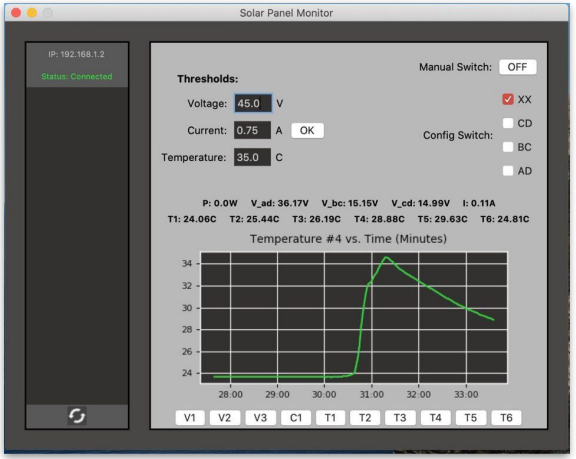
- Responsible for remotely monitoring and configuring the interface box
- Running three threads:
  - Send/Receive thread
  - Command thread
  - Monitor/GUI thread
- Database for storing monitored data
- IP scanner to get all devices on the network



Conclusion

- Project was a success!
  - Customer was more than satisfied
- Tentative plans for 60 units to be installed next Spring





Conclusion (Future Work)

- Hardware:
  - Higher rated relays
  - Solid state switching subsystem
  - Memory space
  - Processor vs. Microcontroller

- Firmware:
  - Optimize libraries
  - Optimize power consumption (i.e. sleep state, active state, reserve state)
  - Multithreading

- Software:
  - Visual grid of solar panels and active boxes
  - Improved GUI visuals
  - Handle multiple users
  - Cleaning code base

Questions?