Data Acquisition System for Soil Sensors

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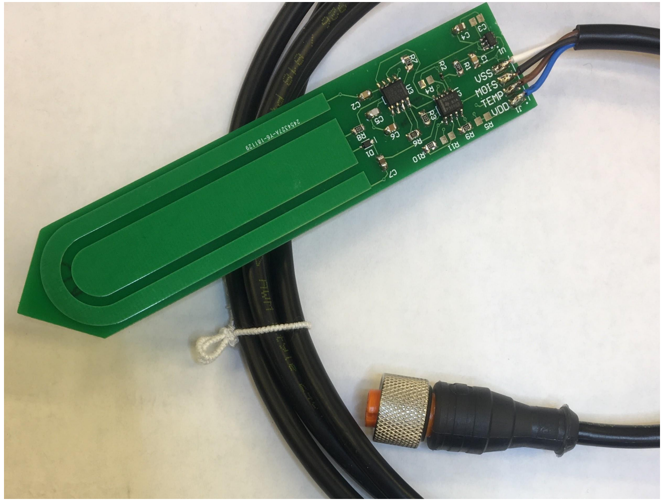
Client/Faculty Adviser: Dr. Halil Ceylan/Shuo Yang

Problem Statement

- The CCEE Department at Iowa State is performing research using unreliable, expensive sensors for monitoring soil moisture and temperature that do not have data acquisition modules included.

Solution

- Create an inexpensive, reliable DAQ to fit our client's requirements
- Use low-cost, off-the-shelf components
- Fabricate sensors to measure moisture content and temperature
- Maintain a functional and professional design



Summary of Requirements

Functional	Non-Functional
Detachable sensors	Sample period of 15 minutes
Rechargeable internal battery	Average battery life of 1 month
Waterproof enclosure	Analog sensor interface
Battery charging indicator	Minimum cable length of 6’
DAQ status LED	Two channels of moisture and temperature measurement
Real Time Clock for time/date stamps	

Budget

- No labor costs or specific budgetary constraints
- Achieved our goal of spending less than $500 throughout entire project

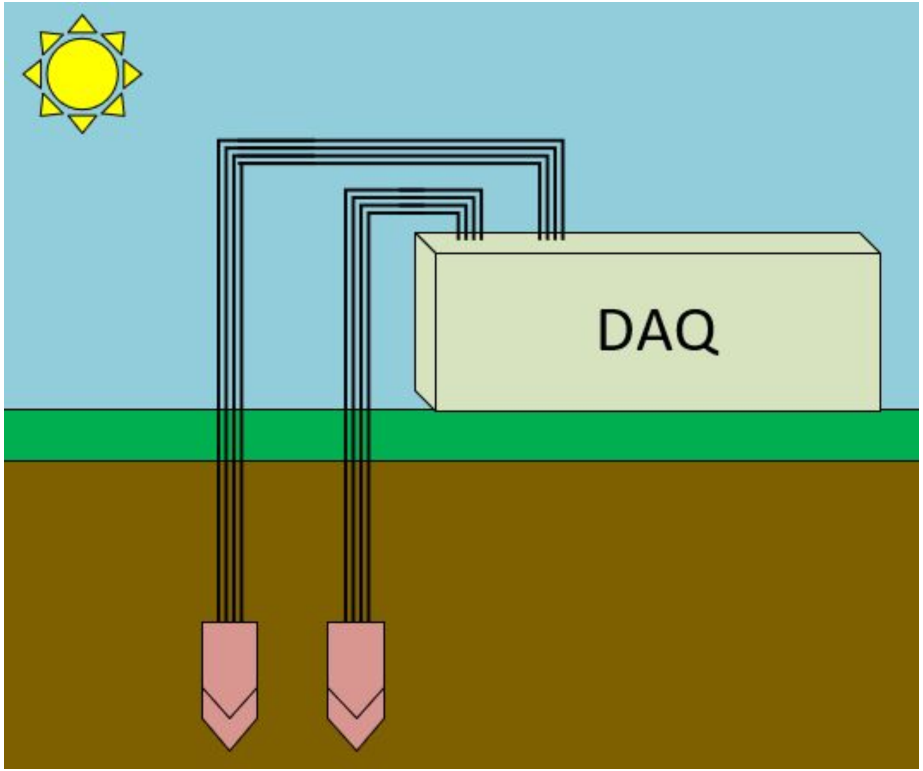
DAQ (qty 1)	**$77.07**
Sensor (qty 2)	**$37.90**
Total System Cost	**$114.97**

Market Research

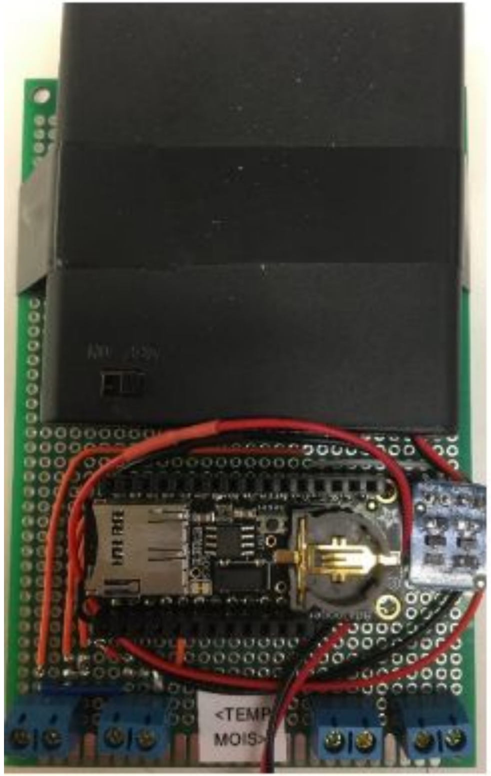
Data Acquisition/Data Loggers	**Associated Sensors**	**Total Cost**
Data Acquisition Module 	Temperature Sensor 	$159 per sensor $230 per Data Acquisition Module **$389 Total**
Data Logger 	Soil Moisture & Temperature Sensor 	$206 per sensor $750 per Data Acquisition Module **$956 Total**

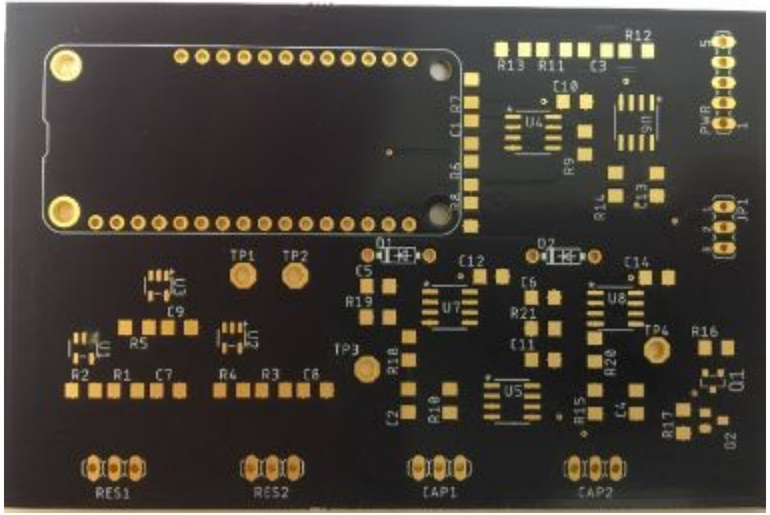
Conceptual Sketch

- Weatherproof enclosure
- Rechargeable battery
- Two sensor channels
- Removable SD card



DAQ Design Revisions



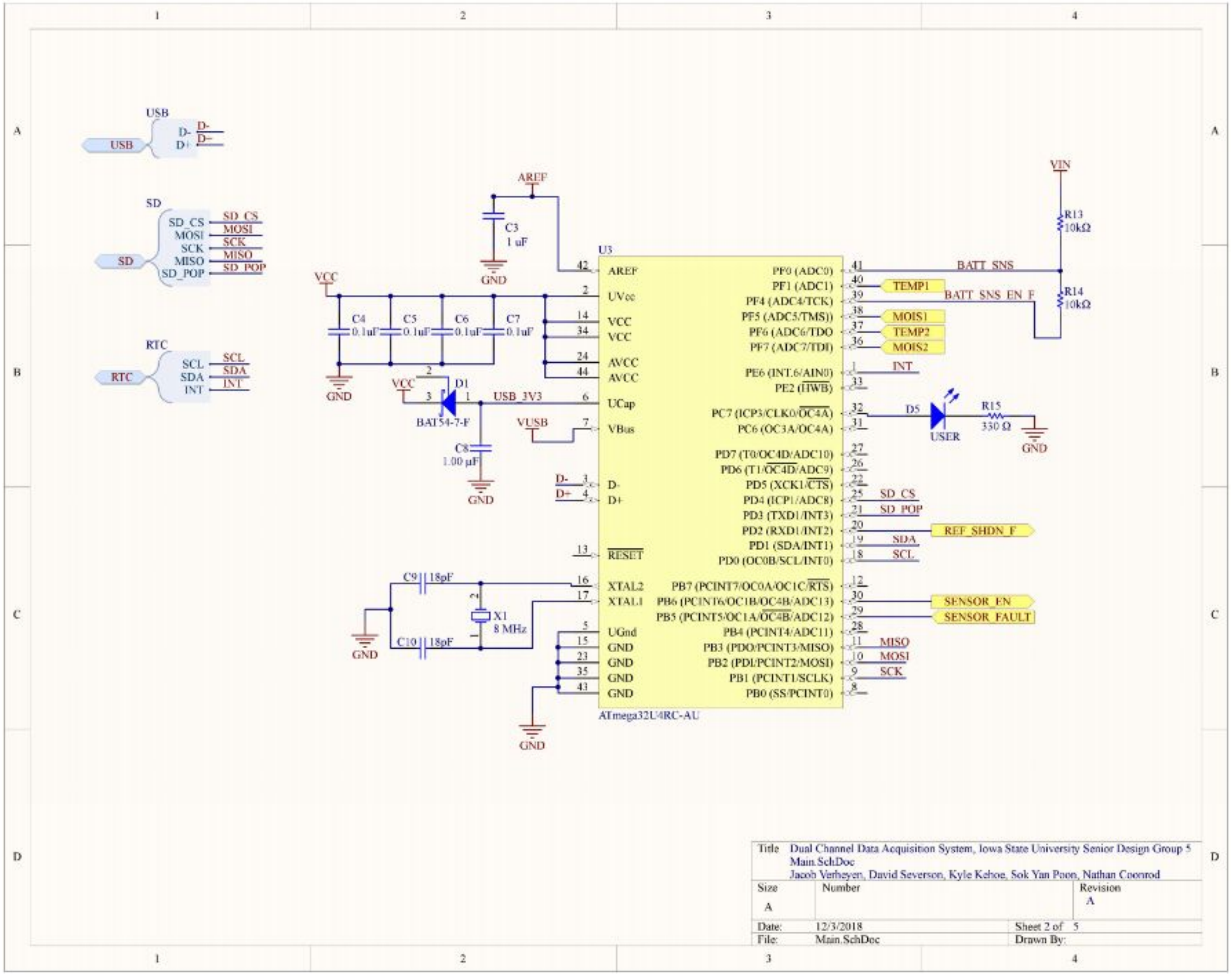


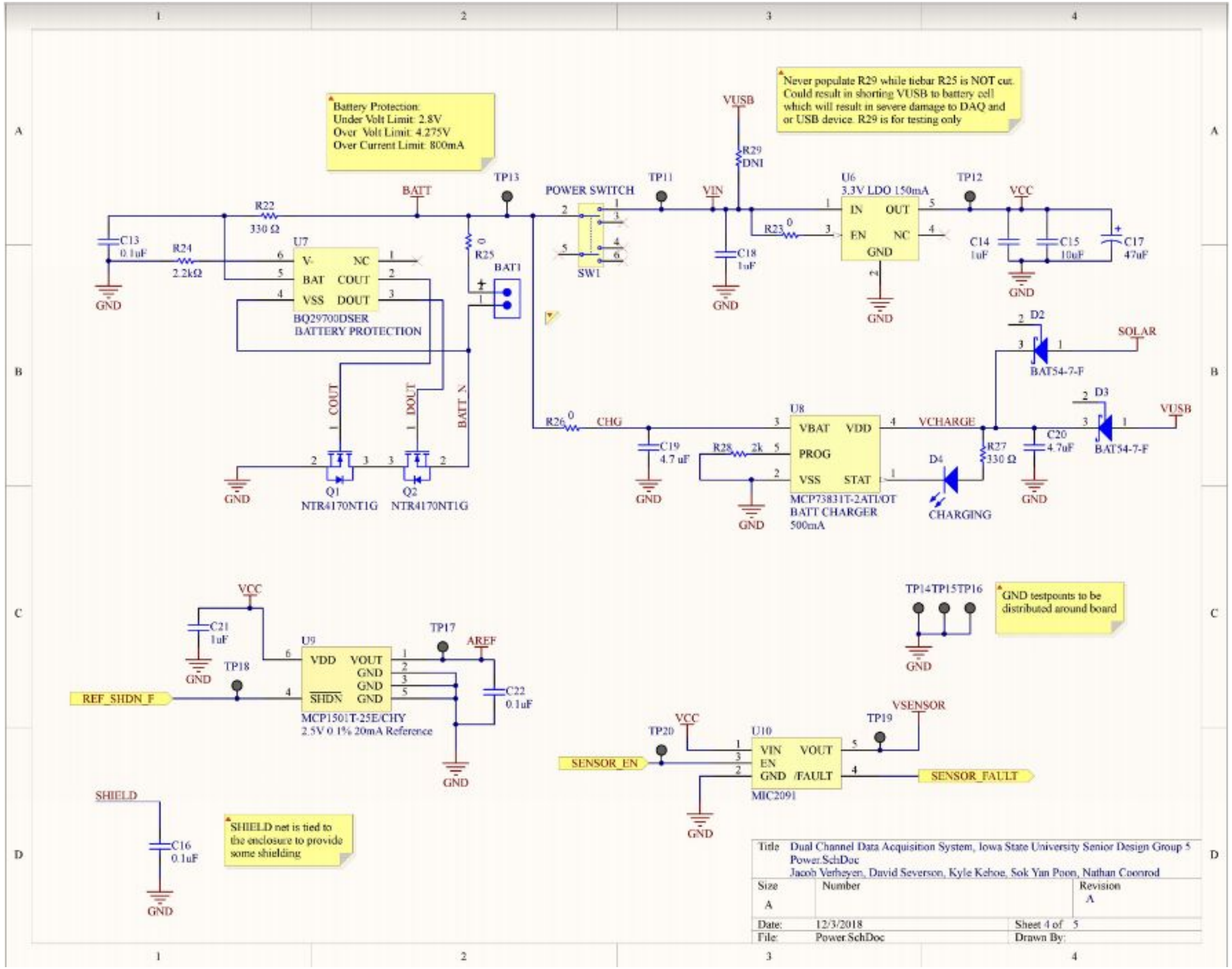
DAQ Hardware Design

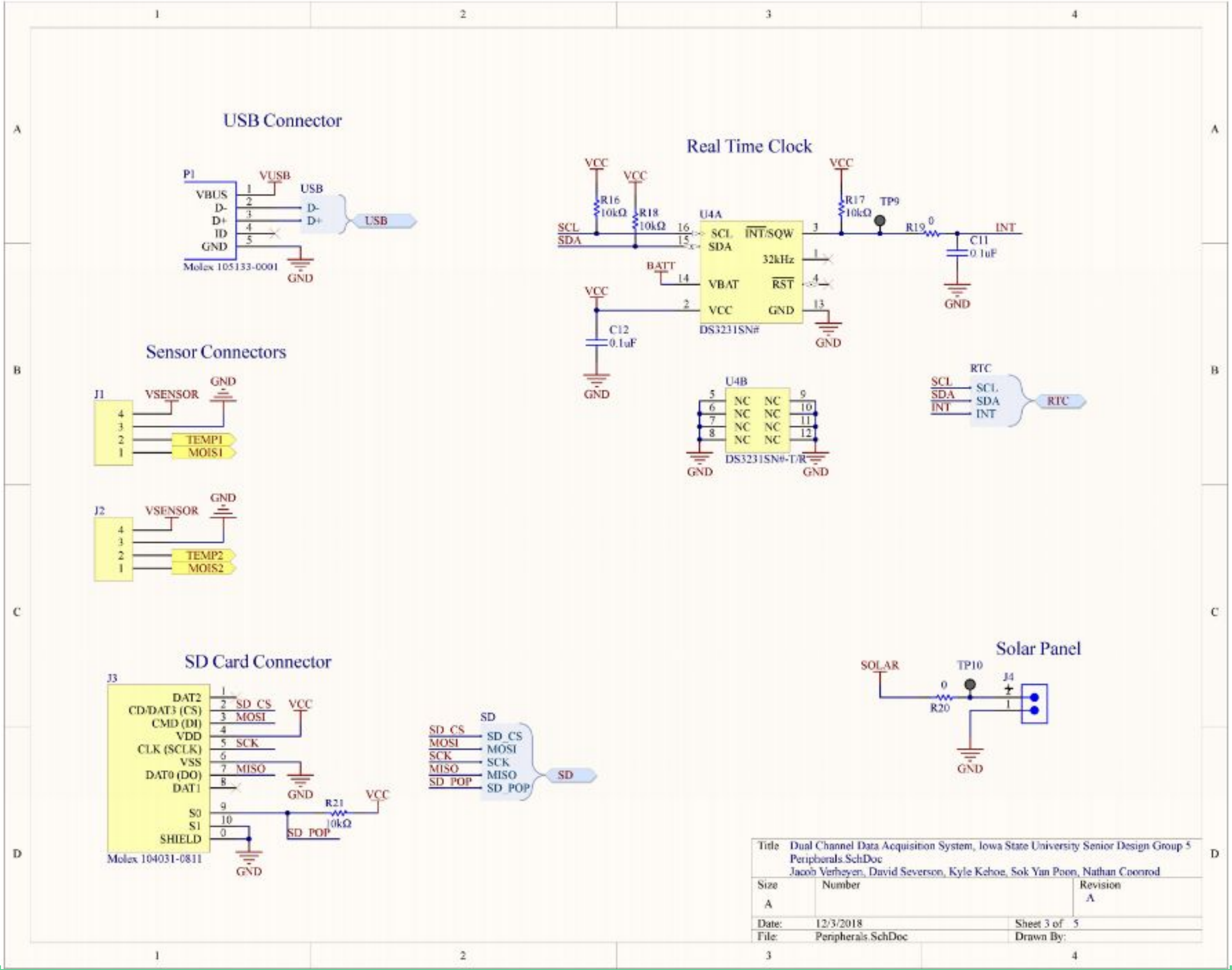
- ATmega32u4 microcontroller
- Real Time Clock (RTC)
- Li-ion 18650 cell
  - Hardware charging and protection ICs
- Micro SD card
- Micro USB for charging and programming

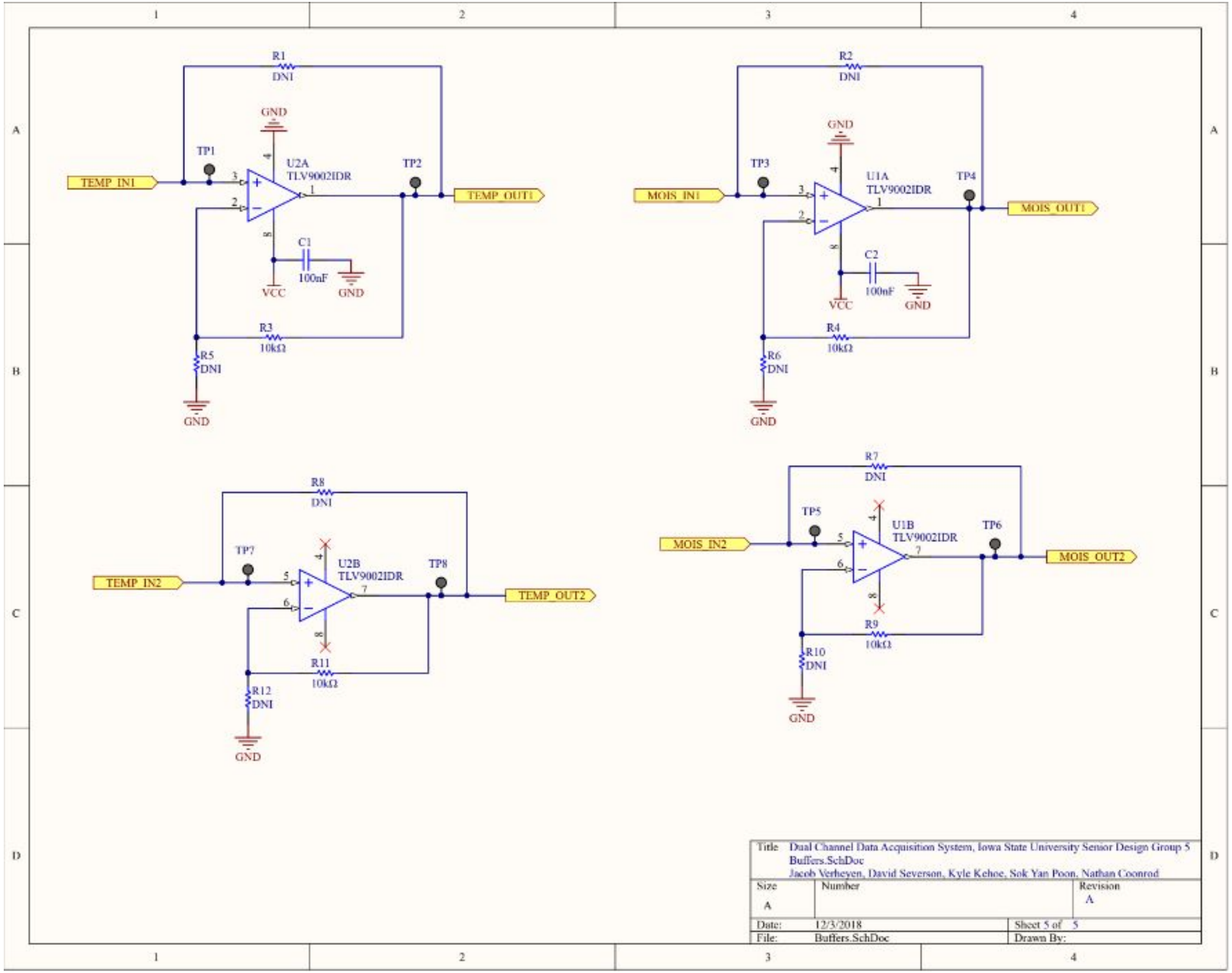
Hardware Implementation

- PCB used as front panel
  - Saves no holes need drilled in box
  - Front panel labeling is free
  - No internal wiring harness needed
  - Reverse mounted LEDs provide waterproof indicators
- RTC used to keep microcontroller in sleep mode
  - ~95% power savings over idle power draw
  - RTC generates interrupt for microcontroller
- Power switch IC to control power to remote sensors
  - Over current fault feature
- User status and charging LED indicators


USB
D-
D+
SD
SD_CS
MOSI
SCK
MISO
SD_POP
RTC
SCL
SDA
INT
AREF
C3
1 uF
GND
VCC
C4 0.1uF
C5 0.1uF
C6 0.1uF
C7 0.1uF
D1
BAT54-7-F
USB_3V3
VUSB
C8
1.00 µF
C9 18pF
C10 18pF
X1
8 MHz
U3
AREF
UVcc
VCC
AVCC
UCap
VBus
RESET
XTAL2
XTAL1
UGnd
PF0 (ADC0)
PF1 (ADC1)
PF4 (ADC4/TCK)
PF5 (ADC5/TMS)
PF6 (ADC6/TDO)
PF7 (ADC7/TDI)
PE6 (INT.6/AIN0)
PE2 (HWB)
PC7 (ICP3/CLK0/OC4A)
PC6 (OC3A/OC4A)
PD7 (T0/OC4D/ADC10)
PD6 (T1/OC4D/ADC9)
PD5 (XCK1/CTS)
PD4 (ICP1/ADC8)
PD3 (TXD1/INT3)
PD2 (RXD1/INT2)
PD1 (SDA/INT1)
PD0 (OC0B/SCL/INT0)
PB7 (PCINT7/OC0A/OC1C/RTS)
PB6 (PCINT6/OC1B/OC4B/ADC13)
PB5 (PCINT5/OC1A/OC4B/ADC12)
PB4 (PCINT4/ADC11)
PB3 (PDO/PCINT3/MISO)
PB2 (PDI/PCINT2/MOSI)
PB1 (PCINT1/SCLK)
PB0 (SS/PCINT0)
ATmega32U4RC-AU
VIN
R13 10kΩ
R14 10kΩ
BATT_SNS
BATT_SNS_EN_F
TEMP1
MOIS1
TEMP2
MOIS2
D5
USER
R15
330 Ω
REF_SHDN_F
SENSOR_EN
SENSOR_FAULT
Title Dual Channel Data Acquisition System, Iowa State University Senior Design Group 5
Main.SchDoc
Jacob Verheyen, David Severson, Kyle Kehoe, Sok Yan Poon, Nathan Coonrod
Size A
Number
Revision A
Date: 12/3/2018
Sheet 2 of 5
File: Main.SchDoc
Drawn By:


Battery Protection:
Under Volt Limit: 2.8V
Over Volt Limit: 4.275V
Over Current Limit: 800mA
Never populate R29 while tiebar R25 is NOT cut. Could result in shorting VUSB to battery cell which will result in severe damage to DAQ and or USB device. R29 is for testing only
VUSB
R29 DNI
BATT
TP13
POWER SWITCH
TP11
VIN
U6 3.3V LDO 150mA
TP12
VCC
R22 330 Ω
C13 0.1uF
R24 2.2kΩ
U7
V- NC
BAT COUT
VSS DOUT
BQ29700DSER
BATTERY PROTECTION
R25 0
BAT1
SW1
C18 1uF
R23 0
IN OUT
EN NC
GND
C14 1uF
C15 10uF
C17 47uF
GND
D2
SOLAR
BAT54-7-F
D3
VUSB
BAT54-7-F
COUT
DOUT
BATT_N
R26 0
CHG
U8
VBAT VDD
PROG
VSS STAT
VCHARGE
R28 2k
C19 4.7 uF
R27 330 Ω
C20 4.7uF
D4
CHARGING
MCP73831T-2ATI/OT
BATT CHARGER
500mA
Q1 NTR4170NT1G
Q2 NTR4170NT1G
TP14 TP15 TP16
GND testpoints to be distributed around board
VCC
C21 1uF
U9
VDD VOUT
GND
GND
SHDN GND
TP17
AREF
TP18
C22 0.1uF
REF_SHDN_F
MCP1501T-25E/CHY
2.5V 0.1% 20mA Reference
VSENSOR
TP19
VCC
TP20
U10
VIN VOUT
EN
GND /FAULT
SENSOR_EN
SENSOR_FAULT
MIC2091
SHIELD
C16 0.1uF
SHIELD net is tied to the enclosure to provide some shielding
Title Dual Channel Data Acquisition System, Iowa State University Senior Design Group 5
Power.SchDoc
Jacob Verheyen, David Severson, Kyle Kehoe, Sok Yan Poon, Nathan Coonrod
Size A
Number
Revision A
Date: 12/3/2018
Sheet 4 of 5
File: Power.SchDoc
Drawn By:


USB Connector
P1
VUSB
VBUS
D-
D+
ID
GND
USB
Molex 105133-0001
GND
Real Time Clock
VCC
R16 10kΩ
R18 10kΩ
R17 10kΩ
TP9
U4A
SCL
SDA
INT/SQW
32kHz
BATT
VBAT
RST
VCC
GND
R19 0
C11 0.1uF
INT
C12 0.1uF
DS3231SN#
U4B
NC
DS3231SN#-T/R
RTC
Sensor Connectors
J1
VSENSOR
TEMP1
MOIS1
J2
TEMP2
MOIS2
SD Card Connector
J3
DAT2
CD/DAT3 (CS)
CMD (DI)
VDD
CLK (SCLK)
VSS
DAT0 (DO)
DAT1
S0
S1
SHIELD
SD_CS
MOSI
SCK
MISO
SD_POP
R21 10kΩ
Molex 104031-0811
SD
Solar Panel
SOLAR
TP10
J4
R20 0
Title Dual Channel Data Acquisition System, Iowa State University Senior Design Group 5
Peripherals.SchDoc
Jacob Verheyen, David Severson, Kyle Kehoe, Sok Yan Poon, Nathan Conrod
Size A
Number
Revision A
Date: 12/3/2018
Sheet 3 of 5
File: Peripherals.SchDoc
Drawn By:


R1
DNI
GND
TP1
U2A
TLV9002IDR
TP2
TEMP_IN1
TEMP_OUT1
C1
100nF
VCC
GND
R3
10kΩ
R5
DNI
GND
R2
DNI
GND
TP3
U1A
TLV9002IDR
TP4
MOIS_IN1
MOIS_OUT1
C2
100nF
VCC
GND
R4
10kΩ
R6
DNI
GND
R8
DNI
TP7
U2B
TLV9002IDR
TP8
TEMP_IN2
TEMP_OUT2
R11
10kΩ
R12
DNI
GND
R7
DNI
TP5
U1B
TLV9002IDR
TP6
MOIS_IN2
MOIS_OUT2
R9
10kΩ
R10
DNI
GND
Title Dual Channel Data Acquisition System, Iowa State University Senior Design Group 5
Buffers.SchDoc
Jacob Verheyen, David Severson, Kyle Kehoe, Sok Yan Poon, Nathan Coonrod
Size A
Number
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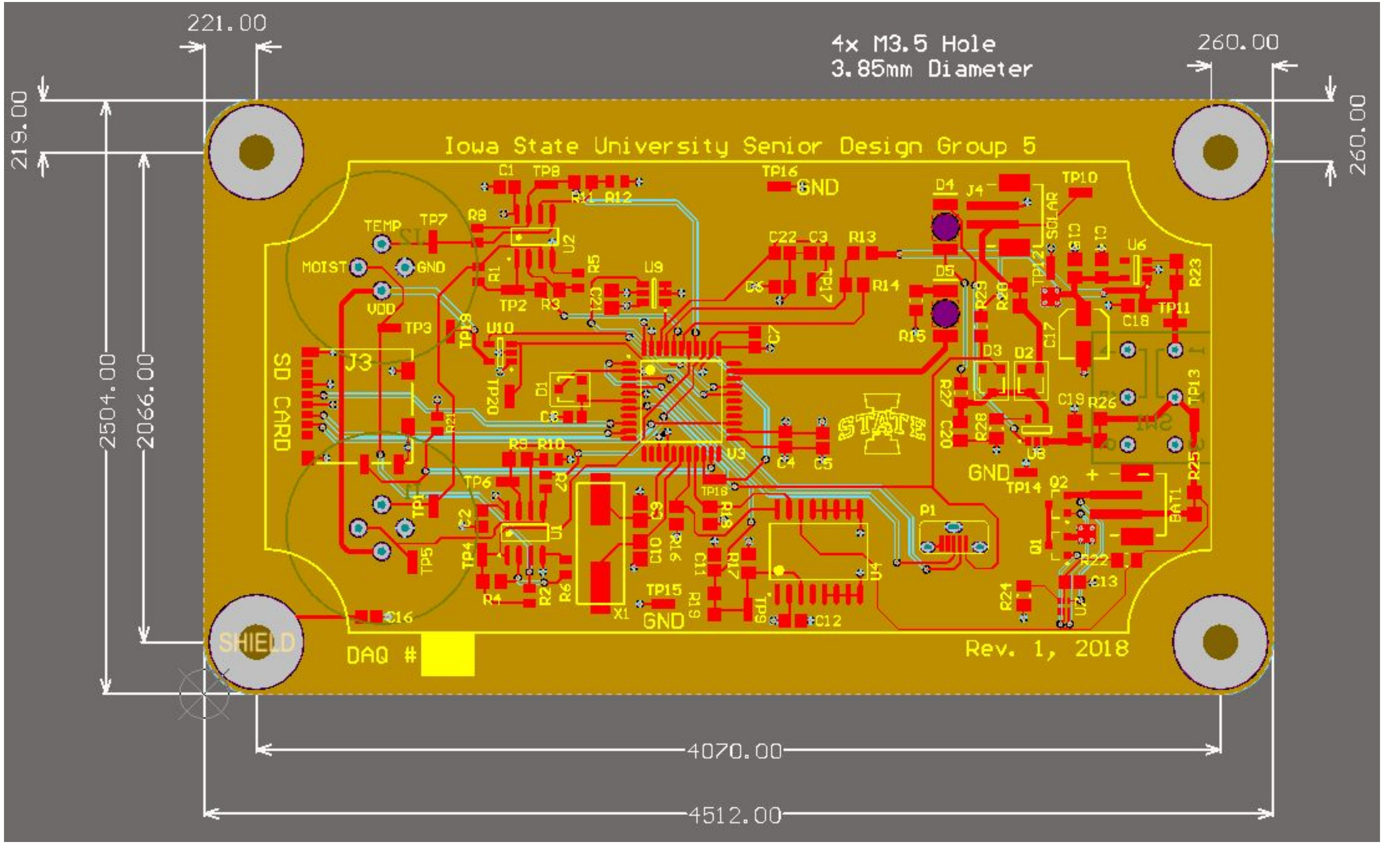
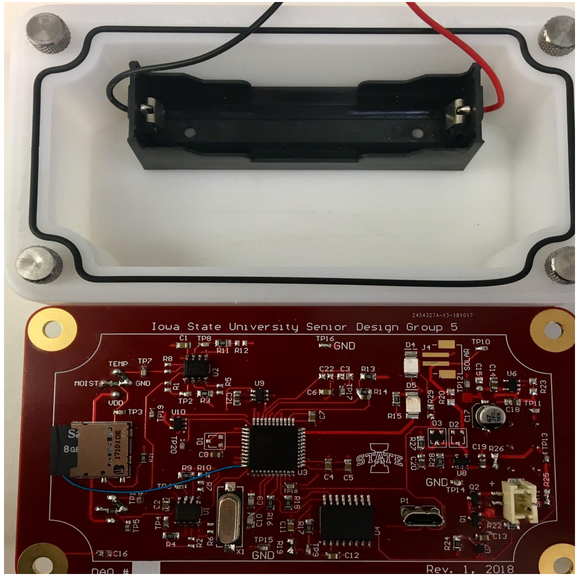
Sheet 5 of 5
File: Buffers.SchDoc
Drawn By:

DAQ PCB Layout



DAQ Mechanical Design

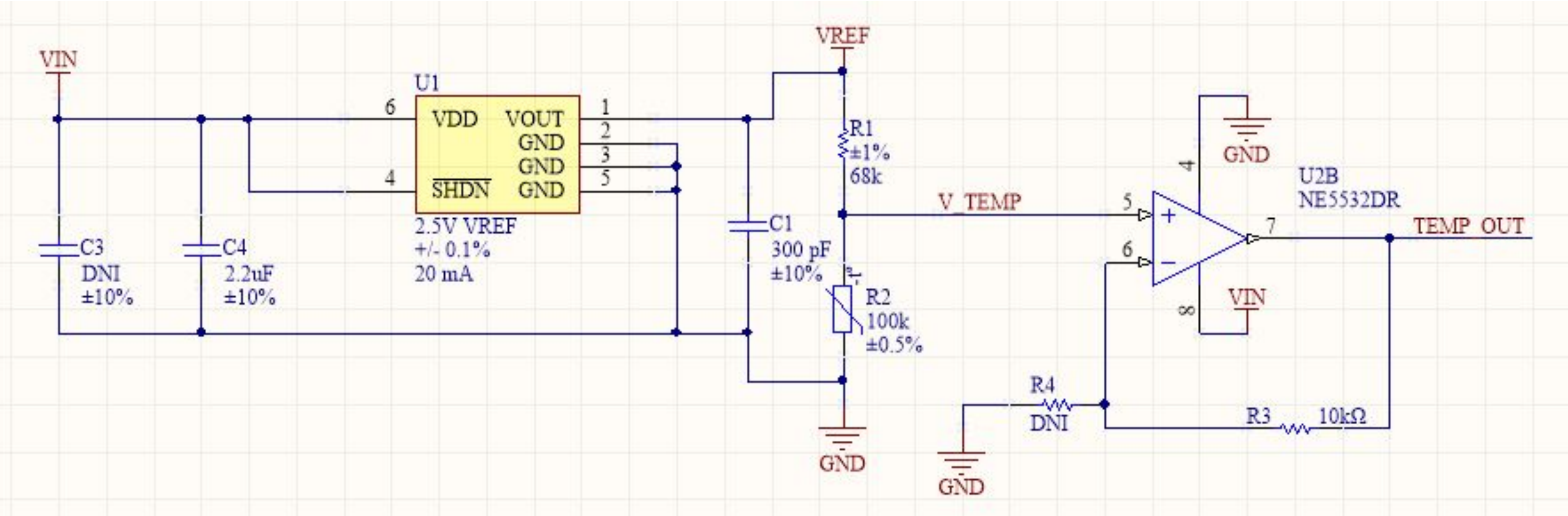
- Custom delrin enclosure
- Waterproof gasket
- PCB front panel with four thumb screws
- Battery holder mounted in bottom of enclosure
- Waterproof power switch
- Reverse mounted indicator LEDs
- M12 cable connectors to sensors



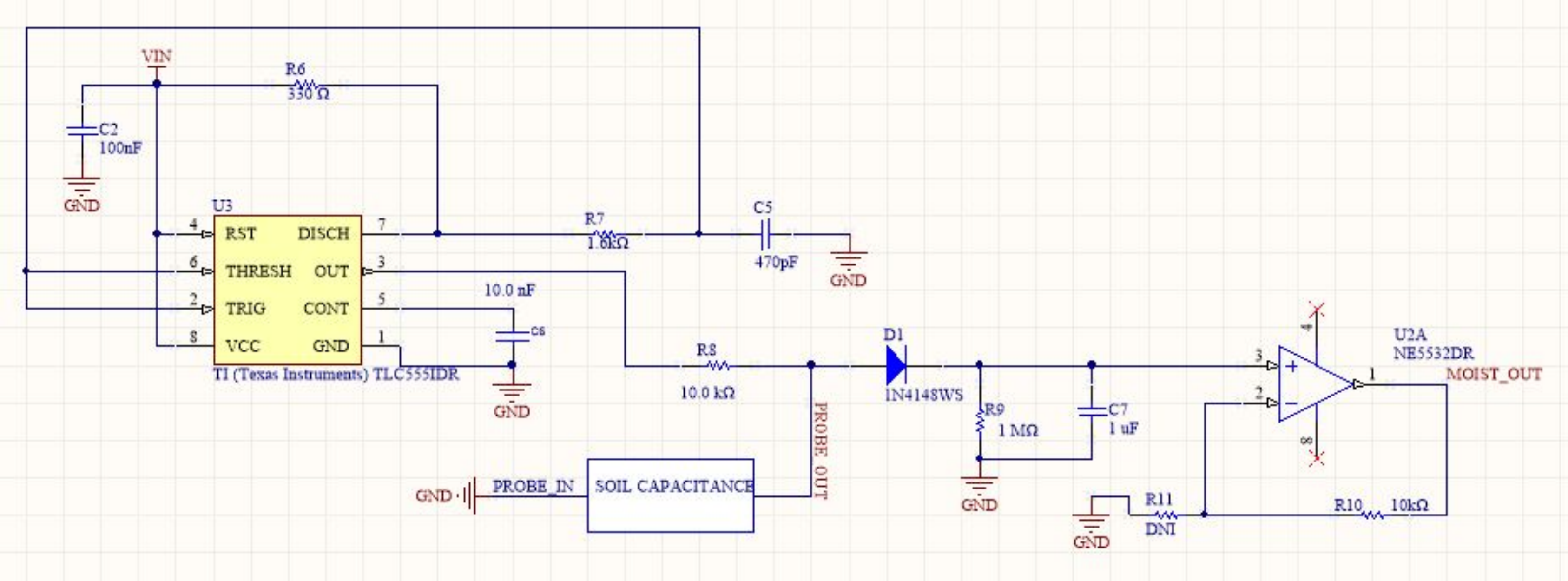
Sensor Design

- Powered by 3.3V supplied by the DAQ. Outputs two analog voltages; one proportional to temperature, and one proportional to moisture content.
- Temperature measurement circuit is very simple, centered around a thermistor.
- Originally tried measuring resistance of soil, but this proved very difficult so we switched to a capacitive approach based on an open source design that we know works.

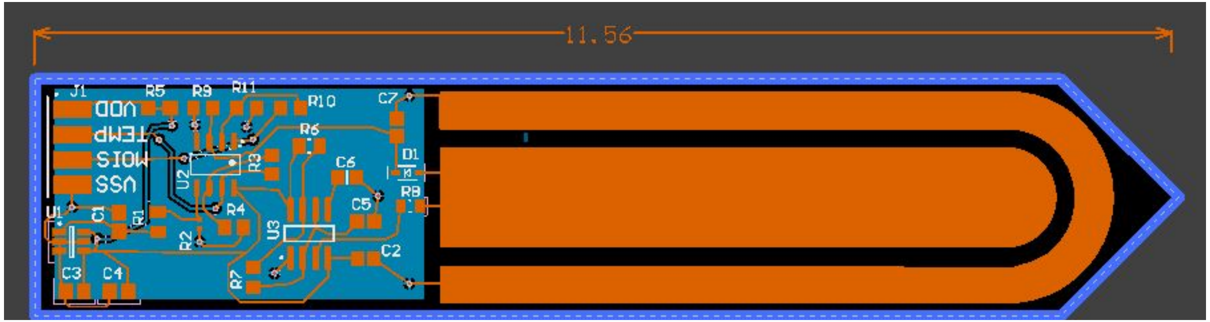
Sensor Temperature Measurement Circuit

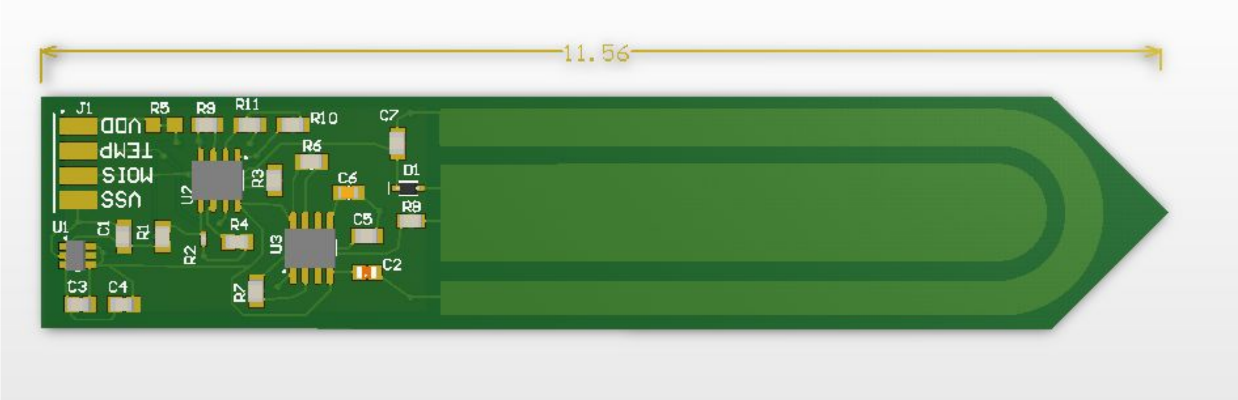


Sensor Moisture Measurement Circuit



Sensor Layout

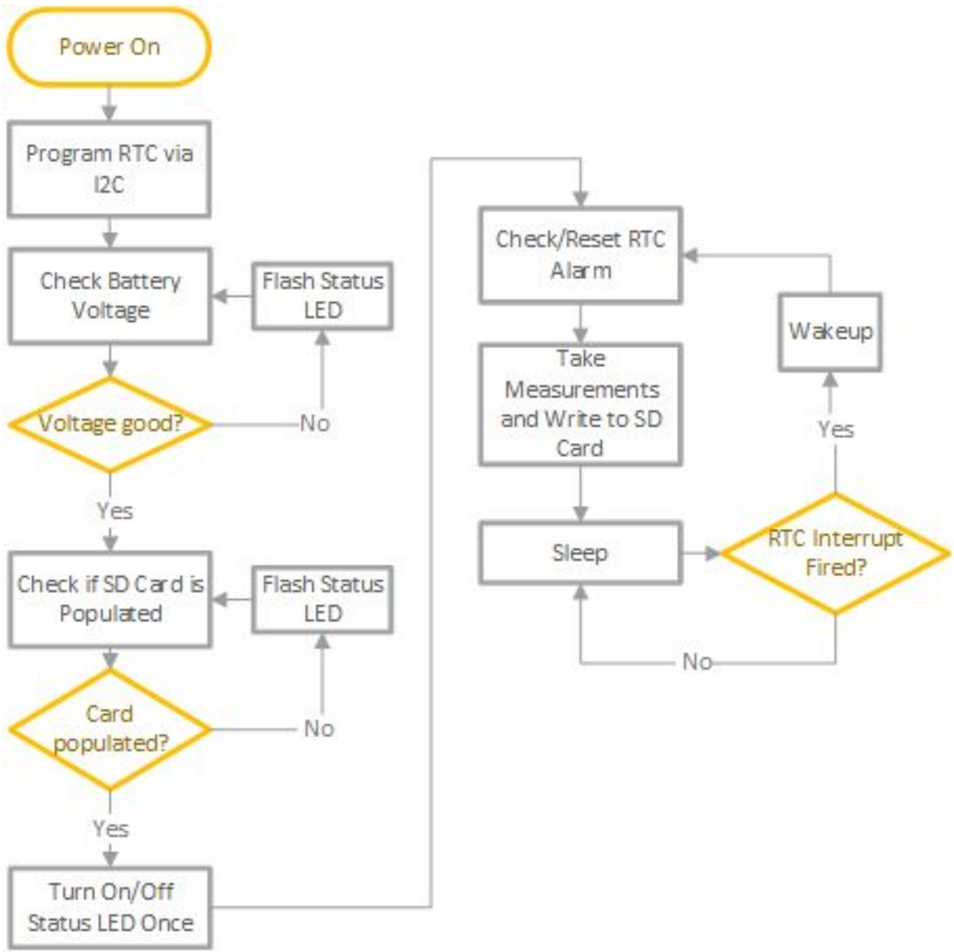




Software Design

- Arduino based for ease of programming
- ATmega32u4 microcontroller
- Used standard Arduino libraries, functions, and public libraries from GitHub
- Referenced data-logging example sketches and modified to obtain data from the required number of channels
- Also looked at example sketches from public libraries as well to understand their functions
  - RTC programming
  - Putting microcontroller to sleep (and waking up)

Software Implementation



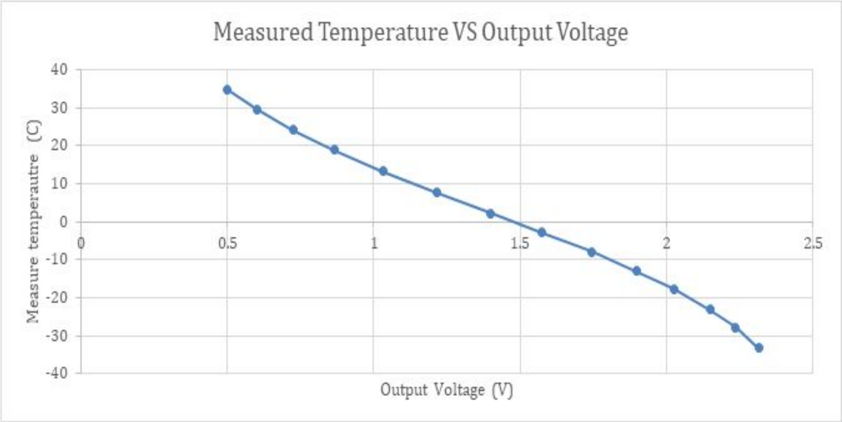
Testing Processes

- Measurement reliability
  - Took measurements at various temperature with the system in temperature chamber
- Temperature accuracy
  - Verified our requirements of -30F to 100F by sweeping temperature using the temperature chamber
- Moisture accuracy
  - Mixture of sand/soil and water used to simulate various moisture conditions

Test Results

DAQ

- Measured power draw for short amount of time when microcontroller wakes up to take readings before going back to sleep
- Determined 3.38 V battery dropout threshold by incrementally changing input to LDO and observing when its output goes out of spec
  - Measured 3.267 V on LDO output (1% error from 3.3V LDO output voltage specification)
- Battery life is ~67 days with 2.6 Ah battery



Sensor

- Temperature sensor: Lowest -33 ◦C output voltage 2.32V; Highest 34 ◦C output voltage 0.498V

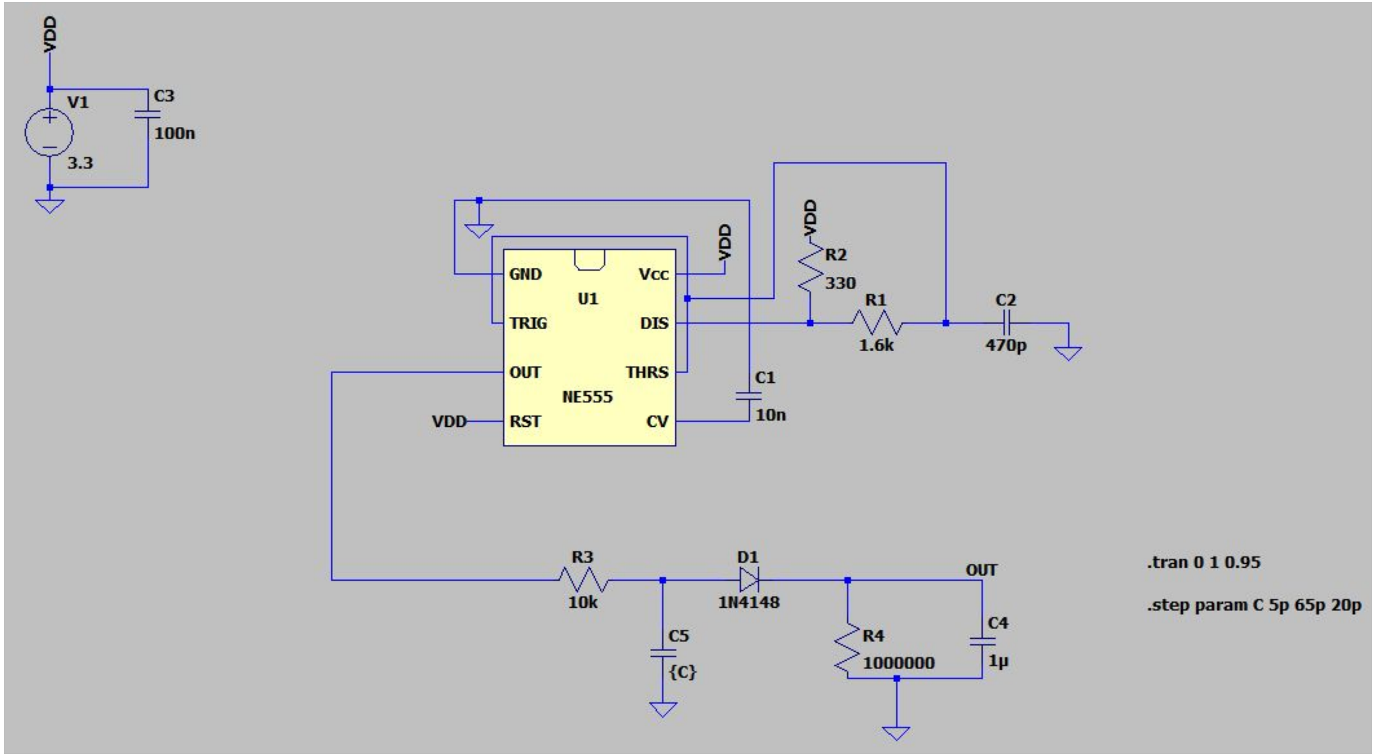
Lessons Learned

- Client relations
- Work effectively as a team
    - “Divide and conquer”
- Temperature and moisture sensor design
- Software implementation: Power sleep mode, wake up interrupt, and data-logging
- Spend enough time thinking at high-level before focusing on low-level details
- Many of our issues stemmed from mechanical problems

Thank You! Any Questions?

Reference Material

Moisture Sensor Simulation Schematic



Moisture Sensor Simulation Results