Village Green Design, Operations, and Maintenance

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Acronyms and Abbreviations

AGM	Absorbed Glass Mat
BC	Black Carbon
°C	Degrees Celsius
CO_2	Carbon Dioxide
DC	Direct Current
DIO	Digital Input Output
DQI	Data Quality Indicator
EEPROM	Electronically Erasable Programmable Read-Only Memory
EPA	Environmental Protection Agency
°F	Degrees Fahrenheit
FIFO	First In, First Out
hr	Hour
I/O	Input/Output
IIS	Internet Information Services
IP	Internet Protocol
IR	Infrared
km/h	Kilometers per Hour
LCD	Liquid Crystal Display
Lpm	Liters per Minute
LVD	Low Voltage Disconnect
mA	Milliampere
mbar	Millibar
mg m^{-3}	Milligrams per Cubic Meter
MHz	Megahertz
min	Minute
m/min	Milliliter per Minute
mm	Millimeter
mph	Miles per Hour
m/s	Meters per Second
mW	Milliwatt
mV	Millivolt
NCAR	National Center for Atmospheric Research
NDIR	Non-dispersive Infrared
nm	Nanometer
NMEA	National Marine Electronics Association
O_3	Ozone
pDR	Personal DataRAM
PM	Particulate Matter
$PM_{2.5}$	Particulate matter less than 2.5 micrometers in diameter
ppb	Parts per Billion
pphm	Parts per Hundred Million
ppm	Parts per Million
PTFE	Polytetrafluoroethylene
RH	Relative Humidity
RTC	Real-Time Clock

s	Second
SD	Secure Digital
slpm	Standard Liters per Minute
Temp	Temperature
TTL	Transistor-Transistor Logic
UART	universal asynchronous receiver-transmitter
$\mu g/m^{-3}$	Microgram per Cubic Meter
μm	Micrometer
UV	Ultraviolet
UV-IR	Ultraviolet-Infrared
V	Volts
VDC	Volts Direct Current
VG	Village Green
VGP	Village Green Project
VOC	Volatile Organic Compound
W	Watts

Acknowledgments

The authors acknowledge Dr. Gayle Hagler (U.S. EPA) and Bobby Sharp (Arcadis, Inc) for their earlier technical contributions in the development of the Village Green air monitoring platform. We also acknowledge the many U.S. EPA, State, municipal, and community-based research partners that provided the opportunity to deploy the Village Green stations where the experiences learned from those deployments have been summarized in this report.

1. Concept and Implementation

1.1 Introduction

The term "village green" refers to outside open areas where people congregate, typically in the center of a town or settlement, such as parks and playgrounds. The Village Green (VG) ambient air quality monitoring system described in this document measures particulate matter (PM) of less than 2.5 micrometers in diameter ($PM_{2.5}$), ozone, wind speed, wind direction, relative humidity (RH), and temperature, along with site-specific measurements in a "village green" type of environment. In the Village Green Project (VGP), data is uploaded in real time to a website for display, logging, and later retrieval. The entire VG air monitoring system, including measurement devices, a solar-powered system, and hardware for the data processing and wireless communication module, is installed in an assembly that is aesthetically inviting to the public and complements a park, playground, or other outdoor setting.

1.2 The Village Green Project Model – Design and History

The VGP design utilizes a pergola/park bench that was developed by SafePlay Systems (Marietta, GA) for the original VGP. This model is based on SafePlay's EcoPlay® design, which utilizes post-consumer recycled plastic material. The power supply consists of two solar panels and a single battery enclosure. A second instrument enclosure is used to protect the instruments, Arduino microcontroller (https://store.arduino.com), and communication hardware.

Figure 1 shows a three-dimensional rendering of the VGP air monitoring system. The end panels are green and embellished with starbursts that are tan in color. The battery and instrument enclosures are mounted in a "trunk" directly behind the bench, as shown in drawing M-1.1 of Appendix A. The roof can be either flat or slightly inclined, with the solar panels mounted on top. The wind sensor support can be mounted to one of the posts, and the height is adjustable. An informational sign can be posted near the structure based on the design shown in drawing M-1.3 of Appendix A. Photos are provided of the Durham, North Carolina, library installation in Appendix E as examples.

The pilot VG station was installed in Durham, North Carolina, in June 2014. Seven additional stations have been built across the U.S. since then. Table 1 shows the VGP locations and their installation dates.

Table 1. VGP Site List by Installation Date

Location	Location Type	Installation Date
Durham, North Carolina	Library	June 2014
Philadelphia, Pennsylvania	Park	March 2015
Washington, D.C.	Park	March 2015
Kansas City, Kansas	Library	March 2015
Oklahoma City, Oklahoma	Botanical Garden	September 2015
Hartford, Connecticut	Museum	November 2015
Chicago, Illinois	School	March 2016
Houston, Texas	Museum	March 2017

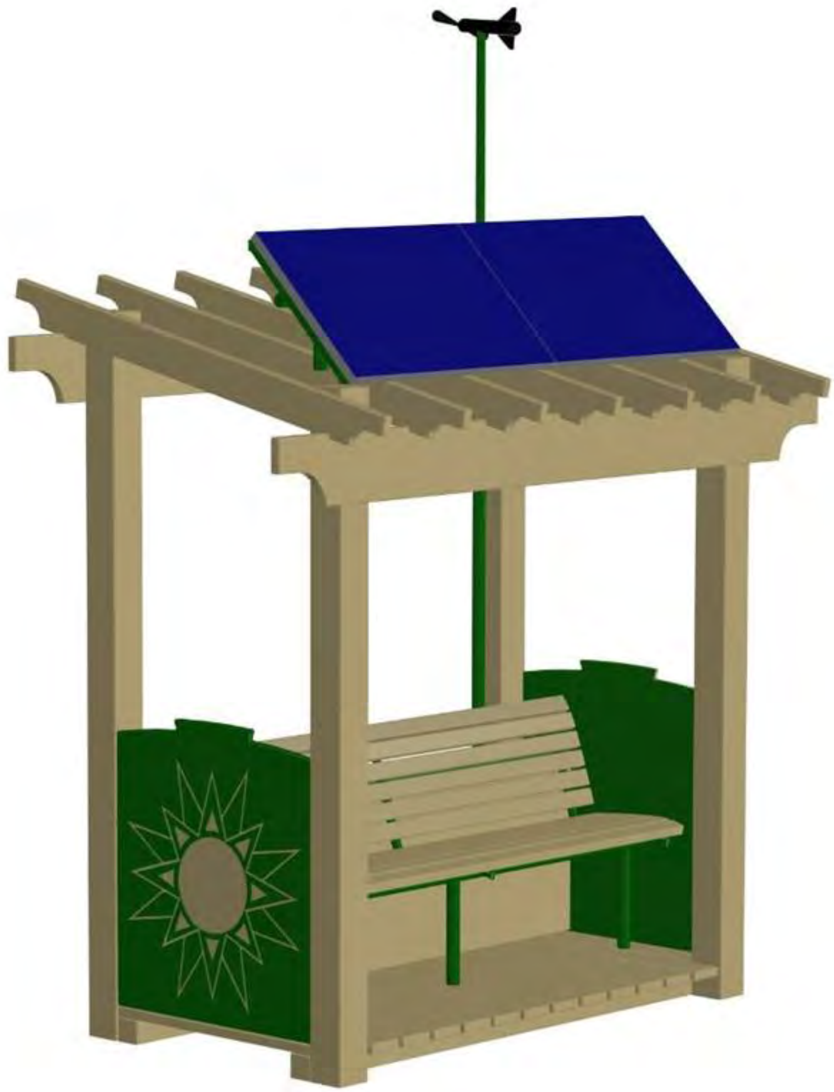

Figure 1. Village Green Project Pergola/Bench Structure.

2. Village Green Project Equipment

The equipment used in the VGP stations is divided into the two categories of primary and secondary equipment. The primary equipment (Table 2) consists of air quality and meteorological instruments that provide data to the user. The secondary equipment includes supporting devices that are required for the stations' operational functions.

Table 2. Air Quality and Meteorological Instruments by Site

	Parameter (Manufacturer/Model)										
Location	**Particulate Matter (PM) [Thermo Fisher Scientific pDR-1500]**	**Ozone (O_3) [2B Technologies OEM-106-L]**	**Wind Speed/Wind Direction [R.M. Young 09101]**	**Relative Humidity/Temperature [Vaisala HMP60]**	**Nitrogen Dioxide (NO_2) and O_3 [Cairpol CairClip]**	**NO_2 [Cairpol CairClip]**	**Rainfall/Precipitation [EML ARG100]**	**Black Carbon (BC) [AethLabs MA 350]**	**Volatile Organic Compound (VOC) [MOCON piD-Tech Blue]**	**Solar Radiation [Apogee SP-110]**	**Carbon Dioxide (CO_2) [CO2meter GC-0015]**
	2.1.1	**2.1.2**	**2.1.3**	**2.1.4**	**2.1.5**	**2.1.6**	**2.1.7**	**S2.1.8**	**2.1.9**	**2.1.10**	**2.1.11**
Durham, NC	X	X	X	X	X					X	X
Kansas City, KS	X	X	X	X	X						
Philadelphia, PA	X	X	X	X	X						
Washington, D.C.	X	X	X	X	X						
Oklahoma City, OK	X	X	X	X	X		X				
Hartford, CT	X	X	X	X	X						
Chicago, IL	X	X	X	X							
Houston, TX	X	X	X	X		X		X	X		

2.1 Primary Air Quality and Meteorological Instruments

2.1.1 Thermo Fisher Scientific pDR-1500

The Thermo Fisher Scientific Company pDR-1500 (Waltham, MA) (Figure 2) is a photometric device used for exposure sampling of airborne PM. The VGP implementation uses a 2.5 µm size selective cyclone to detect only particles that are less than 2.5 µm and hazardous to human health. This cyclone requires a 1.52 Lpm flow rate setpoint. It operates on 5 V and has an RS-232 output.

Figure 2. Thermo Fisher Scientific pDR-1500.

The manufacturer's specifications relevant to the VGP implementation are listed in Table 3. Additional specifications required for the VGP are listed in **bold**.

Table 3. pDR-1500 Manufacturer's Specifications

Accuracy	±5% of reading ± precision (traceable to SAE Fine Test Dust)
Aerodynamic Particle Cut-Point Range	1.0 to 10 µm **(2.5 µm cyclone used)**
Concentration Measurement Range	0.001 to 400 mg/m³ range (auto ranging)
Description	pDR-1500 Aerosol Monitor
Flow Rate	1.0 to 3.5 L/min. **(set to 1.52 L/min for size-selective cut point)**
Logged Data	Average concentration, temperature, RH, barometric pressure, time/date, and data point number **(VGP system logs concentration, temperature, RH, barometric pressure, and flow rate)**
Particle Size Range	0.1 to 10 µm **(2.5 µm cyclone used)**
Precision	± 2% of reading or ±0.005 mg/m³, whichever is greater, for 1 second (2-sigma)2 averaging time, ±0.5% of reading or ±0.0015 mg/m³, whichever is greater, for 10-second averaging time, ±0.2% of reading or ±0.0005 mg/m³, whichever is greater, for 60-second averaging time
Resolution	0.1% of reading or 0.001 mg/m³, whichever is greater
Scattering Coefficient Range	1.5 x 10-6 to 0.6 m-1 (approx.) @ lambda= 880 nm (not displayed)
Serial Interface	USB / RS-232, 19, 200 baud **(RS-232 output used with 232 to transistor-transistor logic (TTL) converter for 5-V universal asynchronous receiver-transmitter (UART) output)**

For additional information about this device, please refer to the user's manual (web link) in Appendix F. Detailed information about the system's operation related to this instrument can be found in Section 8.

2.1.2 2B Technologies OEM-106-L

Figure 3 shows the 2B Technologies OEM-106- L (Boulder, CO). This is an ultraviolet (UV) absorbance-based ambient ozone concentration monitor. This device operates from a 12-volt direct current (VDC) supply and has an RS-232 output.

Figure 3. 2B Technologies OEM-106-L.

The manufacturer's specifications relevant to the VGP implementation are shown in Table 4. Additional specifications required for the VGP are listed in **bold.**

Table 4. 2B Technologies OEM-106-L Manufacturer's Specifications

Range	0-100 ppm
Resolution	0.0001 ppm (0.1 ppb)
Precision & Accuracy	Higher of 0.002 ppm (2 ppb) or 2% of reading
Measurement Principle	UV Absorption at 254 nm, single beam
Measurement Interval	2 s **(set to 10 s averages. VGP polls data every 10 s and averages to minute samples)**
Data Averaging Options	**(10 s)**, 1 min, 5 min, 1 hr
Nominal Flow Rate	~1 Liter/min;
Choice of Units	**(ppb)**, ppm, pphm, μg m^{-3}, mg m^{-3}
Data Outputs	USB, RS-232, 0-2.5 V analog, 4-20 mA (milliampere), LCD (liquid crystal display) **(RS-232 output used with 232 to TTL converter for 5-V UART output)**

Power Requirements	11-28 VDC, nominally 500 mA at 12 V, 6 watts

For additional information about this device, please refer to the user's manual (web link) in Appendix F. Detailed information about the system's operation related to this instrument can be found in Section 8.

2.1.3 R. M. Young Serial Output Wind Sensor: 09101

The wind sensor (Figure 4) is mounted on a pole extending vertically from the VG structure. The R. M. Young (Traverse City, MI) wind sensor reports both wind speed and direction in a serial (RS-485) text string.

Figure 4. R. M. Young's Serial Output Wind Sensor.

The manufacturer's specifications relevant to the VGP implementation are listed Table 5 below. Additional specifications required for the VGP are listed in **<u>bold and underlined</u>**.

Table 5. Wind Sensor Manufacturer's Specifications

Range	Wind speed: 0-100 m/s (224 mph) Wind direction: 0-360°
Resolution	Wind speed: 0.1 unit (m/s, knots, mph, km/h) <u>(m/s)</u> Wind direction: 1°
Accuracy	Wind speed: ±0.3 m/s (0.6 mph) or 1% of reading Wind direction: ±2°
Threshold	Propeller: 1.0 m/s (2.2 mph) Vane: 1.1 m/s (2.5 mph)
Available Outputs Voltage Output	WS: 0-5 VDC for 0-100 m/s WD: 0-5 VDC for 0-540°
Power Requirement:	11-24 VDC, 20 mA
Serial RS-485:	**The RS-485 output is used with the 485-232 converter and the 232 to TTL converter for 5-V UART output (in Generations 1 and 2).** **The RS-485 output is used with the 485 to TTL converter for 5-V UART output (in Generation 3).**
R. M. Young, NCAR, or NMEA protocols	**R. M. Young protocol used** Polled or continuous output

For additional information about this device, please refer to the user's manual (web link) in Appendix F. Detailed information about the system's operation related to this instrument can be found in Section 8.

2.1.4 Vaisala HMP60 Humidity and Temperature Sensor

The Vaisala HMP60 (Woburn, MA) (Figure 5) has 0-2.5 (or 0-5) VDC outputs and is installed in Vaisala's DTR504 solar radiation and precipitation shield (Figure 6). The shield is mounted in the area above the pergola's roof in an area of unrestricted air flow.

Figure 5. Vaisala HMP60 Humidity and Temperature Sensor.

Figure 6. Vaisala DTR504 Solar Radiation and Precipitation Shield.

Table 6 presents the manufacturer's specifications relevant to the VGP implementation. Additional specifications required for the VGP are listed in **<u>bold and underlined</u>.**

Table 6. Vaisala HMP60 Manufacturer's Performance Specifications

PERFORMANCE		
Relative Humidity	Measurement range	0-100 %
	Typical accuracy	
	Temperature range	0-40° C
	0-90 % RH	± 3 % RH
	90-100 % RH	± 5 % RH
	Temperature range	-40-0° C, +40-60° C
	0-90 % RH	± 5 % RH
	90-100 % RH	± 7 % RH
	Humidity sensor	Vaisala INTERCAP
Temperature	Measurement range	-40-60° C
	Accuracy over temperature range	
	10-30° C	± 0.5° C
	-40-10° C, +30-60° C	± 0.6° C
Analog outputs	Accuracy at 20° C	± 0.2 % of FS
	Temperature Dependence	± 0.01 % of FS/° C

PERFORMANCE		
INPUTS and OUTPUTS		
	Operating voltage	5-28 VDC/8-28 VDC with 5 V output
	Current consumption	1 mA average, max. peak 5 mA
	Outputs 2 channels	0-1 VDC/0-2.5 VDC/0-5 VDC/1-5 VDC
	5-VDC input voltage **The Generation 1 and 2 systems use 0 to 5 VDC output** **The Generation 3 system uses 2.5 VDC output**	

For additional information about this device, please refer to the user's manual (web link) in Appendix F. Detailed information about the system's operation related to this instrument can be found in Section 8.

2.1.5 Cairpol CairClip O_3/NO_2

The Cairpol CairClip O_3/NO_2 (Poissy Cedex, France) (Figure 7) is a lightweight, portable, electrochemical sensor for measuring ozone (O_3) and nitrogen dioxide (NO_2) in ppb or micrograms per cubic meter ($\mu g/m^3$) in applications such as personal exposure and indoor and outdoor air quality monitoring. It uses UART serial communication (5 V).

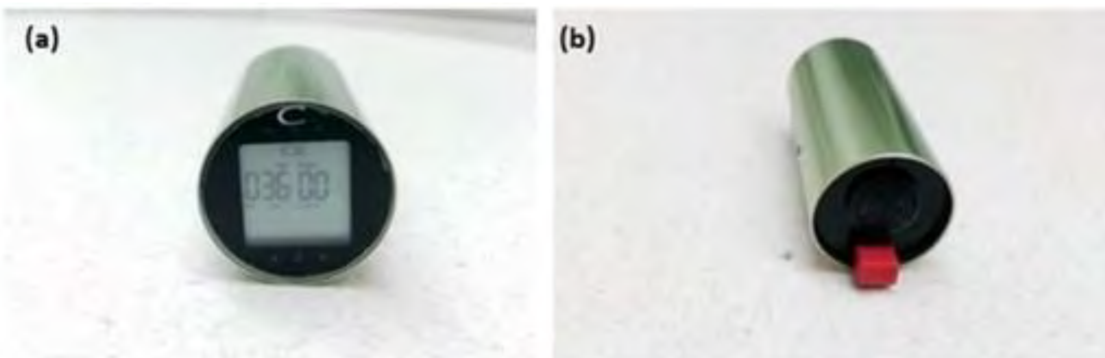

Figure 7. Cairpol CairClip O_3/NO_2.

The manufacturer's specifications relevant to the VGP implementation are listed in Table 7. Additional specifications required for the VGP are listed in **bold and underlined.**

Table 7. Cairpol CairClip O_3/NO_2 Manufacturer's Specifications

Range	0-250 ppb (0 - 240 ppb analog)
Limit of detection [1, 2]	20 ppb
Repeatability at zero [1, 2]	± 7 ppb
Linearity [1, 2]	< 10%
Uncertainty	< 30% [2, 3]
Short term zero drift [1, 2, 4]	< 5 ppb/24 H
Short term span drift [1, 2, 4]	<1% FS [5]/24 H
Long term zero drift [1, 2, 4]	< 10 ppb/1 month
Long term span drift [1, 2, 4]	< 2% FS (5)/1 month

Rise time (T10-90) (1, 2)	< 90 s (180 if large variation of RH)
Fall time (T10-90) (1, 2)	< 90 s (180 if large variation of RH)
Effect of interfering species (1)	Cl_2: around 80% Reduced sulphur compounds negative interference
Temperature effect on sensitivity (2)	< 0.5% / °C
Temperature effect on zero (2)	±50 ppb maximum under operating conditions
Maximum exposure	50 ppm
Annual exposure limit (1-hour average)	780 ppm
Operating conditions	- 20 °C to 40 °C / 10 to 90% RH non-condensing 1013 mbar ± 200 mbar
Recommended storage conditions	Temperature: between 5 °C and 20 °C Air relative humidity: > 15% non-condensing
Power supply(6)	5 VDC/500mA (rechargeable by USB via PC or 100V-240V/5V 0.8A-1.0A with adapter)
Communication interface	USB, UART Analog (UART + 4-20 mA / 0-5 V converter)
(ppb) parts per billion **(UART option for the VGP system)**	
1 According to our operating conditions during tests in laboratory: 20 °C +/- 2 °C / 50% RH +/- 10% / 1013 mbar +/- 5% 2 Values possibly affected by exposures to high gradients of concentration 3 On the basis of recommendations of the Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe for and its enlargement to other gases 4 Full scale continuous exposure 5 FS = Full Scale 6 VRSC = Volatile Reduced Sulfur Compounds 7 The complete discharge of a device (screen turned off) can lead to a deterioration of its performances Any use of the sensor not complying with the conditions specified in herein, including exposures, even short ones, to environments other than ambient air, to dry and / or devoid of oxygen air or other atmosphere not composed in majority of air, even during calibration, will invalidate the warranty.	

For additional information about this device, please refer to the user's manual (web link) in Appendix F. Detailed information about the system's operation related to this instrument can be found in Section 8.

2.1.6 Cairpol CairClip NO_2

The Cairpol CairClip NO_2 (Figure 8) is a lightweight, portable, electrochemical sensor for measuring NO_2 in ppb or $\mu g/m^3$ in applications such as personal exposure and indoor and outdoor air quality monitoring. It uses UART serial communication (5 V). The manufacturer's specifications relevant to the VGP implementation are listed in Table 8. Additional specifications required for the VGP are listed in **bold and underlined.**

Figure 8. CairClip NO_2.

Table 8. Cairpol CairClip NO_2 Manufacturer's Specifications

Range	0-250 ppb (0 - 240 ppb analog)
Limit of detection (1, 2)	20 ppb
Repeatability at zero (1, 2)	± 7 ppb
Linearity (1, 2)	< 10%
Uncertainty	< 30% (2, 3)
Short term zero drift (1, 2, 4)	< 5 ppb/24 H
Short term span drift (1, 2, 4)	<1 % FS (5)/24 H
Long term zero drift (1, 2, 4)	< 10 ppb/1 month
Long term span drift (1, 2, 4)	< 2% FS (5)/1 month
Rise time (T10-90) (1, 2)	< 90 s (180 if large variation of RH)
Fall time (T10-90) (1, 2)	< 90 s (180 if large variation of RH)
Effect of interfering species (1)	Cl_2: around 80% Reduced sulphur compounds negative interference
Temperature effect on sensitivity (2)	< 0.5% / °C
Temperature effect on zero (2)	± 50 ppb maximum under operating conditions
Maximum exposure	50 ppm
Annual exposure limit (1-hour average)	780 ppm
Operating conditions	- 20 °C to 40 °C / 10 to 90% RH non-condensing 1013 mbar ±200 mbar
Recommended storage conditions	Temperature: between 5 °C and 20 °C Air relative humidity: > 15% non-condensing
Power supply(6)	5 VDC/500mA (rechargeable by USB via PC or 100V-240V/5V 0.8A-1.0A with adapter)
Communication interface	USB, UART Analog (UART + 4-20 mA / 0-5 V converter)
UART option for the VGP system	

For additional information about this device, please refer to the user's manual (web link) in Appendix F. Detailed information about the system's operation related to this instrument can be found in Section 8.

2.1.7 Vaisala Rain Gauge QMR102

The Vaisala Rain Gauge QMR102 (Figure 9) is a tipping bucket style rain gauge. As the bucket inside the instrument fills with rainwater, it tips from one side to the other. Each of these tips is counted to calculate the rain rate in mm/hr.

Figure 9. Vaisala Rain Gauge QMR102.

The manufacturer's specifications relevant to the VGP implementation are listed in Table 9. Additional specifications required for the VGP are listed in **bold and underlined.**

Table 9. Vaisala Precipitation Sensor. Manufacturer's Specifications

Funnel Diameter	254 mm
Orifice	500 cm^2
Sensitivity	0.2 mm
Capacity	140 mm/hr
Performance (accuracy)-weather dependent	
< 24 mm/h	<,± 1%
< 140 mm/h	< ± 5%

For additional information about this device, please refer to the user's manual (web link) in Appendix F.

2.1.8 AethLabs Black Carbon MA350

The AethLabs microAeth® MA350 (San Francisco, CA) (Figure 10) is a real-time five-wavelength UV-infrared (IR) black carbon monitor housed in an outdoor-rated case with an automatic filter tape advance system that allows for three to 12 months of continuous measurements utilizing 85 sampling locations. It uses TTL serial communication.

Figure 10. AethLabs microAeth MA350.

Manufacturer specifications relevant to the VGP implementation are listed Table 10. Additional specifications required for the VGP are listed in **bold and underlined.**

Table 10. AethLabs microAeth MA350. Manufacturer's Specifications

Measurement Wavelengths	**880 nm, 625 nm, 528 nm, 470 nm, 375 nm** **(The VGP system only records concentration readings on the UV (375 nm) and IR (880 nm) wavelengths.)**
Flow Rates	**50, 100, or 150 mL/min**
Filter Material	**Polytetrafluoroethylene (PTFE)**
Filter Capacity	**MA350 Filter Tape Cartridge with PTFE material (85 sampling locations)**
Communications	5 V UART

For additional information about this device, please refer to the user's manual (web link) in Appendix F. Detailed information about the system's operation related to this instrument can be found in Section 8.

2.1.9 MOCON piD-Tech Total Volatile Organic Compound (VOC)

The MOCON piD-Tech eVx photoionization detector (Lyons, CO) (blue; Figure 11) is a 0-2 ppm total VOC detector. It uses a low voltage direct current (DC) output.

Figure 11. MOCON piD-Tech Blue.

The manufacturer's specifications relevant to the VGP implementation are listed in Table 11. The VGP uses the blue model. Additional specifications required for the VGP are listed in **<u>bold and underlined</u>.**

Table 11. MOCON piD-Tech Blue Manufacturer's Specifications.

10.6 eV					
Part Number	045-014	Range (ppm)	2	MDQ (ppb)	0.5
Electrical Characteristics					
Supply Voltage			3.25 V – 5.5 V (input voltage regulator included)		
Current			24 mA-36 mA		
Power Consumption			80 mW – 200 Mw dependent upon supply voltage		
Output Signal			0.045 V-2.5 V		
Operating Conditions					
Temperature Range			-20 °C- 60 °C (-4 – 104 °F		
Relative Humidity Range			0-90% non-condensing		
Humidity Response			$\leq$ 1% @ 90 % relative humidity		
Humidity Quenching Effect			$\leq$ 15% @ 90 % relative humidity		
<u>(5-VDC input)</u>					

For additional information about this device, please refer to the user's manual (web link) in Appendix F. Detailed information about the system's operation related to this instrument can be found in Section 8.

2.1.10 Solar Radiation Pyranometer

The Apogee SP-110 (Santa Monica, CA) (Figure 12) is a self-powered, analog sensor with a 0 to 350 millivolt output for measuring solar radiation. The sensor incorporates a silicon-cell photodiode with a rugged, self-cleaning sensor housing design.

Figure 12. SP-110 Pyranometer.

Table 12 lists the manufacturer's specifications relevant to the VGP implementation. Additional specifications required for the VGP are listed in **bold and underlined**.

Table 12. SP-110 Pyranometer Manufacturer's Specifications

Power Supply	Self-powered
Output (sensitivity)	0.20 mV per W m-2
Calibration Factor (reciprocal of sensitivity)	5.0 W m-2 per mV
Calibration Output Range	0 to 50 mV
Calibration Uncertainty	:± 5% (see Calibration Traceability below)
Measurement Repeatability	:< 1%
Non-stability (Long-term Drift):	< 2% per year
Non-linearity: < 1 % (up to 1750 W m-2)	: < 1% (up to 1750 W m^2)
Response Time	< 1 ms
Field of View	180°
Spectral Range	360 nm to 1120 nm
Directional (Cosine) Response	± 5% at 75° zenith angle
Temperature Response:	-0.04 ± 0.04% per C
Operating Environment	-40 to 70 °C; 0 to 100% relative humidity; can be submerged in water up to depths of 30 m
Dimensions	2.40 cm diameter and 2.75 cm height
Mass ((with 5 m of cable)	90 g
Cable	:5 m of shielded, twisted-pair wire. Additional cable available in multiples of 5 m Santoprene rubber jacket (high water resistance, high UV stability, flexibility in cold conditions) Pigtail lead wires
Warranty	4 years against defects in materials and workmanship

For additional information about this device, please refer to the user's manual (web link) in Appendix F. Detailed information about the system's operation related to this instrument can be found in Section 8.

2.1.11 CO_2 Meter Gas Chromatography-0015 CO_2 Sensor

The COZIR gas chromatography (GC)-0015 (Cumbernauld, Scotland) (Figure 13) is a 0-5% CO_2 monitor for ambient CO_2 detection. This monitor uses non-dispersive infrared (NDIR) to measure CO_2. It uses TTL serial output.

Figure 13. GC-0015 Sensor.

The manufacturer's specifications relevant to the VGP implementation are listed in Table 13 below.

Table 13. GC-0015 Sensor. Manufacturer's Specifications

Specifications
Measurement range: 5% to 100% Ultra-low power: 3.3V, 3.5mW Peak current: 33mA Weight: 8 grams Serial communications: 9600/8/1/N Analog voltage output proportional to CO2 concentration
CO_2 Measurement
Sensing Method: NDIR with Gold-plated optics Sample Method: Diffusion / Flow with tube adapter Measurement Range: 0-5%,0-20%,0-100% Accuracy: ±70 ppm ± 5% of reading Response Time Filter: 4 secs to 2 mins (user configurable) refreshed 2x/sec.
Electrical/Mechanical
Power Input: 3.3 ±0.1 volt DC < 3.5 mW

For additional information about this device, please refer to the user's manual (web link) in Appendix F. Detailed information about the system's operation related to this instrument can be found in Section 8.

2.2 Secondary Equipment

2.2.1 Aosong DHT22

The Aosong Electronics Co., Ltd. DHT22 (Guangzhou) (Figure 14) is a low-cost temperature and humidity sensor used to monitor the conditions inside the instrument's enclosure. It runs on 5 V power and outputs at the TTL level logic.

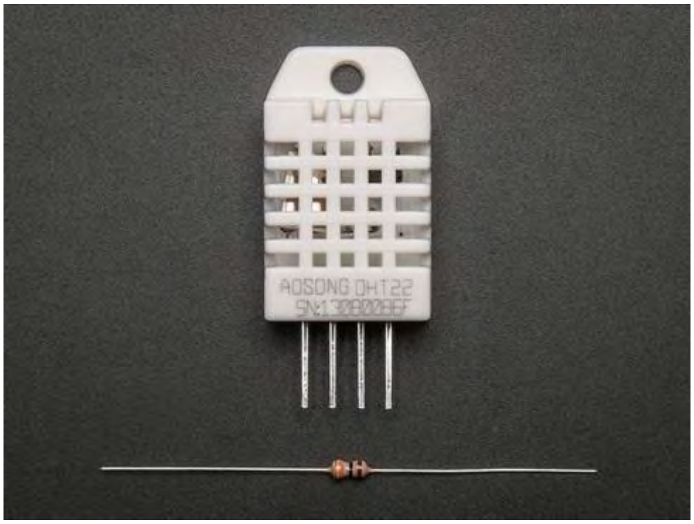

Figure 14. DHT22 Sensor.

The manufacturer's specifications for the DHT22 include the following details:

- 3 to 5 V power and input/output (I/O)
- 2.5 mA maximum current use during conversion (while requesting data)
- Good for 0-100% humidity readings with 2 to 5% accuracy
- Good for -40 to 80 °C temperature readings ±0.5 °C accuracy

2.2.2 AdaFruit LCD Screen and Serial Backpack

The VGP sign displays information to the public on a 16-character x 2 row AdaFruit LCD (New York City, NY). The microprocessor communicates with the LCD serially (Figure 15). A serial backpack for the LCD in installed to facilitate serial communication with the microprocessor. Simple instructions to install the backpack and connect to the microprocessor may be found at https://learn.adafruit.com/usb-plus-serial-backpack according to the schematics found in Appendix A.

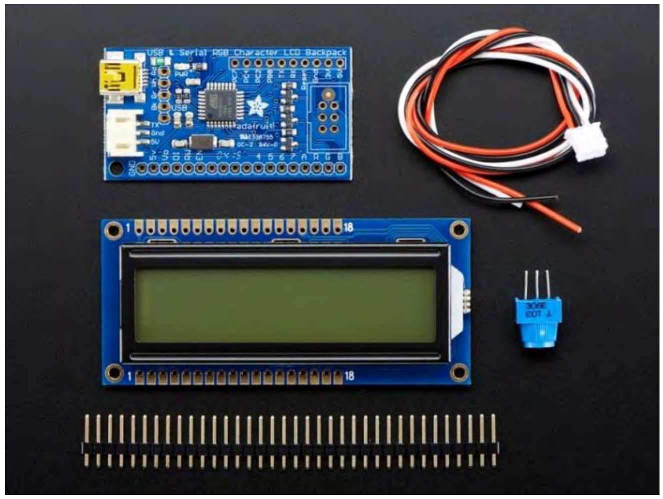

Figure 15. AdaFruit LCD and Serial Backpack.

2.2.3 Cellular Modem

The cellular modem used varies by the system's location. The two most common models used are the Sierra Wireless Raven XE and RV50 (Newark, CA) (Figures 16 and 17). These modems provide 4G data connection for data transmission and an I/O port for remote restarts of the microprocessor. Any 4G modem with an Ethernet interface and telnet interface that can control an I/O signal can be used for the VGP.

Figure 16. Sierra Wireless RV50.

Figure 17. Sierra Wireless Raven XE.

For additional information about these devices, please refer to their respective user's manual (web link) in Appendix F. Detailed information about the system's operation related to these devices can be found in Section 8.

2.2.4 Solar Modules

The solar power system consists of two solar panels and one 12-VDC battery. Two SunWize 110-W SP Series Solar Modules (SW-S110P-E4) (Philomath, OR) are used to power the system (Figure 18). These conform to the U.S. UL 1703 standard.

Figure 18. SunWize 110-Watt SP Series Solar Module (SW-S110P-E4).

2.2.5 Rutland 504 Wind Turbine

The Rutland 504 wind turbine (Fort Lauderdale, FL) (Figure 19) is an optional accessory that can be used to slightly increase the available power. Wind energy is converted to electrical power and used to charge the battery. Stations with a wind charger also use the Rutland 504 Controller to control current delivery to the battery. The turbine can supply up to 80 W of energy.

Figure 19. Rutland 504 Wind Turbine.

2.2.6 Morningstar, Inc. Power Controller

The two SunWize panels are connected in parallel to the Morningstar, Inc. SunSaver SS-20 L 12 V power controller (Newton, PA) (Figure 20). The controller maintains the battery charge and also has a low voltage disconnect (LVD) feature to prevent the battery voltage from dropping below 11.5 VDC.

Figure 20. Morningstar SS-20L-12 V.

2.2.7 Morningstar RD-1 Relay Driver

The Morningstar RD-1 relay driver (Figure 21) is connected to the load side of the power controller to automatically disconnect the instruments prior to LVD, while continuing to provide power to the microcontroller and gateway. This feature conserves power and allows the Arduino processor and Ethernet gateway to stay online for an extended period.

Figure 21. Morningstar's RD-1 Relay Driver.

2.2.8 Battery

A 12-VDC 80-amp hour (Ah) absorbed glass mat (AGM) battery (Figure 22) is used for storage. The Werker (Hartland, WI) model shown in Figure 22 can be used. Some stations use a virtually equivalent Duracell brand (also WKDC12-80P). Larger capacity batteries (or multiple batteries) can be used to increase the station's uptime. Some stations were installed with a second 80-Ah battery in parallel. In this case, the second battery is located outside the main battery enclosure in a separate weather-protected case.

Figure 22. Werker WKDC12-80P 12-Volt 80-Ah AGM Battery.

2.2.9 Circuit Breakers

Circuit breakers are used to isolate some portions of the power system and provide overcurrent protection in the case of a short circuit. An acceptable model (Eaton, Moon Township, PA) is shown in Figure 23. It is important that the breakers be UL 489 listed.

Amperage for each unit is dependent on its position in the circuit. (Refer to schematic 07 in Appendix A.)

- 20A: From Solar Panel to Solar Controller: Eaton FAZ-C20
- 15A: From Battery to Solar Controller: Eaton FAZ-C15
- 3A: From Solar Controller to Load (board power): Eaton FAZ-C3

Figure 23. Eaton Circuit Breaker.

3. Installation Considerations

It is important that a favorable site is selected when contemplating installation of a VGP station in a new location. Several items that should be considered in selecting a site are detailed in the next sections.

3.1 Areas of Expertise

Installing a VG station requires an extended team of experts in multiple disciplines. Although this document and the accompanying video aims to share as much information as possible regarding the steps required to build, install, operate, and maintain a VG station, it is impossible to cover every facet of this procedure. Successfully accomplishing a VGP installation will require a team with experience in the following areas:

Construction/Engineering: The actual installation of the bench can be complicated by site-specific factors. (See the physical installation considerations section of the technical document for a brief overview of the options and their implications.) A team member will need to be able to read, understand, and modify engineering drawings as necessary to ensure the installation plan meets city code requirements and is safe. A team member will also need to be able to perform the actual installation and have access to the equipment necessary to do so. Contractors with these skills and the relevant equipment may need to be employed to do so.

Electronics: The electrical features of this installation are described in Appendix A. However, someone on the team will need to be able to assemble and install the VG station's hardware. It is not feasible to cover every step of this installation, so the ability to interpret and reproduce the system from the schematics provided is necessary.

Software Development: The software libraries included in Appendix B should suffice to support installation of the system as described and locally log data to the secure digital (SD) card. However, software repositories and hardware availability are subject to change. Depending on the system's sensor configuration, the base code will need to be changed to accommodate individual configurations. A basic knowledge of computer programming is required to be able to add, remove, or revise the coding and ensure the correct pins for each sensor are called out in the setup for each individual sensor. One feature that requires a significant change for a new installation is data streaming, as any new project will utilize different server-side variable names and likely a different webserver. This section of the code would have to be modified by someone with computer programming experience.

3.2 Community Impact and Accessibility

The VGP is intended to be used in a public environment to allow the community to access the data it provides and to engage in conversations about air quality. The station's impact on the community once it has been installed and the effectiveness of its selected location should be considered. The station provides an opportunity to engage people of all ages. The location should attract members of the community with an interest in their air quality. Sites chosen by the VG team have included public areas such as libraries, schools, parks, and museums (see Table 1).

Selection of the VG station's location should also consider the tenets of the American Disabilities Act (ADA) to ensure that anyone in the community can access the site. Both the sign and the seating area should be accessible to individuals in wheelchairs.

3.3 Solar Considerations

The VG station requires an unobstructed solar signal to function properly and maintain uptime. This requirement also must be considered when selecting an installation site. The site should be located away from trees or buildings that may obstruct direct sunlight. If possible, the bench should be north or south facing so that the solar panels can be mounted parallel to the VG structure. Information about changing the orientation of the panels can be found in Appendix F (user manual as web link).

Different areas of the U.S. have varying levels of average solar energy. The map shown in Figure 24 indicates how much energy is available on average in a day. At least 5 kWh/m^2/day is recommended for this installation, although stations installed in areas between 4-5 kWh/m^2/day may be supplemented with a wind turbine to provide power. Installation in areas with less than 4 kWh/m^2/day is not recommended due to increased downtime.

For most areas of the U.S., the optimal angle for solar panel installation is 32 ° from the horizontal plane. For a southernmost U.S. installation (Texas or Florida), an angle of 27 ° is recommended. For locations north of Illinois, 36 ° is recommended.

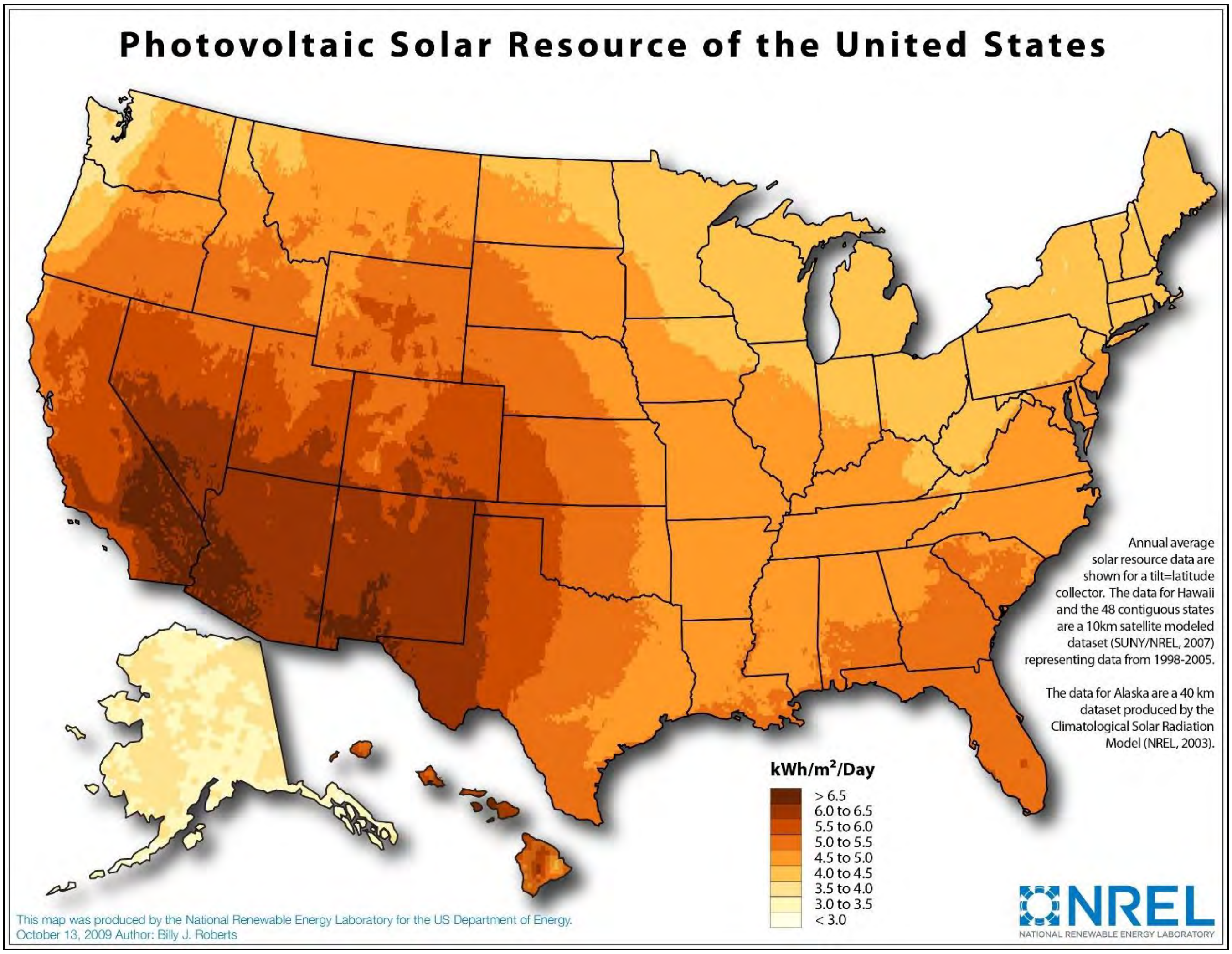

Figure 24. U.S. Solar Energy Map (Source: National Renewable Energy Laboratory; https://www.nrel.gov/gis/solar.html)

3.4 Physical Installation Considerations

When determining where to locate a VG station, how the station will be properly secured to the area and electrically grounded should be considered. Thus, the skills of an engineer with construction experience will be required. Three recommended options for properly securing the bench are described below. More details on these options are available in Appendix A (Schematic 02):

- Option 1: The bench may be mounted directly to an existing surface such as concrete or brick.
- Option 2: The bench may be mounted directly to a concrete slab. This slab then can be placed on top of an existing surface, or the surrounding area can be excavated and the slab installed on the resulting grade.
- Option 3: Piers can be placed underground, and the bench can be mounted to these piers.

Two, 6-foot electrical grounding rods must be used in securing the station, and the local ground covering the area must be penetrable to a depth of 6 feet.

Design choices should be well documented and approved by a professional engineer.

As with any building project involving ground penetration, it is important to ensure the ground below the site is safe to dig by performing site surveys and contacting the local dig line. As permits may be required, the local city, state, or other relevant inspector should be contacted.

4. Instrument Panel

4.1 Overview

The figures in this section show the general assembly for both the Generation 2 and Generation 3 VGP systems.

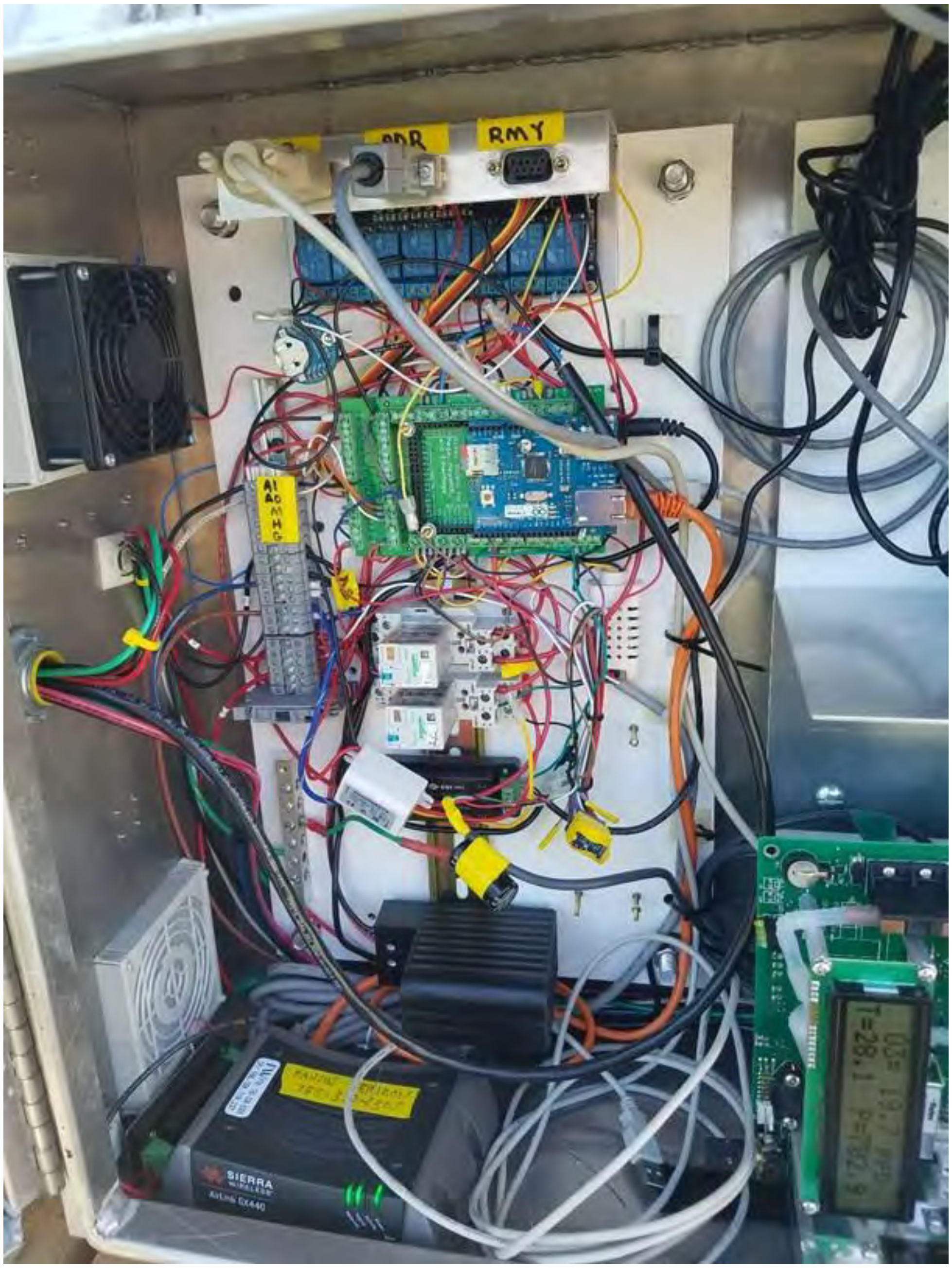

Figure 25. Generation 2 Assembly.

In Figure 25, the Arduino Mega 2560 microcontroller is not visible under the attached Ethernet shield and screw shield. Those components are described in Sections 4.2.2 and 4.2.3.

4.2 Generation 2 Components

The following subsections describe some of the specific components in the Generation 2 VGP system.

4.2.1 Arduino Mega 2560 Microcontroller

The Arduino Mega 2560 microcontroller (Figure 26), based on the ATmega2560, is the main processor for the VGP Generations 1 and 2 designs. The module can poll the instruments, receive and format the returned string, monitor the enclosure temperatures, control the ventilation fan, format the data, and push the data up to a webserver database. The Arduino Mega 2560 provides a compact, low-power, and flexible platform for data processing and wireless communication. The Mega 2560 was chosen rather than other Arduino microcontrollers primarily because of the four UARTs (hardware serial ports) that are used to communicate with the air monitoring instruments and wind monitor. As the VGP system has become more complex, the memory and UART limitations of the Arduino Mega 2560 microcontroller has become insufficient, leading to the use of the newly available Teensy 3.5 (PJRC, Sherwood, OR) microcontroller. Specifications for Mega 2560 controller are presented in Table 15.

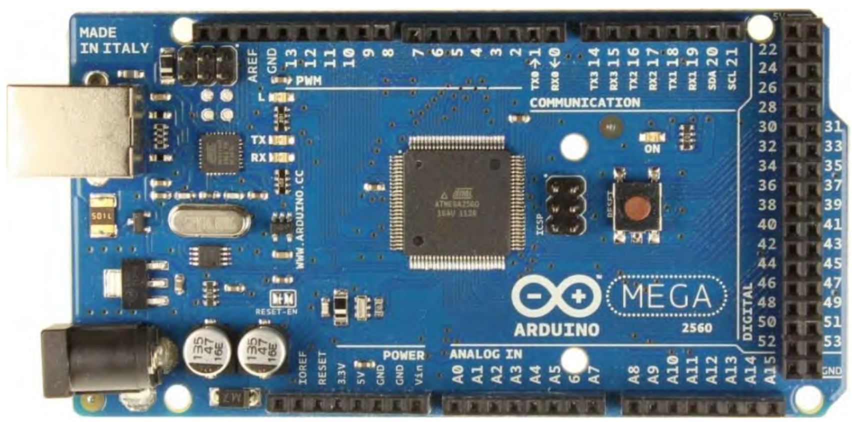

Figure 26. Arduino Mega 2560 Microcontroller.

Table 14. Specifications for the Arduino Mega 2560 Microcontroller

Microcontroller	ATmega2560
Operating Voltage	5-V
Input Voltage (recommended)	7-12 V
Input Voltage (limit)	6-20 V
Digital I/O Pins	54 (of which 15 provide PWM output)
Analog Input Pins	16 (10-bit resolution)
DC Current per I/O Pin	20 mA
DC Current for 3.3 V Pin	50 mA
Flash Memory	256 KB, of which 8 KB is used by the bootloader
SRAM	8 KB
Electronically Erasable Programmable Read-Only Memory (EEPROM)	4 KB
Clock Speed	16 megahertz (MHz)

4.2.2 Mega Screw Shield

The screw shield (Figure 27) used in Generation 2 designs is used to break out the Arduino Mega 2560 header socket connections to the terminal block connections for easier wiring. The screw shield performs no logic or manipulation of any signals and is used only as a physical connection adapter.

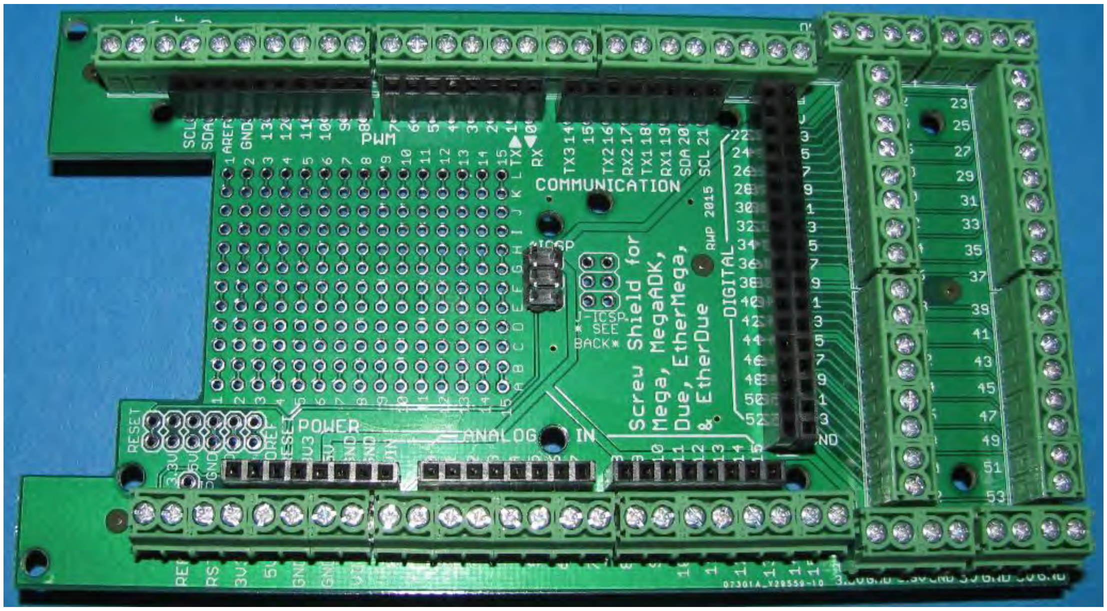

Figure 27. Arduino Mega Screw Shield.

4.2.3 Ethernet Shield

The Arduino Ethernet Shield R3 (assembled, Figure 28) allows an Arduino board to connect to the Internet. It is based on the Wiznet W5100 Ethernet chip (datasheet). The Wiznet W5100 provides a network (Internet protocol [IP]) stack capable of both transmission control protocol and user datagram protocol. It supports up to four simultaneous socket connections. A standard RJ-45 Ethernet connector is used to interface with a 4G modem to allow for data upload and download from AirNow servers.

The Ethernet shield includes a micro-SD (secure digital) card connector, is MEGA compatible, and has an on-board reset controller. The SD card on this shield is used for data logging purposes. Libraries for the Ethernet shield and the SD card are provided by the vendor.

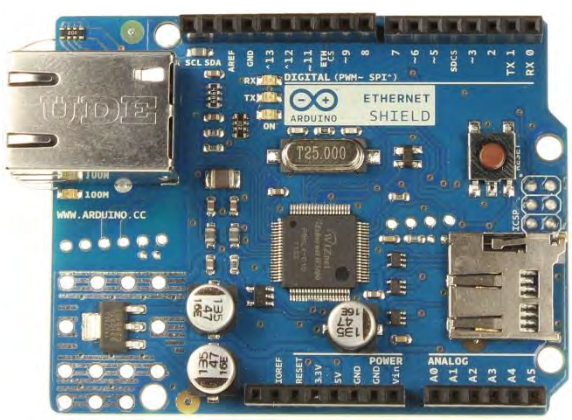

Figure 28. Ethernet Shield.

4.2.4 DS1307 RTC

The Adafruit ChronoDot Real-Time Clock (RTC, Figure 29) is used to keep time on the Mega 2560. It is based on the DS1307 RTC chip and is powered by a 3 V lithium coin cell battery. The ChronoDot is connected to the Mega 2560 via the serial clock and the serial data lines and operates using the DS1307 RTC library.

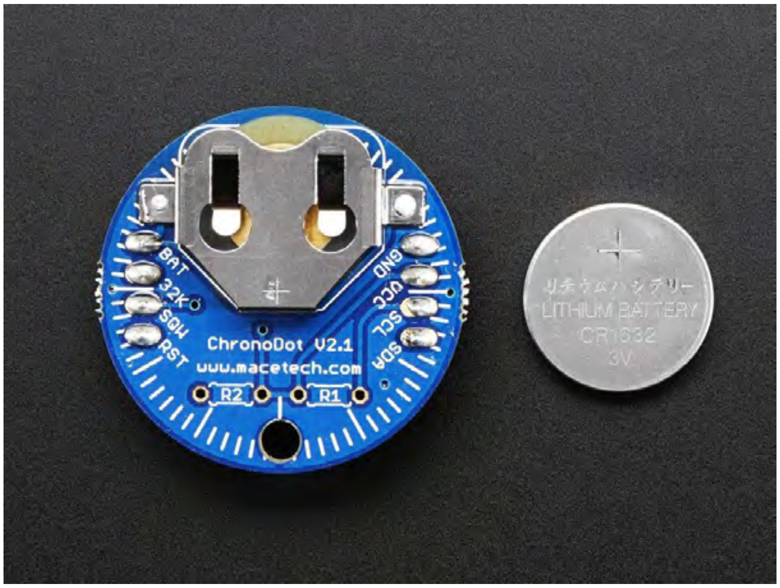

Figure 29. ChronoDot RTC.

4.2.5 RS485 to RS232 converter

The BB Elec 485LDRC9 RS485 to RS232 converter (Ottawa, IL) (Figure 30) is a DIN rail-mounted signal converter used to convert the RS485 signal from the R. M. Young 09101 wind sensor to an RS232 signal that is then converted from RS232 to TTL to communicate with the Mega 2560. The converter requires 12 V and is wired point-to-point from the wind sensor to the RS232 to TTL converter.

Figure 30. BBElec 485LDRC9 RS485 to RS232 Converter.

4.2.6 RS232 to TTL converter

The RS232 to TTL converter (Figure 31) converts RS232 serial signals to the TTL level serial to facilitate transmissions between various components and the Mega 2560. Converters are required for the Thermo Fisher Scientific pDR-1500, the 2B Technologies Ozone 106-OEM, and the R. M. Young 09101. Vendors for RS232 to TTL converter components are constantly changing; thus, each new station installation may have a different manufacturer for this particular component. All converters are based on the MAX232 chip (Section 4.3).

Figure 31. RS232 to TTL Converter.

4.2.7 Relays

4.2.7.1 SainSmart

SainSmart relays (Figure 32) are used to control power to some components in the Generation 2 design. Relays are used to operate the fan, heater, and LCD. A relay is also used to provide power to the pDR-1500 by mimicking a power button press. (See the Generation 2 Schematic 08 in Appendix A.)

Figure 32. SainSmart Relays.

4.2.7.2 Magnecraft

Magnecraft relays (Ottawa, IL) (Figure 33) are used to control power to the instrument's DC power rail and the remote restart of the Mega 2560. The instrument relay is driven by the Morningstar relay driver (See section 2.2.7). The Mega 2560 power relay is driven by the modem's IO pin. (See section 4.2.11) The Generation 2 Schematic 08 may be found in Appendix A.

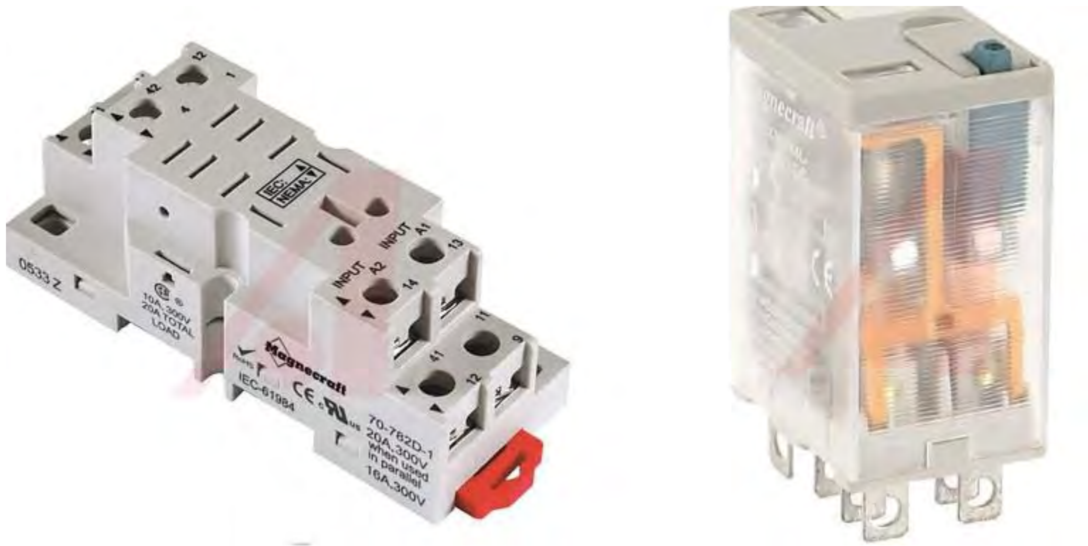

Figure 33. Magnecraft Relay and DIN-Rail Mount.

4.2.8 DC regulators

Multiple DC/DC regulators (Figure 34) are used to convert battery input voltage to stable supplies for various components. The Mega 2560 requires a (9-36)-VDC input to 10-VDC output regulator. The 2B Technologies OEM-106-L requires a (9-36)-VDC input to 12-VDC output regulator. The pDR-1500 requires an (9-36)-VDC input to 5-VDC output regulator.

Figure 34. DC/DC Regulator DIN-Rail Mounted.

4.2.9 Fan

The VGP system is designed to withstand all types of outdoor conditions. Under conditions of extreme heat, defined as greater than 47 °C inside the instrument enclosure, a fan (Figure 35) is automatically activated to force warm air out of the enclosure and force relatively cooler air in from outside the enclosure. The fan is deactivated automatically once the enclosure temperature falls below 42 °C. The fan operates off direct battery voltage, nominally 12 VDC.

Figure 35. Enclosure Fan.

4.2.10 Heater

VGP systems located in northern climates are also designed to operate under extremely low temperature conditions. In these conditions, defined as below -8 °C, a 12-VDC heater (Figure 36) is activated automatically. When conditions inside the closure return to above -5 °C, the heater automatically turns off.

Figure 36. DC Heater.

4.2.11 Modem

The Raven XE modem (Carlsbad, CA) (Figure 17) for the Generation 2 system provides remote restart capabilities for the Mega 2560. A digital output from the modem is controlled via Attention (AT) commands from a wireless connection. This digital output is either grounded or held high (at 5 VDC) depending on the state of a relay variable. The state of this variable, either 0 or 1, can be set with AT commands. The digital output is connected to the Magnecraft relay, which in turn controls power to the Mega 2560. The procedure to remotely restart the Mega 2560 is described in Section 8.3.11. It is possible to use any wireless modem that has 3G or 4G connectivity and a digital output that can be controlled remotely for the VGP.

4.3 Wiring the Arduino Mega 2560 Microcontroller (Generation 2)

The wiring schematic for the Arduino microcontroller is shown in Schematic 08 in Appendix A. On top of the Mega 2560 is a Mega 2560 screw shield (Section 4.2.2) that is used to break out power, analog, and digital connections. The Ethernet shield is installed on top of the screw shield.

The ozone monitor uses a software serial connection over the 12 and 13 digital pins. The PM monitor communicates over Mega serial communication ports 1 and 2, respectively. The wind monitor communicates over RS-485, which feeds an RS-232 to RS-485 converter (Section 4.2.5) connected to Mega serial communication port 3. All RS-232 communications with the Mega port pass through the MAX232 serial TTL to the 232 shields (See section 4.2.6).

The humidity and temperature signals received from the Vaisala HPM60 are sent at 0-5 VDC and are connected to analog pins 0 and 1, respectively. An RTC DS1307 battery-backed shield (Section 4.2.4) is connected to the I2C bus of the Mega and serves as a time reference.

An Arduino relay shield (Section 4.2.7) is connected to digital pins 26 through 29 and is used to activate the instrument enclosure's ventilation fan when the temperature exceeds 47 °C and to deactivate it after the temperature falls below 42 °C.

Depending on which other sensors are selected, additional inputs will need to be wired to the Mega 2560 microcontroller.

Note that all pin references herein are to the default design pins. These pins can change based on the needs of each individual station and would need to be updated within the station's code and/or code libraries.

Wiring the Generation 2 system consists primarily of point-to-point wiring. Following Schematic 08 in Appendix A, all the components must be laid out in a suitable arrangement and wired using the available means and tools. The components selected and included in the parts list (Appendix C) are mainly DIN-mountable for ease of use. (See Figure 25 for the recommended assembly.) It is critical to give <u>close attention to the amperage ratings for all wire used in the assembly, and an individual experienced with circuitry, design, and 12-VDC systems should perform these tasks.</u>

4.4 Generation 3 Architecture

The Generation 2 design was based on specific core system components. The architecture (or microprocessor) used for this design was the Arduino Mega 2560. At the time of this design, the Mega 2560 microprocessor was one of the only Arduino (or Arduino clone) options with three hardware serial ports. The availability of hardware serial ports is central to the function of the VG design. Many of the system's sensors use serial communication and utilize these ports to communicate with the microprocessor. However, as the VG system developed in the years 2014 through 2016, its usage began to approach the memory limits of the Mega 2560. The additional sensors requested also required more than the system's available three hardware serial ports. Fulfilling this requirement meant that any additional sensors would need to utilize software emulation of hardware serial ports; in other words, software would have to simulate what hardware normally performs. The failure to provide for this eventuality presented a problem and required more data processing from the Mega 2560 microprocessor's already limited resources. By 2016, however, the Arduino devices had been redesigned and more options were available to support additional hardware.

The Teensy 3.5 microprocessor is an Arduino clone that is vastly superior to the Mega 2560 microprocessor. It has more processing power, more available memory, and a greater number of hardware serial ports than its predecessor. The VG design team recognized the Teensy 3.5 microcontroller's capabilities as an opportunity to revamp the design's hardware and utilize custom circuit board software to build a complete system board for the VGS. This redesign is intended to improve device uptime and ease of diagnosis and/or replacement when a problem occurs. These subsequent changes in design are reflected in and known as the Generation 3 design (Figure 37).

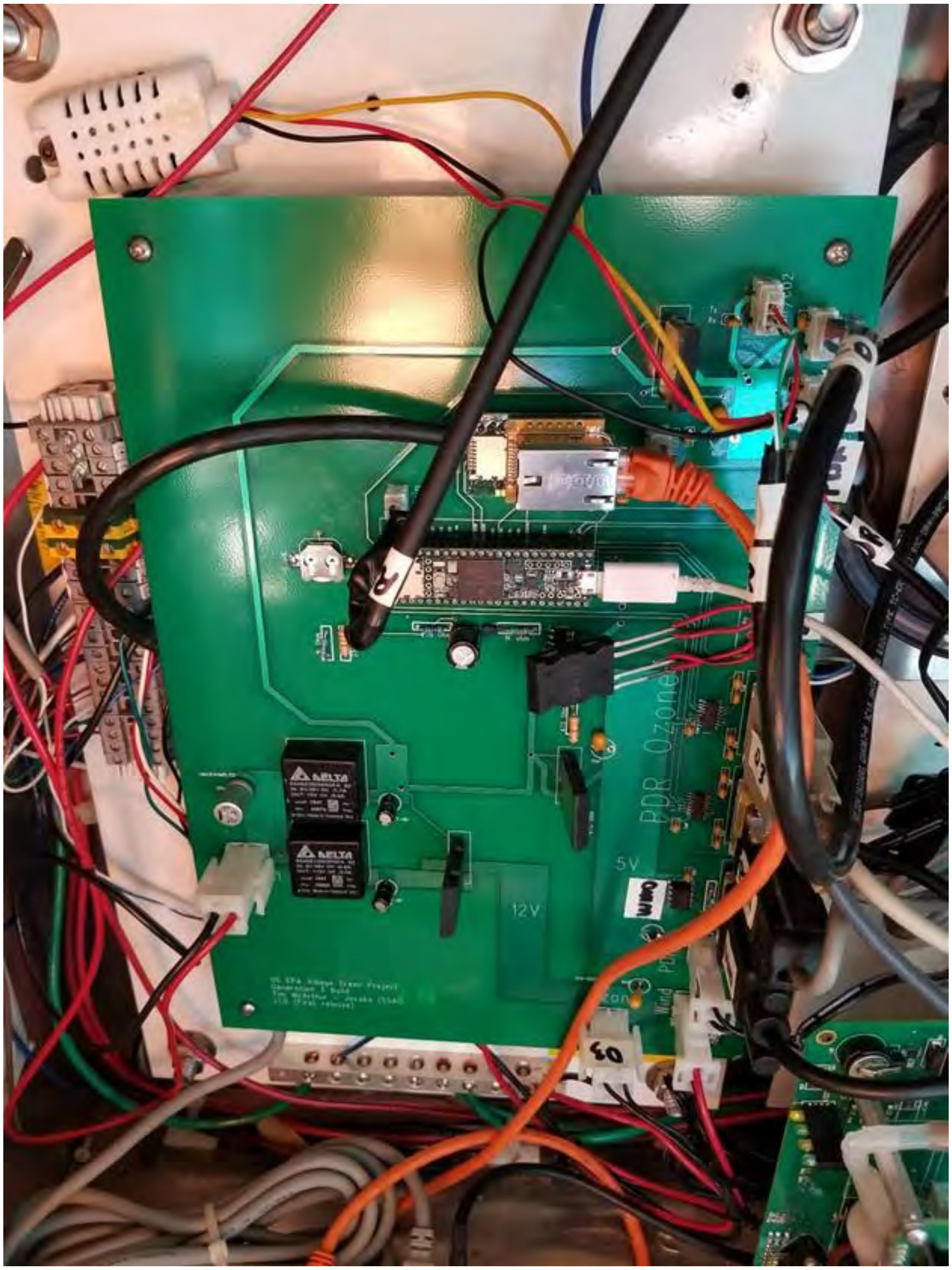

Figure 37. Generation 3 System.

4.5 Generation 3 Components

The following subsections describe some of the specific components in the VGP Generation 3 system.

4.5.1 Teensy 3.5 Microcontroller

The Teensy 3.5 microcontroller (Figure 38) is a third-party Arduino clone that has some significant upgrades over previous Teensy versions and other Arduino-branded microprocessors. Most significantly, the Teensy 3.5 has six dedicated hardware serial ports. The Teensy 3.5 digital pins are 5-V tolerant, which allows UART sensors with 5-V logic to be directly connected to the serial communication ports. It also has significantly increased memory over the Arduino Mega 2560, allowing more code and more variables to be added for additional sensors and potential future expansion.

Figure 38. Teensy 3.5.

The specifications, details, and features of the Teensy 3.5 are detailed below.

- 62 I/O Pins (42 breadboard friendly) (5-V tolerant)
- 25 analog inputs to two analog-to-digital converters (ADCs) with 13-bit resolution (most* 5-V tolerant)
- 2 analog outputs [digital-to-analog converters (DACs)] with 12-bit resolution
- 512K Flash, 192K RAM, 4K EEPROM
- 120 MHz Advanced Risc Machines (ARM) Cortex-M4 with a floating-point unit
- USB full-speed (12-Mbit/sec) port
- Ethernet mac, capable of full 100-Mbit/sec speed
- Native (4-bit Secure Digital Input Output [SDIO]) micro SD card port
- I2S audio port; 4-channel digital audio input and output
- 14 hardware timers
- Cryptographic acceleration unit
- Random number generator

- Cyclic redundancy check (CRC) computation unit
- 6 serial ports (2 with first-in, first-out data management [FIFO])
- 3 SPI ports (1 with FIFO)
- 3 I2C ports (The Teensy 3.6 has a fourth I2C port)
- A real-time clock

*See the Teensy 3.5 microcontrollers' documentation at www.pjrc.com for details on specific analog port tolerances.

4.5.2 Relays

The relays (Figure 39) used for the Generation 3 design were selected because they required only 1.2 V input to activate. Unlike the Mega 2560, the Teensy 3.5 can only output 3.3 V. An IXYS Integrated Circuits Division CPC1709J (Beverly, MA) was selected to serve as the relays. These relays control all power switching in the Generation 3 design, controlling the power supply to the instrument's rail, fan, and heater. In the Generation 3 design, the pDR-1500 "power on" functionality is controlled directly by digital output rather than a relay. The Teensy 3.5 can be reset directly with its reset pin from the modem, instead of via a relay.

Figure 39. Solid State Relay.

4.5.3 MAX232 Chip

The MAX232 chip (MAX232ESE; San Jose, CA) is an RS232 to TTL converter. The Generation 3 design implements this chip directly on the custom circuit board rather than using external converters.

Figure 40. MAX232 Chip.

4.5.4 MAX485 Chip

The MAX485 chip (MAX485, San Jose, CA) is a direct RS485 to TTL converter. The Generation 3 design implements this chip directly on the custom circuit board rather than using external converters.

Figure 41. MAX485 Chip.

4.5.5 DC regulators

Onboard DC converters (Figure 42) convert nominal 12 V battery voltage to stable power supplies for instrument power. The Generation 3 system uses a S24SE12003PDFA (Delta, Taipei, Taiwan, ROC) for 12 V power and a S24SE05003NDFA for 5 V power.

Figure 42. DC/DC Converter.

4.5.6 Timing Circuit

The Generation 3 design utilizes a timing circuit to ensure that automatic restarts of the Teensy 3.5 component due to lockups do not lead to constant power cycling of the instruments. The schematic for this circuit is shown in Figure 43. This circuit provides a few seconds delay between the time when the control pin is grounded and the instrument relay turns off.

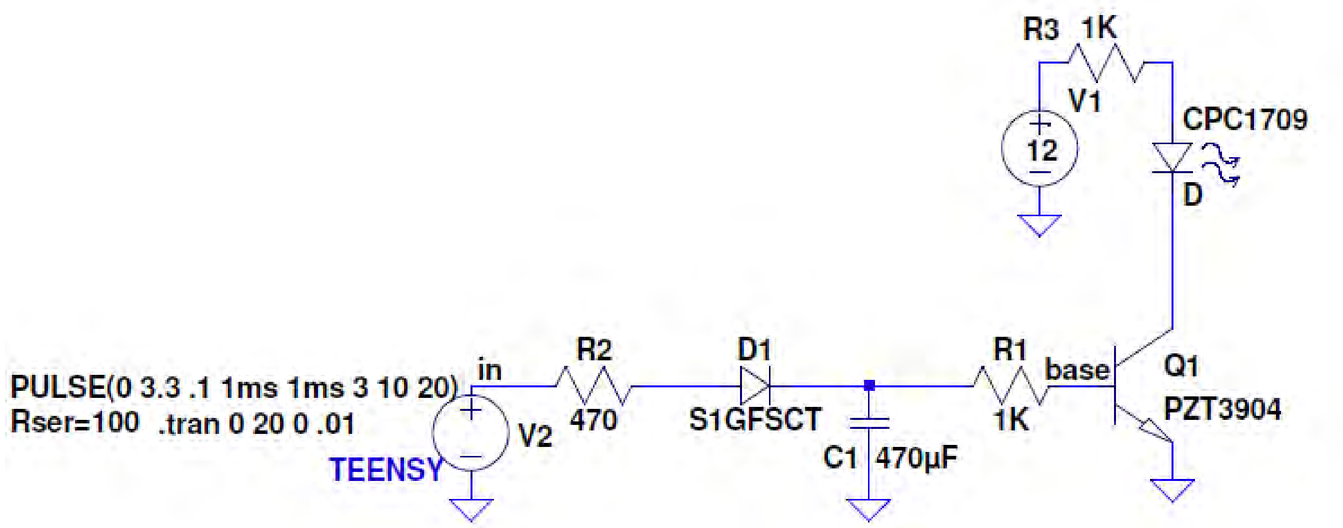

Figure 43. Timing Circuit Schematic.

4.5.7 Ethernet Assembly

The Generation 3 Ethernet Assembly (Figure 44) consists of two components, one WIZNnet wiz850io (Clara, CA), and one sd/Ethernet adapter board for the Teensy 3.2 microcontroller. The wiz850 is an SPI Ethernet module with libraries for programming the Teensy microcontroller, and the adapter board simplifies communication with the component. The wiz850 is stacked on the adapter following the instructions found at https://www.pjrc.com/store/wiz820_sd_adaptor.html for the wiz820. In this instance, the adapter/Ethernet module stack is not soldered to the Teensy 3.5. The stack is simply inserted into the labeled socket on the custom circuit board.

Figure 44. Ethernet Assembly.

4.6 Wiring the Teensy 3.5 (Generation 3)

Some of the wiring is built into the custom printed circuit board in the Generation 3 design. The base board design includes connections for:

- The pDR-1500. This is a TTL-serial connection to the Teensy 3.5 connected through a MAX232 chip for conversion from an RS232 device.
- The 2B Technologies 106-OEM-L. This is a TTL-serial connection to the Teensy 3.5 connected through a MAX232 chip for conversion from an RS232 device.
- The R. M. Young 09101. This is a TTL-serial connection to the Teensy 3.5 connected through a MAX485 chip for conversion from an RS485 device. It is important to note that this connection is half-duplex, which means the wind sensor can communicate with the Teensy 3.5, but the Teensy 3.5 cannot send data to the wind sensor.
- The Vaisala HMP60. This includes two 0-3.3-VDC inputs to the Teensy 3.5’s analog input pins and a 5-VDC output to power the sensor.
- The DHT22 sensor. This includes one signal input to a digital pin and a 5-VDC output to power the sensor (always on).
- The CairClip sensor. This includes one UART serial direct connection to the Teensy 3.5’s serial line and a 5-VDC output to power the sensor.
- The LCD screen. This includes one UART serial direct connection to the Teensy 3.5’s serial line and a 5-VDC output to power the screen.
- The MOCON VOC/Pyranometer. This includes one 0-3.3 VDC input to the Teensy 3.5’s analog pin and a 5-VDC output to power the sensor.
- The AethLabs MA350. This includes one UART serial direct connection to the Teensy 3.5’s serial line and a 5-VDC output to power the sensor.
- Separate power connections are also provided for the pDR-1500 (5 VDC), R. M. Young 09101 (12 VDC), and 2B Technologies 106-OEM-L (12-VDC).

This default configuration allows for various sensors to be installed depending on the individual needs of the station. It is possible to install any other sensor using the same power and communication requirements as the sensors listed here. If sensor changes are made, modifications will need to be made to the microprocessor’s code to accommodate the changes. The base configuration should be deviated from only if there is confidence that the change will not result in damage to the equipment being connected or to the Teensy 3.5. (See Section 4.5.1 for information on the Teensy 3.5’s voltage tolerances.) Note that all the pin references given herein are for the default design pins. These pins can change based on the needs of each individual station and would need to be changed within the station’s code and/or code libraries.

The Generation 3 design still requires wiring from the sensors to the terminal block, as well as wiring from the terminal block to the Molex connectors on the board. It is critical to pay close attention to amperage ratings for all wire used in the assembly, and an individual experienced in circuitry, design, and 12-VDC systems should perform these tasks.

4.7 Arduino Mega 2560 Code

Please see Appendix B for each currently operating Generation 2 station's code.

4.8 Custom printed circuit boards (Generation 3)

Please see Appendix D for the custom circuit board files.

4.9 Teensy 3.5 Code

Please see Appendix B for each currently operating Generation 3 station's code.

5. Web Application Design

The active VGP website can be accessed at https://www.epa.gov/air-research/village-green-project

The web application used for the VG project may not be available for new stations. Therefore, the information herein is provided as one possible recommended approach for hosting VG data.

The web application uses several different web technologies, all of which are based on the *ASP.NET Framework*. The application runs using Internet Information Services (IIS) 7.0 installed on a Microsoft Windows 2008 virtual server (64-bit), which is the foundation of the HTTP server's functionality. Like most applications running on IIS, the VGP web application uses the ASP.NET 4.0 framework, which is the core application layer framework for the project. The VGP web application uses MVC 4 (Model – View – Controller), which is a layer that runs on top of the ASP.NET to provide a high-performance, highly scalable application. The VGP application uses the latest Microsoft Entity Framework to provide the interface between the web application and the database content. The VGP application uses a simple database design based entirely in *Microsoft SQL Server 2008 R2*. The Figure 45 graphic shows the web technologies used and their roles in the VGP design.

The database server and web server design presented in Figure 45 were used in the VGP demonstration. This design may need to be modified based on the hardware and software available at the host location. An example of an HTTP POST command similar to the command used in the VGP is:

```
POST http://host.server.com/VillageGreen/api/Device?
SiteId=%s&O3_PPB=%s&O3_Temp=%s&O3_CellP=%s&O3_Flow=%s&O3_Diode=
%s&PDR_Conc=%s&PDR_Temp=%s&PDR_RH=%s&PDR_Pres=%s&AmbTemp=%s&Am
bRH=%s&WindDirection=%s&WindSpeed=%s&ARD_T=%s&ARD_RH=%s&ARD_ST
AT=%d&Date=%ld&key=%s HTTP/1.0
```

where %s, %d, and %ld would be replaced with the actual value for each variable.

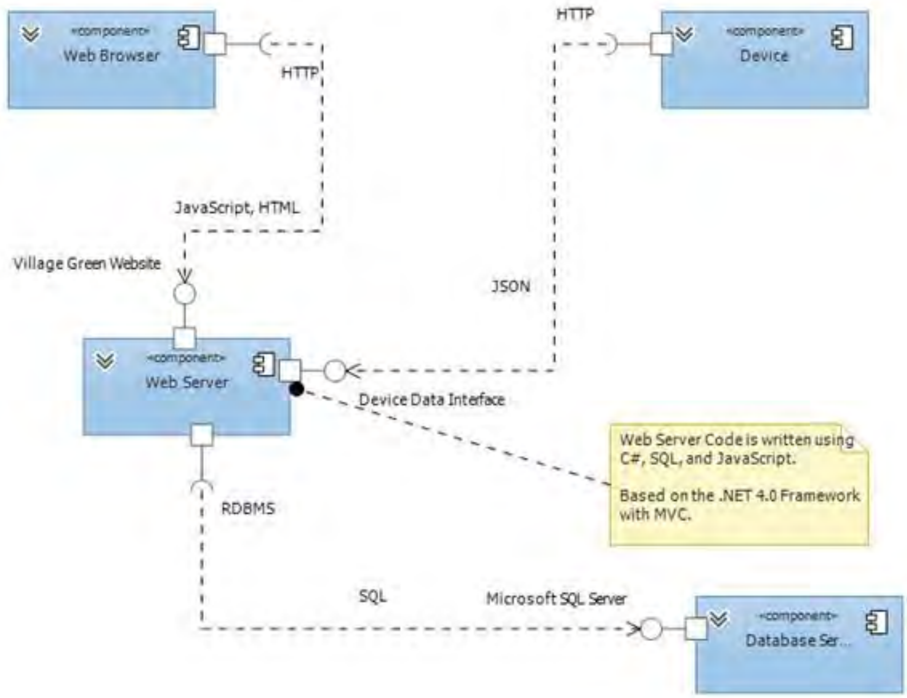

Figure 45. VGP Server Web Design.

6. Data Quality Indicator Checks

The VGP instruments require various maintenance and/or calibration procedures to ensure optimal performance. The recommended maintenance activities and the frequency at which they should be performed to ensure optimal performance are discussed in section 8.4.

Table 16 lists the data quality indicators (DQIs) applied to the measurements collected from the VGP instruments. These checks are performed at the database level and are not performed by the Arduino MEGA 2560. These checks allow the raw data to be archived in the database but prevent the display to the general public of unrealistic measurements or those that may have been compromised by an instrument malfunction. Only the values that clear these DQIs are displayed and plotted on the webpage. Additional or modified DQIs may be needed depending on the instrument selection or site conditions. These DQIs were determined based upon instrument documentation and additional communication with the manufacturer.

Table 15. Data Quality Indicators

Parameter	Analysis Method	Measurement	Criteria
$PM_{2.5}$	pDR-1500, Thermo Fisher Scientific	Average PM concentration	1. PM ≥ 0.1 μg m^{-3}; PM < 200 μg m^{-3} 2. RH < 75%
Ozone	106-OEM-L, 2B Technologies, Inc.	Ozone concentration	1. Ozone < 0.25; Ozone > 200 ppb 2. Cell pressure between 450-825 Torr 3. Flow rate between 600-1200 ccm 4. Temperature in range of 0 to 50 °C 5. For temperatures between 20 to 50 °C, diode voltage in range of 0.6 to 2 V; For temperatures below 20 °C, diode voltage in the range of 0.15 to 2 V.
Wind speed and direction	MODEL 09101, R. M. Young	Wind speed Wind direction	1. Wind speed < 20 m/s 2. Wind direction between 0 and 360 degrees
RH and Temp	Vaisala, HMP60	Temp RH	1. Temp > -20 °C 2. RH ≥ 0%, RH ≤ 100%

7. Troubleshooting

The VGP is a complex system utilizing many parts and a custom code that deciphers and delivers information from components that have not been specifically designed to work together. Since the system's initial deployment, many challenges have had to be overcome, and each new installation results in new developments.

7.1 Required Tools

Before attempting to diagnose and fix any issue with a VGP station, the following tools must be available:

- Grounding equipment –The body must be grounded constantly when accessing the system's components to prevent electrical damage to the system. Grounding tools are described in more detail in Section 8.2.1.
- General tools – A set of small to medium screwdrivers (Phillips and flathead), pliers, cutters, and a light gauge (i.e., photometer).
- Multi-meter – A general purpose multi-meter is sufficient and should be capable of reading DC voltages up to 20 V and resistances up to 10 K. An audible tone for connectivity is recommended.

In addition to these tools, certain communication issues can be diagnosed only by using a logic analyzer. The VGP system utilizes many different communication protocols. Some USB-PC logic analyzers with good resolution are available for approximately $200 to $300. These units are more than sufficient for fieldwork and diagnostics. One such unit is shown in Figure 46.

Figure 46. Logic Analyzer.

7.2 Failure Scenarios

Error! Reference source not found.17 lists the most common failure scenarios and directs the user to specific sections of this document to learn more about potential causes and their resolutions. Please note that these sections do not list all possible causes--the purpose of this information is to assist a qualified technician in diagnosing potential failure points.

Also note that most code-related issues are beyond the scope of this troubleshooting section. The assumption is made that the station was working upon installation and that no major changes have been made to the code since that time.

For all troubleshooting issues, the first step, if possible, is to check the serial monitor output for any statement relevant to the problem. The serial monitor may provide information to help identify the problem more quickly.

Table 17. Common Issues

Instrument	Issue	Section
Entire System	Instruments not on. Powered down.	7.2.1
	Instruments running, but data is not posting.	7.2.2
Thermo Fisher Scientific pDR-1500	Instrument not on. Powered down.	7.2.3
	Instrument running, but data is not posting.	7.2.4
	Readings are inaccurate.	7.2.5
2B 106-OEM-L	Instrument not on. Powered down.	7.2.6
	Instrument running, but data is not posting.	7.2.7
	Readings are inaccurate.	7.2.8
R. M. Young 09101	No data from the sensor.	7.2.9
	Readings are inaccurate.	7.2.10
Vaisala HMP60	No data from the sensor.	7.2.11
	Readings are inaccurate.	7.2.12
Cairpol (O_3/NO_2) Cairpol NO_2	No data from the sensor.	7.2.13
	Readings are inaccurate.	7.2.14
MOCON VOC Sensor	No data from the sensor.	7.2.15
	Readings are inaccurate.	7.2.16
GC-0015 CO_2 Sensor	No data from the sensor.	7.2.17
	Readings are inaccurate.	7.2.18
AethLabs MA350	No data from the sensor.	7.2.19

7.2.1 VGP System Not Operating. Powered Down.

Observation: The entire system appears offline and no instruments are audible.

Recommendation: Check the system voltage (Table 18). There should be 12 to 14 V at the battery and the instrument rail.

Table 16. VGP System Voltage Troubleshooting

~12 V Voltage at Battery?	~12 V Voltage at Instrument Rail?	Instruments On?	Possible Cause	Next Steps/Solution
No	No	No	Dead battery. Poor solar uptime or misconfigured/miswired power system.	Check configuration. Replace battery.
Yes	No	No	No power to instrument rail.	Check disconnect switch, circuit breakers.
Yes	Yes	No	Instrument relay Off.	Check connection to relay driver and make sure battery voltage is within operational range. If off by design, this could be due to extreme temperature conditions. Replace microprocessor.

7.2.2 VGP System Operating. No Data on Website.

Observation: The sound of instruments operating is audible, but nothing is posting.

Recommendation: Check to see if the sign is posting data from the instruments and if the sign is posting AQI data. Review the checklist in Table 19.

Table 17. VGP System Website Connection Troubleshooting

Is Sign Posting all AQ Data?	Is Sign Posting AQI?	Instruments Posting	Possible Cause	Next Steps/Solution
No	No	No	Floating ground in system.	Check all wiring.
Yes	No	No	Web server, signal, or Ethernet communication issues.	Check serial monitor for web post status. Check cell signal quality. If post fails despite good signal, Replace microprocessor and/or Ethernet module.
Yes	Yes	No	Web server or signal issues.	Check serial monitor for web post status. Check cell signal quality.

7.2.3 pDR-1500. Instrument not Powered On.

Observation: The pDR-1500 is not posting. Unit is powered off.

Recommendation:

Review the checklist in Table 20.

Test 1: Check voltage at pDR-1500 barrel-jack connector. (Pass = 5 V, Fail = 0 V)

Test 2: If Test 1 voltage check passes, attempt to manually start the pDR-1500.

Table 18. pDR-1500 Power Troubleshooting

Test 1	Test 2	Possible Cause	Next Steps/Solution
Fail	NA	No power to instrument.	Check connection to pDR power supply.
Pass	Fail	Possible pDR-1500 failure.	Further test in lab setting with dedicated power supply. Replace if needed.
Pass	Pass	Automatic startup failed.	Test physical connection of auto start wiring and relay operation.

7.2.4 pDR-1500. Instrument Running, but Data is not Posting.

Observation: The pDR-1500 is not posting to either the sign or the web. The unit is powered on.

Recommendation:

Review the checklist in Table 21.

Test 1: Is the pDR currently taking a measurement? If so, the screen should show the current concentration.

Test 2: Directly connect the pDR to the PC with the manufacturer's supplied cable. Setup communication according to the manual (web link) contained in Appendix F. Type 'O' in the terminal and press 'Enter'. Does the instrument respond with a reading?

If Test 2 passes, proceed to Test 3.

Test 3: Use a logic analyzer to read the serial logic at the microprocessor input pins. Does the logic analyzer indicate a response at the input pins?

Table 21. pDR-1500 Troubleshooting

Test 1	Test 2	Test 3	Possible Cause	Next Steps/Solution
Fail	Fail	NA	Multiple potential problems.	Manually start the pDR on measurement, check the cable, and repeat Test 2.
Fail	Pass	Fail	Communication issue with microprocessor. Possible chip failure.	Check the MAX232 chip/adapter wiring If there is a switch on the MAX232 adapter, flip it and try again. Replace the MAX232 chip/adapter
Pass	Fail	NA	Instrument/cable issue.	Check the cable for connectivity. The cable to the PC must be a crossover; the cable to the microprocessor is straight through. If the problem persists, contact the manufacturer.

Test 1	Test 2	Test 3	Possible Cause	Next Steps/Solution
Pass	Pass	Fail	Communication issue with microprocessor. Possible chip failure.	Check the MAX232 chip/adapter wiring. If there is a switch on the MAX232 adapter, flip it and try again. Replace the MAX232 chip/adapter.
Pass	Pass	Fail	Communication issue with microprocessor. Possible microprocessor failure.	Doublecheck the code for baud rates and, serial port alignment. Replace the microprocessor.

7.2.5 pDR-1500. Readings are Inaccurate.

Observation: Readings are inaccurate.

Recommendation: See the section on maintenance for activities to check the flow and zero readings. If the problem persists, contact the manufacturer.

7.2.6 2B Tech 106-OEM-L (Ozone). Instrument not Powered On.

Observation: The ozone instrument is not posting. The unit is powered off.

Recommendation: Check the voltage at the ozone barrel-jack connector. If the voltage does not equal 12 V, then check the connections to the ozone power supply. If the voltage is equal to 12 V, the unit is switched on, and the instrument still does not power up, contact the manufacturer.

7.2.7 2B Tech 106-OEM-L (Ozone). Instrument Running, but Data is not Posting.

Observation: The ozone is not posting either to the sign or to the web. The unit is powered on.

Recommendation:

Make sure the baud rate on the instrument and in the program are set according to the specifications noted in Section 8.3.2.

Test 1: Directly connect the ozone instrument to the PC with the manufacturer-supplied cable. Setup communication according to the user's manual (web link) in Appendix F. Does the instrument send a reading to the PC every 10 seconds?

If Test 1 passes, proceed to Test 2.

Test 2: Use a logic analyzer to read the serial logic at the microprocessor input pins. Does the logic analyzer show a response at the input pins?

Table 22. 2B Tech 106-OEM-L (Ozone) Troubleshooting

Test 1	Test 2	Possible Cause	Next Steps/Solution
Fail	NA	Instrument/cable issue.	Check the cable for connectivity. The cable to the PC must be a crossover cable. The cable to the microprocessor is straight through. If the problem persists, contact the manufacturer.

Test 1	Test 2	Possible Cause	Next Steps/Solution
Pass	Fail	Communication issue with the microprocessor. Possible chip failure.	Check the MAX232 chip/adapter wiring. If there is a switch on the MAX232 adapter, flip it and try again. Replace the MAX232 chip/adapter.
Pass	Pass	Communication issue with the microprocessor. Possible microprocessor failure.	Doublecheck the code for baud rates and the serial port alignment. Replace the microprocessor.

7.2.8 Ozone Instrument. Readings are Inaccurate.

Observation: Readings are inaccurate.

Recommendation: See the section on maintenance activities for how to check the flow. If the problem persists, contact the manufacturer.

7.2.9 R. M. Young 09101 (Wind Sensor). Data is not Posting.

Observation: The wind sensor is not posting to either the sign or the web.

Recommendation: Review the checklist in Table 23. Check the voltage at the wind sensor terminal block to ensure that it is ~12-14 V.

Make sure the baud rate on the instrument and in the program are set according to the specifications provided in Section 8.3.3.

Doublecheck the jumper connections as described in Section 8.3.3.

Test 1: Connect the wind sensor to the PC through the RS485 converter. Set up the communication according to the manual (web link) provided in Appendix F. Does the instrument send a reading to the PC every 10 seconds?

If Test 1 passes, proceed to Test 2.

Test 2: Use a logic analyzer to read the serial logic at the microprocessor's input pins. Does the logic analyzer show a response at the input pins?

Table 23. R. M. Young 09101 (Wind Sensor) Troubleshooting

Test 1	Test 2	Possible Cause	Next steps/Solution
Fail	NA	Instrument/cable issue. MAX485 Converter Failure	Check the cable for connectivity and to be sure wiring is correct. Check the MAX485 converter wiring. Replace the MAX485 converter. If the problem persists, contact the manufacturer.
Pass	Fail	Communication issue with microprocessor. Possible chip failure.	Check the MAX485 chip/converter wiring. Check the MAX232 converter wiring. If there is a switch on the MAX232 converter, flip it and try again.

Test 1	Test 2	Possible Cause	Next steps/Solution
			Replace the MAX485 chip/converter. Replace the MAX232 converter.
Pass	Pass	Communication issue with microprocessor. Possible microprocessor failure.	Doublecheck the code for baud rates and for serial port alignment. Replace the microprocessor.

7.2.10 R. M. Young 09101 (Wind Sensor). Data is Inaccurate.

Observation: The data are inaccurate.

Recommendation: See the section on maintenance activities for how to properly align the wind sensor. Make sure that the sensor is located in an open area free from obstructions.

7.2.11 Vaisala HMP60. No Data from Sensor.

Observation: No data are being reported from the sensor.

Recommendation: Check the voltage at the terminal block to the Vaisala HMP60. The voltage should be 5 VDC.

Check the input voltage to the microprocessor inputs. The HMP60 outputs a voltage corresponding to both the temperature and the RH. If the voltage does not correspond to the current conditions, the sensor may need to be replaced.

7.2.12 Vaisala HMP60. Readings are Inaccurate.

Observation: The readings are inaccurate.

Recommendation: Make sure the temperature and the RH wires were not inadvertently swapped. Try swapping these inputs to see if the readings are more accurate.

If the readings simply do not reflect current conditions, you may need to replace the sensor. If the problem persists, it may be because a floating ground is affecting the readings. Check the system's wiring.

7.2.13 Cairpol Sensor. No Data from Sensor.

Observation: No data are available from the sensor.

Recommendation: The Cairpol sensor reading is read-in directly over the serial monitor. Check the output string on the serial monitor to make sure the bit being read is the one following a zero. If the measurement bit is being correctly read-in, any issues should be reported directly to the manufacturer.

If the incorrect bit is being read-in, it can be changed in the code.

If no data are being received for the sensor, make sure the baud rate is correctly set at 9600 baud and check the physical wiring connections.

Check the serial output to see whether bytes are being received from the Cairpol. If a consistent number of bytes are being received, but the number does not match the index check in the Arduino code, it may be necessary to change the value in the code. The Cairpol sensor output varies based on the model, and the precise cause of this variation has not yet been verified. Changing the index count value in the code may make the sensor communicate correctly. Once this value has been changed, check the output of the sensor on the serial monitor to ensure that the correct measurement byte is being received and parsed by the microprocessor. The measurement byte follows the response byte, 0x13.

If no data are being received by the sensor, try using a new microprocessor. If the problem persists, consult the manufacturer.

7.2.14 Cairpol Sensor. Readings are Inaccurate.

Observation: The sensor's readings are inaccurate.

Recommendation: The Cairpol sensor reading is read-in directly over the serial monitor. Check the output string on the serial monitor to ensure that the bit being read is the one that follows the response byte, 0x13. If the measurement bit is being correctly read-in, any issues would need to be addressed by the manufacturer.

If the incorrect bit is being read-in, it can be changed in the code.

7.2.15 MOCON VOC Sensor. No Data from Sensor.

Observation: No data are being reported from the sensor.

Recommendation: The MOCON VOC sensor outputs a DC voltage proportional to concentration. Check power output to the sensor and ensure it is 5 VDC.

If power is connected, check the output voltage from the sensor. Ensure the reading displayed on the serial monitor matches the measured voltage. If the voltage does not match, check the input pin declaration in code.

If the output is 0V, or inconsistent, you may need to replace the sensor.

7.2.16 MOCON VOC Sensor. Readings are Inaccurate.

Observation: The sensor readings are inaccurate.

Recommendation: Normally a user cannot calibrate the sensor and the only remedy is to replace it.

7.2.17 GC-0015 CO_2 Sensor. No Data from Sensor.

Observation: No data is reported from the sensor.

Recommendation: Ensure the sensor is powered by 3.3 V. Modifications are necessary if using the supplied VGP circuit board design files.

Check the serial monitor output to see if data are being received from the sensor. Consult the manual (web link) in Appendix F for expected output format. If output is not being detected or is not in the correct format, check all physical connections.

If the problem persists, use a logic analyzer to check logic at the sensor outputs. If the logic test results in correct output, ensure the correct serial port is called out in code. If the problem persists, the microprocessor may need to be replaced.

7.2.18 GC-0015 CO_2 Sensor. Readings are Inaccurate.

Observation: The sensor readings are inaccurate.

Recommendation: Ensure the sensor is powered by 3.3 V. Modifications are necessary if using the supplied VGP circuit board design files.

7.2.19 AethLabs MA350. No Data from Sensor.

Observation: The sensor is not reporting data.

Recommendation: Connect the sensor to the PC and run the sensor-specific application. For the VGP system, the output should be limited. Make sure the verbose output option is not selected and that the time base is set to 10 seconds. See the application instructions in Appendix F (user manual as web link).

Check to ensure the unit is powered on and running a measurement. The pump should be audible.

Direct connect the MA350 to PC with manufacturer supplied cable. Setup communication according to the user manual and application instructions. Does the instrument reply with a reading every 10 seconds?

If direct communication with the PC fails, there is a problem with the instrument. Contact the manufacturer.

If direct communication with the PC is successful, check all physical connections to the microprocessor and try again. Make sure the correct serial port is called out in code. If the problem persists, try replacing the microprocessor.

8. Operations and Maintenance

8.1 System Overview

A schematic of the overall system setup showing key system components is shown in Figure 47 and Figure 48. In addition to these key components, setups to be used in northern climates are equipped with a wind turbine and heater; setups deployed to other regions do not come with those additions. These figures show the locations of all components, including optional add-ons. See Table 2 to determine which sensors are incorporated into which stations.

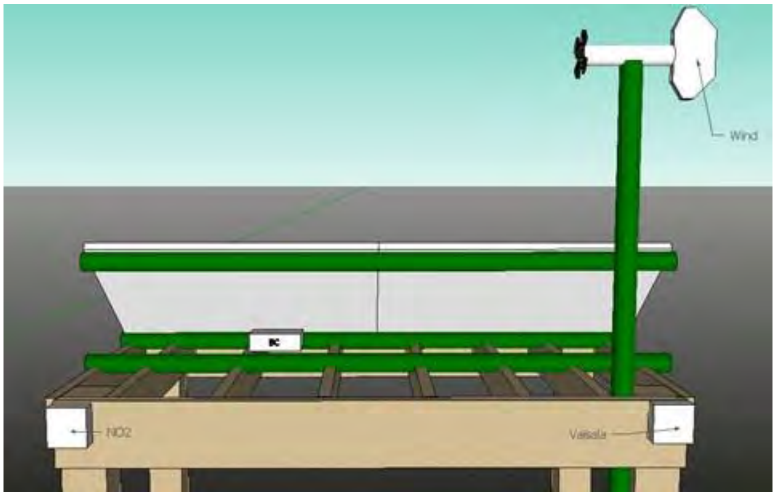

Figure 47. Sensors atop the VGP.

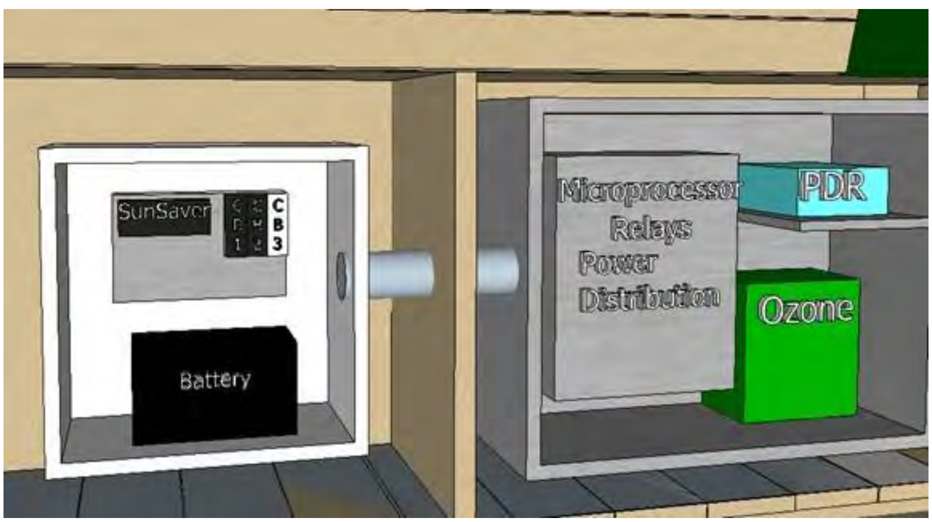

Figure 48. VGP System Layout.

The VGP system is powered by two 110-watt solar panels. The panels are connected to a Morningstar Sunsaver SS-20L-12 V charge controller that maintains the battery voltage. The controller will also disconnect the load if the battery voltage drops below 11.5 VDC and will reconnect it when the voltage is restored to 12.5 VDC. There is also a Morningstar RD-1 relay driver installed that is programmed to drop power to the air monitoring instruments when the voltage is less than 11.65 VDC and reconnect when it is greater than 12.4 VDC. The relay driver allows the instruments to be disabled while allowing the Arduino microcontroller and communications to remain powered. If there is very little solar radiance for an extended period of time and the voltage drops below the 11.5-VDC threshold, the charge controller will drop all power to the instrument box until the battery voltage is restored to 12.5 VDC. Circuit breakers and a disconnect switch to the instrument panel control current flow to the instrument enclosure. All breakers and switches should be in the "ON" position to operate the station.

To turn off the system, turn off the circuit breakers in this order:

CB3: 3A Circuit Breaker from Solar Controller to Load (board power)

CB1: 20A Circuit Breaker from Solar Panel to Solar Controller

CB2: 15A Circuit Breaker from Battery to Solar Controller

Follow this order in reverse to turn the circuit breakers back on.

8.2 Accessing the System

The back panel of the bench must be removed to access the instrument bays. All stations require a key to unlock two paddle locks on the back of the bench's panel. Some stations have an additional two padlocks that require a four-digit code to open, which would have been given to the operators upon installation. To remove the back panel once it is unlocked, lift the panel up slightly, and pull backward away from the bench. Then, fully remove the panel and place it aside. Figure 49 shows the outside of the instrument enclosure. On the left side of the instrument box (as you are facing it) are two dampers. These dampers were added to restrict airflow through the normally open cooling vents and to keep the instruments at or above their operating temperatures under northern wintry conditions. Both the cooling air supply and the exhaust vents have filters installed on them. This naturally restricts the air exchange within the enclosure. Until the instruments begin to shut off under low temperature conditions, it is recommended that these dampers remain open. When operating, the instruments generate sufficient heat to raise the instrument box temperature to approximately 10 °C above the ambient temperature. The northern VGP designs also have a heater installed in the instrument panel to maintain the temperature above -8 °C. To access the instrumentation, a flathead screwdriver should be used to loosen the clamps that hold the door to the instrument box closed. For access to the battery, a key is used to unlock the front of its enclosure.

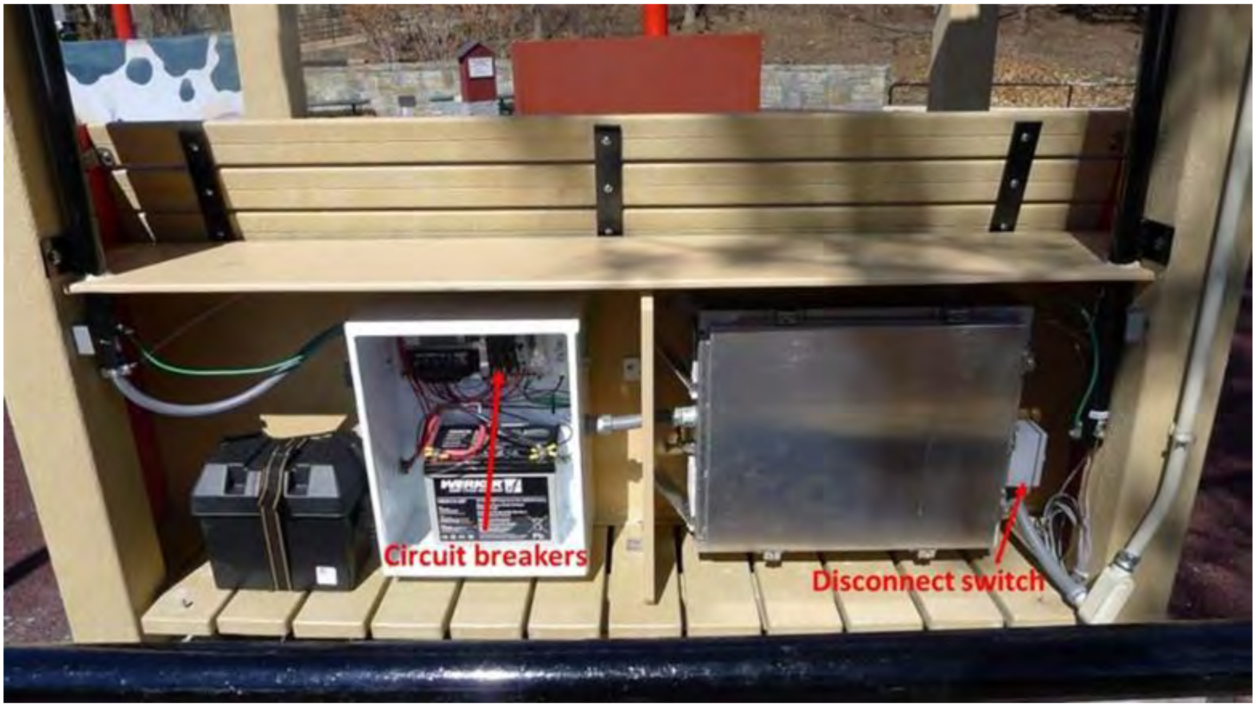

Figure 49. View Inside the Bench Back Panel.

8.2.1 Grounding

Before accessing the system's components, the operator must be grounded to the system's ground to prevent electrical damage to the system. A wrist strap like the one shown in Figure 50 allows the operator's wrist to be physically connected to the grounding rod of the bench. Simply place the wrist strap (with conductive side next to the skin) on the wrist and tighten appropriately. Next, connect the supplied cable from the wrist strap to the clamp. Finally, clamp the wrist strap to a secure ground. Inside the VGP system, all the earth grounds are connected with green wiring or bare copper. Find one of these grounds that is near the working area (within reach) and connect the clamp.

Figure 50. Wrist Strap Grounding System.

8.2.2 Instrument Compartment (Generation 2)

The key components of the VGP station are listed below and labeled in Figure 51 to help the user locate each specific instrument. Although the exact locations may vary some by site, each component is easily identifiable.

1. pDR-1500 instrument
2. 2B Technologies ozone instrument
3. Arduino microcontroller (located behind Ethernet shield and screw shield)
4. RS-232 ports (serial RS-232 to TTL converters are located behind these)
5. DC:DC converter(s)

   Note: One converter is dedicated to the Arduino microcontroller (10 VDC) and another is used to power the pDR-1500 and CairClip (5 VDC). In some cases, a third converter has been installed dedicated to the CairClip to isolate it from the pDR.

6. RS-485 to RS-232 converter and surge protection
7. Cellular Ethernet gateway
8. Terminal strip
9. Relay shield
10. Control relays (2)
11. Heater (only in systems located in colder environments)
12. Enclosure temperature and humidity sensor
13. Real-time clock

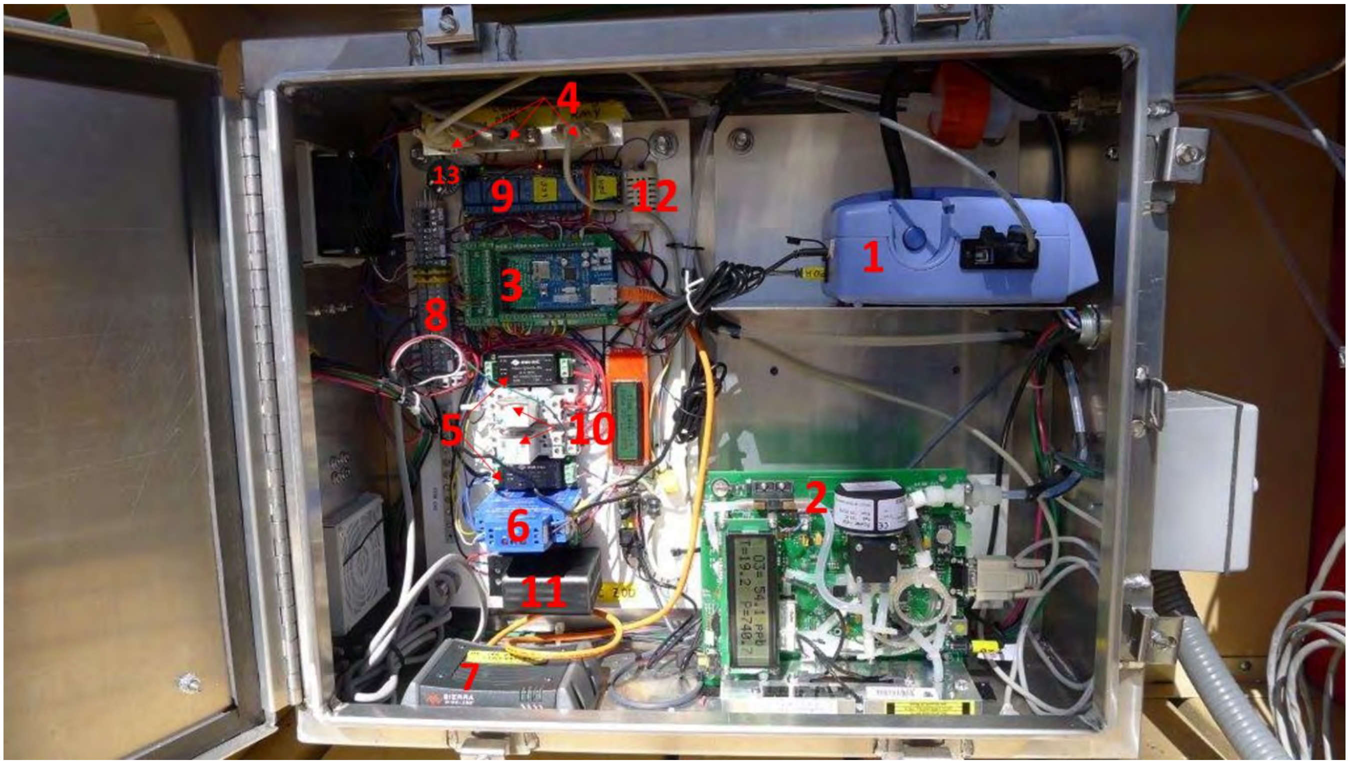

Figure 51. Generation 2 Board (Labeled).

8.2.3 Instrument Compartment (Generation 3)

The key components of the VGP station are listed below and labeled in Figure 52 to help the user locate each specific instrument. The components' precise locations may vary somewhat by site, but each component is easily identifiable.

1. pDR PM instrument
2. 2B ozone instrument
3. Teensy 3.5
4. RS-232 ports
5. MAX232 converters
6. DC:DC converters
7. MAX485 Chip
8. Cellular Ethernet gateway
9. Terminal strip
10. Relays
11. Enclosure temperature and humidity sensor

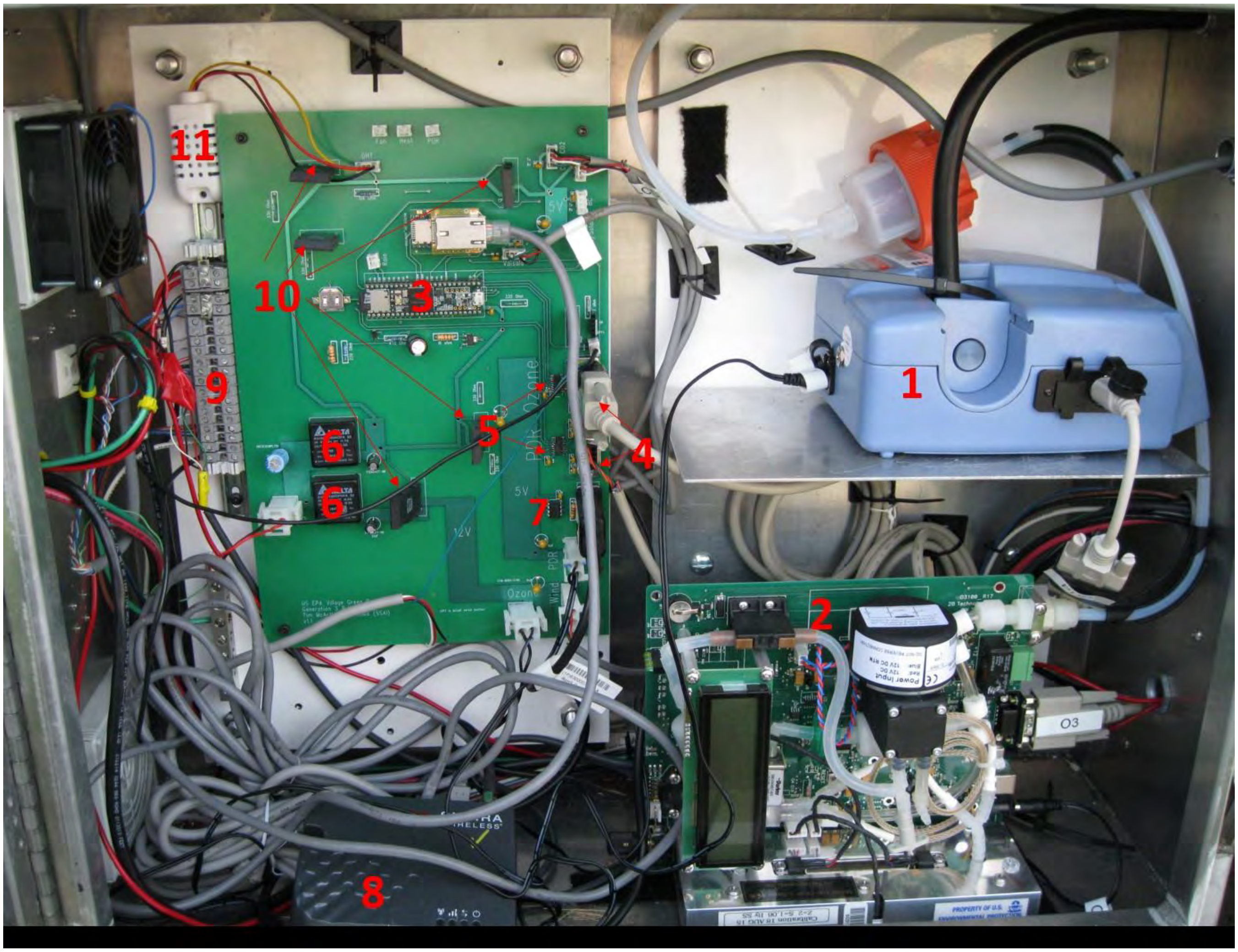

Figure 52. Generation 3 Board (Labeled).

8.3 System Operations

8.3.1 Thermo Fisher Scientific pDR1500

The Thermo Fisher Scientific pDR-1500 communicates with the microprocessor over RS232 communication. This communication conversion is managed by a MAX232 chip. In Generation 2 systems, this chip is located on an adapter board. The D-Sub9 connector from the pDR-1500 is connected to this adapter board, and the adapter board is wired point-to-point to the Mega 2560 screw shield. In Generation 3 systems, the D-Sub9 connector is plugged directly into the custom printed board. Power for this device is driven from a separate 5-VDC:DC converter on the Generation 2 systems and from the 5-V instrument rail on the Generation 3 systems.

For the device to interface with the VG installation, the following modification must be made.

The start button for the pDR device must be activated to turn the instrument on before the sampling mode can be selected via RS232 communication. To automate this procedure, a 3.5-mm panel mount stereo jack is mounted to the back of the unit and the leads are wired to the power button contacts. To "press" the button, the ungrounded lead must be connected to the same ground as the pDR-1500. Since all grounds on the system are connected, this means the leads can be driven to ground via a relay (as in the Generation 2 design), or connected directly to a digital output, which can be driven to ground by the microprocessor (as in the Generation 3 design).

See the Generation 2 and 3 schematics for where to physically connect this lead in the system.

In addition to the power button modification, the pDR-1500's parameters must be set appropriately to work properly with the VGP system:

- Units: $\mu g/m^3$
- Flow setpoint: 1.52 standard liters per minute (slpm) (to maintain the 2.5 µm cut point with the blue cyclone)
- RH correction: Enabled
- Baud rate: 19200

See the manual (web link) in Appendix F for information on how to change these settings.

8.3.2 2B Technologies Ozone 106-L

The 2B Technologies 106-OEM-L Ozone Monitor communicates with the microprocessor over RS232 communication. The communication conversion is managed by a MAX232 chip. In the Generation 2 systems, this chip is located on an adapter board. The 2B Tech 106-OEM-L D-Sub9 connector is connected to this adapter board, and the adapter board is wired point-to-point to the Mega 2560's screw shield. In the Generation 3 systems, the D-Sub9 connector is plugged directly into the custom-printed board. Power for this device is driven from a separate 12-VDC:DC converter on Generation 2 systems and from the 12-V instrument rail on Generation 3 systems.

This instrument must be set as described below to work properly with the VGP system.

- Concentration units: ppb
- Pressure units: torr (mmHg)
- Flow units: ccm
- Baud rate: 4800

See the user's manual (web link) in Appendix F for information on how to change these settings.

8.3.3 R. M. Young 09101

The R. M. Young 09101 wind sensor is powered by 12-24 V and communicates with the microprocessor over RS485 communication. The communication conversion is managed by a RS485 to RS232 converter to an RS232 to TTL converter in Generation 2 systems. In Generation 3 systems, this conversion is managed by a MAX485 chip.

The R. M. Young 09101 wind sensor must be configured as detailed below to work with both Generation 2 and Generation 3 VGP systems.

- Output: R. M. Young protocol, continuous, RS485
- Units: m/s
- Baud rate: 9600

These configuration parameters correspond to the jumper configuration shown in Table 24.

Table 24. Jumper 1 (J1) Configuration (09101)

1	2	3	4	5	6	7
IN	IN	IN	OUT	OUT	OUT	OUT

Jumper 3 (J3) should be right aligned.

See the user's manual (web link) in Appendix F for more information on how to change these settings.

8.3.4 Vaisala QMR102

The Vaisala QMR102's contacts are connected directly to the microprocessor's digital inputs. See the Generation 2 and Generation 3 systems' schematics for information on where to connect this sensor.

8.3.5 Cairpol(s)

The Cairpol CairClip sensors (O_3/NO_2 or NO_2 only) are powered by 5 V and connected directly to the UART TTL on the microcontroller. See the Generation 2 and Generation 3 systems' schematics for information on where to connect this sensor.

The Cairpol CairClip sensor must be set to 9600 Baud.

8.3.6 Vaisala HMP60

The Vaisala HMP60's temperature and humidity sensor is powered by 5 V and connected directly to the microcontroller's analog inputs. See the Generation 2 and Generation 3 systems' schematics for information on where to connect this sensor.

8.3.7 GC-0015 CO_2 Sensor

The GC-0015 CO_2 sensor is powered by 3.3 V and connected directly to the microcontroller's UART inputs. See schematics for the Generation 3 system for information on where to connect this sensor. **This sensor runs off 3.3 V. As of the writing of this document, 5 V is supplied to all sensor input connections on the Generation 3 board. Powering the GC-0015 CO_2 sensor requires modifying the Generation 3 board to supply it with 3.3 V. Properly installing this sensor requires cutting the existing traces and running new traces.**

8.3.8 MOCON VOC Sensor

The MOCON piD-Tech VOC sensor is powered by 5 V and connected directly to an analog input on the microcontroller. See the Generation 3 system's schematics for information on where to connect this sensor.

8.3.9 AethLabs MA350 BC Sensor

The AethLabs MA350 BC sensor is powered by 5 V and connected directly to the UART inputs on the microcontroller. The MA350 sensor operates at 1000000 baud.

8.3.10 Relays

The VGP system has a system of relays to control both instrument and microcontroller/modem power, as described in Section 2.2.7. See the Generation 2 and Generation 3 systems' schematics for information on where to connect this sensor.

8.3.11 Sierra Wireless Raven XE Modem (Generation 2)

The Sierra Wireless Raven XE cellular router is used to upload data collected by the Arduino to an off-site server. The Arduino Ethernet shield is used to enable communication between the microprocessor and the cellular router. The Raven is supplied with a public, static IP address to allow for remote access.

The Raven cellular router allows the Arduino microcontroller to be reset remotely. When the Raven digital output is turned on, the normally closed contact of relay 2CR (see Schematic 07 in Appendix A) opens, disabling power to the Arduino controller. The user then must turn the output off to reenable power to the system. The digital output on the Raven can be used to reset the Arduino controller remotely by using the following procedure:

- From the "cmd" prompt: telnet [XXX.XXX.XXX.XXX] 2332
- To turn off: at*relayout[Y]=1
- To turn on: at*relayout[Y]=0
- [XXX.XXX.XXX.XXX] is the assigned static IP address of the station's modem.
- [Y] is the output number, which may vary by station and is given to the individual stations' operators.

Please note that the brackets above are not part of the syntax and are used in the examples above only to signify the use of a variable.

Example of syntax including the variables:

- From the "cmd" prompt: telnet 167.153.2.98 2332
- To turn off: at*relayout1=0
- To turn on: at*relayout1=1

Mobile applications are also available that allow performing this function from a smartphone. Mocha Telnet Lite is available on the Google Play Store for use with an Android phone.

The Raven XE must be configured with a static IP address for it to be used for remote restarts, and the digital input/output (DIO) settings must allow for AT commands to set the state of the DIO pin. These settings can be found in the product manual (web link) in Appendix F.

8.3.12 Sierra Wireless RV50 (Generation 3)

The Sierra Wireless RV50 cellular router allows the Teensy 3.5 microcontroller to be reset remotely. When the Sierra Wireless RV50 digital output is heightened, the normally closed contact of the board-mounted relay opens, disabling power to the Arduino controller. The user then must to turn the output to ground to reenable power to the system. The digital output on the Sierra Wireless RV50 can be used to reset the Arduino controller remotely by using the following procedure:

- From the “cmd” prompt: telnet [XXX.XXX.XXX.XXX] 2332
- To turn off: at*relayout[Y]=0
- To turn on: at*relayout[Y]=1
- [XXX.XXX.XXX.XXX] is the static IP address assigned to the station’s modem.
- [Y] is the output number, which may vary by station and is provided to the individual station’s operators.

Please note that the brackets shown in the syntax above are not part of the required syntax and are used in the examples above only to signify the use of a variable.

Example of syntax including the variables:

- From the “cmd” prompt: telnet 167.153.2.98 2332
- To turn off: at*relayout1=0
- To turn on: at*relayout1=1

Mobile applications are also available to perform this function from a smartphone. Mocha Telnet Lite is available on the Google Play Store for use on an Android phone.

The RV50 cellular router must be configured with a static IP address for remote restarts, and the DIO settings must allow for AT commands to allow the state of the DIO pin to be set. These settings may be found in the product manual (web link) in Appendix F.

8.3.13 Serial Monitor

The serial monitor displays abundant information. The monitor displays the raw readouts of most of the instruments for debugging purposes, and any errors are printed to the screen.

The serial monitor must be connected to the system to view the debugging information. The procedure is nearly the same whether you are connecting to the Mega 2560 or the Teensy 3.5 The Mega 2560 uses a USB A-B cable, which is similar to most printer communication cables. The Teensy 3.5 uses micro USB cable, similar to what is used by most Android phone chargers. It should be noted that not all Android chargers all four of the cables required for communication with the device.

Plug the appropriate cable into your computer and use a serial communication program, such as TeraTerm or Putty, to connect to the serial monitor.

The serial monitor communicates at 9600 baud. The remainder of the communication settings are the default selections in most serial communication programs.

- Data bits: 8
- Parity: None
- Stop bits: 1

In Generation 3 systems, the level of debugging printed to the screen can be controlled by the user. Follow the instructions seen in the serial monitor to turn debugging on or off for specific instruments.

Type the letter 'D' (case-sensitive) into the serial monitor, then press Enter. The screen will then display a list (like this one), and the instrument to debug can be selected by number (e.g., 1) and then pressing "Enter". This will turn on debugging for only the instrument selected.

Once debugging is complete, type 'F' (case-sensitive) into the serial monitor, then press Enter. The screen will again display a list of instruments to be selected. Once again, select the instrument by number (e.g.,1) and press "Enter". This will turn off debugging for that instrument.

8.4 Maintenance

The VGP's instruments require various maintenance and/or calibration procedures to ensure optimal performance. Table 25 includes the recommended maintenance activities and the frequency with which they should be performed.

Table 25. VGP Maintenance Activities

Instrument	Maintenance/Calibration Requirements	Frequency
Thermo Scientific pDR-1500	Change filter and clean cyclone	Every 3 months
	Calibrate	Every 12 months
	Zero and flow checks	Every 4 months
2B Technologies OEM-106-L	Replace ozone scrubber	Every 6 months
	Replace air pump	Every 18 months
	Replace lamp	Every 2 years
	Calibration check	Every 4 months
R. M. Young 09101	Ensure that the sensor is free to rotate about mast	No recommendation
	Verify meteorological data with data obtained from nearby weather station	Every 4 months
Vaisala HMP60	Ensure that sensor housing is unobstructed	No recommendation

Instrument	Maintenance/Calibration Requirements	Frequency
	Verify temperature and humidity with known standard	Every 4 months
AethLabs MA350	Change filter tape	Every 6 months
	Zero and flow checks	Every 4 months
MOCON pID-Tech Blue	None	No recommendation
SP-110 Pyranometer	None	No recommendation
GC-0015 Sensor	None	No recommendation
Cairpol CairClip NO_2 and CairClip O_3/NO_2	Change filter	Every 4-6 months
	Replace entire sensor	Every 12 months
Vaisala Rain Gauge QMR 102	Clean funnel and level gauge	Every 4 months
	Clean bucket	Every 6 months
	Dynamic calibration (only required if measurement deviates by > 50% from nearby station(s)	Varies

8.4.1 pDR-1500 Flow Check

The pDR flow check is necessary to ensure that the instrument is maintaining the 1.52 slpm flow required for the 2.5 μm cut point of the installed blue cyclone. This flow should be checked with a flow reference device (e.g., MesaLabs DryCal), and should be within an acceptable deviation of ±10% of the set point. The first step in performing the flow check is to briefly remove the blue cyclone and replace it with the total inlet. The total inlet has a hose barb that can be used to connect the flexible tubing between the reference device and the pDR (Figure 53). Confirm that the pDR is operating and take multiple flow readings to verify the values. If the flow check fails, check the sampling inlet for obstructions. If none are found, ensure the flow is set correctly. On the pDR screen, press "escape" to navigate to the screen that shows "operate". From this screen, use the up and down arrows to navigate to the "configure" screen, and then press "enter". Once at this screen, use the up and down arrows until you find the flow set point. Then, ensure that this value is set to 1.52 slpm using the up and down arrows and press 'enter' to select this correct value. Press "escape" to exit to the "configure" screen, navigate back to the "operate" screen, and press "enter" twice. The unit should continue measuring. If flow errors continue, the manufacturer's user manual (see Appendix F, web link) should be consulted.

Figure 53. pDR-1500 Inlet Assembly with Total Inlet.

8.4.2 pDR-1500 Zero Check

The pDR-1500 zero check ensures that the PM measurements made by the pDR device are not being biased by verifying a zero measurement. For this test, attach the high-efficiency particulate air (HEPA) filter supplied with the pDR to the inlet of the instrument via the total inlet hose barb described in the flow check procedure. Make sure the filter is installed with the proper direction of flow denoted by the arrow on the side of the filter. Observe the reported concentration under this condition and re-zero the readout if a 5-minute average readout > 2 $\mu g/m^3$ is observed.

To re-zero the pDR-1500:

- Use the up and down arrows until "Operate" is displayed and then press "Enter".
- Next use the up and down arrows to scroll to the "Zero Instrument" screen.
- From the "Zero Instrument" screen, press "Enter", and the display will advance and show that the unit is currently zeroing. This procedure may take several minutes. The results of this test are displayed only briefly on the screen. Thus, attempting to multi-task at this point in the process will likely cause the results of the zeroing test to be missed and the test needing to be repeated.

After zeroing, and if the proceeding measurement is successful, a "Zero Instrument, Complete: BKG OK" message appears on the screen. If the measurement is successful, but the value is not within the range specified for the instrument, a "Complete: BKG HI" message will appear. If the results of the diagnostic tests indicate a problem with the measurement, a "Failure 0x00ee" message, where "0x00ee" is a hex code indicating the type of error that has occurred, will appear. In this instance, the instrument should be re-zeroed. After three re-zeroing failures, the user should consult with the manufacturer's customer service department. A key providing the meaning of each hex code can be found in the user's manual (web link) in Appendix F.

8.4.3 Other PDR-1500 Maintenance

Changing the pDR-1500 Filter:

To replace the 37-mm filter (shown in Figure 54), place the pDR-1500 on a level surface with the clip attachment facing down. Rotate the plastic knurled filter cover counterclockwise and remove it along with the filter holder within the open cavity, as shown.

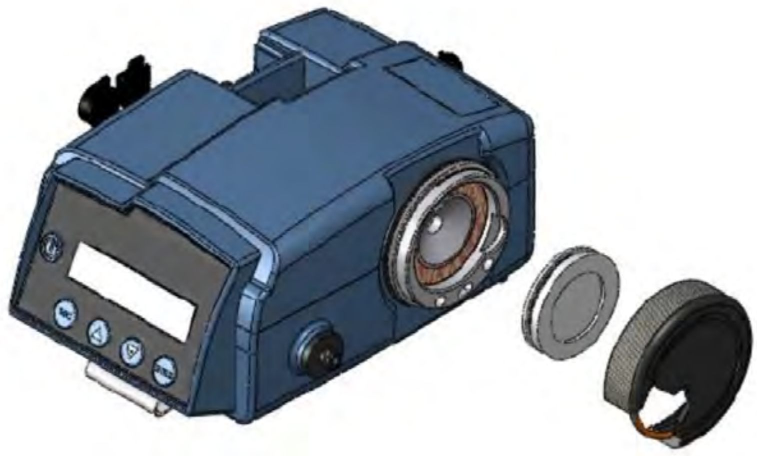

Figure 54. pDR-1500 Filter Housing.

Next, disassemble the filter by taking the top and bottom cassette rings apart. Remove the 37-mm filter and replace it with a new filter. Reassemble the filter assembly and reattach it to the pDR-1500 instrument (Figure 55). A more detailed discussion of this procedure can be found in the pDR-1500's operation manual (web link) in Appendix F.

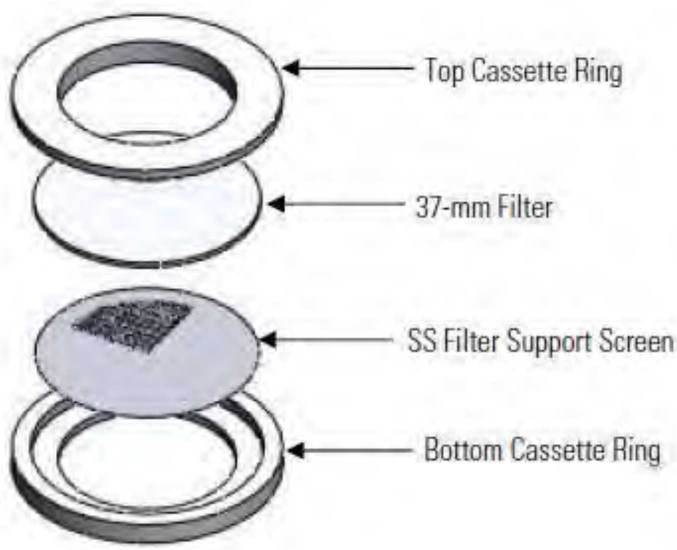

Figure 55. pDR-1500 Filter Assembly.

Cleaning the pDR-1500 Cyclone:

After extensive use, the cyclone on the pDR-1500 can become dirty, and it requires cleaning at least twice a year. To perform this task, first remove the cyclone from the instrument. Next, remove the cap from the cyclone. Clean the cyclone first by wiping the inside with a cotton swab or other appropriate wipe. For further cleaning, the cyclone can be rinsed with methanol and dried by allowing it to sit in the open or by flowing air through it. Once it is clean and dry, the cyclone can be placed back on the instrument for continued use.

8.4.4 pDR-1500 Calibration

pDR-1500 calibrations require the use of a temperature and RH-controlled chamber capable of housing the pDR-1500 unit. A standard aerosol generator is also required. If access to this equipment is unavailable, it is recommended that the pDR-1500 be sent to the manufacturer for calibration.

8.4.5 2B Technologies 106-OEM-L (Ozone) Flow Check

As with the pDR-1500 instrument, the flow check for the 2B ozone instrument is performed using a flow reference device. The inlet filter shown (Figure 56) is housed within an orange filter (see the graphic marked "1" in Figure 56). If the filter has been in operation for a significant amount of time (more than 3 months), it should be replaced prior to performing the flow check (see Section 8.4.7).

Figure 56. 2B 106-OEM-L and Filter Housing.

The check is performed by attaching a reference flow measurement device to the inlet of the filter assembly. On the VGP station, the ozone sample inlet is located beneath the solar panels and above the seating area. The best point at which to connect the flexible tubing to the inlet is just past the bug shield connected to the inlet. To do so, briefly remove the bug shield and connect the flexible tubing to the ¼-inch sample inlet to perform the check. Measure and record at least five readings and average them. An acceptable flow range for this instrument is 700 to 2000 sccm. Should the flow need to be adjusted, a small screw (see "2" in Figure 56) just below the instrument's pump can be rotated to accomplish this task. Rotating the screw clockwise will increase the flow. A target of 1000 to 1100 sccm is typically used, which allows for some decrease in flow from filter loading while still keeping it within an acceptable range.

To change the flow rate reading of the 2B ozone instrument, which is shown in the LCD display, access the “Cfg” submenu from the main menu. The various menu options may be found by scrolling the black knob attached on the left-hand side (see “3” in Figure 56) and are selected by pushing that knob inward. Next, select “Cal” to access that menu option.

From the “Cal” menu, click on the “Fm” submenu to display the calibration factor for the internal flow meter.

Fm is a multiplicative factor that when increased also increases the displayed flow. Fm can be used to change the flow rate to match that measured by a calibrated flow meter connected to the instrument’s inlet. Further explanation of these procedures can be found in the 2B operator’s manual (Appendix F, web link). Because there is a wide range of acceptable flow rates for the instrument, this adjustment does not need to be performed unless the 2B reading is significantly different from that of the reference device.

8.4.6 Changing the Ozone Scrubber(s)

The entire flow path of the ozone monitor must be cleaned and a new ozone scrubber installed at least annually (Figure 57). To replace the ozone scrubber, first disconnect the tubing from both ends of the scrubber assembly (from the white ozone scrubber and the green disc filter). Replace the old scrubber unit with the new unit and reconnect the tubing as before. A detailed procedure for cleaning the flow path and replacing the ozone scrubber of the OEM-106-L can be found in Appendix F (web link).

Figure 57. Ozone Scrubber Locations.

8.4.7 Changing the Ozone Filter

The entire flow path of the ozone monitor must be cleaned and a new ozone scrubber installed at least annually (Figure 57). To replace the ozone scrubber, first disconnect the tubing from both ends of the scrubber assembly (from the white ozone scrubber and the green disc filter). Replace the old scrubber unit with the new unit and reconnect the tubing as before. A detailed procedure for cleaning the flow path and replacing the ozone scrubber of the OEM-106-L can be found in Appendix F (web link).

Figure 58. Ozone Filters.

The filter (Savillex, Minnetonka, MN), which is used to protect the instrument from PM contamination, should be replaced every three months. To replace the filter, first turn the 2B instrument off. Next, disconnect the filter housing (shown in Figure 56) from the inlet line and take the housing apart by unscrewing the cap. Remove the used filter and replace it with a new filter (Figure 58). Reassemble the filter housing, reattach it to the inlet line, and restart the 2B instrument.

8.4.8 Ozone Lamp and Pump Replacement

The ozone lamp and pump will fail over time. To keep the system operational without downtime, it is recommended to replace these components according to the schedule in the operator's manual (Appendix F, web link). The VGP instruments require various maintenance and/or calibration procedures to ensure their optimal performance. Table 12 includes the recommended maintenance activities and the frequency with which they should be performed.

These replacements can be performed following the instructions in the user's manual (web link) in Appendix F or the unit can be returned to the manufacturer for replacement.

8.4.9 Temperature and RH Check

The ambient temperature and RH are measured via a Vaisala HMP 60 humidity and temperature sensor (Figure 59). The results of these measurements are displayed on the Arduino's LCD and logged to the micro SD card. They can also be observed locally using a terminal program on a computer attached to the USB port of the Arduino (Section 8.3.13). Checks on the performance of this sensor are made by comparing these measurements with a temperature and humidity reference device. An Omega HH310 meter is shown in Figure 59 as an example of a reference device. The user is free to use any transfer standard or reference device that is available and that complies with existing quality assurance requirements. Acceptable values for temperature are within ±2 °C of the reading and ±10% of the humidity reading. To compare these values to those of the reference device, simply place the reference probe near the Vaisala shield and allow adequate time for the readings to stabilize. Record data from both devices using the previously referenced options and ensure the readings are within the acceptance criteria.

The temperature and RH sensors produce voltages proportional to their values. These voltages are measured by the Arduino processor, and a linear correction is applied to convert them to engineering units. If the values measured fall outside the acceptable quality assurance range, the values obtained can be used to create a calibration curve and the factors can be changed or the Vaisala HMP60 can be replaced.

Figure 59. Handheld Temperature/RH Meter.

8.4.10 Wind Speed and Direction Check

The wind speed and direction are measured by using a serial output wind sensor (R. M. Young, Model 09101), the output from which is displayed on the Arduino LCD inside the instrument panel and logged to the micro SD card. These data can also be viewed on the serial monitor. (See the communication section of the video for instructions related to this task.) Currently, these data are compared with the wind speed and direction data from a local airport, NOAA, or other website with logged weather data for the time at which field observations were made. Wind direction should agree with the logged weather data within ±20 °C, and the wind speed should agree within ±3 m/s of the data.

Buildings and trees that are near the sensor will significantly affect these readings, and therefore correlation may be poor in a comparison of readings with those of a remote reference station. If site-specific factors affect comparisons with a local weather station's data, an alternative evaluation may be conducted on-site by comparing the real-time wind direction against a research grade compass reading and the wind speed against a portable wind sensor.

If the readings do not agree with the reference readings, check to ensure the sensor is correctly oriented. See the manual (web link) in Appendix F for instructions on how to orient the wind sensor.

8.4.11 Precipitation Calibration/Maintenance

If an installation is equipped for precipitation measurement, a Vaisala tipping bucket rain gauge (QMR102) can be installed on the rooftop of the pergola. The gauge uses a traditional tipping method that provides a dry contact closure at each tip.

Maintenance of the gauge includes inspecting the funnel for damage or blockage. Debris such as leaves or other materials must be removed from the funnel. The plastic filter at the base of the funnel is not removable; however, the funnel itself can be removed from the base and can be cleaned by pouring water backwards through the spout. The funnel is required to be level, and adjustments to the mount should be made as needed. The bucket below the funnel should be cleaned at least twice a year to ensure a correct measurement. The user's guide (web link) for the QMR102 can be found in Appendix F and contains a detailed procedure for the dynamic calibration of the tipping bucket.

8.4.12 Cairpol Sensor Maintenance

The Cairpol CairClip O_3/NO_2 and/or Cairpol CairClip NO_2 sensor is installed on select VG stations for evaluation purposes only. The calibration of the Cairpol sensor is performed by the manufacturer prior to shipping. No additional calibrations need to be performed on the unit. This device has an approximate one-year life expectancy and should be returned to the manufacturer for replacement at that time.

A particulate filter installed on the end of the unit must be changed after six months of operation. To change the filter, remove it by grasping its edge and pulling down. Replace it with a new filter and allow 12 hours for the Cairpol sensor signal to stabilize, as specified by the manufacturer.

8.4.13 MA350 Flow Check

If the AethLabs MA350 Black Carbon sensor is installed on the station, its flow should be checked at the same time as the pDR-1500 and 2B Technologies ozone sensors by using a reference device. The MA350 sensor uses special fittings for its inlet connections that can be obtained from the manufacturer. A minimum of five flow readings should be taken and recorded along with their average. The target flow rate for this device is 150 mL/min. If the flow measurement fails, ensure that the flow is set properly. The flow setpoint can be set using the AethLabs software. See Appendix F (web link) for more information.

8.4.14 MA350 Zero Check

To zero check the MA350 sensor, simply connect a particulate filter to the device inlet and ensure the readings go to zero. As this sensor is still experimental, any issues that arise with questionable readings should be communicated directly to the manufacturer.

8.4.15 MA350 Cartridge Replacement

The MA350 measures concentrations optically by reading attenuation at specific locations on an automatically advancing filter tape cartridge. The positions on this cartridge are limited, and therefore it must be replaced occasionally. The runtime for each cartridge will depend on ambient loading conditions and is estimated to be approximately six months. Replacement cartridges can be purchased directly from the manufacturer.

To replace the cartridge, loosen the flathead screw on the top of the instrument's front panel. The cartridge will be locked in place. Scroll to "Release Tape" on the menu, navigating by using the left or right panel buttons beneath the screen. Press the center button to select the correct option, and the cartridge will make a sound as it is released. Remove the old tape and replace it with a new unit. Before beginning a new measurement, scroll to "Clamp Tape" on the menu by navigating using the left or right panel buttons beneath the screen. Press the center button to select the correct option and the cartridge will make a sound as it locks into place. Once the cartridge is installed, new measurements can commence.

APPENDICES

Appendices listed as available as separate files may be obtained at the EPA Science Inventory website. https://cfpub.epa.gov/si/

Science Inventory is a searchable database of research products from EPA. Science Inventory records provide descriptions of the product, contact information, and links to available printed material or websites.

Appendix A. Drawings and Schematics

Appendix A will include all drawings and schematics for existing systems. Some of the schematics will need to be modified from the originals. Appendix A will also include new drawings for Generation 3 systems. All schematics and drawings in Appendix A will be either (.pdf) or (.html) and will be readily accessible to any user with Adobe and web-browsing capabilities.

Appendix A is provided in separate files.

- 00 -SafePlay Bench Drawing.pdf
- 01 -SafePlay Supports.pdf
- 02 -Village Green Foundation Options.pdf
- 03a-Sign Support M-1.3.pdf
- 03b-Sign Support M-1.4.pdf
- 04-Solar Panel Support.pdf
- 05-Rotated Solar Panel Support M-1.pdf
- 06-PM Sampling Line M-1.6.pdf
- 07-Power Schematic - Gen 2.pdf
- 08-Sensor-Signals Schematic Gen 2 v2.pdf
- 08-Sensor-Signals Schematic Gen 2.pdf
- 09-Wind Mast Edited M-1.2.pdf

10 -vg gen 3 design-schematic1v2.html

Appendix B. Arduino Code

Appendix B is provided in separate files.

Appendix C. Parts List

Appendix C is provided in separate files.

- Gen 2 Parts List – Appendix (pdf)
- Gen 3 Parts List – Appendix (pdf)

Appendix D. Circuit Board Designs

Appendix D is provided in a separate file. See “read me” file.

- Gen3 VG v2.123

Appendix E. Photos

Appendix E is provided in a separate file.

- Appendix E - Photos COMPLETE (July 2014).pdf

Appendix F. User Manuals

Appendix F is provided as web links.

File Name	Manual
https://twobtech.com/docs/manuals/model_106-L_revG-2.pdf	Ozone Monitor Operation Manual 2B Technologies, Inc. Operation Manual Models 106-MH and OEM-106-MH
http://cairpol.com/en/home/ Please contact the manufacturer for the manual.	Cairpol CairSens – UART Version Communications Protocol Measured data download
http://www.co2meters.com/Documentation/Manuals/Manual-GSS-Sensors.pdf	GSS Sensor User's Manual COZIR™, SprintIR™, MISIR™ and MinIR™ Sensors August, 2015 Rev. I CO2 Measurement Specialists
http://www.vaisala.fi/Vaisala%20Documents/User%20Guides%20and%20Quick%20Ref%20Guides/HMP60%20and%20HMP110%20Series%20User's%20Guide%20in%20English.pdf	Vaisala USER'S GUIDE Vaisala Humidity and Temperature Probes HMP60 and HMP110 Series
https://aethlabs.com/sites/all/content/microaeth/maX/MA200%20MA300%20MA350%20Operating%20Manual%20Rev%2002%20Mar%202018.pdf	microAeth® MA Series MA200, MA300, MA350 Operating Manual AethLabs
https://tools.thermofisher.com/content/sfs/manuals/EPM-manual-PDR1500.pdf	MIE pDR-1500 Instruction Manual Active Personal Particulate Monitor Part Number 105983-00 11Aug2017
http://products.baseline-mocon.com/Asset/piDTECH%20eVx%20Data%20SheetD039.2.pdf	piD-TECH® eVx™ OEM PHOTOIONIZATION SENSORS Mocon
https://www.vaisala.com/en Please contact the manufacturer for the manual.	Automatic Weather Station MAWS101 & MAWS201 USER'S GUIDE M210243en-A January 2002 Vaisala
https://www.sierrawireless.com/~/media/support_downloads/airlink/docs/user_guides/rvn_pp_x_userguides/raven%20xe%20verizon_userguide_v4.ashx	Raven XE for Verizon User Guide 20080616 Rev 4.0 Sierra Wireless

File Name	Manual
https://2n1s7w3qw84d2ysnx3ia2bct-wpengine.netdna-ssl.com/wp-content/uploads/2014/02/RD.IOM_.Operators_Manual.01.EN_.pdf	RELAYDRIVER™ Logic Module Accessory Installation and Operation Manual Four Channel Relay Driver Morningstar Corporation
http://www.youngusa.com/Manuals/09101-90(J).pdf	METEOROLOGICAL INSTRUMENTS INSTRUCTIONS WIND MONITOR - SE MODEL 09101 P/N: 09101-90 REV: I111215 R. M. Young Company
https://www.marlec.co.uk/wp-content/uploads/2013/03/Rutland-504-efurl-A5-PRINT.pdf	Rutland 504 Windcharger & Rutland 504 efurl Owner's Manual Installation and Operation Doc No: SM-150 Issue C 17.03.14
https://source.sierrawireless.com/resources/airlink/hardware_reference_docs/airlink_rv_series_userguide/#	AirLink RV50 Hardware User Guide 4117313 Rev 1 Sierra Wireless
https://www.apogeeinstruments.com/content/SP-110-manual.pdf	Apogee Instruments, Inc. OWNER'S MANUAL PYRANOMETER Models SP-110 and SP-230 Copyright © 2016 Apogee Instruments, Inc.
https://www.morningstarcorp.com/wp-content/uploads/2014/02/SS3.IOM_.Operators_Manual.01.EN_.pdf	SUNSAVER PV SYSTEM CONTROLLERS Installation and Operation Manual SunSaver Models Included in this Manual: ••SS-6-12V / SS-6L-12V ••SS-10-12V ••SS-10L-12V / SS-10L-24V ••SS-20L-12V / SS-20L-24V Morningstar Corporation
http://dealer.sunwize.com/emart_documents/4742/SWPB-Modules.pdf	SunWize Technologies SunWize® SP Series Solar Modules Industrial Solar Electric Modules: 90 Watts – 150 Watts / 12 Volts