



apogee[®]

INSTRUMENTS

OWNER'S MANUAL

EPAR SENSOR

Model SQ-617

Rev: 30-Aug-2022



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CERTIFICATE OF COMPLIANCE

EU Declaration of Conformity

This declaration of conformity is issued under the sole responsibility of the manufacturer:

Apogee Instruments, Inc.
721 W 1800 N
Logan, Utah 84321
USA

for the following product(s):

Models: SQ-617
Type: ePAR Sensor

The object of the declaration described above is in conformity with the relevant Union harmonization legislation:

| | |
|-------------|--|
| 2014/30/EU | Electromagnetic Compatibility (EMC) Directive |
| 2011/65/EU | Restriction of Hazardous Substances (RoHS 2) Directive |
| 2015/863/EU | Amending Annex II to Directive 2011/65/EU (RoHS 3) |

Standards referenced during compliance assessment:

| | |
|-----------------|--|
| EN 61326-1:2013 | Electrical equipment for measurement, control, and laboratory use – EMC requirements |
| EN 63000:2018 | Technical documentation for the assessment of electrical and electronic products with respect to the restriction of hazardous substances |

Please be advised that based on the information available to us from our raw material suppliers, the products manufactured by us do not contain, as intentional additives, any of the restricted materials including lead (see note below), mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB), polybrominated diphenyls (PBDE), bis (2-ethylhexyl) phthalate (DEHP), butyl benzyl phthalate (BBP), dibutyl phthalate (DBP), and diisobutyl phthalate (DIBP). However, please note that articles containing greater than 0.1 % lead concentration are RoHS 3 compliant using exemption 6c.

Further note that Apogee Instruments does not specifically run any analysis on our raw materials or end products for the presence of these substances, but we rely on the information provided to us by our material suppliers.

Signed for and on behalf of:
Apogee Instruments, August 2022

Bruce Bugbee
President
Apogee Instruments, Inc.



CERTIFICATE OF COMPLIANCE

UK Declaration of Conformity

This declaration of conformity is issued under the sole responsibility of the manufacturer:

Apogee Instruments, Inc.
721 W 1800 N
Logan, Utah 84321
USA

for the following product(s):

Models: SQ-617
Type: ePAR Sensor

The object of the declaration described above is in conformity with the relevant UK Statutory Instruments and their amendments:

| | |
|---------------|--|
| 2016 No. 1091 | The Electromagnetic Compatibility Regulations 2016 |
| 2012 No. 3032 | The Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations 2012 |

Standards referenced during compliance assessment:

| | |
|--------------------|--|
| BS EN 61326-1:2013 | Electrical equipment for measurement, control, and laboratory use – EMC requirements |
| BS EN 63000:2018 | Technical documentation for the assessment of electrical and electronic products with respect to the restriction of hazardous substances |

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Further note that Apogee Instruments does not specifically run any analysis on our raw materials or end products for the presence of these substances, but we rely on the information provided to us by our material suppliers.

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Apogee Instruments, August 2022

Bruce Bugbee
President
Apogee Instruments, Inc.

INTRODUCTION

Radiation that drives photosynthesis is called photosynthetically active radiation (PAR) and, historically, is defined as total radiation across a range of 400 to 700 nm. PAR is almost universally quantified as photosynthetic photon flux density (PPFD) in units of micromoles per square meter per second ($\mu\text{mol m}^{-2} \text{s}^{-1}$, equal to microEinsteins per square meter per second) summed from 400 to 700 nm (total number of photons from 400 to 700 nm). However, ultraviolet and far-red photons outside the defined PAR range of 400-700 nm can also contribute to photosynthesis and influence plant responses (e.g., flowering).

Data from recent studies indicate that far-red photons synergistically interact with photons in the historically defined PAR range of 400-700 nm to increase photochemical efficiency in leaves (Hogewoning et al., 2012; Murakami et al., 2018; Zhen and van Iersel, 2017; Zhen et al., 2019). Measurements from whole plants and plant canopies indicate adding far-red photons (using far-red LEDs with peaks near 735 nm and outputting photons across a range of about 700-750 nm) to radiation sources outputting photons in the 400-700 nm range increases canopy photosynthesis equal to the addition of the same number of photons in the 400-700 nm range for multiple species, and C3 and C4 photosynthetic pathways, but far-red photons alone are photosynthetically inefficient and result in minimal photosynthesis (Zhen and Bugbee, 2020a; Zhen and Bugbee, 2020b).

This research suggests that far-red photons drive canopy photosynthesis with similar efficiency as photons in the traditional PAR range when they are acting synergistically with photons in the 400-700 nm range, meaning when far-red photons are added to radiation sources outputting 400-700 nm photons. Thus, far-red photons need to be included in the definition of PAR (Zhen et al., 2021).

Sensors that measure PPFD are often called quantum sensors due to the quantized nature of radiation. A quantum refers to the minimum quantity of radiation, one photon, involved in physical interactions (e.g., absorption by photosynthetic pigments). In other words, one photon is a single quantum of radiation. Sensors that function like traditional quantum sensors but measure a wider range of wavelengths can be thought of as an 'extended range' quantum sensor.

Typical applications of traditional quantum sensors include incoming PPFD measurement over plant canopies in outdoor environments or in greenhouses and growth chambers and reflected or under-canopy (transmitted) PPFD measurement in the same environments. The extended photosynthetically active radiation (ePAR) sensor detailed in this manual uses a detector that is sensitive to radiation from $383\text{-}757 \text{ nm} \pm 5 \text{ nm}$, which allows it to measure photons from Far-red.

Apogee Instruments SQ-600 series ePAR sensors consist of a cast acrylic diffuser (filter), photodiode, and signal processing circuitry mounted in an anodized aluminum housing. A cable to connect the sensor to a measurement device is also included. SQ-600 series ePAR sensors are designed for continuous photon flux density measurements in indoor or outdoor environments. The SQ-617 sensors output a digital signal using SDI-12 communication protocol.

Hogewoning et al. 2012. Photosynthetic Quantum Yield Dynamics: From Photosystems to Leaves. *The Plant Cell*, 24: 1921–1935.

Murakami et al. 2018. A Mathematical Model of Photosynthetic Electron Transport in Response to the Light Spectrum Based on Excitation Energy Distributed to Photosystems. *Plant Cell Physiology*. 59(8): 1643–1651.

Zhen and Van Iersel. 2017. Far-red light is needed for efficient photochemistry and photosynthesis. *Journal of Plant Physiology*. 209: 115–122.

Zhen et al. 2019. Far-red light enhances photochemical efficiency in a wavelength-dependent manner. *Physiologia Plantarum*. 167(1):21-33.

Zhen and Bugbee. 2020a. Far-red photons have equivalent efficiency to traditional photosynthetic photons: Implications for redefining photosynthetically active radiation. *Plant Cell and Environment*. 2020; 1–14.

Zhen and Bugbee. 2020b. Substituting Far-Red for Traditionally Defined Photosynthetic Photons Results in Equal Canopy Quantum Yield for CO₂ Fixation and Increased Photon Capture During Long-Term Studies: Implications for Re-Defining PAR. *Frontiers in Plant Science*. 11:1-14.

Zhen et al. 2021. Why Far-Red Photons Should Be Included in the Definition of Photosynthetic Photons and the Measurement of Horticultural Fixture Efficacy. *Frontiers in Plant Science*. 12:1-4.

SENSOR MODELS

This manual covers the digital model SQ-617 ePAR SDI-12 Sensor (in bold below). Additional models are covered in their respective manuals.

| Model | Signal |
|---------------|---------------|
| SQ-610 | Self-powered |
| SQ-612 | 0-2.5 V |
| SQ-614 | 4-20 mA |
| SQ-615 | 0-5 V |
| SQ-616 | USB |
| SQ-617 | SDI-12 |
| SQ-618 | Modbus |



A sensor's model number and serial number are located on the bottom of the sensor. If the manufacturing date of a specific sensor is required, please contact Apogee Instruments with the serial number of the sensor.

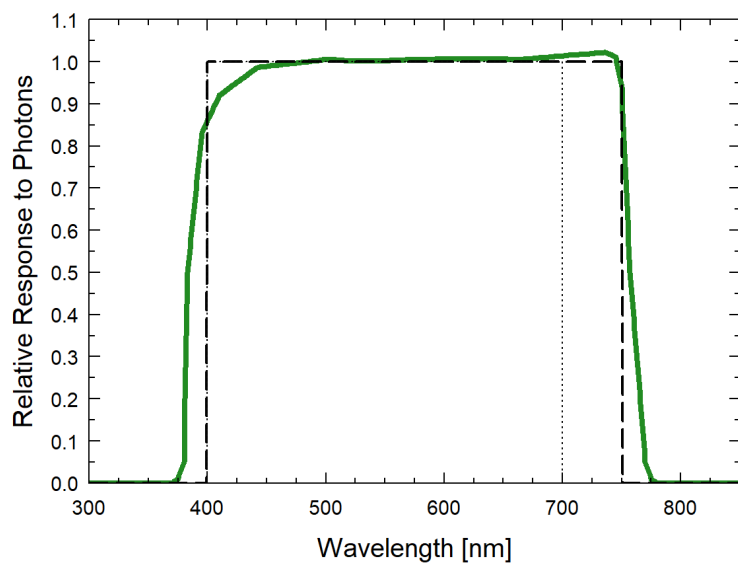
SPECIFICATIONS

| SQ-617-SS | |
|---------------------------------|---|
| Input Voltage | 5.5 to 24 V DC |
| Current Draw | 1.4 mA (quiescent), 1.8 mA (active) |
| Calibration Uncertainty | ± 5 % (see Calibration Traceability below) |
| Measurement Range | 0 to 4000 $\mu\text{mol m}^{-2} \text{s}^{-1}$ |
| Measurement Repeatability | Less than 0.5 % |
| Long-term Drift (Non-stability) | Less than 2 % per year |
| Non-linearity | Less than 1 % (up to 4000 $\mu\text{mol m}^{-2} \text{s}^{-1}$) |
| Response Time | 0.6 s, time for detector signal to reach 95 % following a step change; fastest data transmission rate for SDI-12 circuitry is 1 s |
| Field of View | 180° |
| Spectral Range | 383 to 757 nm ± 5 nm (wavelengths where response is greater than 50 %; see Spectral Response below) |
| Directional (Cosine) Response | ± 2 % at 45° zenith angle, ± 5 % at 75° zenith angle (see Directional Response below) |
| Azimuth Error | Less than 0.5 % |
| Tilt Error | Less than 0.5 % |
| Temperature Response | -0.11 ± 0.04 % per C |
| Uncertainty in Daily Total | Less than 5 % |
| Housing | Anodized aluminum body with acrylic diffuser |
| IP Rating | IP68 |
| Operating Environment | -40 to 70 C; 0 to 100 % relative humidity; can be submerged in water up to depths of 30 m |
| Dimensions | 30.5 mm diameter, 37 mm height |
| Mass (with 5 m of cable) | 140 g |
| Cable | 5 m of two conductor, shielded, twisted-pair wire; TPR jacket; pigtail lead wires; stainless steel (316), M8 connector |
| Warranty | 4 years against defects in materials and workmanship |

Calibration Traceability

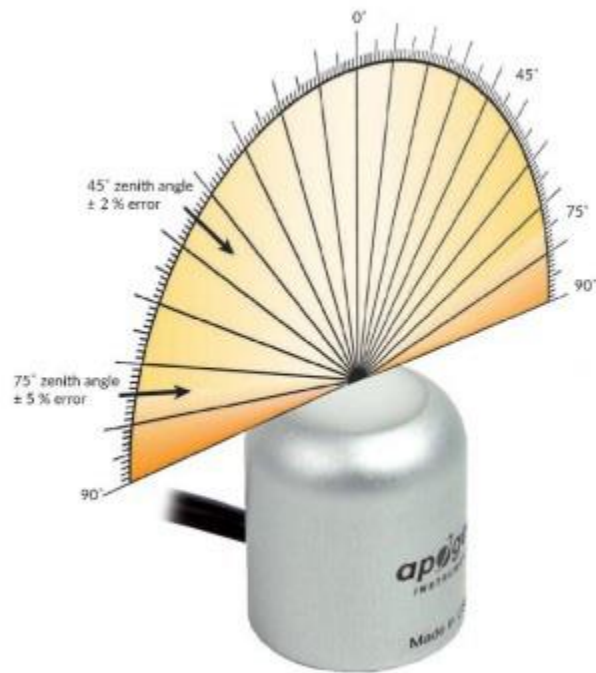
Apogee Instruments SQ-600 series ePAR sensors are calibrated through side-by-side comparison to the mean of four transfer standard sensors under a reference lamp. The transfer standard sensors are recalibrated with a quartz halogen lamp traceable to the National Institute of Standards and Technology (NIST).

Spectral Response

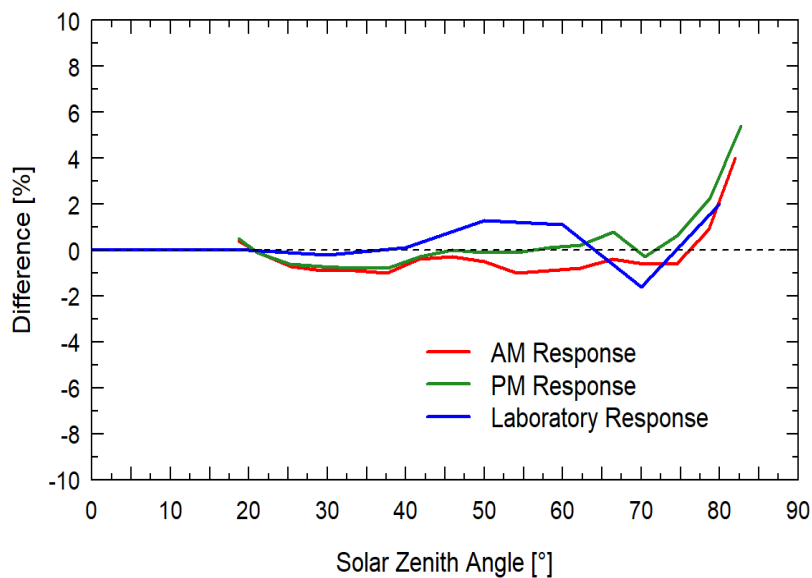


Mean spectral response measurements of four replicate Apogee SQ-600 series ePAR Sensors. Incremental spectral response measurements were made at 10 nm increments across a wavelength range of 370 to 800 nm in a monochromator with an attached electric light source. Measured spectral data from each quantum sensor were refined and normalized by comparing measured spectral response of the monochromator/electric light combination to measured spectral differences from a quantum sensor reference.

Cosine Response



Directional, or cosine, response is defined as the measurement error at a specific angle of radiation incidence. Error for Apogee SQ-600 series ePAR Sensor is approximately $\pm 2\%$ and $\pm 5\%$ at solar zenith angles of 45° and 75° , respectively.



Mean directional (cosine) response of seven Apogee series quantum sensors. Directional response measurements were made on the rooftop of the Apogee building in Logan, Utah. Directional response was calculated as the relative difference of quantum sensors from the mean of replicate reference quantum sensors (LI-COR models LI-190 and LI-190R, Kipp & Zonen model PQS 1). Data were also collected in the laboratory using a reference lamp and positioning the sensor at varying angles.

DEPLOYMENT AND INSTALLATION

Mount the sensor to a solid surface with the nylon mounting screw provided. To accurately measure photon flux density incident on a horizontal surface, the sensor must be level. An Apogee Instruments model AL-100 leveling plate is recommended for this purpose. To facilitate mounting on a cross arm, an Apogee Instruments model AL-120 mounting bracket is recommended.



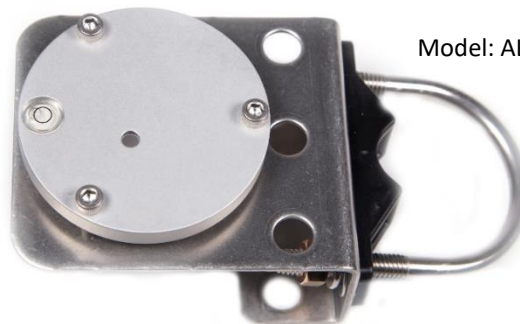
Nylon Screw: 10-32 x 3/8



Nylon Screw: 10-32 x 3/8

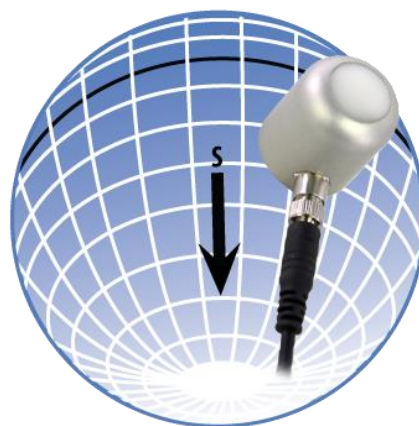


Model: AL-100



Model: AL-120

To minimize azimuth error, the sensor should be mounted with the cable pointing toward true north in the northern hemisphere or true south in the southern hemisphere. Azimuth error is typically less than 0.5 %, but it is easy to minimize by proper cable orientation.



In addition to orienting the cable to point toward the nearest pole, the sensor should also be mounted such that obstructions (e.g., weather station tripod/tower or other instrumentation) do not shade the sensor. **Once mounted, the blue cap should be removed from the sensor.** The blue cap can be used as a protective covering for the sensor when it is not in use.

CABLE CONNECTORS

Apogee offers cable connectors to simplify the process of removing sensors from weather stations for calibration (the entire cable does **not** have to be removed from the station and shipped with the sensor).

The ruggedized M8 connectors are rated IP68, made of corrosion-resistant marine-grade stainless-steel, and designed for extended use in harsh environmental conditions.

Instructions

Pins and Wiring Colors: All Apogee connectors have six pins, but not all pins are used for every sensor. There may also be unused wire colors inside the cable. To simplify datalogger connection, we remove the unused pigtail lead colors at the datalogger end of the cable.

If a replacement cable is required, please contact Apogee directly to ensure ordering the proper pigtail configuration.

Alignment: When reconnecting a sensor, arrows on the connector jacket and an aligning notch ensure proper orientation.

Disconnection for extended periods: When disconnecting the sensor for an extended period of time from a station, protect the remaining half of the connector still on the station from water and dirt with electrical tape or other method.

Tightening: Connectors are designed to be firmly finger-tightened only. There is an o-ring inside the connector that can be overly compressed if a wrench is used. Pay attention to thread alignment to avoid cross-threading. When fully tightened, 1-2 threads may still be visible.

WARNING: Do **not** tighten the connector by twisting the black cable or sensor head, only twist the metal connector (yellow arrows).



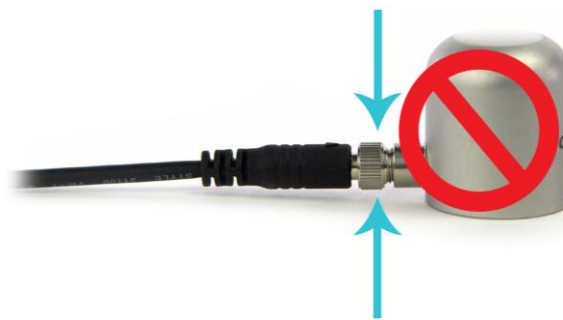
Cable connectors are attached directly to the head.



A reference notch inside the connector ensures proper alignment before tightening.



When sending sensors in for calibration, only send the sensor head.



Finger-tighten firmly

OPERATION AND MEASUREMENT

The SQ-617 ePAR sensor has an SDI-12 output, where extended photosynthetically active radiation is returned in digital format. Measurement of SQ-617 ePAR sensors requires a measurement device with SDI-12 functionality that includes the M or C command.

Wiring



Sensor Calibration

All Apogee SDI-12 ePAR sensor models (SQ-600 series) have sensor-specific calibration coefficients determined during the custom calibration process. Coefficients are programmed into the microcontrollers at the factory.

SDI-12 Interface

The following is a brief explanation of the serial digital interface SDI-12 protocol instructions used in Apogee SQ-617 ePAR sensors. For questions on the implementation of this protocol, please refer to the official version of the SDI-12 protocol: <http://www.sdi-12.org/specification.php> (version 1.4, August 10, 2016).

Overview

During normal communication, the data recorder sends a packet of data to the sensor that consists of an address and a command. Then, the sensor sends a response. In the following descriptions, SDI-12 commands and responses are enclosed in quotes. The SDI-12 address and the command/response terminators are defined as follows:

Sensors come from the factory with the address of “0” for use in single sensor systems. Addresses “1 to 9” and “A to Z”, or “a to z”, can be used for additional sensors connected to the same SDI-12 bus.

“!” is the last character of a command instruction. In order to be compliant with SDI-12 protocol, all commands must be terminated with a “!”. SDI-12 language supports a variety of commands. Supported commands for the Apogee Instruments SQ-617 ePAR sensors are listed in the following table (“a” is the sensor address. The following ASCII Characters are valid addresses: “0-9” or “A-Z”).

Supported Commands for Apogee Instruments SQ-617 ePAR Sensors

| Instruction Name | Instruction Syntax | Description |
|---|--------------------|--|
| Acknowledge Active Command | a! | Responds if the sensor with address a is on the line |
| Send Identification Command | aI! | Responds with sensor information |
| Measurement Command | aM! | Tells the sensor to take a measurement |
| Measurement Command w/ Check Character | aMC! | Tells the sensor to take a measurement and return it with a check character |
| Change Address Command | aAb! | Changes the sensor address from a to b |
| Concurrent Measurement Command | aC! | Used to take a measurement when more than one sensor is used on the same data line |
| Concurrent Measurement Command w/ Check Character | aCC! | Used to take a measurement when more than one sensor is used on the same data line. Data is returned with a check character. |
| Address Query Command | ?! | Used when the address is unknown to have the sensor identify its address, all sensors on data line respond |
| Get Data Command | aD0! | Retrieves the data from a sensor |
| Verification Command | aV! | Returns sensor coefficients as multiplier, offset, solar multiplier, and immersion effect correction factor |
| Running Average Command | aXAVG! | Returns or sets the running average for sensor measurements. |

Make Measurement Command: M!

The make measurement command signals a measurement sequence to be performed. Data values generated in response to this command are stored in the sensor's buffer for subsequent collection using "D" commands. Data will be retained in sensor storage until another "M", "C", or "V" command is executed. M commands are shown in the following examples:

| Command | Response | Response to 0D0! |
|---------------|---------------|--|
| aM! or aM0! | a0011<cr><lf> | Returns $\mu\text{mol m}^{-2} \text{s}^{-1}$ |
| aM1! | a0011<cr><lf> | Returns millivolt output |
| aM2! | a0011<cr><lf> | Returns $\mu\text{mol m}^{-2} \text{s}^{-1}$ |
| aM3! | a0011<cr><lf> | Returns immersed $\mu\text{mol m}^{-2} \text{s}^{-1}$ for underwater measurements |
| aM4! | a0011<cr><lf> | Returns angle offset from vertical in degrees. (0 degrees if pointed up, 180 degrees if pointed down.) Available in sensors with serial number 3033 or greater. |
| aMC! or aMC0! | a0011<cr><lf> | Returns $\mu\text{mol m}^{-2} \text{s}^{-1}$ w/CRC |
| aMC1! | a0011<cr><lf> | Returns millivolt output w/ CRC |
| aMC2! | a0011<cr><lf> | Returns $\mu\text{mol m}^{-2} \text{s}^{-1}$ w/ CRC |
| aMC3! | a0011<cr><lf> | Returns immersed $\mu\text{mol m}^{-2} \text{s}^{-1}$ for underwater measurements w/ CRC |
| aMC4! | a0011<cr><lf> | Returns angle offset from vertical in degrees w/CRC. (0 degrees if pointed up, 180 degrees if pointed down.) Available in sensors with serial numbers 3033 or greater. |

where a is the sensor address ("0-9", "A-Z", "a-z") and M is an upper-case ASCII character.

The data values are separated by the sign "+", as in the following example (0 is the address):

| Command | Sensor Response | Sensor Response when data is ready |
|---------|------------------|------------------------------------|
| 0M0! | 00011<cr><lf> | 0<cr><lf> |
| 0D0! | 0+2000.0<cr><lf> | |
| 0M1! | 00011<cr><lf> | 0<cr><lf> |
| 0D0! | 0+400.0<cr><lf> | |
| 0M2! | 00011<cr><lf> | 0<cr><lf> |
| 0D0! | 0+2000.0<cr><lf> | |
| 0M3! | 00011<cr><lf> | 0<cr><lf> |
| 0D0! | 0+2000.0<cr><lf> | |
| 0M4! | a0011<cr><lf> | 0<cr><lf> |
| 0D0! | 0+90.2<cr><lf> | |

where 2000.0 is $\mu\text{mol m}^{-2} \text{s}^{-1}$.

Concurrent Measurement Command: aC!

A concurrent measurement is one which occurs while other SDI-12 sensors on the bus are also making measurements. This command is similar to the “aM!” command, however, the nn field has an extra digit and the sensor does not issue a service request when it has completed the measurement. Communicating with other sensors will NOT abort a concurrent measurement. Data values generated in response to this command are stored in the sensor's buffer for subsequent collection using “D” commands. The data will be retained in the sensor until another “M”, “C”, or “V” command is executed:

| Command | Response | Response to 0D0! |
|---------------|----------------|--|
| aC! or aC0! | a00101<cr><lf> | Returns $\mu\text{mol m}^{-2} \text{s}^{-1}$ |
| aC1! | a00101<cr><lf> | Returns millivolt output |
| aC2! | a00101<cr><lf> | Returns $\mu\text{mol m}^{-2} \text{s}^{-1}$ |
| aC3! | a00101<cr><lf> | Returns immersed $\mu\text{mol m}^{-2} \text{s}^{-1}$ for underwater measurements |
| aC4! | a00101<cr><lf> | Returns angle offset from vertical in degrees. (0 degrees if pointed up, 180 degrees if pointed down.) Available in sensors with serial number 3033 or greater. |
| aCC! or aCC0! | a00101<cr><lf> | Returns $\mu\text{mol m}^{-2} \text{s}^{-1}$ w/CRC |
| aCC1! | a00101<cr><lf> | Returns millivolt output w/ CRC |
| aCC2! | a00101<cr><lf> | Returns $\mu\text{mol m}^{-2} \text{s}^{-1}$ w/ CRC |
| aCC3! | a00101<cr><lf> | Returns immersed $\mu\text{mol m}^{-2} \text{s}^{-1}$ for underwater measurements w/ CRC |
| aCC4! | a00101<cr><lf> | Returns angle offset from vertical in degrees w/CRC. (0 degrees if pointed up, 180 degrees if pointed down.) Available in sensors with serial numbers 3033 or greater. |

where a is the sensor address (“0-9”, “A-Z”, “a-z”, “*”, “?”) and C is an upper-case ASCII character.

For example (0 is the address):

| Command | Sensor Response |
|---------|------------------|
| 0C0! | 000101<cr><lf> |
| 0D0! | 0+2000.0<cr><lf> |
| 0C1! | 000101<cr><lf> |
| 0D0! | 0+400.0<cr><lf> |
| 0C2! | 000101<cr><lf> |
| 0D0! | 0+2000.0<cr><lf> |
| 0C3! | 000101<cr><lf> |
| 0D0! | 0+2000.0<cr><lf> |
| 0C4! | 000101<cr><lf> |
| 0D0! | 0+90.2<cr><lf> |

where 2000.0 is $\mu\text{mol m}^{-2} \text{s}^{-1}$ and 400.0 is mV.

Change Sensor Address: aAb!

The change sensor address command allows the sensor address to be changed. If multiple SDI-12 devices are on the same bus, each device will require a unique SDI-12 address. For example, two SDI-12 sensors with the factory address of 0 requires changing the address on one of the sensors to a non-zero value in order for both sensors to communicate properly on the same channel:

| Command | Response | Description |
|---------|-----------|----------------------------------|
| aAb! | b<cr><lf> | Change the address of the sensor |

where a is the current (old) sensor address ("0-9", "A-Z"), A is an upper-case ASCII character denoting the instruction for changing the address, b is the new sensor address to be programmed ("0-9", "A-Z"), and ! is the standard character to execute the command. If the address change is successful, the datalogger will respond with the new address and a <cr><lf>.

Send Identification Command: a!

The send identification command responds with sensor vendor, model, and version data. Any measurement data in the sensor's buffer is not disturbed:

| Command | Response | Description |
|---------|------------------------------------|--|
| "a!" | a13Apogee SQ-617vvvxx...xx<cr><lf> | The sensor serial number and other identifying values are returned |

where a is the sensor address ("0-9", "A-Z", "a-z", "*", "?"), 521 is the sensor model number, vvv is a three-character field specifying the sensor version number, and xx...xx is serial number.

Running Average Command

The running average command can be used to set or query the number of measurements that are averaged together before returning a value from a M! or MC! command. For example, if a user sends the command "0XAVG10!" to sensor with address 0, that sensor will average 10 measurements before sending the averaged value to the logger. To turn off averaging, the user should send the command "aXAVG1" to the sensor. To query the sensor to see how many measurements are being averaged, send the command "aXAVG!" and the sensor will return the number of measurements being averaged (see table below). The default for sensors is to have averaging turned off.

| Command Name | Characters Sent | Response | Description |
|-----------------------|-----------------|----------|---|
| Query running Average | aXAVG! | an | a = sensor address, n = number of measurements used in average calculation. Note: n may be multiple digits. |
| Set running Average | aXAVGn! | a | a = sensor address, n = number of measurements to be used in average calculation. Note: n may be any value from 1 to 100. |

Spectral Error

Quantum sensors are the most common instrument for measuring PPFD, because they are about an order of magnitude lower cost the spectroradiometers, but spectral errors must be considered. The spectral errors in the table below can be used as correction factors for individual radiation sources.

Spectral Errors for PPFD Measurements with Apogee SQ-610 Series ePAR Sensors

| Radiation Source (Error Calculated Relative to Sun, Clear Sky) | SQ-610 Series PPFD Error [%] |
|--|---------------------------------|
| Sun (Clear Sky) | 2.5 |
| Sun (Cloudy Sky) | 2.6 |
| Cool White Fluorescent (T5) | -0.5 |
| Metal Halide | 0.7 |
| Ceramic Metal Halide | 0.3 |
| Mogul Base HPS | 0.3 |
| Dual-ended HPS | 0.6 |
| Cool White LED | -1.0 |
| Warm White LED | -0.4 |
| Blue LED (442 nm) | -2.7 |
| Cyan LED (501 nm) | -0.7 |
| Green LED (529 nm) | -0.7 |
| Amber LED (598 nm) | -0.4 |
| Red LED (666 nm) | -0.3 |
| Far Red LED (737 nm) | 4.5 |

Immersion Effect Correction Factor

When a radiation sensor is submerged in water, more of the incident radiation is backscattered out of the diffuser than when the sensor is in air (Smith, 1969; Tyler and Smith, 1970). This phenomenon is caused by the difference in the refractive index for air (1.00) and water (1.33) and is called the immersion effect. Without correction for the immersion effect, radiation sensors calibrated in air can only provide relative values underwater (Smith, 1969; Tyler and Smith, 1970). Immersion effect correction factors can be derived by making measurements in air and at multiple water depths at a constant distance from a lamp in a controlled laboratory setting.

Apogee SQ-610 series ePAR sensors have an immersion effect correction factor of 1.25. This correction factor should be multiplied by PPFD measurements made underwater to yield accurate PPFD.

Further information on underwater measurements and the immersion effect can be found on the Apogee webpage (<http://www.apogeeinstruments.com/underwater-par-measurements/>).

Smith, R.C., 1969. An underwater spectral irradiance collector. *Journal of Marine Research* 27:341-351.

Tyler, J.E., and R.C. Smith, 1970. *Measurements of Spectral Irradiance Underwater*. Gordon and Breach, New York, New York. 103 pages.

MAINTENANCE AND RECALIBRATION

Blocking of the optical path between the target and detector can cause low readings. Occasionally, accumulated materials on the diffuser of the upward-looking sensor can block the optical path in three common ways:

1. Moisture or debris on the diffuser.
2. Dust during periods of low rainfall.
3. Salt deposit accumulation from evaporation of sea spray or sprinkler irrigation water.

Apogee Instruments upward-looking sensors have a domed diffuser and housing for improved self-cleaning from rainfall, but active cleaning may be necessary. Dust or organic deposits are best removed using water, or window cleaner, and a soft cloth or cotton swab. Salt deposits should be dissolved with vinegar and removed with a cloth or cotton swab. **Salt deposits cannot be removed with solvents such as alcohol or acetone.** Use only gentle pressure when cleaning the diffuser with a cotton swab or soft cloth to avoid scratching the outer surface. The solvent should be allowed to do the cleaning, not mechanical force. **Never use abrasive material or cleaner on the diffuser.**

It is recommended that sensors be recalibrated every two years. See the Apogee webpage for details regarding return of sensors for recalibration (<http://www.apogeeinstruments.com/tech-support-recalibration-repairs/>).

TROUBLESHOOTING AND CUSTOMER SUPPORT

Independent Verification of Functionality

If the sensor does not communicate with the datalogger, use an ammeter to check the current drain. It should be near 1.4 mA when the sensor is not communicating and spike to approximately 1.8 mA when the sensor is communicating. Any current drain greater than approximately 6 mA indicates a problem with power supply to the sensors, wiring of the sensor, or sensor electronics.

Compatible Measurement Devices (Dataloggers/Controllers/Meters)

Any datalogger or meter with SDI-12 functionality that includes the M or C command.

An example datalogger program for Campbell Scientific dataloggers can be found on the Apogee webpage at <https://www.apogeeinstruments.com/content/Quantum-Digital.CR1>.

Modifying Cable Length

SDI-12 protocol limits cable length to 60 meters. For multiple sensors connected to the same data line, the maximum is 600 meters of total cable (e.g., ten sensors with 60 meters of cable per sensor). See Apogee webpage for details on how to extend sensor cable length (<http://www.apogeeinstruments.com/how-to-make-a-weatherproof-cable-splice/>).

RETURN AND WARRANTY POLICY

RETURN POLICY

Apogee Instruments will accept returns within 30 days of purchase as long as the product is in new condition (to be determined by Apogee). Returns are subject to a 10 % restocking fee.

WARRANTY POLICY

What is Covered

All products manufactured by Apogee Instruments are warranted to be free from defects in materials and craftsmanship for a period of four (4) years from the date of shipment from our factory. To be considered for warranty coverage an item must be evaluated by Apogee.

Products not manufactured by Apogee (spectroradiometers, chlorophyll content meters, EE08-SS probes) are covered for a period of one (1) year.

What is Not Covered

The customer is responsible for all costs associated with the removal, reinstallation, and shipping of suspected warranty items to our factory.

The warranty does not cover equipment that has been damaged due to the following conditions:

1. Improper installation, use, or abuse.
2. Operation of the instrument outside of its specified operating range.
3. Natural occurrences such as lightning, fire, etc.
4. Unauthorized modification.
5. Improper or unauthorized repair.

Please note that nominal accuracy drift is normal over time. Routine recalibration of sensors/meters is considered part of proper maintenance and is not covered under warranty.

Who is Covered

This warranty covers the original purchaser of the product or another party who may own it during the warranty period.

What Apogee Will Do

At no charge Apogee will:

1. Either repair or replace (at our discretion) the item under warranty.
2. Ship the item back to the customer by the carrier of our choice.

Different or expedited shipping methods will be at the customer's expense.

How to Return an Item

1. Please do not send any products back to Apogee Instruments until you have received a Return Merchandise



Authorization (RMA) number from our technical support department by submitting an online RMA form at www.apogeeinstruments.com/tech-support-recalibration-repairs/. We will use your RMA number for tracking of the service item. Call (435) 245-8012 or email techsupport@apogeeinstruments.com with questions.

2. For warranty evaluations, send all RMA sensors and meters back in the following condition: Clean the sensor's exterior and cord. Do not modify the sensors or wires, including splicing, cutting wire leads, etc. If a connector has been attached to the cable end, please include the mating connector – otherwise the sensor connector will be removed in order to complete the repair/recalibration. **Note:** *When sending back sensors for routine calibration that have Apogee's standard stainless-steel connectors, you only need to send the sensor with the 30 cm section of cable and one-half of the connector. We have mating connectors at our factory that can be used for calibrating the sensor.*

3. Please write the RMA number on the outside of the shipping container.

4. Return the item with freight pre-paid and fully insured to our factory address shown below. We are not responsible for any costs associated with the transportation of products across international borders.

Apogee Instruments, Inc.
721 West 1800 North Logan, UT
84321, USA

5. Upon receipt, Apogee Instruments will determine the cause of failure. If the product is found to be defective in terms of operation to the published specifications due to a failure of product materials or craftsmanship, Apogee Instruments will repair or replace the items free of charge. If it is determined that your product is not covered under warranty, you will be informed and given an estimated repair/replacement cost.

PRODUCTS BEYOND THE WARRANTY PERIOD

For issues with sensors beyond the warranty period, please contact Apogee at techsupport@apogeeinstruments.com to discuss repair or replacement options.

OTHER TERMS

The available remedy of defects under this warranty is for the repair or replacement of the original product, and Apogee Instruments is not responsible for any direct, indirect, incidental, or consequential damages, including but not limited to loss of income, loss of revenue, loss of profit, loss of data, loss of wages, loss of time, loss of sales, accrument of debts or expenses, injury to personal property, or injury to any person or any other type of damage or loss.

This limited warranty and any disputes arising out of or in connection with this limited warranty ("Disputes") shall be governed by the laws of the State of Utah, USA, excluding conflicts of law principles and excluding the Convention for the International Sale of Goods. The courts located in the State of Utah, USA, shall have exclusive jurisdiction over any Disputes.

This limited warranty gives you specific legal rights, and you may also have other rights, which vary from state to state and jurisdiction to jurisdiction, and which shall not be affected by this limited warranty. This warranty extends only to you and cannot be transferred or assigned. If any provision of this limited warranty is unlawful, void, or unenforceable, that provision shall be deemed severable and shall not affect any remaining provisions. In case of any inconsistency between the English and other versions of this limited warranty, the English version shall prevail.

THIS WARRANTY CANNOT BE CHANGED, ASSUMED, OR AMENDED BY ANY OTHER PERSON OR AGREEMENT

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