OWNER'S MANUAL

RADIATION FROST DETECTOR

Model SF-110

Rev: 20-Jan-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: SF-110
Type: Radiation Frost Detector

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 50581:2012	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, January 2022

Bruce Bugbee
President
Apogee Instruments, Inc.

INTRODUCTION

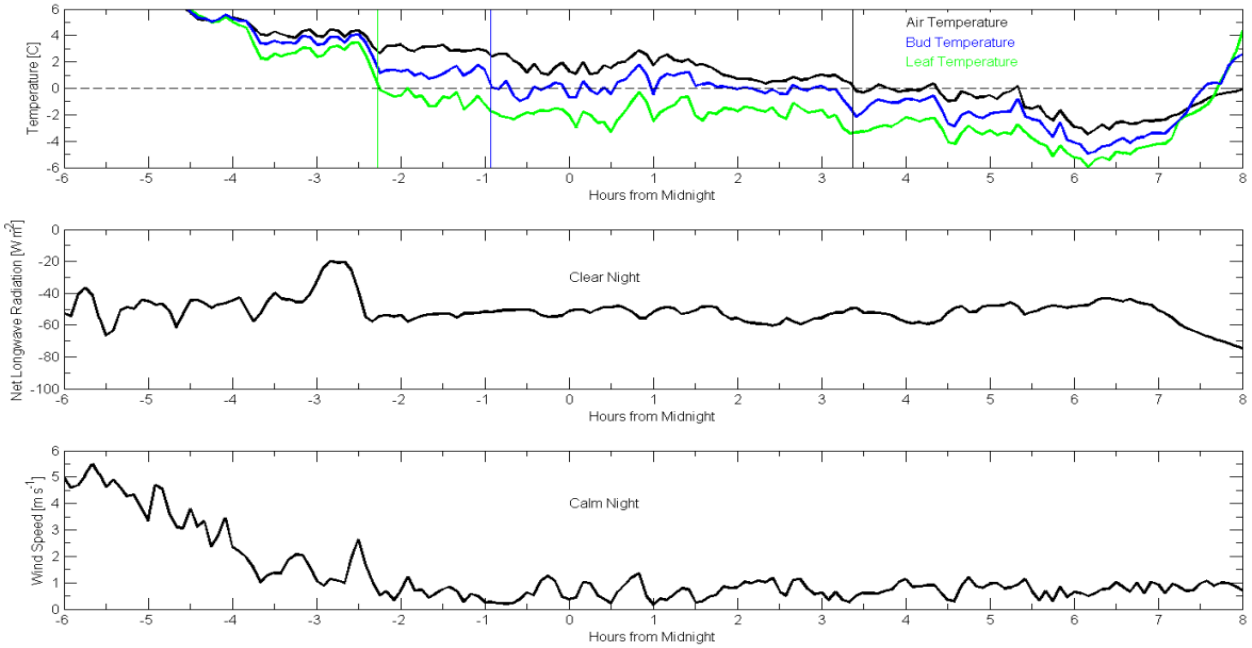
In January 2022, the SF-110 (formerly called the leaf and bud temperature sensor) underwent a redesign to improve performance and ruggedness. As part of this redesign, the bud temperature sensor was removed, as it was determined the leaf measurement was most critical. The SF-110 was renamed the radiation frost detector.

Frost damage to plants can have a large impact on crop yield and quality. Protection of crops during frost events is dependent on the accuracy of plant temperature predictions. Often, air temperature is not a reliable predictor of timing, duration, and severity of frost events because plant canopy temperatures can be significantly different than air temperature under certain environmental conditions.

On clear, calm nights, plant leaf temperature can drop below freezing even if air temperature remains above 0 C (see figure on page 5). This is called a radiation frost and is caused by the lack of air mixing (wind) near the surface and a negative net longwave radiation balance at the surface (more longwave radiation is being emitted from the surface than what the surface is absorbing from the clear sky). Under cloudy and/or windy conditions, radiation frost events do not occur.

Apogee model SF-110 radiation frost detectors are designed to approximate plant leaf temperatures for prediction of frost events. SF-110 radiation frost detectors are intended for applications in cropped fields and orchards when air temperatures will be near freezing and where air temperature measurements are not a good predictor of frost formation.

Apogee Instruments SF-110 radiation frost detectors consist of a precision thermistor combined with a simulated leaf. The sensor is designed to mimic a plant leaf. SF-110 radiation frost detectors provide close approximations of leaf temperature and can be used to predict frost on leaves. The detector is weatherproof and designed for continuous temperature measurement in the same environmental conditions to which plants are exposed. The SF-110 detector outputs one analog voltage signal (when supplied with an input voltage) that is related to the resistance of a thermistor. The resistance is directly related to simulated leaf temperature.



Simulated leaf (green trace in top panel) temperature from an Apogee model SF-110 compared to air temperature (black trace in top panel) and simulated bud (blue trace in top panel) temperature throughout a clear (net longwave radiation is plotted in middle panel), calm (wind speed is plotted in bottom panel) night during spring in Logan, Utah. Simulated leaf temperatures reached the freezing point approximately 5.5 hours before air temperature.

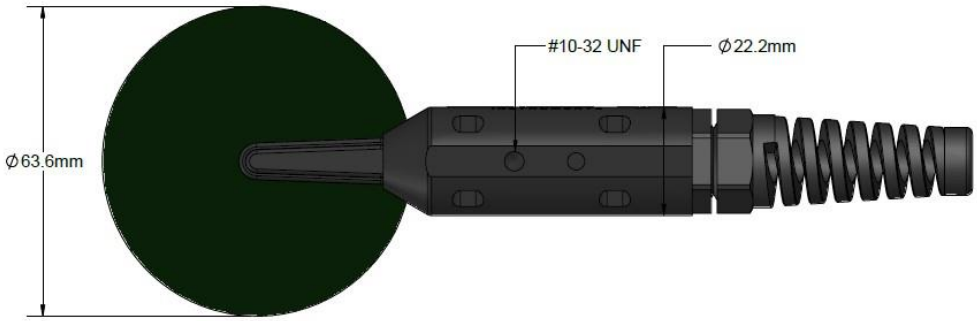
SENSOR MODELS

SF-110 radiation frost detectors use the same precision thermistors as Apogee ST series thermistor temperature sensors, but the thermistor is mounted into a simulated leaf. SF-110 detectors are rugged and weatherproof and are designed to be exposed to ambient environmental conditions.

A sensor's model number and serial number are located on a label near the cable connector. If you need the manufacturing date of your sensor, please contact Apogee Instruments with the serial number of your sensor.

SPECIFICATIONS

	SF-110
Measurement Range	-50 to 70 C
Measurement Uncertainty	0.1 (from 0 to 70 C); 0.2 C (from -25 to 0 C); 0.4 C (from -50 to -25 C)
Measurement Repeatability	Less than 0.05 C
Long-term Drift (Non-stability)	Less than 0.02 C per year (when used in non-condensing environments where the annual average temperature is less than 30 C; continuously high temperatures or continuously humid environments increase drift rate)
Equilibration Time	10 s
Self-Heating	Less than 0.01 C (typical, assuming pulsed excitation of 2.5 V DC); 0.08 C at 5 C (maximum, assuming continuous input excitation of 2.5 V DC)
Operating Environment	-50 to 70 C; 0 to 100 % relative humidity
Input Voltage Requirement	2.5 V DC excitation (recommended, see Operation and Measurement section)
Output Voltage Requirement	2.5 V DC
Current Draw	0.1 mA DC at 70 C (maximum, assuming continuous input excitation of 2.5 V DC)
Dimensions	17.5 cm length, 2.2 cm pipe diameter, 6.0 cm disk diameter (see diagram below)
Mass	75 g
Cable	5 m of three conductor, shielded, twisted-pair wire; cable is available in 5, 10, and 20 m lengths (custom lengths available by request); TPR jacket (high water resistance, high UV stability, flexibility in cold conditions); pigtail lead wires



DEPLOYMENT AND INSTALLATION

Apogee SF-110 radiation frost detectors should be mounted within—or very near—the plant canopy where frost detection is desired. This ensures the simulated leaf is in the same environment as the actual leaves.

An Apogee Instruments model AM-260 mounting bracket can be used to mount the detector to a cross arm or pole. The AM-260 allows adjustment of the angle of the detector. Mounting the detector with a slight downward slope, or tilt to one side, is recommended to minimize moisture/debris build-up on the simulated leaf.

CABLE CONNECTORS

Apogee sensors offer 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.

Inline cable connectors are installed 30 cm from the head (pyranometer pictured)

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.

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

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 from a station, protect the remaining half of the connector still on the station from water and dirt with electrical tape or other method.

When sending sensors in for calibration, only send the short end of the cable and half the connector.

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.

Finger-tighten firmly

OPERATION AND MEASUREMENT

Connect the detector to a measurement device (meter, datalogger, controller) capable of inputting 2.5 V DC, and measuring and displaying or recording a millivolt (mV) signal (an input measurement range of 0 to 2500 mV is required to cover the entire temperature range of the detector). In order to maximize measurement resolution and signal-to-noise ratio, the input range of the measurement device should closely match the output range of the thermistor.

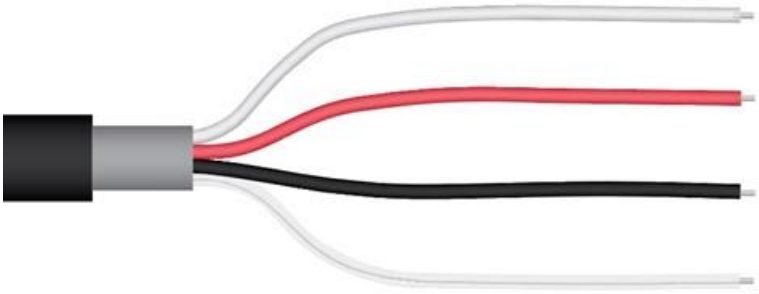
VERY IMPORTANT: In January 2022, the SF-110 (formerly called the leaf and bud temperature sensor) underwent a redesign to improve performance and ruggedness. As part of this redesign, the bud temperature sensor was removed, as it was determined the leaf measurement was most critical. The SF-110 was renamed the radiation frost detector.

Radiation Frost Detector

Leaf and Bud Temperature Sensor

RADIATION FROST DETECTORS WIRING

Wiring for Radiation Frost Detectors (as of January 2022)



White: Therm 1 (positive leaf thermistor lead)

Red: Excitation channel (excitation for leaf thermistor)

Black: Therm 1 (negative leaf thermistor lead)

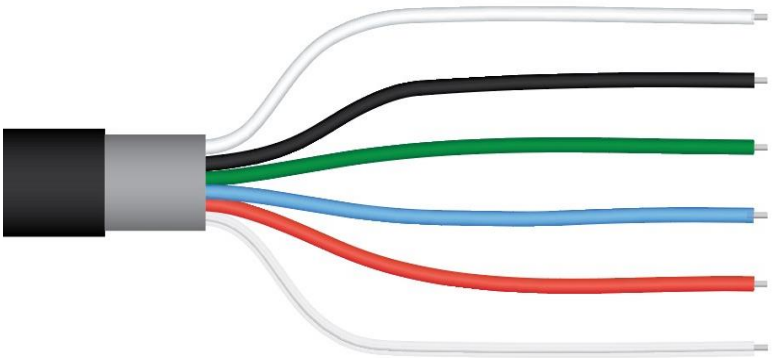
Clear: Shield/Ground

Measurement devices (e.g., datalogger, controller) do not measure resistance directly, but determine resistance from a half-bridge measurement, where an excitation voltage is input across the thermistor and an output voltage is measured across the bridge resistor (circuit diagram shown on page 13 is for simulated leaf thermistor).

LEAF AND BUD TEMPERATURE SENSORS WIRING (OLD DESIGN)

VERY IMPORTANT: Apogee changed all wiring colors of our bare-lead sensors in March 2018. To ensure proper connection to your data device, please note your serial number then use the appropriate wiring configuration below.

Wiring for Leaf and Bud Temperature Sensor Serial Numbers 1138 and above



White: Therm 1 (positive leaf thermistor lead)

Black: Therm 1 (negative leaf thermistor lead)

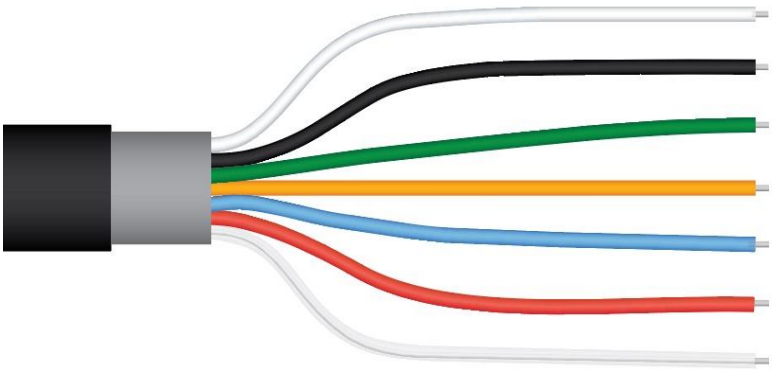
Green: Therm 2 (positive bud thermistor lead)

Blue: Therm 2 (negative bud thermistor lead)

Red: Excitation channel (excitation for leaf and bud thermistor)

Clear: Shield/Ground

Wiring for Leaf and Bud Temperature Sensor Serial Numbers range 0-1137



White: Excitation channel (excitation for bud thermistor)

Black: Single-ended channel (positive leaf thermistor lead)

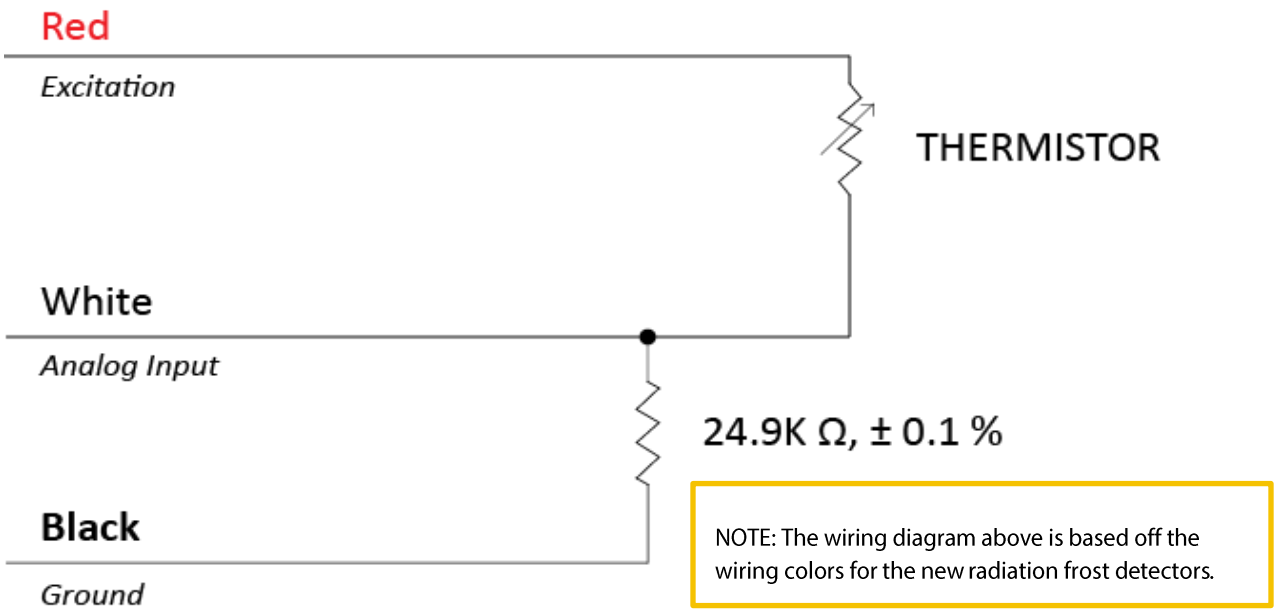
Green: Single-ended channel (positive bud thermistor lead)

Orange: Analog ground (negative bud thermistor lead)

Blue: Analog ground (negative leaf thermistor lead)

Red: Excitation channel (excitation for leaf thermistor)

Clear: Analog ground (shield wire)



An excitation voltage of 2.5 V DC is recommended to minimize self-heating and current drain, while still maintaining adequate measurement sensitivity (mV output from thermistor per C). However, other excitation voltages can be used. Decreasing the excitation voltage will decrease self-heating and current drain but will also decrease thermistor measurement sensitivity. Increasing the excitation voltage will increase thermistor measurement sensitivity but will also increase self-heating and current drain.

Conversion of Thermistor Resistance to Temperature

The thermistor in the simulated leaf has a resistive element where resistance changes with temperature. Thermistor resistance (R_T, in Ω) is measured with a half-bridge measurement, requiring an excitation voltage input (V_{EX}) and a measurement of output voltage (V_{OUT}):

$$R_T = 24900\left(\frac{V_{EX}}{V_{OUT}} - 1\right) \qquad (1)$$

where 24900 is the resistance of the bridge resistor in Ω. From resistance, temperature (T_K, in Kelvin) is calculated with the Steinhart-Hart equation and thermistor specific coefficients:

$$T_K = \frac{1}{A + B\ln(R_T) + C(\ln(R_T))^3} \qquad (2)$$

where A = 1.129241 x 10^{-3}, B = 2.341077 x 10^{-4}, and C = 8.775468 x 10^{-8} (Steinhart-Hart coefficients). If desired, measured temperature in Kelvin can be converted to Celsius (T_C):

$$T_C = T_K - 273.15 \qquad (3)$$

MAINTENANCE AND RECALIBRATION

Apogee SF-110 radiation frost detectors are weatherproof and are designed to be continuously deployed in outdoor conditions. When detectors are not is use, it is recommended that they be removed from the measurement environment, cleaned, and stored. SF-110 detectors deployed in the field should be periodically cleaned to remove all dust and debris.

The thermistor in SF-110 detectors is not factory calibrated, but it comes with a generic calibration (see Steinhart-Hart coefficients in OPERATION AND MEASUREMENT section). A custom calibration can be derived by comparing the temperature from the simulated leaf thermistor to a reference temperature measurement. Often, a simple offset can be used to make the measured temperature match the reference temperature.

TROUBLESHOOTING AND CUSTOMER SUPPORT

Independent Verification of Functionality

Apogee SF-110 radiation frost detectors yield an independent resistance that is proportional to simulated leaf temperature. A quick and easy check of functionality of the thermistor can be accomplished with an ohmmeter.

To check the simulated leaf circuit, connect the lead wires of the ohmmeter to the red and white wires from the detector. The resistance should read 10 kΩ (10,000 ohms) at 25 C. If detector temperature is less than 25 C, resistance will be higher. If detector temperature is greater than 25 C, resistance will be lower. Connect the lead wires of the ohmmeter to the white and black wires from the detector. The resistance should read 24.9 kΩ and should not vary. Connect the lead wires of the ohmmeter to the red and black wires from the sensor. The resistance should be the sum of the resistances measured across the red and white wires, and white and black wires (e.g., 10 kΩ plus 24.9 kΩ at 25 C).

Compatible Measurement Devices (Dataloggers/Controllers/Meters)

Measurement of thermistor resistance requires an input excitation voltage, where 2.5 V DC is recommended. A compatible measurement device should have the capability to supply the necessary voltage.

The sensitivity (mV output from thermistor per C) of the temperature measurements varies with the excitation voltage and varies as a function of temperature. With an excitation voltage of 2.5 V DC, the sensitivity is lowest near the ends of the measurement range, -50 and 70 C. A compatible measurement device (e.g., datalogger or controller) should have resolution of at least 0.6 mV, in order to produce temperature resolution of less than 0.1 C across the entire temperature measurement range (less than 0.05 C from -35 to 45 C).

An example datalogger program for Campbell Scientific dataloggers can be found on the Apogee webpage at http://www.apogeeinstruments.com/content/Radiation-Frost-Detection-Sensor.CR1.

Modifying Cable Length

When the detector is connected to a measurement device with high input impedance, detector output signals are not changed by splicing on additional cable in the field. Tests have shown that if the input impedance of the measurements device is 1 mega-ohm or higher then there is negligible effect on the SF-110 leaf and bud temperature sensor, even after adding up to 100 m of cable. See Apogee webpage for details on how to extend sensor cable length (http://www.apogeeinstruments.com/how-to-make-a-weatherproof-cable-splice/). For cable extensions, shielded, twisted pair cable is recommended, in order to minimize electromagnetic interference. This is particularly important for long lead lengths in electromagnetically noisy environments.

The precision bridge resistors are located at the pigtail end of the cable. Thus, the SF-110 cable should not be shortened, otherwise the bridge resistor will be removed.

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 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 other 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, accruement 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 by 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