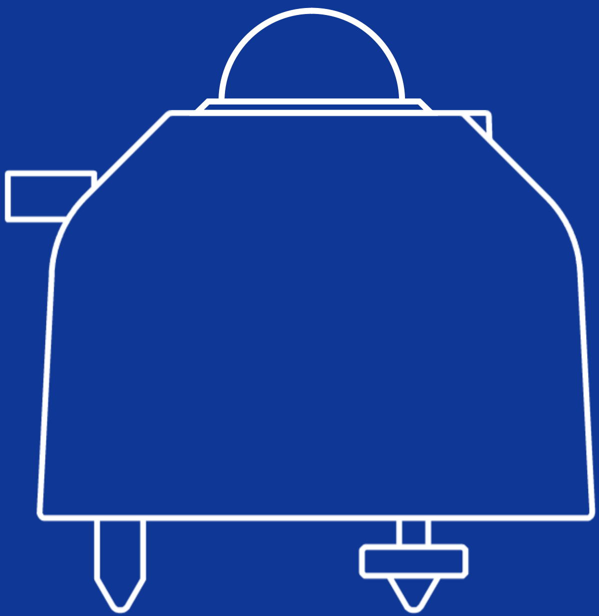
INSTRUCTION MANUAL

Pyranometer
ISO9060: 2018 Class B
ISO9060: 1990 First Class

MS-60
MS-60S



EKO

1. Index

2. Important User Information

Thank you for using EKO Products.

Reading this manual is recommended prior to installation and operation of the product. Keep this manual in safe and handy place for whenever it is needed.
For any questions, please contact us at below:

2-1. Contact Information

EKO INSTRUMENTS CO., LTD.			
Asia, Oceania Region			
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2-2. Warranty and Liability

For warranty terms and conditions, please contact EKO Instruments or your distributer for further details.
EKO guarantees that the product delivered to customer has been tested to ensure the instrument meets its published specifications. The warranty included in the conditions of delivery is valid only if the product has been installed and used according to the instructions provided in this operating manual.

In case any manufacturing defect[s] will occur, the defected part[s] will be repaired or replaced under warranty; however the warranty will not be applicable if:

- Any modification or repair has been done by other than EKO service personnel.
- The damage or defect is caused by disrespecting the specifications mentioned on the product brochure or instruction manual.

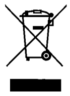
2-3. About Operating Manual

This manual was issued: 2019/07/30

Version Number: 4

2-4. Environment

1. WEEE Directive 2002/96/EC [Waste Electrical and Electronic Equipment]



In August of 2005, the European Union [EU] implemented the EU WEEE Directive 2002/96/EC and later the WEEE Recast Directive 2012/19/EU requiring Producers of electronic and electrical equipment [EEE] to manage and finance the collection, reuse, recycling and to appropriately treat WEEE that the Producer places on the EU market after August 13, 2005. The goal of this directive is to minimize the volume of electrical and electronic waste disposal and to encourage re-use and recycling at the end of life.

EKO products are subject to the WEEE Directive 2002/96/EC. EKO Instruments has labeled its branded electronic products with the WEEE Symbol [figure Trash bin] to alert our customers that products bearing this label should not be disposed of in a landfill or with municipal or household waste in the EU.
If you have purchased EKO Instruments branded electrical or electronic products in the EU and are intending to discard these products at the end of their useful life, please do not dispose of them with your other household or municipal waste. Disposing of this product correctly will help save valuable resources and prevent any potential negative effects on human health and the environment, which could otherwise arise from inappropriate waste handling.

2. RoHS Directive 2002/95/EC

EKO Instruments has completed a comprehensive evaluation of its product range to ensure compliance with RoHS Directive 2002/95/EC regarding maximum concentration values for substances. As a result all products are manufactured using raw materials that do not contain any of the restricted substances referred to in the RoHS Directive 2002/95/EC at concentration levels in excess of those permitted under the RoHS Directive 2002/95/EC, or up to levels allowed in excess of these concentrations by the Annex to the RoHS Directive 2002/95/EC.

2-5. ISO/IEC 17025

EKO Instruments Co. Ltd. calibration laboratory is accredited by Perry Johnson Laboratory Accreditation, Inc. [PJLA] to perform pyranometer and pyrheliometer calibrations in accordance with the requirements of ISO/IEC17025, which are relevant to calibration and testing.

EKO is a unique manufacturer who can offer calibration service for pyranometers and pyrheliometers in-house. Based on the applied calibration methods EKO provides the best quality solar sensor calibrations compliant to the international standards defined by ISO/IEC17025 / 9847 [Indoor method] and ISO9059 [Outdoor method] [Certification: L13-94-R2 / www.pjlabs.com]

ISO/IEC17025 provides a globally accepted basis for laboratory accreditation that specifies the management and technical requirements. With calibrations performed at the EKO Instruments laboratory we enable our customers to:

- Clearly identify the applied calibration methods and precision
- Be traceable to the World Radiation Reference [WRR] through defined industrial standards:
  - ISO9846 Calibration of a pyranometer using a pyrheliometer
  - ISO9847 Calibration of field pyranometer by comparison to a reference pyranometer
  - ISO9059 Calibration of field pyrheliometers by comparison to a reference pyrheliometer
- Obtain repeatable and reliable calibration test results through consistent operations

Our clients will obtain a highly reliable data by using an ISO/IEC17025 calibrated sensor. Our Accredited lab is regularly re-examined to ensure that they maintain their standards of technical expertise.

2-6. CE Declaration

IMPORTANT USER INFORMATION

DECLARATION OF CONFORMITY

We: EKO INSTRUMENTS CO., LTD
1-21-8 Hatagaya Shibuya-ku,
Tokyo 151-0072 JAPAN

Declare under our sole responsibility that the product:

Product Name: Pyranometer
Model No.: MS-60, MS-60S

To which this declaration relates is in conformity with the following harmonized standards of other normative documents:

Harmonized standards:

EN 61326-1:2006 Class A [Emission]
EN 61326-1:2006 Class A [Immunity]

Following the provisions of the directive:
EMC-directive: 89/336/EEC
Amendment to the above directive: 93/68/EEC

Date: April 4 , 2019

Position of Authorized Signatory: General Manager of R & D Department

Name of Authorized Signatory: Shuji Yoshida

Signature of Authorized Signatory: Shuji Yoshida

3. Safety Information

EKO Products are designed and manufactured with consideration for safety; however, please make sure to read and understand this instruction manual thoroughly to be able to operate the instrument safely in the correct manner.

WARNING CAUTION	Attention to user; pay attention to the instructions given on the instruction manual with this sign.
HIGH VOLTAGE WARNING	High voltage is used; pay special attention to instructions given in this instruction manual with this sign to prevent electric leakage and/or electric shocks.

3-1. General Warnings

1. Setup

- The installation base or mast should have enough load capacity for the instrument to be mounted. Fix the pyranometer securely to the base or mast with bolts and nuts; otherwise, the instrument may drop due to gale or earthquake, which may lead to unexpected accidents.
- Make sure the instrument and the cables are installed in a location where they will not get soaked.
- When using this instrument by connecting to a measuring instrument, make sure to connect the shield cable to either the signal ground terminal on the measuring instrument side or GND [the reference potential on the single end input side]. Noise may be included in the measurement data.
- Although this product is tested to meet EMC Directive compliance requirements, it may not fully satisfy its primary specification/performance when using this product near following locations where strong electromagnetic wave is generated. Please pay attention to the installation environment.

  Outdoor: High voltage power line, power receiver/distribution facility, etc.

  Indoor: Large-size chiller, large rotation device, microwave, etc.
- Do not use this product in environment where corrosive gas, such as ammonia and sulfurous acid gas, are generated. It may cause malfunction.
- Do not install in area that cause salt damages. It may cause malfunction by paint peeling off or corrosion. When installing in area with risk of salt damages, make sure to take following measures:
  1. Wrap the connector with self-fusing tape.
  2. Change the fixing screw to bolt screw made of aluminum.
  3. Run the cables in resin pipe or metal pipe treated with salt-resistant paint such as molten zinc plating.
  4. Periodically clean.

- Do not use this instrument in vacuum environment.
- If the cable and main unit are in risk for getting damaged by birds and small animals, protect the cable and the main unit by using:
  1. Reflective tape
  2. Repellent
  3. Cable duct
  4. Installing bird-spike
- When using the 0 to1V, please prepare the precision resister 100Ω. If 0-1V output is not selected as a purchase option, 0-1V output is off. Or the setting can be changed with the 485 / USB conversion cable and dedicated software.

2. Handing

- Be careful with glass dome when handling instruments. Strong impact to this part may damage the glass and may cause injuries by broken glass parts.
- When carrying the MS-60 with sunscreen attached, always hold the instrument from the bottom. Holding only the sunscreen part may lead to dropping the sensor as it comes off from the sunscreen.

3. Power Supply [MS-60S]

- Make sure to ground the power supply. When grounding is insufficient, it may cause not only measurement error due to noise, but also cause electric shock and leakage accidents.
- Check the voltage and types of specified power supply before connecting this instrument. When improper power supply is connected, it may cause malfunction and/or accident.
- Use this instrument with 0.5A fuse connected to the power supply line in series. Without connecting the fuse, it has risks of generating heat and fire due to large-current flowing by the power supply when internal damage on the electronics will occurs.

4. Introduction

4-1. Introduction

The MS-60 sensor is perfectly suited for sampling 10-minute averages of the solar radiative flux in horizontal or tilted measurement configurations. It is fully compliant with the “Spectrally flat Pyranometer of Class B” of ISO9060: 2018 norm.

The MS-60 Pyranometer is sensitive within the spectral range from 285 to 3000nm. It can be applied within the most demanding applications for solar radiation measurements.
The practical light-weight anodized aluminum housing, the highly efficient sensor coating and the precision-machined hemispherical glass dome provide the good performance characteristics of the MS-60. The EKO MS-60 is a perfect balance between cost-effectiveness and quality.

With combination of optional MV-01 [ventilator + heater unit], reduces the dew condensation and accumulation of dusts and snow on glass dome by continuously blowing air.

Each MS-60 is calibrated and tested at EKO upon manufacture against EKO’s reference sensors, which are fully traceable to the WRR [World Radiometric Reference] maintained at the PMOD/WRC [Physikalisch-Meteorologisches Observatorium Davos/World Radiation Center] in Davos, Switzerland. Besides, EKO provides a unique calibration service for pyranometers and pyrheliometers compliant to the international standards defined by ISO/IEC17025/9847/9059 [Outdoor calibration method]. When an ISO/ IEC17025 calibrated sensor is purchased, EKO offers sensor at nearly constant calibration uncertainty. The Accredited lab is regularly re-examined to ensure that they maintain their standards of technical expertise.

ISO 9060, an international industry standard, was revised to the 2nd edition in 2018. Along with this revision, the Pyranometers are classified in order of the highest grade "Class A" "Class B" "Class C" and for Pyranometers that meet the response time and spectral selectivity criteria, "fast response pyranometer" and "spectrally flat radiometer" are classified as a sub-category.

1. MS-60

The analog MS-60 can be used in traditional sensor networks in combination with a data logger with high-resolution mV input channels. The sensor has a light-weight anodized aluminum housing and precision-machined hemispherical glass dome to provide good performance characteristics. The MS-60 is a perfect balance between cost-effectiveness and quality.

2. MS-60S

The MS-60S with smart sensor technology and onboard diagnostic functions. 4 different output types can be selected, which is a great benefit for system integrators who work with various industrial standards. This new Smart transducer will also have additional features such as internal temperature and humidity sensors and a tilt sensor for remote sensor diagnostics. These additional internal sensors will help the user to monitor the stability of the irradiance sensors as well as to ensure its proper installation and maintenance practices.

Up to 100 smart sensors can be connected in one network. The signal converter settings can be changed using the optional RS485 / USB converter cable and the configurator software.

Category of ISO9060: 2018

“spectrally flat pyranometer of class B”

Key features:

- Outputs (**MODBUS 485 RTU**, **SDI-12**, **4-20mA**, configurable 0-10mA / 0-1V with external 100Ω precision shunt resistor)
- Wide range of voltage supplies available [DC 5 to 36 V]
- With built-in tilt / role sensor to check the sensor position over time
- Humidity and temperature sensor to monitor the sensor temperature and condition of the drying agents (silica gel) inside the sensor body.

4-2. Package Contents

Check the package contents first; if any missing item or damage is noticed, please contact EKO immediately.

Table4-1. Package Contents

Contents	MS-60 / 60S
Pyranometer	○
Output Cable *	○
Sunscreen	○
Calibration Certificate	○
Quick Start Guide	○
Instruction Manual	Not included in the package [Please download from EKO Website]
Inspection Report	-
Fixing Bolts	[M5] x2 [Bolt Length: 75mm]
Washers	[M5] x4
Nuts	[M5] x2

* Standard length is 10m for signal cable. For different length of cables [e.g. to meet your application needs] please contact EKO or your local distributor.

5. Getting Started

5-1. Parts Descriptions

Each part name and its main function is described below.

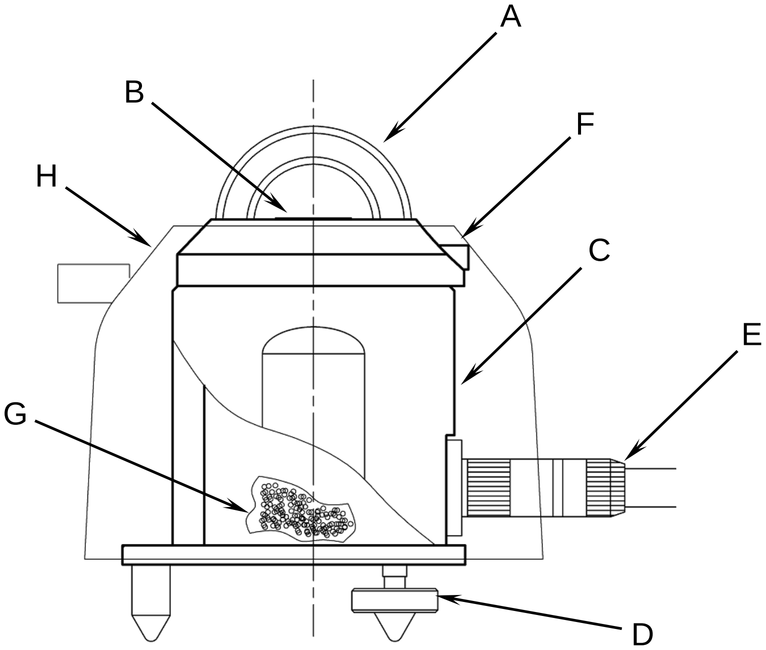


Figure 5-1. Pyranometer Parts Name

Table 5-1. Parts Name

Parts Name
A. [Inner, Outer] Glass Dome
B. Detector
C. Body
D. Leveling Screw
E. Cable, Connector
F. Spirit level
G. Silica-gel
H. Sunscreen

1. Inner and Outer Glass Domes

2 glass domes create a sealed environment for the detector and protects it against the dirt, rain and wind. Besides the mechanical protection, the optical properties of the glass domes minimize the undesired influence of long wave radiation on the shortwave radiation: the domes of the EKO pyranometers are only transparent for radiation emitted by the sun. Hence they block the undesired infrared radiation emitted by the Earth's atmosphere. The glass domes of all EKO thermopile pyranometers permit to measure the cosine-weighted global solar irradiance over the entire hemisphere, i.e. with a field-of-view of 180 degree.

2. Detector

Thermopile, which generates voltage proportional to temperature difference [Seebeck Effect], is used for the detector. When light is irradiated on the sensor, temperature of the detector increases; creating the temperature difference at cold junction [body part] will generate electromotive force on the thermopile. The pyranometer will output this electromotive force as voltage, and by measuring this voltage to determine the solar irradiance. The thermopile detector, which is the heart of the sensor, determines the majority of the measurement properties [e.g. response time, zero offset B, non-linearity, sensitivity, etc.]. EKO thermopile detectors are very stable in time due to the black absorber material, which has high absorption and no wavelength dependency is used on the detector surface.

3. Sunscreen, Body and Spirit Level

Sunscreen prevent body temperature increase generated by direct sun-light. Weather resistant metal is used for the body, which has resistant against decrease of nocturnal radiation and heat radiation, and rain and dusts. The integrated sprit level is used to setup and maintain the sensor in a horizontally leveled position.

4. Drying agent

A silica-gel is used to keep the sensor volume dry. The dry air inside the sensor body prevents condensation of humidity on the inside of the glass dome.

5. Cable and Cable Connector

All pyranometers are shipped with a 10 meter long output cable as standard length*.
Durable materials are used for the cable and connector, and pin terminals are attached at the end of the cable for easy connection with data logger terminal block.

* If longer cables, round terminals or fork terminals are required, please contact EKO Instruments or your distributor. [Also see [7. Specification, 7-4. Accessories List] for optional items.]
The connector should be protected by the self-fusing tape when the pyranometers are used in the areas with the risk of the salt damage.

5-2. Setup

In order to obtain representative measurements from pyranometers, several criteria with respect to setup and mounting of the instruments have to be considered.

The ideal mounting position for pyranometers is a location which has a full hemispheric field-of-view without any obstructions [such as buildings, trees, and mountain]; however, it might be difficult to find such locations. Therefore in practice, it is ideal to install in a position which is free from obstructions at 5° above horizon.
The setup location should be easily accessible for periodic maintenance [glass dome cleaning, etc.], and avoid surrounding towers, poles, walls or billboards with bright colors that can reflect solar radiation onto the pyranometer. A strong physical impact to the pyranometer can lead to product damage and/or may cause changes to the sensitivity.

1. Installing at Horizontal or Tilted Positions

1) Check the installation base where the pyranometer has to be mounted and make sure it has two fixing holes with the appropriate pitch. The pitch sizes of the fixing holes are as follows [in mm]:

Table 5-2. Fixing Hole Pitch and Bolt Size for Pyranometers

	MS-60 / MS-60S
Fixing Hole Pitch	65 mm
Fixing Bolt Size	M5 x 75 mm

2) Setup the pyranometer with the signal cable connector facing the nearest Earth's pole.
In the Northern hemisphere, the connector should be orientated North, in the Southern hemisphere, the connector should be orientated South. If the signal cable connector is facing towards the sun, the temperature of the connector increases and may cause measurement error due unwanted thermoelectric power invited by the connector temperature increase.

3) Remove a sunscreen.
The sunscreen can be removed by loosening the knurling screw and sliding it towards the spirit level direction.
*When carrying the MS-60 with sunscreen attached, always hold the instrument from the bottom. Holding only the sunscreen part may lead to dropping the sensor as it comes off from the sunscreen.

4) Adjust the pyranometer in a horizontal position by using the 2 levelling screws observing the air bubble in the spirit level while manipulating the levelling screws. The instrument is levelled horizontally if the air bubble is in the centre ring.
If the pyranometer is not levelled properly, the pyranometer readings are affected by cosine and azimuth errors. Periodically check the spirit level and adjust the pyranometer's position if necessary.

[Installing at Tilted Position]

After the MS-60 is adjusted to horizontal position in levelled surface, install it on tilted mounting position. *When installing the instrument, do not remove the levelling feet or fixed feet; if the levelling feet are removed, it may cause abnormal output values due to the thermal effects from the mounting part.

In the case of MS-60S, it is possible to acquire tilt information obtained from the built-in tilt sensor through Modbus RTU.

5) Fasten the pyranometer to the base with the 2 bolts [included] and put the sunscreen back on the pyranometer.

2. Wiring

To extend the cable lifetime, make sure that the cables are not exposed to direct sun light or rain/wind by lining the cable through a cable conduit. Cable vibrations will potentially cause noise in the output signal. Fasten the cable so that the cable does not swing or move by wind blowing.

Exposure of the signal cable to excessive electromagnetic emissions can cause noise in the output signal as well. Therefore the cable should be lined at a safe distance from a potential source generating EMC noise, such as an AC power supply, high voltage lines or telecom antenna.

- Wiring Procedure

1) Connect the output cable to the pyranometer by inserting the cable connector to the connector on the body then turn the screw cap.
   *Make sure to check the pin layout of the connector before connecting the cable. If the connector cannot be easily inserted, DO NOT use any force, as it will damage the connector. Visually check the pin layout again before retrying to insert the connector. *Make sure to fasten the screw cap by turning it all the way.

2) Connect the output cable:
   2-1. <u>How to Connect MS-60</u> [See Table 5-3. Wire Color Codes also]
   Connect the wires with colors that correspond to each terminal to voltmeter or data logger.
   <u>*Always connect the shield cable.　Failing to do so, it will lead to causing noise.</u>

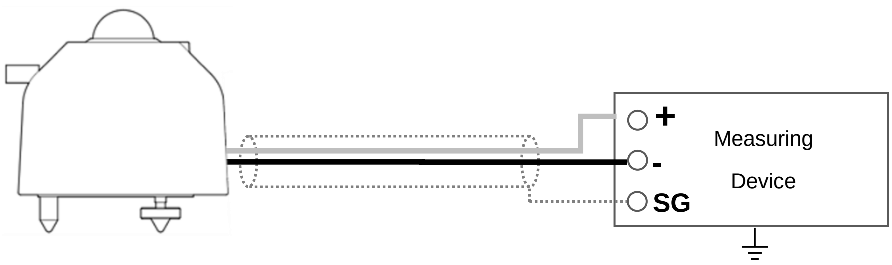


Figure 5-2. How to connect MS-60

2-3. How to Connect MS-60S [See Table 5-4. Wire Color Codes also]

A] How to connect 4-20mA

Connect the output cable end, DC power supply [5 to 36 V], and ammeter as shown in the figure below. Install a fuse [0.5A] in series between the DC power supply [+] and the MS-60S connection as shown below for over current protection.

* When precision resistors are connected in parallel and acquired at voltage value, keep the precision shunt resistor maximum value at 150Ω.

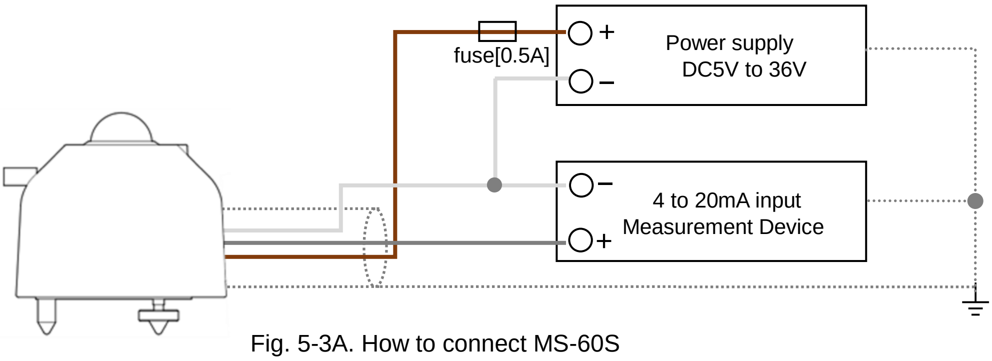


Fig. 5-3A. How to connect MS-60S

B] How to connect 0-1V[optional]

The default output is 4-20mA. If 0 to 1V output is not selected as a purchase option, 0 to 1V output is off. Or the setting can be changed with the 485 / USB conversion cable and dedicated software.

Connect the output cable end, DC power supply [5 to 36 V], precision resistor 100Ω [* please prepare resister separately], and voltage measurement device as shown in the figure below. Install a fuse [0.5A] in series between the DC power supply [+] and the MS-60S connection as shown below for over current protection.

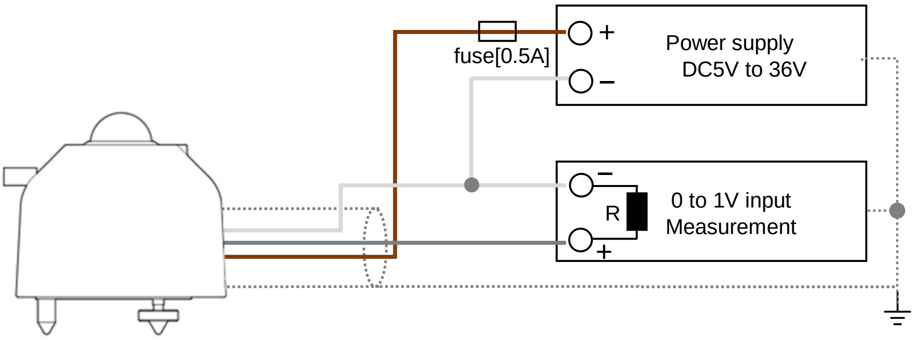


Fig. 5-3B. How to connect MS-60S

C] How to connect Modbus RTU

Connect the output cable end and DC power [5 to 36 V], RS485 / USB converter or data logging device as shown in the figure below. Install a fuse [0.5A] in series between the DC power supply [+] and the MS-60S connection as shown below for over current protection.

When connecting to a PC

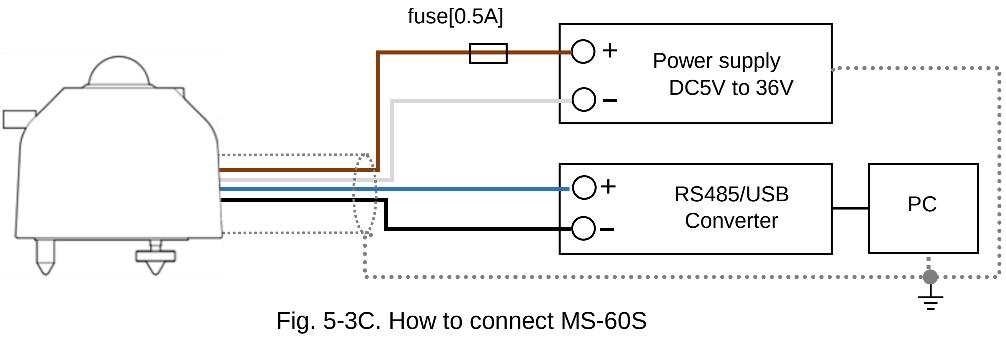


Fig. 5-3C. How to connect MS-60S

When connecting to a Data Logger

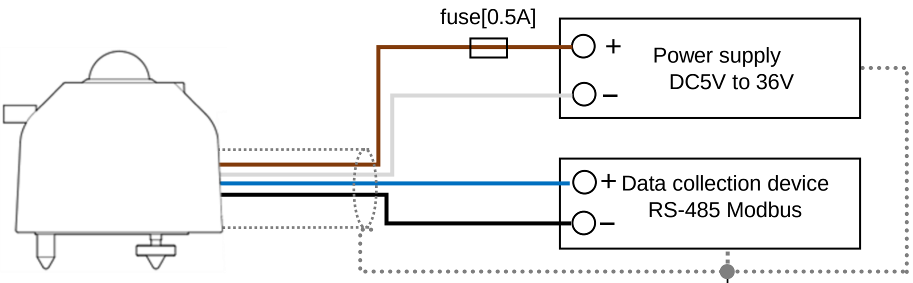


Fig. 5-3D. How to connect MS-60S

D] How to connect SDI-12

Connect the output cable end, DC power supply [12 V], and data logging device as shown in the figure below. Install a fuse [0.5A] in series between the DC power supply [+] and the MS-60S connection as shown below for over current protection.

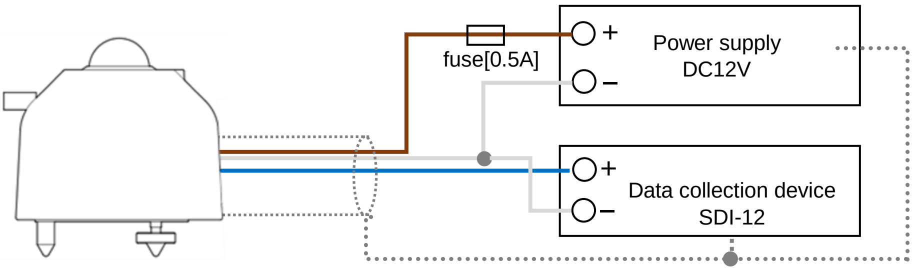


Fig. 5-3E. How to connect MS-60S

2-3. How to Connect Communication with Modbus RTU

MS-60S can connect to a system that communicates with Modbus RTU by using RS-485. Maximum of 100 units can be connected, and individual address can be assigned.

Connection of MS-60S to the RS-485 communication network is shown below.

Master represents the data logging device [such as PC], and slaves represent devices such as MS-60S.

Connect the + and – for the master to [A] and [B] for each MS-60S. Also at the end of network, connect a 120Ω termination resistor.

Modbus address is the last 2 digits of the product serial number. If the last 2 digits are "00", the address will be "100".

[*]Communication errors may occur depending on the connection distance and the number of connections. In that case, please use RS485 booster or repeater.

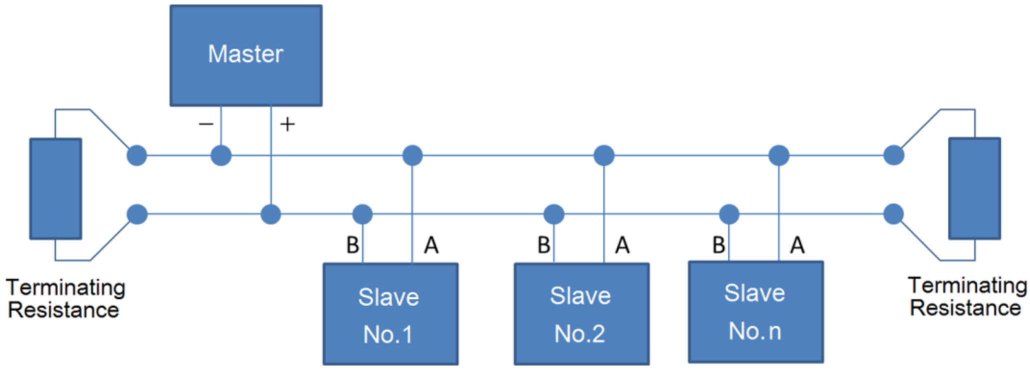


Figure 5-4. Communication Connection with Modbus RTU

2-4. How to Connect Communication with SDI-12

Connect the output cable terminal to voltmeter or data logger with corresponding wire colors described below. Make sure the cable length between the connecting slave [such as pyranometers] and data collecting device to be less than 60m. Shield must be connected, or noise may occur.

Also see 7-3. Output Cable for cable arrangements.

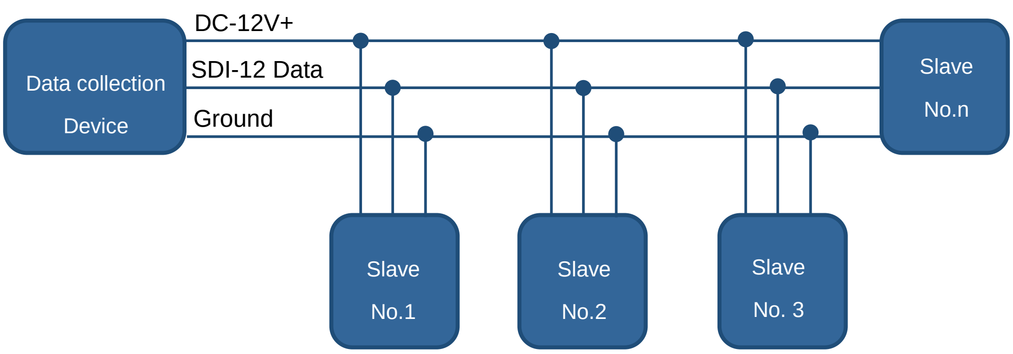


Figure 5-5. Communication Connection with SDI-12

2-5. Wire Assignments

Also see [7-3. Output Cables].

Table 5-3. Wire Color Codes [MS-60]

No.	Cable Color	MS-60
1.	White	mV [+]
2.	Black	mV [-]
Shield	Shield	FG

Table 5-4. Color Codes of cable[MS-60S]

No.	**Cable Color**	**4-20mA**	**Modbus**	SDI-12	0-1V *
1.	Brown	DC 5 to 36V [+]	DC 5 to 36V [+]	DC12V	DC5 to 36V [+]
2.	White	4-20mA [-] / GND	GND	GND	0-10mA[-] / 0-1V[-] / GND
3.	Blue	---	RS485/B/+	SDI-12 Data	---
4.	Black	---	RS485/A/－	---	---
5.	Gray	4-20mA [+]	---	---	0-10mA[+] / 0-1V[+]
Shield	Shield	FG	FG	FG	FG

*When selecting 0-1V output, a precision resistor is required separately. The output depends on the accuracy of the resistor.

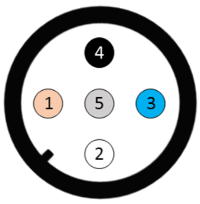


Figure 5-6. Connector pin number of MS-80/80S

Each number corresponds to the number in Table 5-4.

5-3. Measuring Solar Irradiance

1. Solar Irradiance Measurement

1) In case of MS-60 [mV output]:

Global solar Irradiance [W/m^2] can be determined by measuring the output voltage [mV] divided by the individual sensor sensitivity [μV/W・m^{-2}]. The output voltage is measured by a measuring device such as voltmeter or data logger. If solar irradiance is measured continuously, it is recommended to use data logger which has sufficient recording capacity and calculation function.

Procedure for solar irradiance measurement is described below:

a. Configuration with a Data logger

If the measurement range can be selected on the data acquisition system, select the measurement range, which can accurately measure the signal over a range of 0 to 20mV. The solar irradiance assumed that it does not exceed 1,400W/m^2 in both horizontal and tilted measurement positions. The maximum output voltage can be calculated by multiplying the maximum solar irradiance with the calibration factor [e.g. when the sensitivity of the MS-60 pyranometer is about 10μV/W・m^{-2} or 0.010mV/W・m^{-2}, the maximum output voltage is about 1,400W/m^2 times 0.010mV/W・m^{-2} = 14mV].

b. Calculate the Solar Irradiance [W/m^2].

The solar irradiance in Watts per meter squared [W/m^2] is obtained when the output voltage ***E*** [μV] is divided by the sensitivity of the pyranometer ***S*** [μV/W・m^{-2}]. This calculation is expressed by the following formula:

$$\boldsymbol{I}\ [\mathrm{W/m^2}] = \frac{\boldsymbol{E}\ [\mu\mathrm{V}]}{\boldsymbol{S}\ [\mu\mathrm{V/W \cdot m^{-2}}]}$$

*The sensitivity ***S*** for the pyranometer is stated on the calibration certificate and the product label.

2) In Case of MS-60S [4-20mA Output]

a. Configure the Measurement Range

If the measurement range can be selected on the data acquisition system, select the measurement range which can accurately measure the signal within a range of 4 to 20mA. The global broad-band solar irradiance assumed that it does not exceed 1,400W/m^2 in both horizontal and tilted measurement positions. When this is converted into MS-60S output, the result will be 20mA [default].The output for the MS-60S [4-20mA output] is set to be 1,600W/ m2 at 20mA.

b. Calculate the Solar Irradiance [W/m^2]

When the solar irradiance current value is ***A*** [mA], the solar irradiance ***I*** [W/m^2] can be determined by the following formula:

$$\boldsymbol{I}\ [\mathrm{W/m^2}] = \frac{\boldsymbol{A}\ [\mathrm{mA}] - 4}{\boldsymbol{Sa}\ [\mathrm{mA/W \cdot m^{-2}}]}$$

Sa=0.01 (default setting)

3) MS-60S [0-1VOutput]

a. Setup the measurement range on the measuring device.

Setup the measurement range on the measuring device.

If the measurement range can be selected, chose the range which can measure between 0 to 1V accurately.

Same for installing either in slope or horizontally, maximum solar irradiance is considered at 1,400W/m^2, thus it is setup [default] so that the output of MS-60S [0-1V conversion] should be 1,600W/m^2 at 1V.

b. Calculate the Solar Irradiance [W/m^2]

When the solar irradiance voltage value is ***V*** [V], the solar irradiance ***I*** [W/m^2] can be determined by the following formula:

$$\boldsymbol{I}\ [\mathrm{W/m^2}] = \frac{\boldsymbol{V}\ [\mathrm{V}]}{\boldsymbol{Sv}\ [\mathrm{V/W \cdot m^{-2}}]}$$

Sv=1/1,600 (default setting)

4) MS-60S [Modbus RTU Output, SDI-12 Output]

When using the digital output (Modbus or SDI-12) by default the irradiance conversion is performed on-board and is one of the measurement parameter within the data string.

2. Integration of Measurement Value:

In continuous operation mode the pyranometer is usually connected to a programmable data logger system. Hence, sampling rates and data reduction methods can be defined right at the beginning of the data acquisition process.

The response time that is given in the specifications of the EKO pyranometers states the amount of time, which is necessary to reach 95% of the final measurement value. It is also possible to define a 63.2% response [which is equal to 1-1/e]. This time constant, represented by the symbol τ, is 3 times smaller than the values specified by EKO. The recommended[1] sampling rate for pyranometers is smaller than τ. So, for EKO pyranometers, the sampling rates that have to be programmed in the data logger systems should not exceed the values as given in Table 7-1.

Performing averaging and/or integration of measurement data can be meaningful to, e.g., reduce the data volume or to meet application-specific requirement. Note that shorter sampling rates allow to use shorter averaging/integration times [example for MS-60: <10 second sampling rate, 1 minute averaging period]. It could also be meaningful to store not only average values, but to keep track of all statistical values during the averaging period, namely: average, integral, minimum and maximum values, and standard deviation.

As a general recommendation, the averaging/integration period should be as short as possible, but long enough to reduce the data volume to store the processed data safely.

[1]“Guide to Meteorological Instruments and Methods of Observation”, WMO reference document No. 8.

Examples:

The total daily radiant energy in Joule per meter squared [J/m^2] is obtained by integrating the solar irradiance over time. To calculate the total daily radiant energy in Joule per meter square [J/m^2], multiply the averaged solar irradiance ***I*** [W/m^2] by the averaging interval period [s]. Then sum-up the total data number [n] of averaged data points in one day.

Its physical unit is expressed with [J/m^2] and can be calculated with J = W・S

$$\mathrm{DTI} = \sum_{k=1}^{n} I_k \times t$$

6. Maintenance & Troubleshooting

6-1. Maintenance

Using the EKO pyranometers, accurate results can be obtained if the glass dome and the condition of the instrument are maintained properly. Environmental conditions, such as for instruments mounted near highly frequented traffic lanes or airports, may have a deteriorating effect on the materials. Therefore, proper maintenance is needed and has to be adapted to the local environmental conditions.
The following table describes the common maintenance tasks that should be performed on a regular basis:

Table 6-1. Maintenance Items1

Maintenance Item	Frequency	How To	Effect
Clean Glass Dome	Several times per week	Keep the glass dome clean by wiping with a soft cloth and alcohol	The irradiance measurement will be affected due to a change in transmittance of glass dome.
Check Appearance Condition	Weekly	Check for cracks and scratches on the glass dome and body.	May lead to water leakage due to rain/dew, which causes damage of the detector inside the pyranometer.
Check Spirit level	Weekly	Verify if the pyranometer is levelled by checking the bubble is in the center ring of spirit level. [When the pyranometer is setup in horizontal position]	An additional cosine/azimuth error will be introduced.
Check Cable Condition	Weekly	Verify if the cable connector is properly connected, tightened to the instrument, and how cable is lined; make sure the cable is not swinging by wind.	A disconnected cable will cause sporadic reading errors or failure of operation. If the cable is damaged, it may lead to noise or electric shock.
Check Setup Base Condition	Weekly	Check if the instrument is tightened properly to the mounting base plate and the base plate and/or table is securely fastened in a proper condition.	Loose instruments and/or mounting plates can lead to damages of the instruments and/or injury.
Check the Sunscreen	Weekly, Before/After Bad Weather	Verify if the sunscreen is securely fixed on the body, and knurling screw is securely tightened.	May lead to damaging the instrument and/or lead to increasing measurement error due to temperature increase by sunscreen coming off.
Recalibration	Every 2 Years	To maintain the best possible measurement accuracy, recalibration of the pyranometer is recommended. Contact EKO for more details and requests for a recalibration and maintenance service.	Due to natural aging of materials the detector properties of the pyranometer can change in time which affects the sensor sensitivity.

Table 6-2. Maintenance Items2

Maintenance Item	Frequency	How To	Effect
Data	Weekly	Check the daytime irradiance data and compare to previous days or adjacent pyranometers	When large difference occur operating problems or installation issues can be detected.
Data	Weekly	Check night time irradiance values	Nighttime offsets and sensor stability issues can be revealed.
Data	Weekly	For the S-series with Modbus output check the body temperature.	Temperature changes can cause offsets and change of sensitivity due to the detector Temperature dependency.
Data	Weekly	For the S-series with Modbus output check the relative humidity.	The condition of the drying agent can slightly change over time. The acceptable limits for the RH < 90 %
Data	Weekly	For the S-series with Modbus output check the tilt position.	Any change in tilt position after the installation can affect the measurements due to the cosine response of the sensor.

6-2. Calibration and Measurement Uncertainty

It is recommended to recalibrate MS-60 pyranometer once every 2 years in order to verify the good quality of the solar radiation measurements. Below explains about the calibration methods of EKO pyranometers and the calibration uncertainty. For further information about recalibration and maintenance procedures, please contact EKO or find on the EKO website [http://eko-eu.com].

EKO is a unique manufacturer who can offer calibration service for pyranometers and pyrheliometers in-house. Based on the applied calibration methods EKO provides the best quality solar sensor calibrations compliant to the international standards defined by ISO/IEC17025 / 9847 [Indoor method] and ISO9059 [Outdoor method] [Certification: L13-94-R2 / www.pjlabs.com]

1. Calibration Method

MS-60 is calibrated indoors according to the ISO 9847 international standard against a 1000W/m^2 AAA class solar simulator radiation source and designated calibration facility.

<u>Indoor Calibration Procedure</u>

As the calibration procedure, 1] place both reference and production pyranometers in the center of the light in horizontal position at the same distance from the solar simulator; 2] alternatively irradiate the reference and production pyranometers with 1000W/m^2 continuously and measure the output [mV] from each pyranometer for a specified time; 3] From the reference output [mV] and sensitivity [µV//W/m^2], calculate the irradiance [W/m^2]; 4] finally the sensitivity [µV/W/m^2] value is calculated by division of the pyranometer output [mV] and reference irradiance [W/m^2].

<u>Measurement Uncertainty of Indoor Calibration</u>

The calibration uncertainty becomes smaller as the calibration is performed with a constant ambient temperature and using a solar simulator with stable light source; hence the repeatability of indoor calibration method is better than 99%.

The expanded calibration uncertainty depends on the pyranometer model, and its result is stated on the calibration certificate.

The pyranometer calibration uncertainty is determined with consideration of uncertainty of the reference pyranometer and maximum variation of incident light during the measurement of production pyranometer and reference pyranometer.

2. Calibration Traceability

The Internal reference pyranometer maintained at EKO is traceable to the absolute cavity pyrheliometer which is directly compared against the WRR [World Radiometric Reference] Primary Standard [Absolute Cavity] maintained at PMOD [Davos, Switzerland]. The logger system used for the calibration measurement is traceable to JEMIC [Japan Electric Meters Inspection Cooperation].

Internal reference pyranometer is calibrated directly compared against the pyrheliometer, which is measured against the EKO absolute cavity, and 2 units of internal reference pyranometers by Shading Method [[A New Method for Calibrating Reference and Field Pyranometers [1995]] Bruce W Forgan] every one year.

EKO absolute cavity is directly traceable to WRR by comparing against WRR every 5 years.

6-3. Troubleshooting

Read the following in case of any sensor trouble. If any questions should remain, please contact EKO for further technical support.

Table 6-3. Troubleshooting

Failure		Action
There is no output.	MS-60	Make sure that the sensor cable is connected properly to the instrument. To verify the connection, measure the impedance of output cable [between the "+" and the "-" wires] and check if the measured impedance is within the proper range as shown in the specification table.
	MS-60S	Make sure that the sensor is properly connected, and type of power supply and voltage values are appropriate. Also check the communication settings [i.e. port, baud rate, converter ID] are appropriate.
Output value is too low		The glass dome maybe soiled with rain or dust. Clean the glass dome with a soft cloth. The output may be decreased due to regular change. Recalibrate periodically.
Negative output signal during night-time.		Pyranometers generate an output signal, which is proportional to the temperature differences between the sensor's so-called hot and cold junctions. Night-time offset can occur when the dome temperature will cool down below the temperature of the detector.28587
Unusual noise		Check the shield connection and make sure it is connected securely. Check to make sure the output cable is not swinging by wind; take necessary measure by fixing or lining the cables through metal pipe. Check for any objects which emit electromagnetic wave around the instrument and or cable. Attach 2 or more ferrite cores at the end of the cable.

7. Specification

7-1. Specifications

1. Pyranometer Specifications

The comparison table below, Table 7-1, shows typical values for the characteristic parameters of the EKO Pyranometers and the corresponding values of the ISO 9060: 2018 standard. The content of the characteristic item is partly changed from ISO 9060: 1990. Please also refer to "A-2. Pyranometer Characteristics List".

Table 7-1 Specification: Specifications are indicated as typical values.

Characteristics		MS-60	MS-60S
	ISO9060: 2018	Class B	
	[ISO9060: 1990]	[First class]	
	Spectrally flat	○	○
	Fast response	---	---
Response time [95% output]	＜20 Sec	＜18 Sec	＜18 Sec
Zero off-set a -200W/m²	±15 W/m²	±5 W/m²	±5 W/m²
Zero off-set b 5K/hr	±4 W/m²	±2 W/m²	±2 W/m²
Total zero off-set c	±21 W/m²	±2 W/m²	±2 W/m²
Non-stability	±1.5 %/1yr	±1.5 %/1yr	±1.5%/1yr
Nonlinearity	±1 %	±1 %	±1 %
Directional response	±20 W/m²	±18 W/m²	±18 W/m²
Spectral error	±1	±0.1%	±0.1%
Spectral selectivity	±3 %	±2 %	±2 %
Temperature response -10 to +40℃	±2 %	±2 %	±2 %
Temperature response -20 to +50℃	---	±4 %	±4 %
Tilt response	±2 %	±1 %	±1 %
Additional signal processing error	±5 W/m²	---	±1 W/m²

The content of the characteristic item is partly changed from ISO 9060:1990. Please also refer to "A-2. Pyranometer Characteristics".

Table 7-2. Other Specification

Characteristics	MS-60	MS-60S
Field of View	2π[sr]	
Wavelength range	285 to 3000 nm	
Operating Temperature	-40 to +80℃	
[1] Maximum Operation Irradiance	2000 W/m^2	
Spirit level accuracy	0.1°	
Environmental Protection [IP Code]	IP67 Equivalent [IEC60529, JIS C0920]	
Mass	0.37 kg	0.39 kg
Surface Treatment	Anodized	
Sensitivity	7 - 14 $\mu V/W \cdot m^{-2}$	7 -14 $\mu V/W \cdot m^{-2}$ [4-20mA : 0-1,600$W \cdot m^{-2}$] [0-1V : 0-1,600$W \cdot m^{-2}$]
Impedance [at 25°C]	60-100 Ω	---
Tilt sensor accuracy	---	±1°
Humidity sensor	---	±1%
Output Cable [outer diameter]	AWG22: 0.3mm^2×2pins [Φ4.8mm]	AWG20: 0.5mm^2×5pins [Φ6.7mm]
Output Cable Terminal	Pin-Terminal [1.25-11S]	Pin-Terminal [0.3-9.5]
Output [or Signal]	Voltage [mV]	**Default MODBUS 485 RTU**, **SDI-12**, **4-20mA**, [2]configurable 0-10mA / 0-1V with external 100Ω precision shunt resistor
Resolution	---	< 0.01$W \cdot m^{-2}$[3]
Input Power Supply	---	DC5 – 36V ±10% [SDI12: DC12V]
Average Power Consumption	---	<0.2W

[1]The operational maximum irradiance is defined as the maximum irradiance exposure level. Beyond this point damage may occur to the sensor.

[2] Sensor setting can be changed by connecting the sensor to a PC (Use the optional RS-485 to USB converter cable and download the free configuration software from the WKO website

[3] When 4-20mA is 0-1600$W \cdot m^{-2}$, 0-1V : 0-1600$W \cdot m^{-2}$.(default)

7-2. Dimensions

Below table and figures give the pyranometer dimensions for each model.

Table 7-3. Dimensions

	MS-60 / 60S
A. Fixing Hole Pitch	65 mm
B. Body Height	91.5 mm
C. Levelling Screw Height	16 mm
D. Width [including Sunscreen/Cover]	Φ96 mm
E. Overall Height [approx.]	107.5 mm

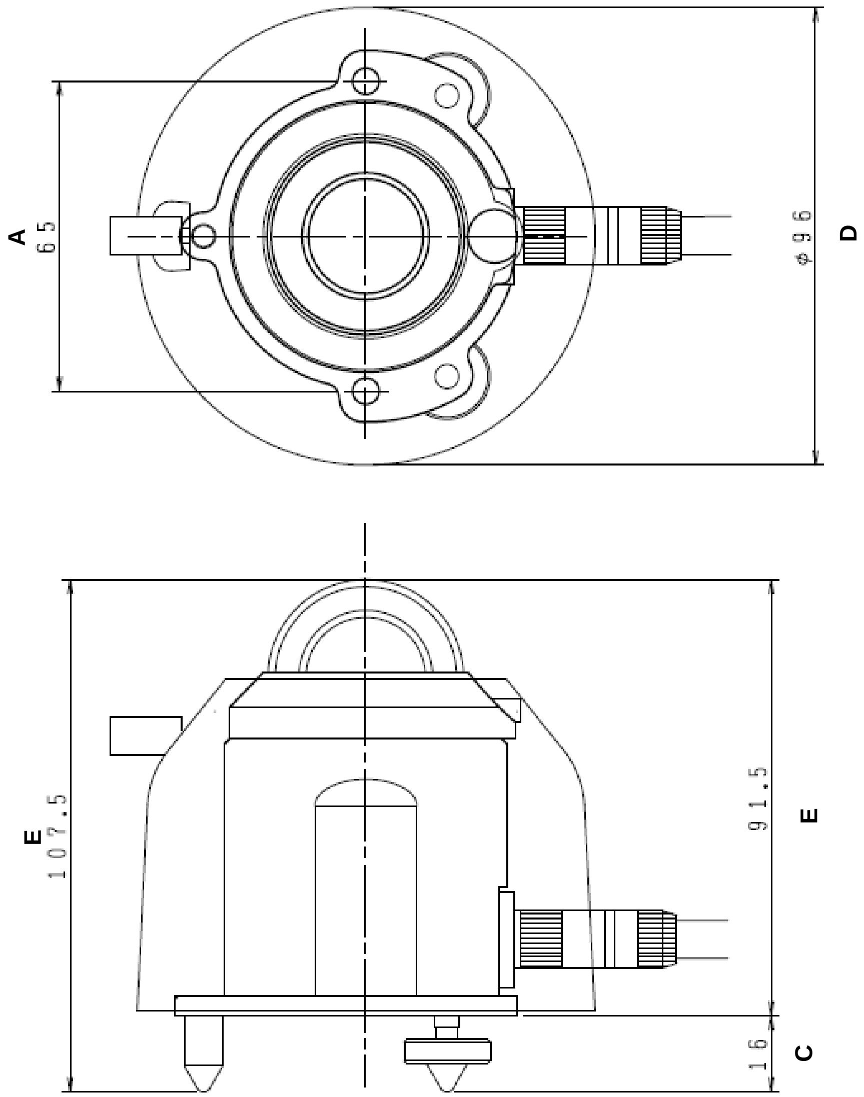


Figure 7-1. Outer Dimensions

7-3. Output Cables

See [5-2. Installation, 2. Wiring] for instruction

1. Output Cable for MS-60

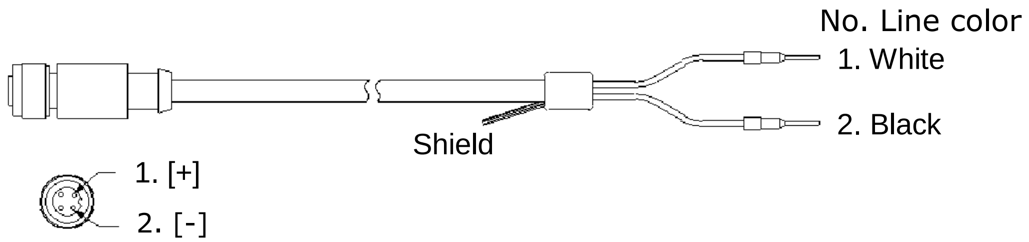


Figure 7-2. Output Cables (MS-60)

2. Output Cable for MS-60S

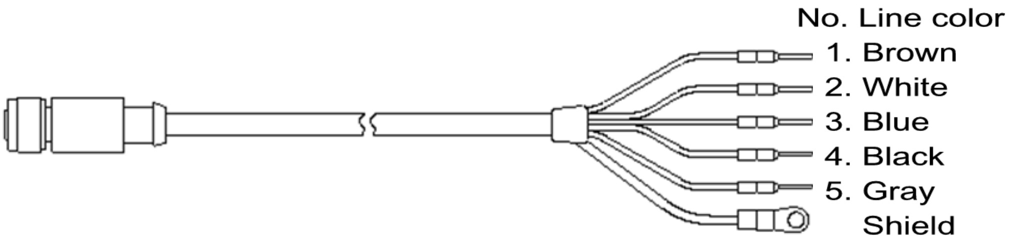


Figure 7-3. Output Cables (MS-60S)

7-4. Accessories List

Table 7-4. Accessories List

Option Items	Remarks
* Output Cable	Cable Length: 20m, 30m, 50m Terminals: Fork Terminals, Round Terminals, Pin Terminals
Ventilation Unit with Heater	Model: MV-01
RS485 / USB Converter Cable	Converts from RS485 → USB for the communication with MS-60S and allows to connect to PC with USB terminal

* The standard cable length is 10m

*The setting can be changed with the RS485 / USB conversion cable and dedicated software.

APPENDIX

A-1. Radiometric Terms

Table A-1. Definitions of Terms

Hemispheric Solar Irradiance	Cosine-weighted solar irradiance received over a solid angle of 2πsr on a plane surface, expressed in units of W/m^2 or kW/m^2.
Global Solar Irradiance, Global Horizontal Irradiance [GHI]	Hemispherical solar irradiance received on a horizontal plane surface, expressed in units of W/m^2 or kW/m^2.
Direct Solar Irradiance, Direct Normal Irradiance [DNI]	Normal-incidence solar irradiance received over a small solid angle which includes the circumsolar irradiance, expressed in units of W/m^2 or kW/m^2.
Diffuse Solar Irradiance, Diffuse Horizontal Irradiance [DHI]	Hemispherical solar irradiance without the direct solar irradiance, i.e. indirect irradiance of the scattered solar radiation [by air molecules, aerosol particles, clouds, etc.], expressed in units of W/m^2 or kW/m^2.
Pyranometer	A radiometer designed to measure the hemispheric solar irradiance over the wavelength range of about 300 to 3000nm.
Pyrheliometer	A radiometer designed to measure the direct solar irradiance over a certain solid angle including the circumsolar irradiance.
World Radiation Reference [WRR]	Radiometric reference instrument system, which has an uncertainty of less than +/-0.3%, expressed in SI units. This reference is maintained by the World Meteorological Organization [WMO], and it has been issued since January 1, 1980
ISO9060	An ISO norm [International Standard]. The first edition was published in 1990, then the second edition was revised in 2018. Based on the performance of each characteristic, Pyranometer is classified into three classes A, B, and C, and specifications of "Spectrally flat radiometer" and "Fast response radiometer" are set as sub-categories. Pyrheliometer is classified into 4 classes of AA, A, B and C based on the performance of each characteristic, and specifications of "spectrally flat radiometer" and "Fast response radiometer" are set as sub-categories.

A-2. Pyranometer Characteristics

Table A-2. Pyranometer Characteristics [see also CIMO Guide, WMO No. 8, 2008]

Response Time	The time [seconds] of a pyranometer sensor to reach 95% of its final output signal. [ISO 9060: 2018 added] If the response time reach to 95% is less than 0.5 seconds, "fast response" is attached to the applicable class as a subcategory.
Zero Off-Set a	Response [dark-signal] to 200W/m2 net thermal radiation [ventilated]
Zero Off-Set b	Response [dark-signal] to 5K per hour change in ambient temperature
Total Off-set c	[ISO 9060: 2018 added] Total zero off-set including the effects a], b] and other sources
Non-Stability	Rate of change [%] of the pyranometer sensitivity per year.
Nonlinearity	Percentage deviation from the responsivity at 500W/m2 due to any change of irradiance within the range 100W/m2 to 1,000W/m2.
Directional Response	Also referred to as cosine error [W/m2]; the range of errors caused by assuming that the normal incidence responsivity is valid for all directions when measuring, from any direction, a beam radiation whose normal incidence irradiance is 1,000W/m2 [ISO 9060: 2018 modified] Include the zenith angle of zenith angle 90 ° or more.
Spectral error	[ISO 9060: 2018 added] Maximum spectral mismatch error of Pyranometer [%] with respect to spectral irradiance at AM 1.5 and AM 5 under multiple atmospheric conditions on fine weather against the reference standard spectral irradiance defined by IEC60904-3: 2016 Photovoltaic devices - ”Measurement principles for terrestrial photovoltaic [PV] solar devices with reference spectral irradiance data.”
Spectral selectivity	Percentage deviation of the product of spectral absorptance and spectral transmittance from the corresponding mean within the range 0.35μm to1.5μm.
Spectrally flat Pyranometer	[ISO 9060: 2018 added] If the spectral selectivity is less than 3 %, "spectrally flat" is attached to the applicable class as a subcategory.
Temperature Response	[ISO 9060: 2018 modified] Percentage maximum output error due to any change of ambient temperature between -10 to 50℃ against the output at 20℃.
Tilt Response	[ISO 9060: 2018 modified] Percentage deviation from the responsivity at 0˚ tilt [horizontal] due to change in tilt from 0˚ to 180˚ at 1,000W/m2.
Additional processing errors	[ISO 9060: 2018 added] Error generated when converting the analog output of Pyranometer or Pyrheliometer into a digital signal with a signal converter etc.

A-3. Configurator Software [MS-60S]

With the dedicated software which can be downloaded from the EKO website and optional communication cable for converter setting, configurations can be changed.

1. Software Installation

1) Download the latest version “SensConf.zip” file [compressed file: Zip format] from the MS-60S product page on EKO website.
2) When the “SensConf.zip” file is opened, “SensConf.exe” file [program file] is decompressed.
3) Move the file to the appropriate folder.

2. Hardware Preparation

Once the software is installed, connect the devices necessary for configuring.

After software installation, connect the USB connector of “RS485 / USB conversion cable” to PC, and clamp the MS-60S output cable terminal with the crocodile clip on the other end of the cable.

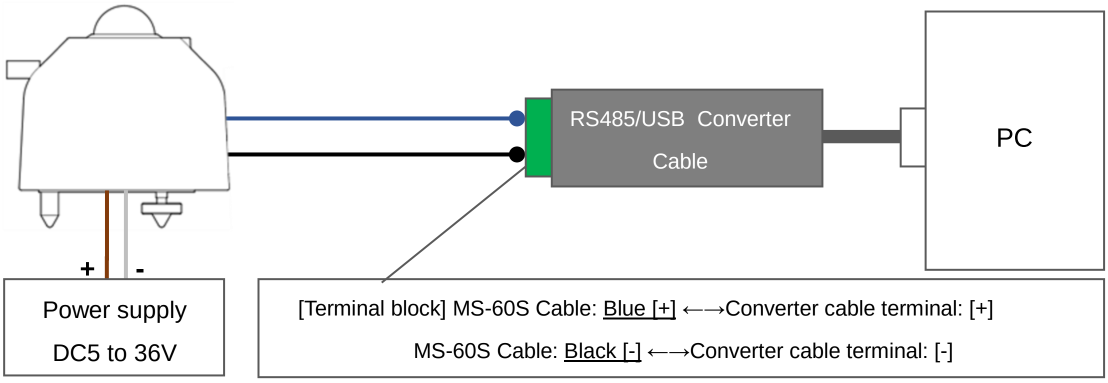


Fig. A-1. Connection diagram of RS485 / USB conversion cable

3. Change of setting contents

Here describes how to change the configurations such as MS-60S output range and sensitivity.

First, install the software and connect the devices and PC with “RS485/USB conversion cable”.

1) Start the software by clicking the “SensConf.exe”
2) After the software is start-up, “COM Setting” window opens. [1] Select the port number for the USB connected with RS485/USB conversion cable from the “Port” pulldown list, [2] select the combination of baud rate [2400/4800/9600/19200/38400/115200] and parity check [None/Even/Odd] from the pulldown list, and [3] enter the MS-60S address in the “Modbus Address”, then finally press the “OK” button.

   <u>Modbus address is the last 2 digits of the product serial number. If the last 2 digits are “00”, the address will be “100”.</u>

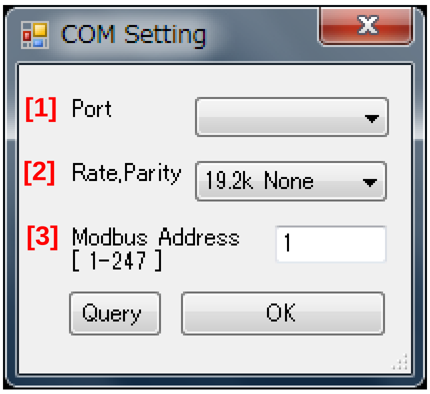


Fig. A-2. COM Setting

When Modbus address is unknown

MS-60S address that is connected to PC [RS485/USB] one-to-one can be confirmed by pressing "Query" and following procedure.

1. Turn off the converter power. ※ Please do not unconnect the Blue[+] and Black[-] cables.
2. Press "OK" button.
3. Turn on the converter power within 5 seconds.

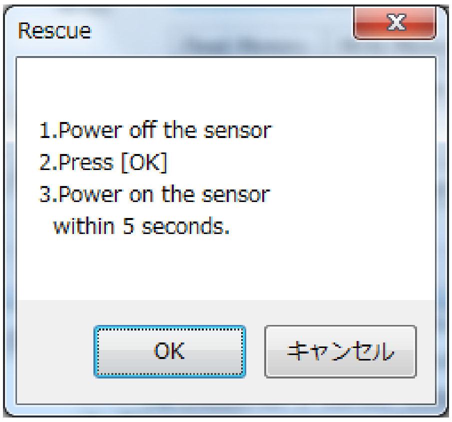


Fig. A-3. Rescue

When the communication with converter is achieved, following dialog appears and displays the address for converter that is connected.

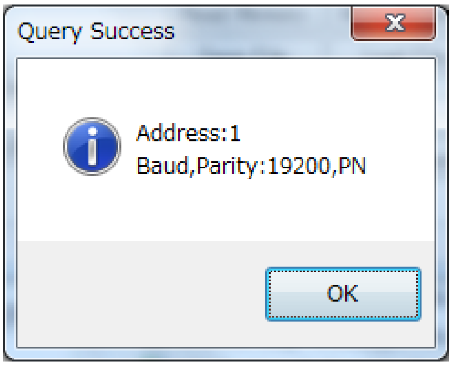


Fig. A-4. Query Success

3] Main window open.
4] When "Read Memory" is pressed, configurations are read from the MS-60S memory and displayed on the window.

Displayed contents [configuration] of Main Window are shown below.

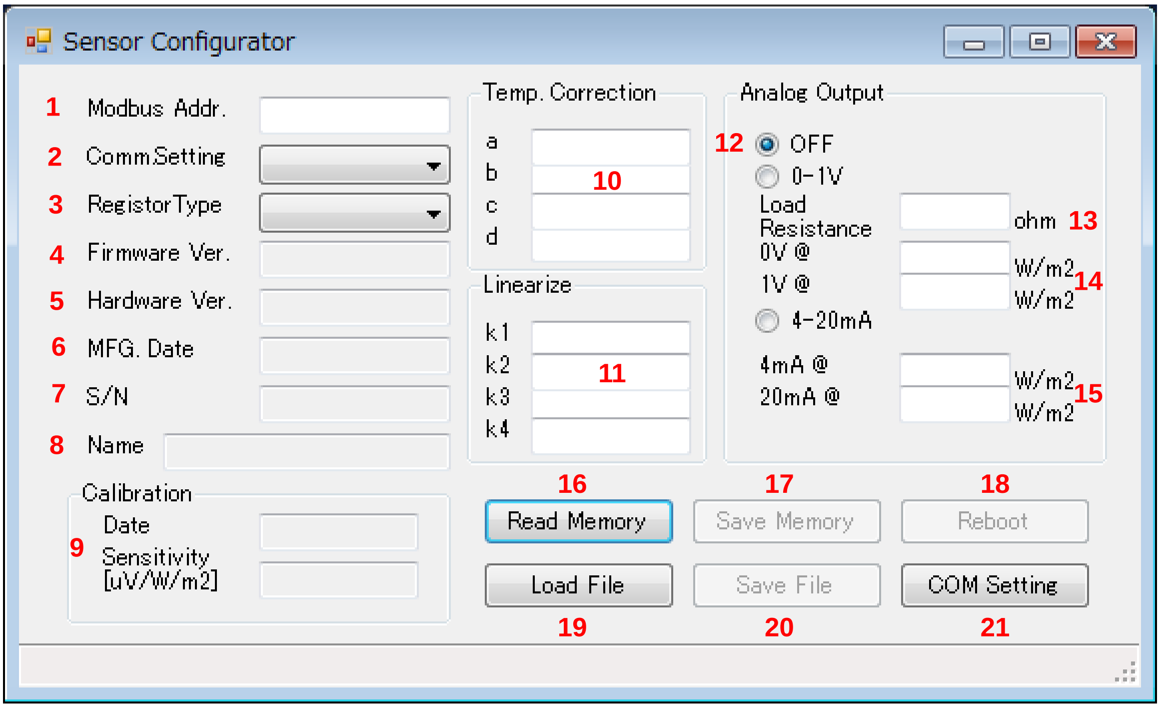


Fig. A-5. Main Screen

Table A-3. Main screen display contents

#	Notation name	Details
1	Modbus Addr.	Modbus address number [1 to 100] to be connected [Default: The last 2 digits of the MS-60S serial number is setup as address number. If the number is "0X", the "X" would be the address number. In the case of "00", the address would be "100".
2	Comm.Setting	Communication setting. This can be selected from the combination of baud rate [2400/4800/9600/19200/38400/115200] and parity check [None/Even/Odd]. [Default: 19200/None]
3	Registor Type	Registor type can be selected from 4 types: EKO [Default]/MC-20/KZ Type/HF Type. *Use only when communication installation of master device does not change in the case of installing different product, such as swapping pyranometers. Registry responses corresponding against the requests to registry number for the following product before swapping: MC-20: compatible to MS-80M/60M/40M KZ Type: compatible to Kipp&Zonen SMP-3/6/10/11/21/22 FH Type: compatible to Hukseflux SR30-D1/SR20-D2/SR15-D1/SR15D-D2A2/SR05-D1A3/SR05-D1A3-PV/ SR05-D2A2
4	Firmware Ver.	Firmware version information [cannot be changed]
5	Hardware Ver.	Hardware version information [cannot be changed]
6	MFG. Date	Manufacturing date information [cannot be changed]
7	S/N	Product serial number [cannot be changed]
8	Name	Product name [cannot be changed]
9	Calibration Date/	Product calibration date, sensitivity [cannot be changed]

	Sensitivity	
10	Temp. Correction	Temperature compensation. Compensated based on the temperature data, which temperature characteristics caused by the change of ambient temperature, measured with pt100 and the 4 temperature correction factors [a, b, c, and d]: $ETC[E, T] = E / TC1[T], TC1[T] = a + b \times T + c \times T^2 + d \times T^3$ *ETC [E,T]* : Measurement voltage that compensated the temperature *E* : Measurement voltage *TC1[T]* : correction factor *T* : Measured temperature [Internal] *a, b, c, d* : Correction factor Default values {a: 1, *b*: 0, *c*: 0, *d*: 0}: Setup that does not use linearity correction <u>Linearity correction is not used in the default setting. Unless there is any special reason, it is recommended not to change this setting.</u>
11	Linearize	Linearity correction. When you want to change the output linearity against the solar irradiance, it can be corrected using 4 linearity correction factors [*k1, k2, k3, k4*]. To compensate, setup each item for the approximation used for compensation like below formula.: $I = [k1 + [k2 \times ETC[E, T] + [k3 \times ETC[E, T]^2] + [k4 \times ETC[E, T]^3]] / S$ *I* : Solar irradiance after the linearity correction *ETC[E,T]* : Measurement voltage after the temperature compensation mentioned above. *S* : Pyranometer sensitivity *k1, k2, k3, k4* : Correction factor [Ex.] If *k1* is changed, offset output [μV] can be changed. Default values {*k1*: 0, *k2*: 1, *k3*: 0, *k4*: 0}: Setup that does not use linearity correction <u>Linearity correction is not used in the default setting. Unless there is any special reason, it is recommended not to change this setting.</u>
12	Analog output	Switches the analog output. Select from: OFF/ 0-1V /4-20mA
13	Load Resistor	Enter the actual value for 100Ω that is used during 0-1V output.
14	0V to 1V	Setup the solar irradiance [W/m^2] corresponding to 0-1V output. [Default: 0V=0W/m^2、1V=1600W/m^2]
15	4-20mA	Setup the solar irradiance [W/m^2] corresponding to 4-20mA output. [Default: 4mA=0W/m^2、20mA=1600W/m^2]
16	Read Memory	Reads and displays the information on #1 to 15 from the memory.
17	Save Memory	Writes the changed contents to MS-60S memory. To save the changed contents permanently, press Reboot.
18	Reboot	Reboot.
19	Load File	Reads the configuration from the file. The file name is “XXX.xml”
20	Save File	Writes the current configuration to the file. The file name is “XXX.xml”
21	COM Setting	Opens the communication setting window.

A-4. Configurator Software [MS-60S Modbus RTU]

Communication data format is determined by the Modbus protocol.

Table A-4. Communications Specifications

※1: The open protocol for the serial communication which is developed by Modicon.

※2: When there is no parity bit, stop bit will be 2 bits; for other cases, stop bit will be 1 bit.

Specification	Details
Telecommunication Standard	EIA RS-485
Topology	Multi-drop [Master: 1, Slave: 100, Total: 100]
Communication protocol	Modbus slave RTU[※1] [Slave]
Communication speed [baud rate]	2400, 4800, 9600, 19200 [Default], 38400, 115200 bps
Data Length	8bits
Stop Bit	1bit [Default] / 2bits[※2]
Parity Bit	None [Default] / odd / even
Communication Distance	Maximum 1.2km [theoretical value]
Error Detection	CRC-16

※1: The open protocol for the serial communication which is developed by Modicon.

※2: When there is no parity bit, stop bit will be 2 bits; for other cases, stop bit will be 1 bit.

Table A-5. Data Format

Start	Address	Function	Data	CRC	End
T1-T2-T3-T4 A silent interval [≧3.5 char]	16bit	8bit	n * 8bit	16bit	T1-T2-T3-T4 A silent interval [≧3.5 char]

Modbus Data [RTU]

Table A-6. Function Code

Code: decimal	Function
03	Read Holding Registers

Table A-7. Data Contents

Data type	Overview
UINT16	Without code, 16bit integer value
SINT16	With code, 16 bit integer value
UINT32	Without code,32 bit integer value
SINT32	With code,32 bit integer value
FLOAT32	IEEE754 32bit Single precision floating point
STR	A string[ASCII Code]

Table A-8. Retained data contents in the registry

Address number: Only 0 to 99 Read、Read/Wire is possible after 100

Address	Data Type	Description	Details [described later]
0	UINT16	Model Number	A
1	UINT16	Status	B
2, 3	FLOAT32	Solar Irradiance [W/m^2]	
50, 51	FLOAT32	AD Input voltage [mV]	
52, 53	FLOAT32	Pt100 thermistor value [Ω] Measurement range ｛0 to 250Ω｝	
54, 55	FLOAT32	Pt100 temperature [℃]	
56, 57	FLOAT32	Internal temperature [℃]	
58, 59	FLOAT32	Internal humidity [RH%]	
60	UINT16	Power supply voltage value [mV]	
61	UINT16	Reference voltage value [=2,048 [mV]]	
62	UINT16	Digital→Analog conversion voltage [mV]	
63	UINT16	Analog power supply voltage [5,000 [mV]]	
64	UINT16	Digital power supply voltage [3,300 [mV]]	
80, 81 82, 83	FLOAT32 FLOAT32	Tilt Angle [°] Role Angle [°]	C
84 85 86	SINT16	X axis count value Y axis count value Z axis count value	D
90	UINT16	Message count value	E
91	UINT16	CRC Error count value	F
92	UINT16	Exception error occurrence count value	G
100	UINT16	Firmware version	
101	UINT16	Hardware version	
102	UINT16	Product type [Switching between Pyranometer/Pyrgeometer/UV radiometer]	H
103	UINT16	Modbus address	I
104	UINT16	Serial communication setting	J
105	UINT16	Register type	K
106	UINT16	Digital filter time constant	L
107	UINT16	Analog input setting	M
108	UINT16	Analog output setting	N
109, 110 to 127, 128	FLOAT32	Calibration value of analog input setting 9 types in combination of amplifier type and range	

129, 130	FLOAT32	Pt100 Calibration value	O
131, 132	FLOAT32	Analog output calibration value	P
133, 134	FLOAT32	Shunt resistor for 0-1V output	Q
135, 136	FLOAT32	Irradiance at 0V [W/㎡] [At 0-1V output]	
137, 138	FLOAT32	Irradiance at 1V [W/㎡] [At 0-1V output]	
139, 140	FLOAT32	Irradiance at 4mA [W/㎡] [At 4-20mA output]	
141, 142	FLOAT32	Irradiance at 20mA [W/㎡] [At 4-20mA output]	
143 144 145	SINT16	Tilt sensor X axis offset value Tilt sensor Y axis offset value Tilt sensor Z axis offset value	R
146 147 148	SINT16	Tilt sensor X axis 1G value Tilt sensor Y axis 1G value Tilt sensor Z axis 1G value	S
149 150 151	SINT16	Tilt sensor X axis origin Tilt sensor Y axis origin Tilt sensor Z axis origin	T
152, 153	UINT32	Manufacturing date[YYYYMMDD type]	U
154, 155	UINT32	Serial number	V
156[0, 1] 157[2, 3] 158[4, 5] 159[6, 7] 160[8, 9] 161[10, 11] 162[12, 13] 163[14, 15]	STR	Sensor name	W
164, 165 166, 167 168, 169 170, 171	FLOAT32	Temperature correction factor[coefficient: a, b, c, d]	X
172, 173 174, 175 176, 177 178, 179	FLOAT32	Linear correction factor[coefficient: k1, k2, k3, k4]	Y
180, 181	UINT32	Calibration date[YYYYMMDD type]	Z
182, 183	FLOAT32	Sensitivity [μ V/W/m^2]	
184, 185	UINT32	Calibration history 0[Calibration date,YYYYMMDD type]	
186, 187	FLOAT32	Calibration history 0[Sensitivity [μ V/W/m^2]]	
188, 189	UINT32	Calibration history 1[Calibration date,YYYYMMDD type]	
190, 191	FLOAT32	Calibration history 1[Sensitivity [μ V/W/m^2]]	

192, 193	UINT32	Calibration history 2[Calibration date,YYYYMMDD type]	
194, 195	FLOAT32	Calibration history 2[Sensitivity [μ V/W/m^2]]	
196, 197	UINT32	Calibration history 3[Calibration date,YYYYMMDD type]	
198, 199	FLOAT32	Calibration history 3[Sensitivity [μ V/W/m^2]]	
200, 201	UINT32	Calibration history 4[Calibration date,YYYYMMDD type]	
202, 203	FLOAT32	Calibration history 4[Sensitivity [μ V/W/m^2]]	

[Detailed description of retained data]

A. Model Number [Address Number: 0]
Pyranometer: "0x0110", Pyrgeometer: "0x0120" *Do not change from the factory setting.

B. Status [Address Number: 1] Value: 0 [Always "0"]

C. Tilt angle, Role angle [Address Number: 80, 81 and 82, 83] Unit: °
Tilt angle: North-South tilt angle. When the pyranometer cable is facing north, the inclination to the west is indicated with positive value and the inclination to the east is indicated with minus. Maximum angle: ± 90 °
Role angle: East-West tilt angle. When the pyranometer cable is facing north, the inclination to the west is indicated with positive value and the inclination to the east is indicated with minus. Maximum angle: ± 90 °

D. X-axis/Y-axis/Z-axis Counts [Address Number: 84 to 86]
Values corresponding to the tilt for each axis of tilt sensor [±2G =±8,192].

E. Message Count Value [Address Number: 90]
Data counts received properly.

F. CRC Error Count Value [Address Number: 91]
Data counts failed to acquire with CRC error.

G. Exception Error Occurrence Count Value [Address Number: 92]
Error counts failed to acquire due to exception error caused by some abnormality.

H. Product Type [Address Number: 102]
Apply the arithmetic equation for each product. Do not change from the factory setting .

I. Modbus Address [Address Number: 103]
The last 2 digits of the product serial number is setup as address number in default.
Ex.] S/N SXXXXXX05: Address = 5, S/N SXXXXXX00: Address = 100 [when "00", the address is "100"]

J. Serial Communication Setup [Address Number: 104] Value: 6 [Default]
Select with number [3] from the combination of baud rate and parity bit.

Table A-9: Communication setting

#	Communication speed [bps]	Parity bit	#	Communication speed [bps]	Parity bit
0	2400	None	10	19200	Even
1	2400	Even	11	19200	Odd
2	2400	Odd	12	38400	None
3	4800	None	13	38400	Even
4	4800	Even	14	38400	Odd
5	4800	Odd	15	115200	None
6	9600	None	16	115200	Even
7	9600	Even	17	115200	Odd
8	9600	Odd			
9	19200	None			

K. Register Type [Address Number: 105]

Select from 4 modes to operate. When operated with other than the mode 1, some functions will be unavailable. {1: Original, 2: MS-XXM mode, 3: KZ mode, 4: HF mode}

L. Digital Filter Constant [Address Number: 106] Value: 1000 [Fixed]

M. Analog Input Setting [Address Number: 107]

From the combination of amplifier type and input range, it is selected with number [#].

Do not change from the factory setting.

TableA-10: Analog input setting

#	Amplifier type	Input range	#	Amplifier type	Input range
0	* OPA	200 mV	5	PGA	256 mV
1	OPA	20 mV	6	PGA	128 mV
2	** PGA	2048 mV	7	PGA	64 mV
3	PGA	1024 mV	8	PGA	32 mV
4	PGA	512 mV	9	PGA	16 mV

* OPA: Operational amplifier、** PGA: Programmed gain amplifier

N. Analog Output Setting [Address Number: 108] Value: 0 [Default]

Select and setup from the following numbers: {0: No analog output, 1: 0-1V output, 2: 4-20mA, 3: Manual}

O. Pt100 Calibration Value [Address Number: 129, 130]

Pt100 offset can be corrected by ratio ["1" = 100%, no correction]

P. Analog Output Calibration Value [Address Number: 131, 132]

Correction value for analog output power

Q. Load Resistor for 0-1V Output [Address Number: 133, 134] Value: 100 [Default]

Precision resistor value [Ω] used when analog 0-1V output is selected.

R. Tilt Sensor Offset Value [Address Number: 143, 144, 145]

Offset value of each tilt for the acceleration sensor X/Y/Z-axises

S. Tilt Sensor 1G Value [Address Number: 146, 147, 148]

Value at the time of 1G of each tilt with acceleration sensor X/Y/Z-axises

T. Origin Point of Tilt Sensor [Address Number: 149, 150, 151]

Value for X/Y/Z-axises at the time of horizontal position [value after adding the offset]

U. Manufactured Date [Address Number: 152, 153]

Date in the format of YYYYMMDD [Exm: May 31, 2019 = “20190531”]

V. Serial Num ber [Address Number: 154, 155]

Serial number by the 32bit integer value [Maximum Value: 4294967295]

W. Sensor Name [Address Number: 156, 157, 158, 159, 160, 161, 162, 163]

Maximum of 16 characters with ASCII code [Contains 2 characters worth in 1 address].

When not all 16 characters are not used, end with “Null” character.

X. Temperature Correction Factor [Address Number: 164, 165, 166, 167, 168, 169, 170, 171]

Parameter for correcting the temperature characteristics caused by the ambient temperature change [1 set with 2 addresses] *Temperature correction is not setup in default setting.

$ETC\,[E, T] = E / TC1\,[T]$, $TC1\,[T] = a + b \times T + c \times T^2 + d \times T^3$

Whereas:

ETC [E,T] : Measurement voltage that compensated the temperature

E : Measurement voltage

TC1[T] : Correction factor

T : Measured temperature [Internal]

a, b, c, d : Correction factor

[a: Address 164/165, b: Address 166/167, c: Address 168/169, d: Address 170/171]

Default Value {a: 1、b: 0、c: 0、d: 0} Setting that does not use temperature correction

Y. Coefficient for Linearity Correction [Address Number: 172, 173, 174, 175, 176, 177, 178, 179]

Parameter to correct the linearity error of output against the solar irradiance [k1, k2, k3, k4]

*Linearity correction is not setup in default setting. Do not change this value.

If linearity compensation is necessary, refer to the following compensation formula:

$I = [k1 + [k2 \times ETC\,[E, T] + [k3 \times ETC\,[E, T]^2\,] + [k4 \times ETC\,[E, T]^3\,]] / S$

Whereas:

I : Solar irradiance after the linearity correction

ETC[E,T] : Measurement voltage after the temperature correction mentioned previously

S : Pyranometer sensitivity

k1, k2, k3, k4 : Correction factor: Offset output [μV] can be changed with k1 is changed.

[k1: Address 172/173, k2: Address 174/175, k3: Address 176/177, k4: Address 178/179]

Default Value {k1 : 0, k2 : 1, k3 : 0, k4 : 0} Setting that does not use linearity correction

Z. Calibration Day [Address Number: 180, 181]

Date in the format of YYYYMMDD [Exm: May 31, 2019 = “20190531”]

Data example

1. Data frame from Master to the Slave No. 0x01 for inquiring the solar irradiance

Node No.	Function No.: Read out holding register	Starting register No.		Read out register value			
		[High]	[Low]	[High]	[Low]		
0x01	0x03	0x00	0x02	0x00	0x02	CRC	CRC

*0xXX is hexadecimal

2. Response data frame from Node No. 0x01 to Master

Node No.	Function No.: Holding register readout	Data length	Register No.2 [0x02]		Register No.3 [0x03]			
			[High]	[Low]	[High]	[Low]		
0x01	0x03	0x04	0x??	0x??	0x??	0x??	CRC	CRC

*0x?? is response value [hexadecimal]

Data Conversion

1. Conversion method when the data format is STR
   - Data format after conversion: ASCII[Please convert according to ASCII code table]

   Conversion example: Data conversion of Model name [Address No.156 to No.163]

   Conversion result: MS-60 _ _ _ _ _ _ _ _ _ _ _

Address No.	156		157		158		159		160		161		162		163	
MS-60S Output Data	4d	53	2d	36	30	20	20	20	20	20	20	20	20	20	20	20
Conversion result	M	S	-	6	0	_	_	_	_	_	_	_	_	_	_	_

2. Conversion method when the data format is UINT16
   - Output data format: UINT16 [Hexadecimal: Please convert hexadecimal numbers to decimal numbers]]
   - Data format after conversion [Decimal number]

   Conversion example: Data conversion of power supply voltage and reference voltage [addresses 60 to 61]

   Conversion result: Power supply voltage 5000 [mV], reference voltage 2048 [mV]

Address No.	60		61	
MS-60S Output Data	2F	12	08	00
Conversion result	12050		2048	

3. Data conversion when the data format is FLOAT [32 base numbers]

- Output data format: FLOAT [hexadecimal number]
- Converted data format: decimal number

Conversion Example: Data conversion of solar irradiance [Address 2 to 3]

The FLOAT data will be in the following order:

As shown in the example, put the data for No. 2 [before] and the data for No. 3 [after] together to make them as one data before conversion.

Next, calculate the data before conversion according to the IEEE754 standard.

Conversion result: 820.52 [W/m2]

Address No.	2		3	
Output Data	21	47	44	4d
Pre-conversion data	444D2147			
Conversion result	820.52			

A-5. Communication Specifications [MS-60S SDI-12]

The SDI-12 is designed according to the following communication specifications.

Table A-11. Communication specification

Item	Description
Communication protocol	SDI-12 Version 1.4
Baud rate	1,200 bps
Data length	7bit
Stop bit	1
Parity bit	Even
Communication distance	Within 60m

Table A-12. SDI12 command list

command	Response example	Description
?!	a<CR><LF>	Check the address number of the device connected. [This is possible only when devices are connected one-to-one.]
a!	a<CR><LF>	Check the device with address number “a” that it is active.
aAb!	b<CR><LF>	Change the device address with address number “a” to “b”.
* aI!	Details[described later]	Request the identification information of the device with address number “a”
aM!	a0011<CR><LF>	Request the device with address number “a” to perform measurement only one time.
aD0!	+1000.0<CR><LF>	Request the device with address number “a” to send data. The device will return the W/m^2 value.
aMC!	a0011<CR><LF>	Request the device with address number “a” to start measurement, and request CRC making sure the command has been properly accepted.
aC! aC0!	a00101<CR><LF>	Request to the device with address number “a” to take simultaneous measurement to the device with bus connection.
aCn!	a00101<CR><LF>	Request to the device with address number “a” to take various types of measurement to the device with bus connection.
aCC!	a00101<CR><LF>	Request the device with address number “a” to start continuous measurement, and request error detection making sure the command has been properly accepted.
aR0!	0+0.0<CR><LF>	Request the device with address number “a” to perform measurement only one time. The device will return the W/m^2 value.
aRC0!	0+0.0EmT<CR><LF>	Request the device with address number “a” to start continuous measurement, and request error detection making sure the command has been properly accepted. The device will return the W/m^2 value.

* Example of response by "aI!" Command: “a18EKOMS-60vvvxx…xx<CR><LF>”
  EKO: Manufacturer, MS-60: Model name, vvv: Version number[3 digits], xxxxxxx: Serial Number

A-6. Recalibration

When MS-60 is calibrated at an external calibration laboratory, in practice slight differences can be expected relative to the MS-60 manufacturer calibration scale and lab-scale. A difference in the calibration measurement results can be explained by the differences with respect to the method of calibration, reference sensors, sensor characteristics and measurement conditions.
In case the sensor needs to be adapted to the new calibration scale, there are two ways to adopt the sensor sensitivity.

1. MS-60
   The scale difference can be applied as a relative factor. A conversion multiplication factor can be applied to calculate the irradiance. In this case, the original manufacturer calibration remains unchanged. The multiplication factor can be applied in the data logger or processing software.
2. MS-60S
   The scale difference can be applied to the sensitivity figure default to the sensor. This can be done through the EKO "SensConf" Software. Since the internal sensor sensitivity figure is specified in µV/W/m^2, the sensitivity figure can be changed relative to the irradiance scale change.

Example:

The sensor recalibration revealed a difference with respect to the irradiance measured by the MS-60 relative to the lab-scale. The MS-60 irradiance readings are underestimated and can be adapted by lowering the MS-60 sensitivity factor, which can be calculated with following:

$$S_{new} = I_{MS80} / I_{ref} \times S_{origin}$$

Where:

S_{new} :	New Sensitivity of MS-60 [µV/W/m^2]
S_{origin} :	Original sensitivity of MS-60 [µV/W/m^2]
$I_{MS\text{-}60}$:	Irradiance measured by MS-60 [W/m^2]
I_{ref} :	Reference Irradiance [W/m^2]

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