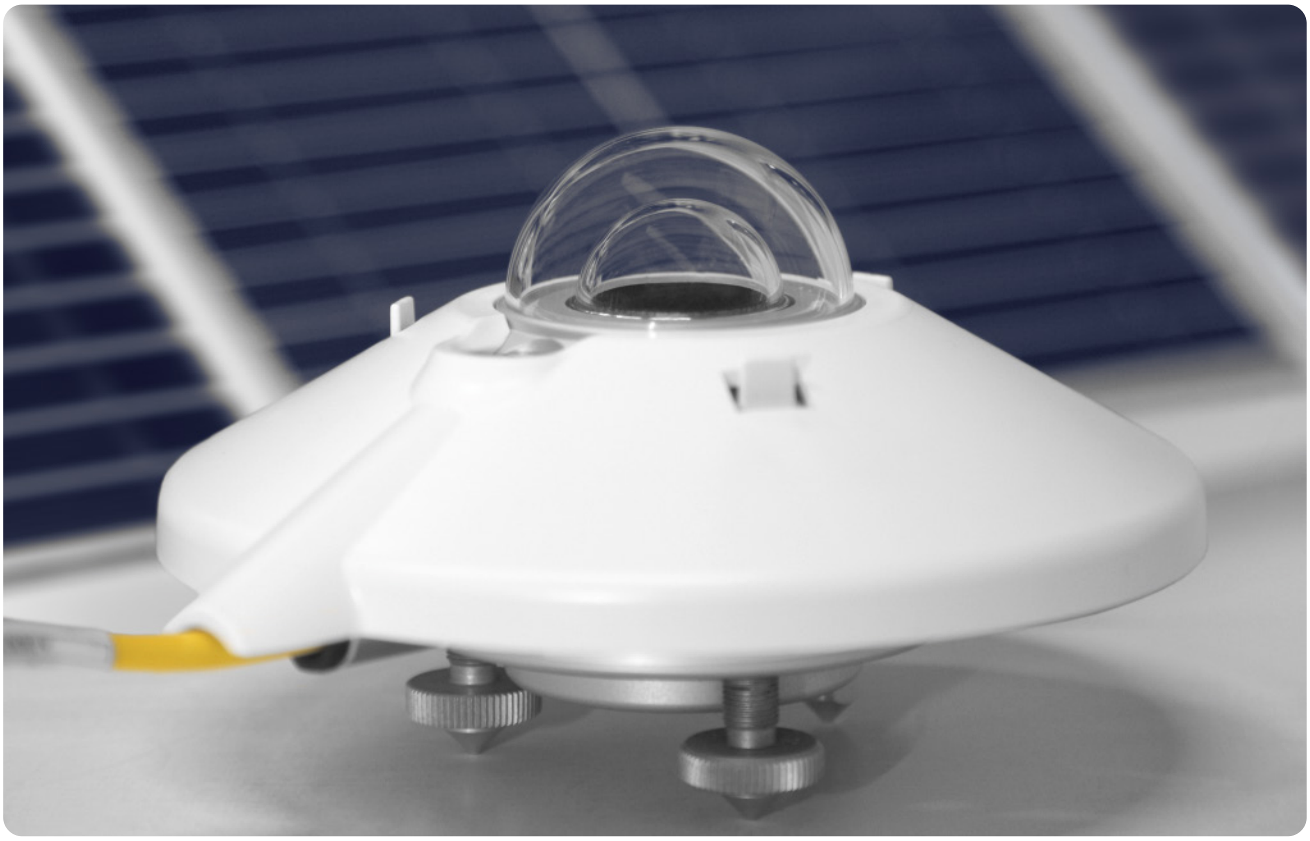

Instruction Manual

SMP series • Smart Pyranometer

Important User Information

Dear customer, thank you for purchasing a Kipp & Zonen instrument. It is essential that you read this manual completely for a full understanding of the proper and safe installation, use, maintenance and operation of your new SMP series pyranometer.

We understand that no instruction manual is perfect, so should you have any comments regarding this manual we will be pleased to receive them at:

Kipp & Zonen B.V.
Delftechpark 36, 2628 XH Delft, - or
P.O. Box 507, 2600 AM Delft,
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F: +31 (0) 15 2620 351
support@kippzonen.com
www.kippzonen.com

Warranty and liability

Kipp & Zonen guarantees that the product delivered has been thoroughly tested to ensure that it 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 supplied by Kipp & Zonen.

Kipp & Zonen shall in no event be liable for incidental or consequential damages, including without limitation, lost profits, loss of income, loss of business opportunities, loss of use and other related exposures, however incurred, rising from the faulty and incorrect use of the product.

Modifications made by the user may affect the instrument performance, void the warranty, or affect the validity of the CE declaration or other approvals and compliances to applicable International Standards.

Manual document number: V1405
Publication date: 1st May 2014

Declaration of Conformity

CE

We	**Kipp & Zonen B.V.** Delftechpark 36, 2628 XH Delft P.O. Box 507, 2600 AM Delft The Netherlands

Declare under our sole responsibility that the products:

Models	**SMP3 and SMP11**
Type	**Smart Pyranometer**

to which this declaration relates are in conformity with European Harmonised Standards as published in:

Official Journal of the EC, Issue: C246 (05-10-2005)

The compliance of the product has been based on:

Emissions	**EN 61326-1:2000**
Immunity	**EN 61326-1:2000**
Safety	**EN 61010-1:2001**
Radio part	**NA**

following the provisions of the directives (if applicable):

EMC-directive	**2004/108/EC**
Electrical safety	**2005/95/EC**

Delft, 1st February 2012

B.A.H. Dieterink
President
Kipp & Zonen B.V.

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1. Introduction

Throughout this manual the following symbols are used to indicate to the user important information.

General warning about conditions, other than those caused by high voltage electricity, which may result in physical injury and/or damage to the equipment or cause the equipment to not operate correctly.

Note Useful information for the user

1.1 Product overview

According to International Standard ISO 9060:1990 and the World Meteorological Organisation (WMO) a pyranometer is the designated type of instrument for the measurement of hemispherical (global or diffuse) solar radiation integrated over the wavelength range from 0.3 μm to 3 μm (300 nm to 3000 nm). All pyranometers within the SMP series are compliant with one of the classes specified by the international standard.

This manual, together with the instruction sheet, provides information related to the installation, maintenance, calibration, product specifications and applications of the SMP series pyranometers.

If any questions should remain, please contact your local Kipp & Zonen representative or e-mail the Kipp & Zonen customer and product support department at: **support@kippzonen.com**

Please go to **www.kippzonen.com** for information about other Kipp & Zonen products, or to check for any updates to this manual or software.

1.1.1 The pyranometer

The SMP series instruments are high quality radiometers designed for measuring short-wave irradiance on a plane surface (radiant flux, W/m^2), which results from the sum of the direct solar radiation and the diffuse sky radiation incident from the hemisphere above the instrument.

SMP pyranometers feature internal digital signal processing and interfaces optimised for industrial data acquisition and control systems. Kipp & Zonen has developed a smart interface that features RS-485 Modbus® data communication for connection to programmable logic controllers (PLC's), inverters, digital control equipment and the latest generation of data loggers. Amplified Voltage or Current outputs are also included for devices that have high-level analogue inputs or current loop interfaces.

There are two models in the SMP series, SMP3 and SMP11, and both are available in two versions. One has an analogue voltage output of 0 to 1 V, the other has an analogue current output of 4 to 20 mA. Both have a 2-wire RS-485 interface with Modbus® (RTU) protocol.

Digital signal processing provides faster response times and, with an integrated temperature sensor, corrects for the temperature dependence of the detector sensitivity.

To achieve the required spectral and directional characteristics SMP Series pyranometers use thermopile detectors and glass domes. SMP3 and SMP11 both have built-in bubble levels and adjustable levelling feet. Snap-on sun shields reduce solar heating of the housings. The waterproof connectors have gold-plated contacts.

The pyranometers are normally delivered with a waterproof plug pre-wired to a high quality signal cable, typically this is 10 m long but other lengths are available. The instruments can also be ordered with a plug only, for the user to fit their own cable.

SMP3 features a 64-junction thermopile sensing element with a highly absorptive, and spectrally flat, black coating to capture incoming radiation and convert it to an electrical signal. This detector is protected by a high quality glass dome which is 4 mm thick. The housing is completely sealed.

SMP11 has a larger housing than SMP3 with increased thermal mass. Its 32-junction thermopile sensing element features faster response, better linearity and a wider measurement range than the SMP3. There are two high quality concentric glass domes, 2 mm thick, which provide improved directional error and thermal isolation. The radiometric levelling is more accurate and SMP11 has a drying cartridge with replaceable desiccant.

Features and specifications of the SMP3 and SMP11 pyranometers are explained later in this manual.

1.1.2 International Standards

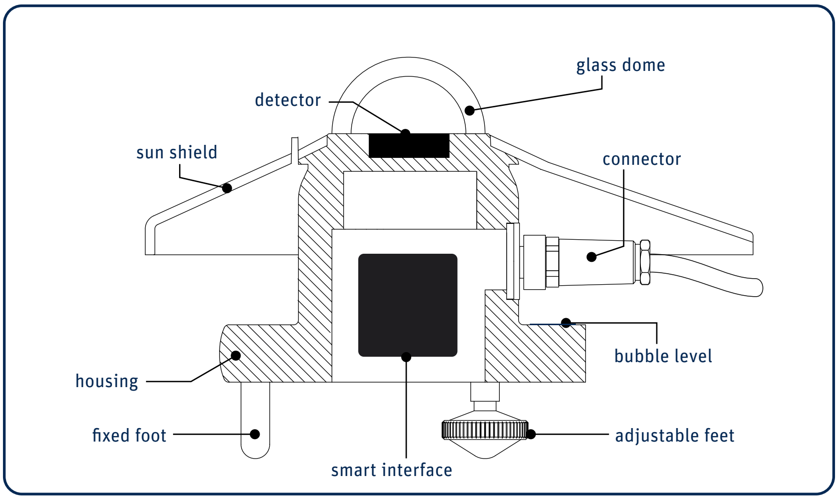
SMP3 is fully compliant with the requirements of ISO 9060:1990 for a Second Class Pyranometer.

SMP11 is fully compliant with the requirements of ISO 9060:1990 for a Secondary Standard Pyranometer..

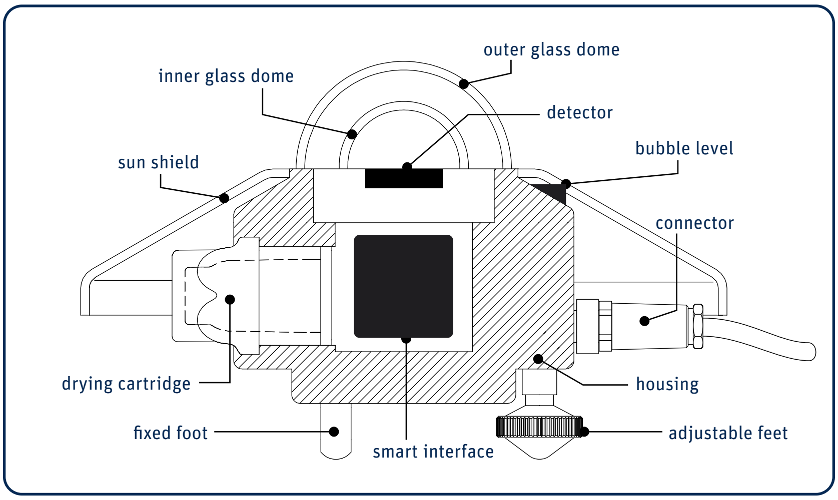
SMP series pyranometers are calibrated in accordance with Annex A.3 of ISO 9847 'Calibration of Field Pyranometers by Comparison to a Reference Pyranometer'. Annex A.3 refers to 'Calibration Devices Using Artificial Sources'. Calibrations are traceable to the World Radiometric Reference (WRR) in Davos, Switzerland.

SMP series pyranometers comply with IEC 60904-1 'Photovoltaic devices - Part 1: Measurement of Photovoltaic Current-Voltage Characteristics'.

1.2 Key parts of the SMP3 pyranometer



1.3 Key parts of the SMP11 pyranometer



2. Installation

Please follow the instructions in this section carefully for the mechanical and electrical installation of the SMP series pyranometers.

Do not turn on power to the instrument until instructed to do so.

Note Do not connect the instrument to a computer until instructed to do so.

Note Do not turn on power to the operating computer until instructed to do so.

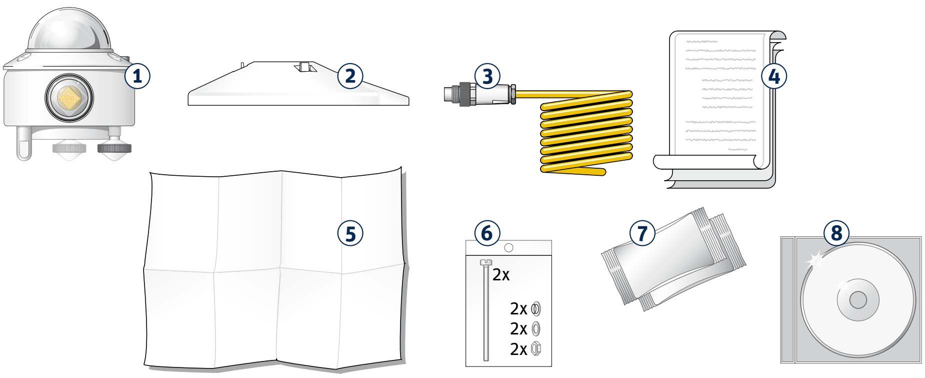
2.1 Included with the product

Check the contents of the shipment for completeness (see below) and note whether any damage has occurred during transport. If there is damage, a claim should be filed with the carrier immediately. In the case of damage and/or the contents are incomplete, contact your local Kipp & Zonen representative or e-mail the Kipp & Zonen customer and product support department at: **support@kippzonen.com**

Although all SMP radiometers are weather-proof and suitable for use in harsh environmental conditions, they have some delicate mechanical parts. Please keep the original packaging for safe transport of the radiometer to the measurement site, or for use when returning the radiometer for calibration.

The following items are included with SMP pyranometers:

① Smart Pyranometer
② Sun screen
③ Cable, pre-wired with 8-pins connector or connector only for customer cable
④ Calibration certificate
⑤ Instruction sheet
⑥ Pyranometer fixing kit SMP3; 2 each of stainless steel M5 x 30, M5 x 40 and M5 x 50 mm screws, nut, flat washer
Pyranometer fixing kit SMP11; 2 each of stainless steel M5 x 80 mm screw, nut, flat washer, nylon insulation ring
⑦ 2 Dessicant bags (SMP11 only)
⑧ CD with product documentation and software



2.2 Tools required

The tools required to fit an SMP series pyranometer to a support are a 4 mm (M5 socket head screw) Allen key and a 8 mm (M5 nut) wrench / spanner. Normally, the drying cartridge for the SMP11 should be hand-tight, but a 16 mm or 5/8” open-ended wrench / spanner can be used to loosen it.

2.3 Location and support

The instruction sheets contain all the outline information necessary for the correct installation of the pyranometers. Further detail for specific types of installation and application are given later in this section.

Check the condition of the desiccant in the SMP11 and replace before installation, if necessary; for example after a long storage period.

When using the digital output it might be convenient to set the Modbus® address prior to visiting the site, otherwise a computer and RS-485 / USB converter may be required during installation.

2.4 Installation for measurement of horizontal global irradiance

The following steps must be carefully taken for optimal performance of the instrument.

2.4.1 Location

Ideally, the site for the radiometer should be free from any obstructions to the hemispherical view from the plane of the detector. If this is not possible, the site should be chosen in such a way that any obstruction over the azimuth range between earliest sunrise and latest sunset should have an elevation not exceeding 5° (the apparent sun diameter is 0.5°).

This is important for an accurate measurement of the direct solar radiation component. The diffuse solar radiation is less influenced by obstructions near the horizon. For instance, an obstruction with an elevation of 5° over the whole azimuth range of 360° decreases the downward diffuse solar radiation by only 0.8 %.

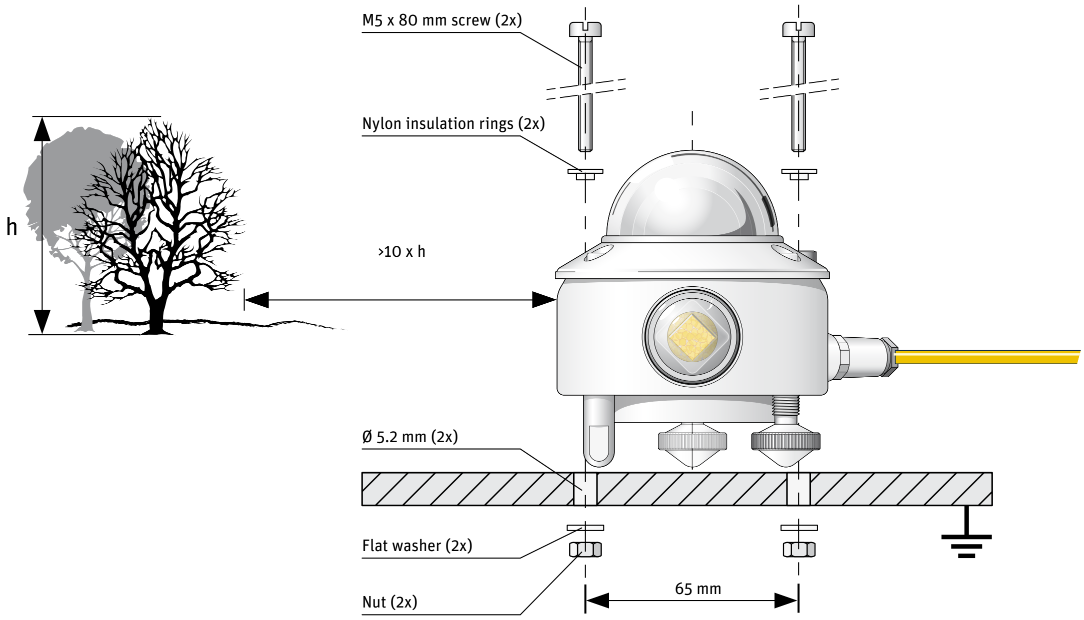
It is evident that the radiometer should be located in such a way that a shadow will not be cast upon it at any time (for example by masts or ventilation ducts). Note that hot exhaust gas (> 100 °C) will produce some radiation in the spectral range of the radiometer and cause an offset in the measurements. The radiometer should be distant from light-coloured walls or other objects likely to reflect sunlight onto it, or emitting short-wave radiation.

The radiometer should be readily accessible for cleaning the outer dome, checking that it is level and inspecting the desiccant.

2.4.2 Mounting

The SMP pyranometer is provided with two holes for 5 mm bolts. Two nylon insulation rings and two each of stainless steel bolts, washers and nuts are provided in the fixing kit. The pyranometer should first be secured lightly with the bolts to a solid and stable mounting stand or platform as shown below. The nylon insulators are important to prevent corrosion between the screws and the pyranometer housing.

The mounting stand temperature may vary over a wider range than the air temperature. Temperature fluctuations of the pyranometer body can produce offset signals, therefore it is recommended to isolate the pyranometer thermally from the mounting stand by placing it on its three feet. Ensure that there is a good electrical contact with the ground to conduct away currents in the cable shield induced by lightning.



Note After recalibration and/or reinstallation ensure that the nylon insulators are refitted.

2.4.3 Orientation

In principle no special orientation of the instrument is required, although the World Meteorological Organisation (WMO) recommends that the signal lead (connector) is pointed towards the nearest pole, to minimise heating of the electrical connections. This is also where any mounting pole, or other support, should be located in order that shadows do not fall on the instrument.

2.4.4 Levelling

Accurate measurement of the global radiation requires proper levelling of the detector surface. Level the instrument by turning the two adjustable feet to bring the bubble of the spirit level centrally within the marked ring. For easy levelling, first use the screw nearest to the spirit level.

Note It is ideal that the bubble should be completely within the marked ring. However, in fact, the pyranometer is level within the specified accuracy when the bubble is at least half within the ring.

2.4.5 Securing

Secure the pyranometer tightly with the two stainless steel bolts. Use the two nylon insulators to avoid contact between the aluminium body and the steel screws. Ensure that the pyranometer maintains the correct levelled position when it is tightened.

2.4.6 Fitting the connector and cable

Locate the plug correctly in the radiometer socket, it only fits one way, and push it in. Screw the plug locking ring hand-tight. Over-tightening may damage the waterproof seal. Secure the cable so that it cannot blow in the wind or cause a shadow on the instrument.

Note The cable should be arranged with a curve below the instrument so that water drips off, rather than running along the cable up to the connector.

2.4.7 Fitting the sun shield

Finally, clip on the sun shield to prevent excessive heating of the radiometer body. The bubble level is visible through the top of the sun shield for routine checks and the shield 'tail' helps to protect the connector.

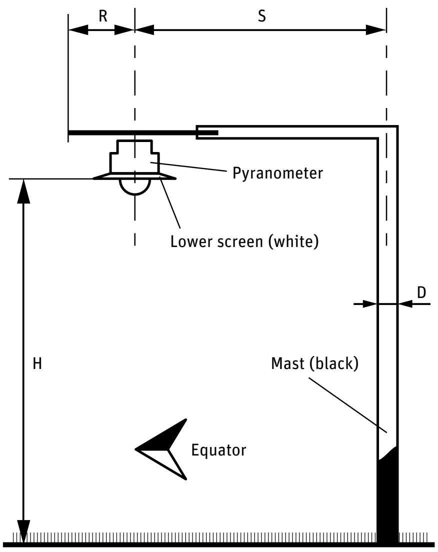
2.5 Installation for measurement of tilted global irradiance

When a pyranometer is mounted on a large flat tilted surface the temperature of this surface can rise considerably (more than 10 °C) above air temperature. It is advised to pre-adjust the levelling feet on a horizontal surface for easy mounting of the instrument parallel to the inclined surface. It improves the measurement accuracy when the body is thermally isolated by its feet from the surface. This promotes thermal equilibrium between the dome(s) and the housing and decreases zero offsets.

For accurately and securely fixing a pyranometer at an angle to a surface an adjustable tilt mounting kit is available. See Accessories in chapter 3.

2.6 Installation for measurement of reflected global irradiance

In the inverted position the pyranometer measures reflected global radiation. The height above the surface (H) depends upon its roughness. The WMO recommends a height of 1 m to 2 m above a uniform surface covered by short grass.



The mounting device should not interfere significantly with the field of view of the instrument. The mounting plate above the pyranometer prevents excessive heating of the housing by downwards solar radiation and. The glare screen has an angle of 5° and is fitted to the pyranometer to prevent direct illumination of the domes by the sun at sunrise and sunset. It is available as an accessory kit for the SMP11 only.

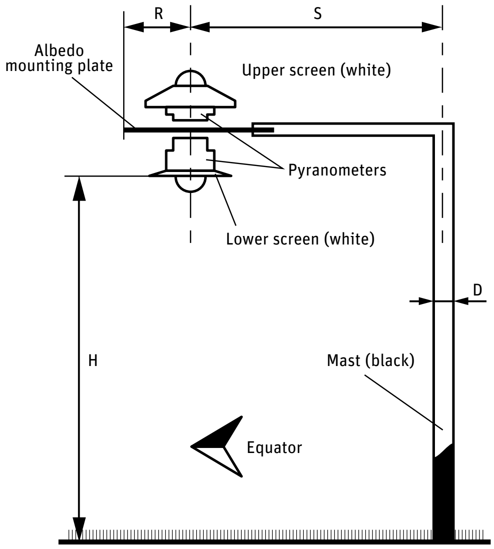
Thermal offset signals generated in the pyranometer are 5 times more significant in the measurement of reflected radiation due to the lower irradiance level.

The mast shown intercepts a fraction $D/2\pi S$. of the radiation coming from the ground. In the most unfavourable situation (sun at zenith) the pyranometer shadow decreases the signal by a factor R2/H2.

As a guide, a black shadow below the pyranometer with a radius of 0.1 x H decreases the signal by 1 %, and 99 % of the signal will originate from an area with a radius of 10 x H.

2.7 Installation for measurement of albedo

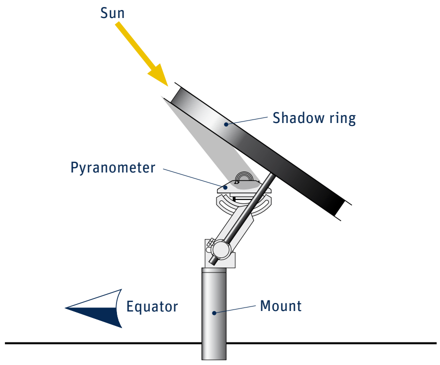
An albedometer consists of two identical pyranometers that measure the incoming global solar radiation and the radiation reflected from the surface below. Albedo is the ratio of the two irradiances, and varies from 0 (dark) to 1 (bright).



Two SMP3's can be mounted back to back with the standard fixing kit, and the accessory mounting rod screwed into one of them, to make an albedometer. For two SMP11's a mounting plate is required. The CMF 1 mounting plate is used for unventilated SMP11's and the CMF 2 for ventilated instruments. There is no ventilation unit for the SMP3.

The requirements for installation of the upper pyranometer are the same as for horizontal global irradiance. The requirements for installation of the lower pyranometer and mast are the same as for reflected global irradiance.

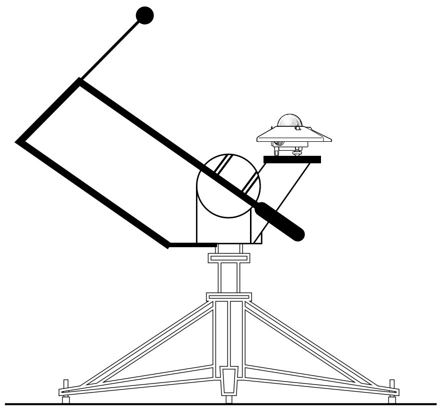
2.8 Installation for measurement of horizontal diffuse irradiance



For measuring the diffuse radiation from the sky, the direct solar radiation must be blocked from the pyranometer dome(s).

A static shadow ring can be used to intercept the direct solar radiation. This requires frequent manual adjustment as the sun's arc in the sky changes. At times the shadow ring also intercepts a significant proportion of the diffuse sky radiation. Therefore, post-processing of the recorded data is necessary to correct for this.

Kipp & Zonen produces a universal shadow ring, model CM 121, which is suitable for use at all latitudes.



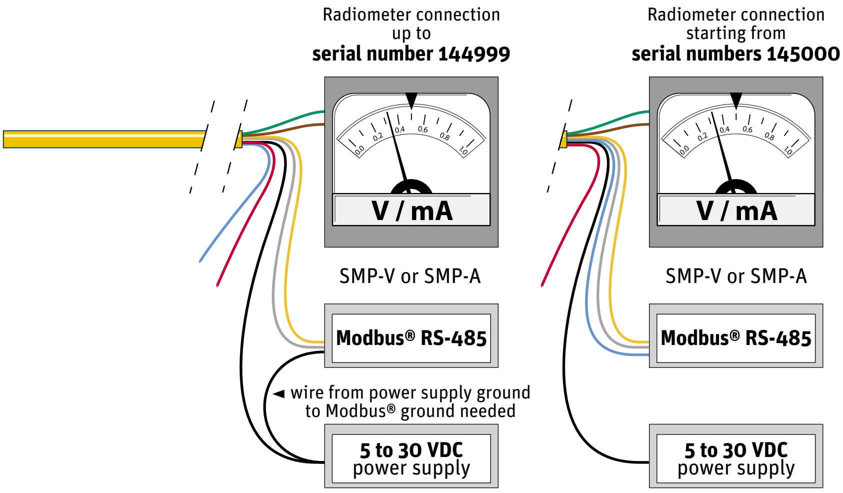
The alternative to a shadow ring is to use a two-axis automatic sun tracker, such as one of the models from Kipp & Zonen. The sun tracker uses location and time information to calculate the position of the sun and point at it accurately under all weather conditions.

The sun tracker can be fitted with a small disk or sphere mounted on an articulated shading assembly. The shadow of the disk or sphere is adjusted to cover the pyranometer dome(s) completely and it will then be shaded correctly throughout the year without adjustment.

2.9 Electrical connections

As standard SMP pyranometers are supplied with a waterproof connector pre-wired to 10 m of high quality yellow cable with 8 wires and a shield covered with a black sleeve. Longer cables are available as options. The colour code of the wires and the connector pin numbers are shown below and on the instruction sheet.

Special attention is needed to prevent power or ground loops when connecting the SMP to multiple readout devices. Connecting the RS-485 to a grounded circuit and the analogue output to a floating circuit can cause unacceptable ground loops. This may cause differential voltages outside the SMP specifications and will damage the unit. We recommend using either the analogue or the digital output but not both. The maximum differential between either of the Modbus® RS-485 lines (yellow and grey) and the power ground / RS-485 common line (black) is 70 VDC.



RADIOMETER CONNECTION

Wire	Function	Connect with
3 Green	Analogue out	V+/4-20 mA(+)
6 Brown	Analogue ground	V–/4-20 mA(–)
4 Yellow	Modbus® RS-485	B/B'/+
5 Grey	Modbus® RS-485	A/A'/–
7 White	Power 5 to 30 VDC (12 V recommended)	
8 Black	Power ground / RS-485 Common	
1 Red	None	Not connected
2 Blue	Modbus® common / Ground	
Shield	Housing	Ground *

* Connect to ground if radiometer not grounded

The blue wire is not connect with radiometers with serial number up to 144999

First connect all wires before plugging into the radiometer

The shield of the cable is connected to the aluminium radiometer housing through the connector body. Preferably, secure the radiometer with its levelling screws on a metal support with a good connection to ground (e.g. by using a lightning conductor) and do not connect the cable shield at the readout end.

If there is no good ground connection at the pyranometer, the shield at the cable end should be connected to ground at the readout equipment. Lightning can induce high voltages in the shield but these will be led off at the pyranometer or readout equipment.

Note Long cables may be used, but the cable resistance must be smaller than 0.1% of the impedance of the readout equipment for the analogue outputs and may affect the baud rate of the RS-485 digital connection.

2.9.1 Power connection

The minimum power supply voltage for SMP pyranometers is 5 VDC. However, for optimal performance it is advised to use 12 VDC, especially when long cables are used. 5-volt power can only be used in combination with a short cable, maximum 10 m.

It is advised to protect the output of the power supply with a fast blowing fuse of maximum 250 mA rating.

Typical power consumption SMPX-V for maximum output (1 V)		
5 VDC	50 mW	(approx. 10.0 mA)
12 VDC	55 mW	(approx. 4.5 mA)
24 VDC	60 mW	(approx. 2.5 mA)

Maximum power consumption 65 mW at the highest input voltage.
Maximum input current 12.5 mA at the lowest input voltage.
Maximum inrush current 200 mA.

Typical power consumption SMPX-A for max output (20 mA)		
5 VDC	77 mW	(approx. 28 mA with 100 Ω load resistor)
12 VDC	83 mW	(approx. 24 mA with 100 Ω load resistor)
24 VDC	100 mW	(approx. 6 mA with 100 Ω load resistor)

The above mW values represent the dissipation within the SMPX-A. For the total power the energy in the load resistor has to be added.

For supply voltages below 12 Volts or above 20 Volts it is advised to use a load resistor of less than 500 Ω to keep the power consumption as low as possible.

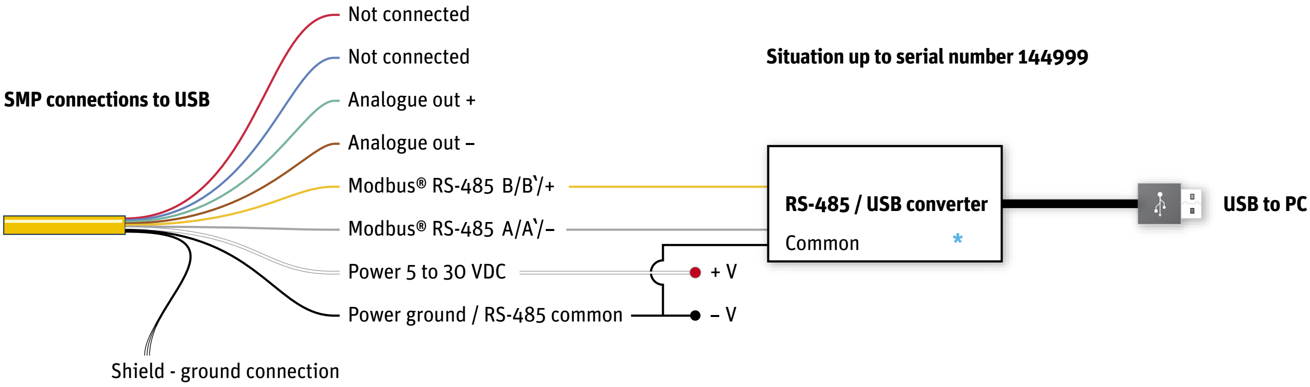
2.9.2 Data connection

Connection to a Personal Computer by Universal Serial Bus (USB)

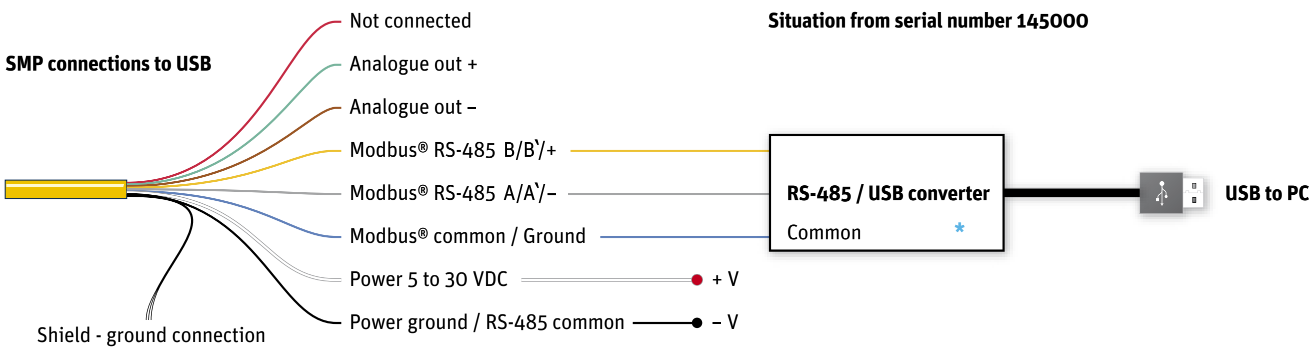
The connection depends on the use of a RS-485 to USB converter.

The converter **must** have galvanic isolation between the inputs and outputs to prevent possible damage to the SMP digital interface. This is particularly an issue with portable computers (laptops, etc.) in which the power supplies can generate large voltage spikes.

A suitable converter is the model USOPTL4 from B & B Electronics. One end has the USB connector to the PC the other end has a connector with screw terminals for the instrument wires. This RS-485 converter is powered from the USB interface, so no additional power adaptor is necessary.



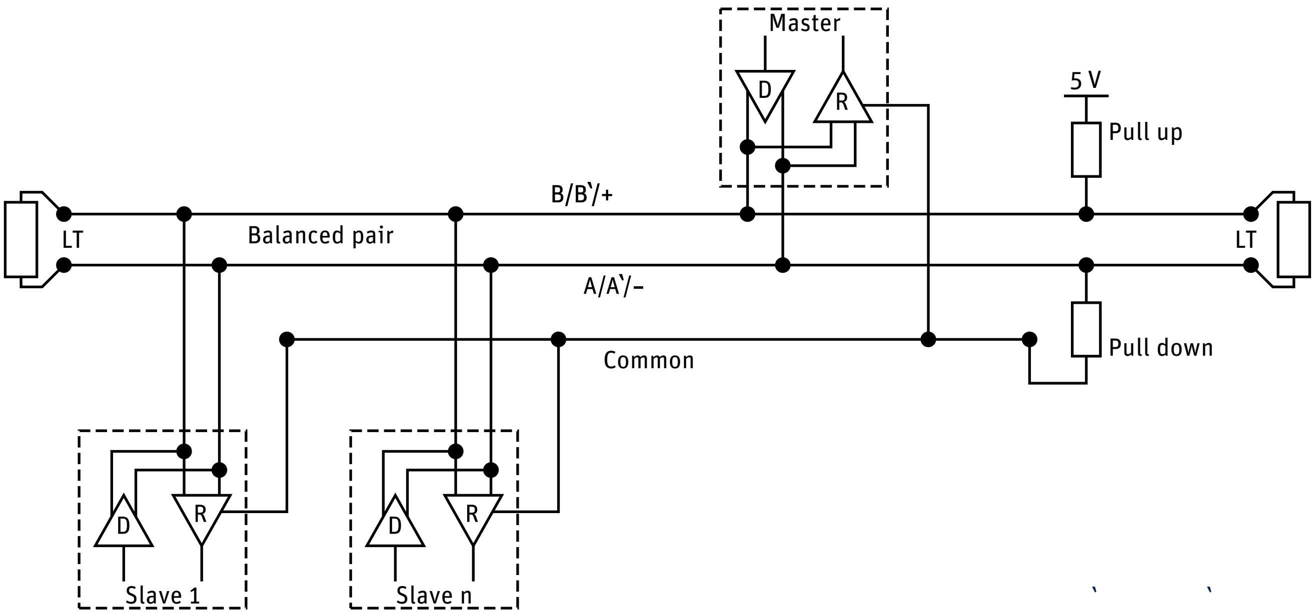
*Note Switches on the converter should be set for RS-485, 2-wire operation and Echo off.



***Note** Switches on the converter should be set for RS-485, 2-wire operation and Echo off.

Connection to a RS-485 Network

The digital interface can be connected to a 2-wire RS-485 network as shown below.



The slaves and master may be a SMP pyranometer or other devices. If a SMP pyranometer is the last device on the network a line terminator (LT), consisting of a 120 Ω or 150 Ω resistor, must be connected between terminals A/A /- and B/B /+. Never place this line termination on the derivation cable. It is also required to install the pull up and pull down resistors as shown. The value of these resistors must be between 650 Ω and 850 Ω.

2.9.3 Analogue voltage output

The SMP3-V and SMP11-V (voltage output versions) have been factory set such that an output of 0 Volts represents -200 W/m² (this will never be reached in practice), and the full-scale output of 1 Volt represents 2000 W/m².

The voltage output range in W/m² can be changed by the user with the supplied PC software. The maximum recommended irradiance for the SMP3 is 2000 W/m² and for the SMP11 is 4000 W/m².

The measurement range must start from a negative value in order to show (small) negative readings, for example night-time offsets, because the analogue output itself cannot go negative. For the default setting of 0 to 1 Volt representing -200 to 2000 W/m² the range is actually 2200 W/m² with a zero offset of 200 W/m².

The irradiance value ($E_{\downarrow solar}$) for the default setting can be simply calculated as shown below.

$$E_{\downarrow solar} = (V \times 2200) - 200$$

$E_{\downarrow solar}$ = Solar radiation [W/m²]
V = Output of radiometer [Volt]

If the pyranometer is used in atmospheric conditions it is advised to keep the range as factory set.

2.9.4 Analogue current output

The SMP3-A and SMP11-A (current output versions) have been factory set such that an output of 4 mA represents 0 W/m² and the full-scale output of 20 mA represents 1600 W/m².

The current output range in W/m² can be changed by the user with the supplied PC software. The maximum recommended irradiance for the SMP3 is 2000 W/m² and for the SMP11 is 4000 W/m².

Negative inputs will make the output go below 4 mA and no zero offset is needed.

For the default setting of 4 to 20 mA representing 0 to 1600 W/m², each mA represents 100 W/m².

The irradiance value ($E_{\downarrow solar}$) for the default setting can be simply calculated as shown below.

$$E_{\downarrow solar} = (mA - 4) \times 100$$

$E_{\downarrow solar}$ = Solar radiation [W/m²]
mA = Output of radiometer [mA]

2.9.5 Recommended cable types

Where cables need to be extended, or the customer prefers to provide their own cables, they should be suitable for outdoor used and UV resistant.

Recommended types	
RS-485	Ethernet CAT 5 shielded twisted pair (STP)
0 to 1 V	Shielded 2-core signal cable
4 to 20 mA	Shielded twisted pair control cable

3. Accessories

Below is a brief description of the accessories available for SMP series pyranometers. Detailed information can be found on our website, where the brochures and manuals for these accessories can be viewed and downloaded.

3.1 Diffuse radiation measurement

For measuring diffuse radiation a shading device is required. Kipp & Zonen can offer several options for SMP pyranometers:

Shadow ring CM 121B for a SMP3 or an unventilated SMP11
Shadow ring CM 121C for a ventilated SMP11

This shadow ring needs to be adjusted manually every 3-5 days and corrections made for the sky obscuration by the ring.

An automated and more accurate way to measure diffuse radiation is to use an automatic sun tracker fitted with a shading mechanism:

2AP sun tracker + shading ball assembly
SOLYS 2 sun tracker + shading ball assembly

3.2 Ventilation

To further improve measurement accuracy of the SMP11 pyranometer the CVF 3 ventilation unit can be used. CVF 3 has a tacho output to monitor the fan speed and 5 or 10 Watt heater. The advantages of a CVF 3 are:

Lower thermal offsets
No precipitation or condensation on the dome
Less dirt on the dome
Frost, snow or ice can be melted
Less frequent cleaning required

3.3 Mountings

For mounting pyranometers the following plates and brackets are available:

Mounting rod for SMP3
CMF 1 mounting fixture with rod for mounting one or two unventilated SMP11's
CMF 2 mounting plate with rod for mounting one or two ventilated SMP11's
CMB 1 mounting bracket to fix and adjust a mounting rod to a mast, pole or wall
Adjustable tilt mounting kit allows tilting of a SMP pyranometer (e.g. in the same plane as a PV panel), It has a clear scale for setting the desired angle.

3.4 Glare screen kit

When a SMP11 pyranometer is mounted looking downwards, to measure reflected radiation, it should be fitted with the glare screen kit. The screen blocks radiation coming from the 5° below the horizon of the pyranometer, to prevent direct illumination of the domes by the sun at sunrise and sunset.

3.5 Cables

As standard a 10 m long cable with a pre-wired waterproof connector plug is supplied. Optional longer cables are available, or a loose connector only for you to fit to your own cable.

25 m cable with connector
50 m cable with connector
Loose connector without cable

4. Software installation and configuration

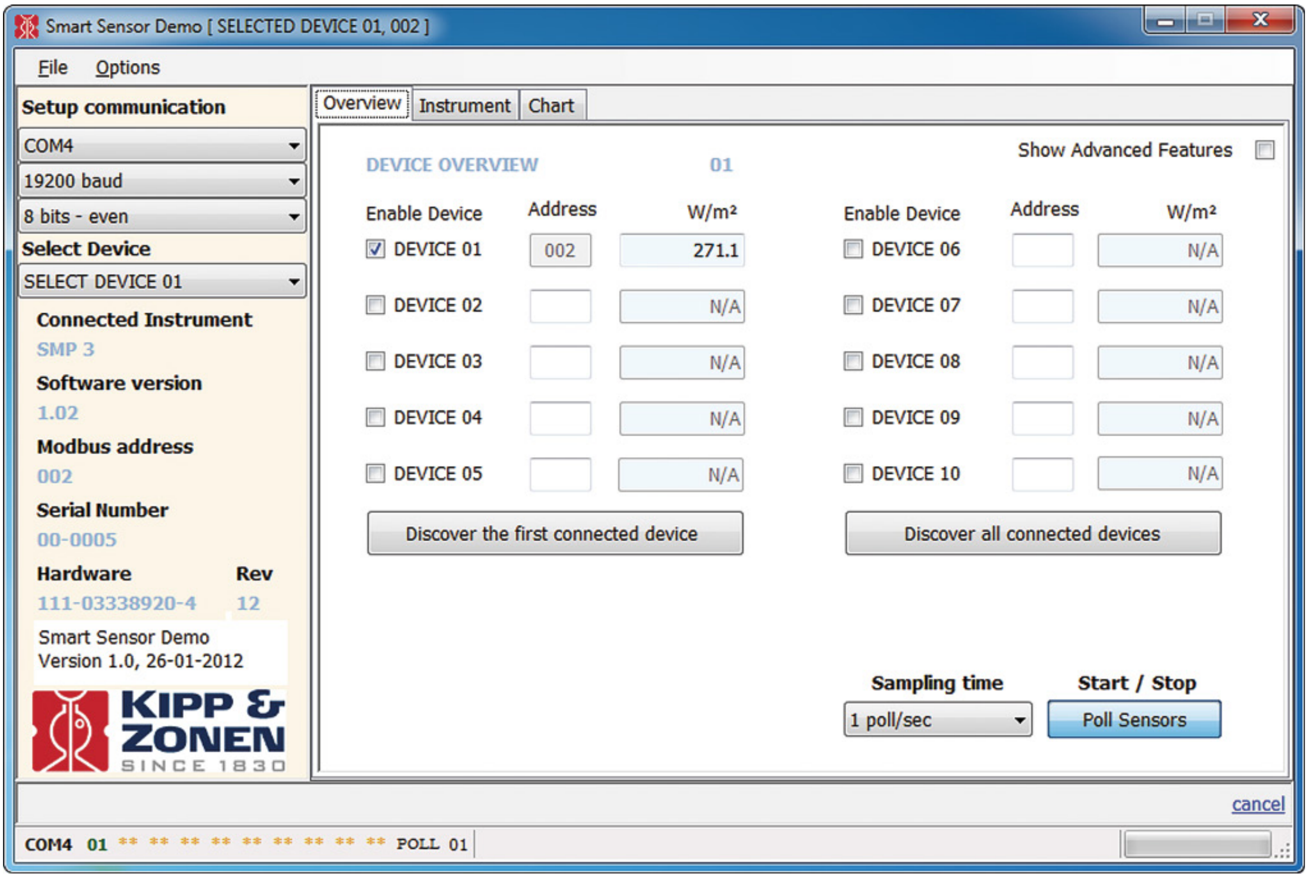
SMP pyranometers are delivered with a software programme SmartSensorDemo.exe, This software is supplied on a CD-ROM. The operating computer must be running on a 32-bit or 64-bit version of Windows™ XP or Windows™ 7. Insert the CD into the CD/DVD ROM drive of the operating computer and follow the on-screen installation instructions.

Note Before installing the software it is advised to disconnect all Modbus® devices except for the device that you wish to configure. Refer to section 2.9.2 'Data Connection'.

The program is for testing the instrument and setting parameters. Basic data logging and display of data on a PC is also possible. The software can handle up to 10 SMP pyranometers at the same time connected to the same RS-485 to USB converter. This software is not intended for continuous long-term measurement, which should be done through the RS-485 network controller.

4.1 Set up communication

When the Smart Sensor Demo program is opened there are 3 basic functions available; 'Overview', 'Instrument' and 'Chart'.

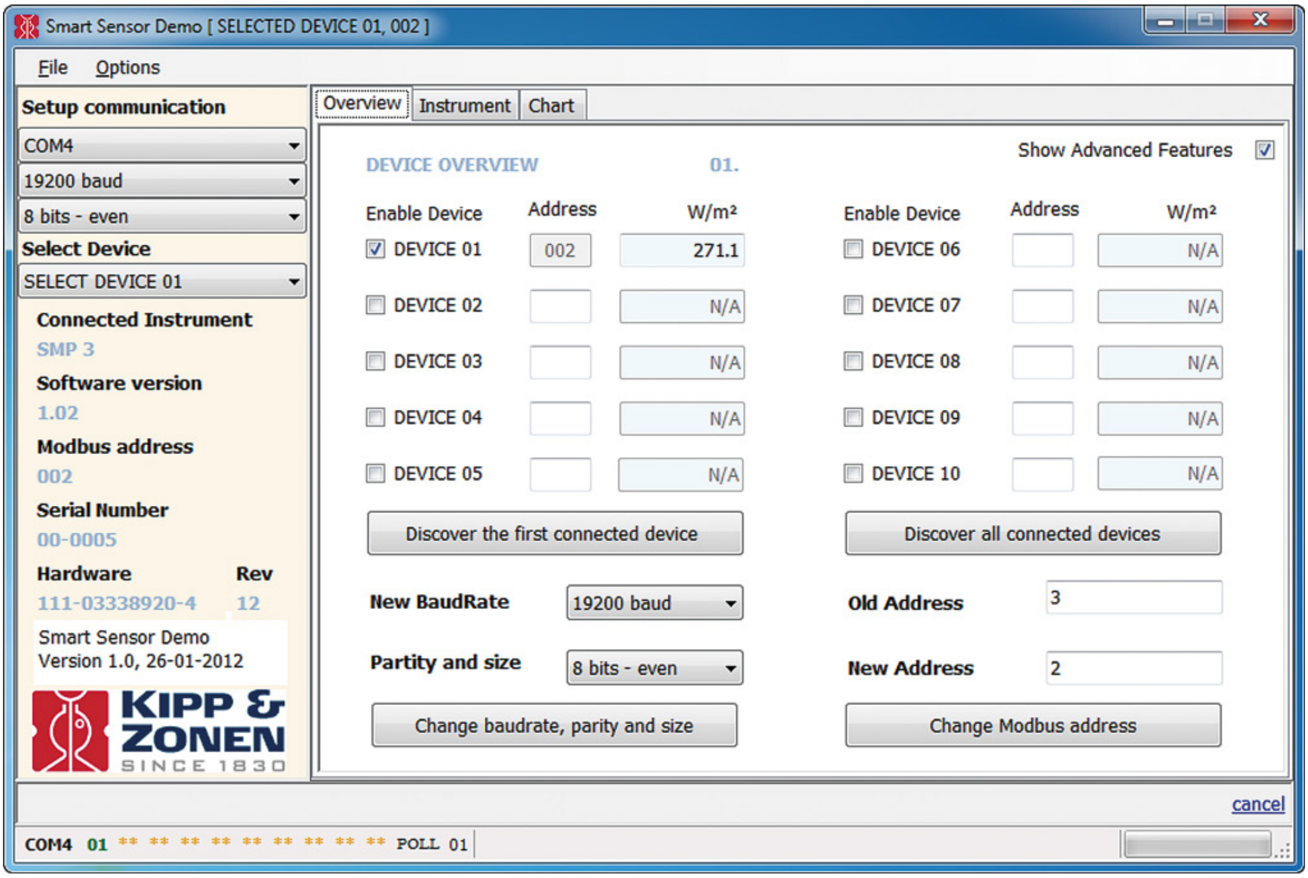


With the 'Overview' tab active the communication parameters can be set as follows:

1. Select the communication port where the RS-485 converter is connected
2. Set the baud rate (19200 is the default setting)
3. Set the number of data bits and parity (8 bits with even parity is the default setting)
4. Set the sampling time (1 poll per second is the default setting)
5. Press the button 'Discover the first connected device' (or press 'Discover all connected devices' if there is more than one device connected)

4.2 Change the Modbus® address

With the 'Overview' tab active, ticking the 'Show Advanced Features' box in the upper right hand corner brings up the possibility to change the Modbus® address.



The default Modbus® address of all SMP pyranometers is 1. Before you can use the instrument in your network you must reconfigure the address to a unique number. Each Modbus® device connected to a network must have a unique address.

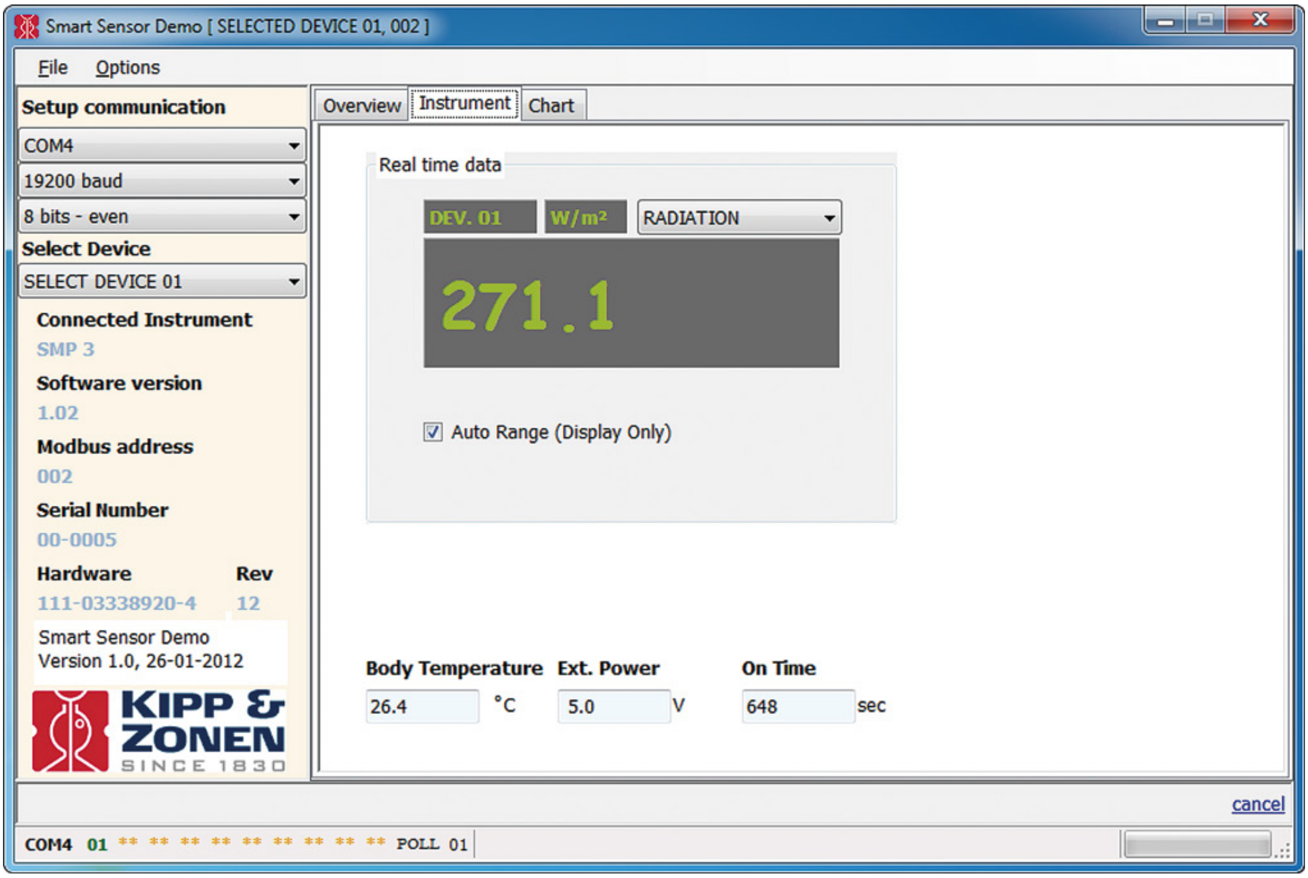
1. Enter the old Modbus® address, this can be found with the button 'Discover all connected devices' (for example, enter 1).
2. Enter the new Modbus® address. This must be a unique number (for example, 24).
3. Press the 'Change Modbus address' button.

When the address has been changed the SMP pyranometer will restart itself.

4.3 Instrument data

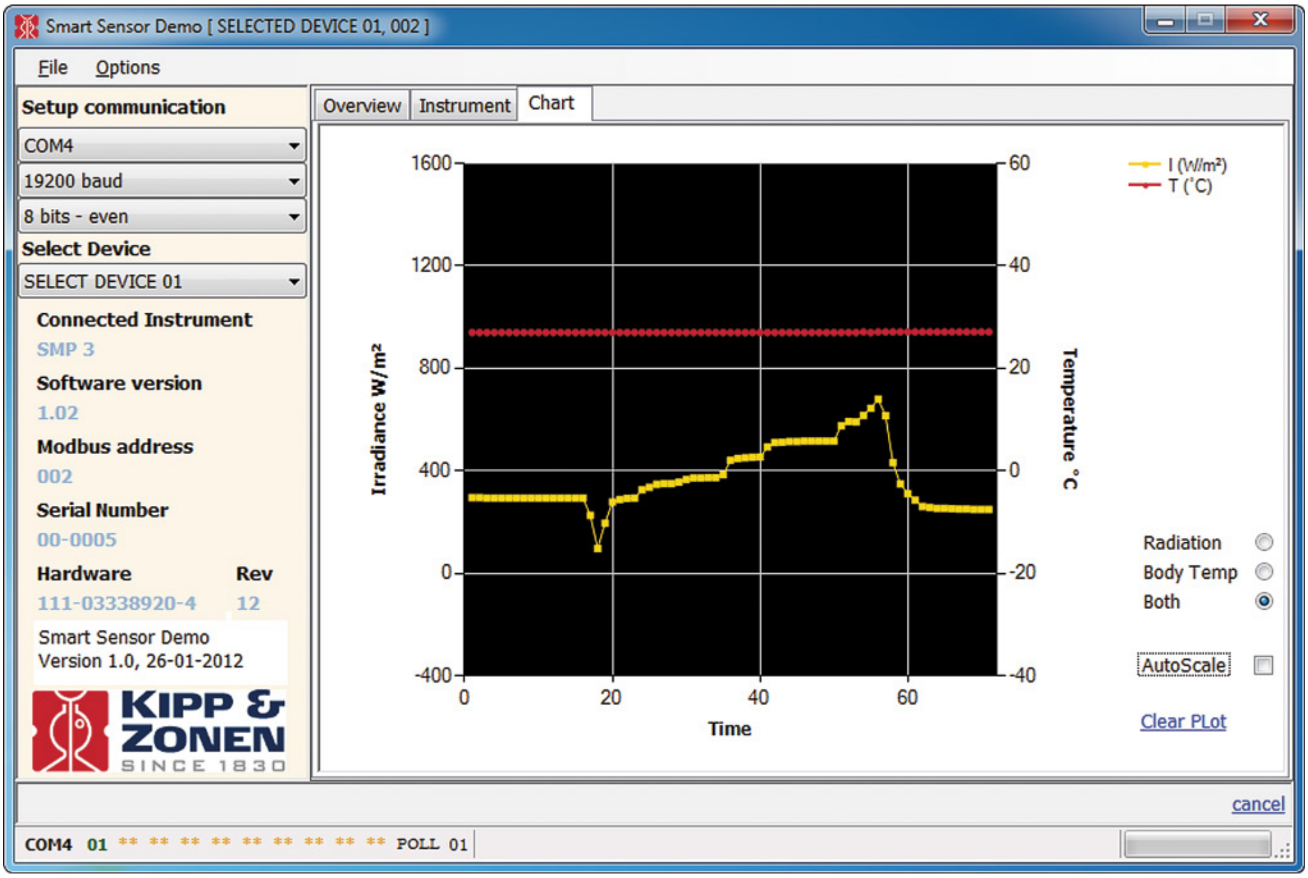
With the ‘Instrument’ tab active the connected SMP measurements are displayed. If multiple SMP’s are connected the display will show alternating values from the different instruments. The large display showing the radiation can be changed to (Body) Temperature.

The Body Temperature, SMP Power Supply Voltage and Time since power on are displayed in the lower part of the screen.



4.4 Chart

With the Chart' tab active the pyranometer measurements can be displayed as a graph.



It will show the last 250 measurements of irradiance ('Radiation' in W/m²) and/or the pyranometer housing temperature ('Body Temp' in °C), as an accumulating graph. Vertical scaling can be set to maximum or automatic.

4.5 Data logging

Under File in Smart Sensor Demo the data logging can be set. The data format options are txt or csv. The csv log file has the following format:

SMP-05.csv

	A	B	C	D	E	F	G	H
1	[11-1-2012 10:47:26]							
2								
3	DATE	TIME	SLAVE	SERIALNR	RADIANCE W/m2	TEMP C	POWER V	
4	11-1-2012	10:47:33	1	00-0005	826.6	29.9	5.0	
5	11-1-2012	10:47:43	1	00-0005	825.5	29.9	5.0	
6	11-1-2012	10:47:53	1	00-0005	826.6	29.9	5.0	
7	11-1-2012	10:48:03	1	00-0005	827.1	29.9	5.0	
8	11-1-2012	10:48:13	1	00-0005	827.9	29.9	5.0	
9	11-1-2012	10:48:24	1	00-0005	828.0	29.9	5.0	
10	11-1-2012	10:48:34	1	00-0005	827.0	29.9	5.0	

Together with the Modbus® address and the radiation data the body temperature and the power supply voltage to the SMP pyranometer are recorded.

At the bottom of the Smart Sensor Demo screen the message ‘The logfile C:\SMPdata\SMP11-005.csv is open, press F12 to Append Data.’ can be shown. With F12 a new data set can be linked to an existing file. Below is an example of a .txt file with linked data from 2 days.

[11-1-2012 11:08:14]
DATE;TIME;SLAVE;SERIALNR;RADIANCE W/m^2;TEMP C;POWER V
2012-01-11;11:08:15;001;00-0005; 708;30.7; 5.0;
2012-01-11;11:08:16;001;00-0005; 708;30.7; 5.0;
2012-01-11;11:08:17;001;00-0005; 708;30.7; 5.0;

[12-1-2012 9:20:17]
DATE;TIME;SLAVE;SERIALNR;RADIANCE W/m^2;TEMP C;POWER V
2012-01-12;09:20:30;001;00-0005; 928;22.8; 5.0;
2012-01-12;09:20:37;001;00-0005; 929;22.8; 5.0;
2012-01-12;09:20:38;001;00-0005; 929;22.8; 5.0;

5. Operation and measurement

SMP series pyranometers only require suitable sources of power and radiation (light) to operate and make measurements. However, it is necessary to connect them to some sort of readout or data storage device in order to save the measurements, there is no internal data memory.

5.1 Data collection

An optimal setting for the data interval is to sample every second and store one minute averages. For setting up the combination of pyranometer and data storage please refer to the manual of the data collection device.

Take care when using the analogue output to match the output range of the pyranometer closely to the input range of the data collection device to maximise the available resolution and minimise noise.

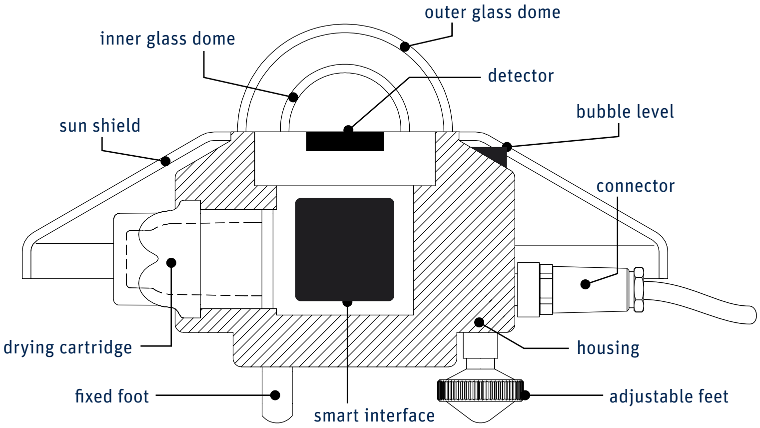
This can be done by determining the maximum expected analogue output of the pyranometer in your application and taking the minimum input range of your data collection device that can just handle that signal.

5.2 Key parts of SMP series pyranometers

The detectors of the SMP3 and SMP11 are based on passive thermal sensing element called a thermopile. Although the detector construction differs between models, the fundamental working principle is applicable to both radiometers.

The thermopile responds to the total energy absorbed by a unique black surface coating developed by Kipp & Zonen, which is non-spectrally selective. The thermopile warms up and the heat generated flows through a thermal resistance to a heat-sink, the pyranometer housing. The temperature difference across the thermal resistance of the detector is converted into a small voltage as a linear function of the absorbed irradiance.

The rise of temperature in the thermopile is easily affected by wind, rain and thermal radiation losses to the environment (for example, a 'cold' sky) and the delicate black coating must be protected. Therefore the detector of the SMP11 is shielded by two domes (the entry-level SMP3 has only one dome to reduce size and cost). These domes allow equal transmittance of the direct solar component for every position of the sun in the hemisphere above the detector.



A drying cartridge in the SMP11 radiometer housing is filled with replaceable silica gel and prevents condensation on the inner sides of the domes, which can cool down considerably on clear windless nights. The SMP3 has a sealed construction with a non-replaceable internal drying cartridge.

5.2.1 Dome(s)
The material of the radiometer dome(s) defines the spectral measurement range of the instrument. In general 97 to 98 % of the solar radiation spectrum will be transmitted through the domes and will be absorbed by the detector. The solar irradiance can come from any direction within the hemisphere above the radiometer and therefore the domes are designed to minimize errors in measurement at all incident angles (the directional response).

SMP3 pyranometers have a single 4 mm thick optical quality glass dome. The SMP11 has one inner dome and one outer dome. Each is 2 mm thick and of higher quality glass, with a broader spectral range and finer finishing and tolerances, than the SMP3.

5.2.2 Detector
The thermopile sensing element is made up of a large number of thermocouple junction pairs connected electrically in series. The absorption of thermal radiation by one of the thermocouple junctions, called the active (or 'hot') junction, increases its temperature. The differential temperature between the active junction and a reference ('cold') junction kept at a fixed temperature produces an electromotive force directly proportional to the differential temperature created.

This is a thermoelectric effect. The sensitivity of a pyranometer depends on the individual physical properties of the thermopile and its construction. The sensitivity of each thermopile is unique and therefore each radiometer has an individual calibration factor. This sensitivity is stored in the SMP pyranometer configuration memory.

The unique black coating on the top surface of the thermopile has a rough structure that effectively 'traps' more than 97 % of the incident radiation and heats up the hot junctions. The black-coated thermopile forms the detector, which has a spectral selectivity of less than 2 %. This means that within the spectral range of the pyranometer, the absorption for each wavelength is equal to within 2 %. The black absorptive coating is one of the most crucial and delicate parts of the pyranometer, Kipp & Zonen's provides the best possible stability over a long period of time under all meteorological circumstances.

5.2.3 Housing
The radiometer housing accommodates all the key parts of a SMP pyranometer. The anodized aluminium parts are lightweight and give high mechanical and thermal stability to the instrument. The stainless steel fixings are isolated where necessary to prevent electrolytic corrosion.

Due to fine mechanical construction SMP pyranometers are virtually sealed and comply with international standard IP 67. SMP3 and SMP11 can be levelled with two adjustable feet using the bubble level, situated next to the dome of the instrument. For ease of maintenance the bubble level is visible from above without removing the snap-on white sun shield. The sun shield acts to protect all the external parts and to reduce solar heating of the housing.

5.2.4 Drying cartridge
The entry-level SMP3 has a completely sealed construction with a non-replaceable drying cartridge. However, this also makes it non-serviceable. For serviceability of the higher performance and price SMP11 the construction cannot be sealed. In this case water vapour can 'breathe' into the housing, mainly due to temperature and pressure changes.

To keep the detector and electronics dry and to prevent condensation forming inside the domes with temperature changes a self-indicating silica gel desiccant is used to absorb humidity within the pyranometer. When fresh the desiccant has an orange colour. After some time absorbing moisture the colour will change to clear (transparent). At this time the silica gel is not fully saturated, but should be replaced with fresh orange desiccant as soon as possible. Replacement desiccant is available through Kipp & Zonen representatives.

5.2.5 Cable and connector

For ease of installation and replacement during re-calibration of the radiometer, the SMP series are provided with a waterproof cable socket fitted to the pyranometer housing. The matching waterproof plug is normally supplied pre-wired to a very high quality yellow cable selected for low noise, very wide temperature range and UV resistance.

Cables come pre-wired to the connector plug in a range of lengths, 10 m is standard. 25 m, 50 m and 100 m lengths are also available. The connector plug can also be supplied loose for the user to fit to their own cable.

6. Maintenance and re-calibration

SMP pyranometers are simple to maintain and do not require any special tools or training. There are no service items requiring scheduled replacement, only the desiccant of the SMP11 requires changing when needed.

6.1 Daily maintenance

On clear windless nights the outer dome temperature of horizontally placed radiometers will decrease, even to the dew point temperature of the air, due to infrared radiation exchange with the cold sky. The effective sky temperature can be 30 °C lower than the ground temperature.

Depending upon the weather conditions dew, glazed frost or hoar frost can be precipitated on the top of the dome and can stay there for several hours in the morning. An ice cap on the dome is a strong diffuser and increases the pyranometer signal drastically, up to 50 % in the first hours after sunrise. Snow may completely cover the dome.

The frequency of cleaning is highly dependent upon the local weather and environmental conditions, such as dust, airborne pollutants or salt spray in marine environments. Ideally, the dome of the pyranometer should be cleaned every morning before sunrise. In all cases the frequency of cleaning can be reduced by the use of a ventilation unit (SMP11 only), with the heaters switched on when necessary.

Note Clean the dome using pure alcohol or distilled water and a lint-free cloth. Ensure that no smears or deposits are left on the dome.

6.2 Monthly maintenance

Check the desiccant in the drying cartridge. This is a self-indicating silica-gel. When it requires replacement the colour changes from orange to clear.

To replace the desiccant unscrew the cartridge from the radiometer housing, if it is tight a 16 mm or 5/8" open-ended wrench / spanner can be used to loosen it. Remove the cap from the end of the cartridge and safely dispose of the used silica-gel. Refill with fresh desiccant, and refit the end cap to the cartridge. Make sure that the o-ring seal and its seat in the housing are clean, grease with Vaseline if it is dry.

Note Screw in the drying cartridge hand-tight only, to avoid distorting the o-ring seal.

Desiccant refill packs are available from Kipp & Zonen. One pack is sufficient for one complete refill.

Check that the pyranometer is level and adjust if necessary.
Check that the sun shield is firmly clipped on.

6.3 Yearly maintenance

Check all the electrical connections. Unscrew the plugs, clean if necessary and then reconnect.
Check cables for damage caused by accident or by rodents.
Check the instrument mountings and any base supports are secure.

6.4 Calibration

An ideal radiometer gives an output that is proportional to the absolute irradiance level. This relationship can be expressed as a constant ratio called 'sensitivity'. SMP series pyranometers are very stable instruments, but they do change very slightly with time. This is largely due to exposure of the black detector coating to UV solar radiation. Re-calibration is recommended every two years. Normally this is carried out at the Kipp & Zonen factory or at an authorised calibration facility.

6.4.1 Calibration principle

At the Kipp & Zonen factory pyranometers are calibrated, or re-calibrated, in our laboratory according to ISO 9847:1992 'Solar energy - Calibration of field pyranometers by comparison to a reference pyranometer', Annex A 'Calibration devices using artificial sources'. The specific method is given in Annex A.3.1 and is described in the standard as the 'Kipp & Zonen (calibration) device and procedure'.

This is based on a side-by-side comparison of the test pyranometer with a reference pyranometer of the same type under a stable artificial sun. Kipp & Zonen uses a 150 W Metal-Halide high-pressure gas discharge lamp with precise voltage stabilisation. The irradiance at the radiometers is approximately 500 W/m^2.

The reference pyranometers are regularly calibrated outdoors at the World Radiation Centre (WRC) in Davos, Switzerland. The spectral content of the laboratory calibration lamp differs from the outdoor solar spectrum at the World Radiation Centre. However, this has no consequences for the transfer of calibration, because the reference and test radiometers have the same characteristics.

To minimise stray light from the walls and the operator, the light is restricted to a small cone around the two radiometers. The test radiometer and the reference radiometer are placed side by side on a small rotating table. The lamp is centred on the axis of this table. The table is used to interchange the positions of the pyranometers to allow for inhomogeneity of the light field.

The pyranometers are illuminated and after time for the output to stabilise the readings of both radiometers are integrated over a measurement period. The lamp housing and beam restrictors heat up and emit long-wave infrared radiation which warms up the pyranometer dome(s) slightly. This causes a small offset that is embodied in the pyranometer response under illumination. To determine this offset, both radiometers are shaded, and after time to stabilise the signals of both radiometers are integrated over a period.

The radiometer positions are interchanged by rotating the table and the whole procedure is repeated.

The sensitivity of the test pyranometer is calculated by comparison to the reference pyranometer readings and the calibration certificate is produced. At Kipp & Zonen the complete process is automated under computer control, including programming the SMP pyranometer with the correct calibration factors and default output range settings.

Kipp & Zonen produces the manually operated CFR Calibration Facility for Radiometers for customers to make their own pyranometer calibrations to ISO 9847, Annex A.3.1. A special interface is available as an accessory to enable calibration of SMP series pyranometers with the CFR.

6.4.2 Calibration traceability to the WRR

Our reference pyranometers are calibrated at the World Radiation Centre (WRC) in Davos, Switzerland by comparison to the World Radiometric Reference (WRR). They are also fully characterized for linearity, temperature dependence and directional response to enable transfer of the sensitivity under the measurement conditions in Davos to our calibration laboratory conditions.

Kipp & Zonen keeps at least two reference instruments for each pyranometer model. These reference instruments are sent alternate years to the WRC for calibration, so that production and calibration in Delft can carry on without interruption.

Kipp & Zonen calibration certificates include an overview of the calibration method, details of the reference pyranometer used, traceability to the WRR, and the uncertainty in the full calibration chain from the WRR to the pyranometer being calibrated.

7. Specifications

Kipp & Zonen reserves the right to make changes to specifications and other product documentation without prior notice.

7.1 Optical and electrical

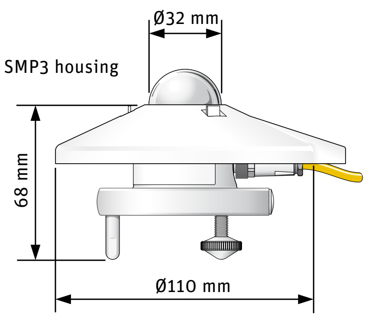
Specifications	SMP3	SMP11
ISO 9060:1990 CLASSIFICATION	Second Class	Secondary Standard
Response time (63 %)	< 1.5 s	< 0.7 s
Response time (95 %)	< 12 s	< 2 s
Zero offsets (a) thermal radiation (200 W/m^2) (b) temperature change (5 K/hr)	 < 15 W/m^2 < 5 W/m^2	 < 7 W/m^2 < 2 W/m^2
Non-stability (change/year)	< 1 %	< 0.5 %
Non-linearity (0 to 1000 W/m^2)	< 1 %	< 0.2 %
Directional error (up to 80 ° with 1000 W/m^2 beam)	< 20 W/m^2	< 10 W/m^2
Temperature dependence of sensitivity	< 3 % (-20 °C to +50 °C) < 5 % (-40 °C to +70 °C)	< 1 % (-20 °C to +50 °C) < 2 % (-40 °C to +70 °C)
Tilt error (at 1000 W/m^2)	< 1%	< 0.2%
Other specifications		
Analogue output	-V version: 0 to 1 V -A version: 4 to 20 mA	-V version: 0 to 1 V -A version: 4 to 20 mA
Analogue output range	-V version: -200 to 2000 W/m^2 -A version: 0 to 1600 W/m^2	-V version: -200 to 2000 W/m^2 (1) -A version: 0 to 1600 W/m^2
Digital output	2-wire RS-485	2-wire RS-485
Digital output maximum range	-400 to 2000 W/m^2	-400 to 4000 W/m^2
Digital communication protocol	Modbus®	Modbus®
Level accuracy	1 °	0.1 °
Operating temperature	-40 °C to +80 °C	-40 °C to +80 °C
Ingress Protection (IP)	67	67
Spectral range (50 % points)	300 to 2800 nm	285 to 2800 nm
Supply voltage	5 to 30 VDC	5 to 30 VDC
Power consumption (at 12 VDC)	-V version: 55 mW -A version: 100 mW	-V version: 55 mW -A version: 100 mW
Expected daily uncertainty	< 10 %	< 2 %
Documentation	Calibration certificate traceable to WRR, multi-language instruction sheet, manual and software on CD-ROM	Calibration certificate traceable to WRR, multi-language instruction sheet, manual and software on CD-ROM
Recommended applications	Economical solution for efficiency and maintenance monitoring of PV power installations, routine measurements in weather stations, agriculture, horticulture and hydrology	High performance for PV panel and thermal collector testing, solar energy research, solar prospecting, materials testing, advanced meteorology and climate networks
(1) The analogue output range of SMP11 can be rescaled by the user to a maximum of -200 to 4000 W/m^2		
SMP instruments have a standard cable length of 10 m. Optional cable lengths 25 m and 50 m		
Note: The performance specifications quoted are worst-case and/or maximum values		

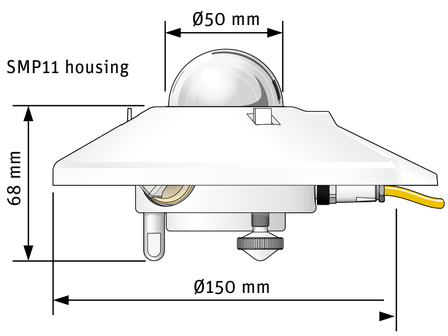
7.2 Dimensions and weight

Weight without cable:

SMP3 - 0.3 kg

SMP11 - 0.6 kg





8. Trouble shooting

There are no user-serviceable parts within the SMP pyranometer and it must not be opened without the agreement and instruction of Kipp & Zonen.

8.1 Output signal not present or incorrect

The following contains a procedure for checking the instrument in case it appears that it does not function correctly:

1. Check the SMP pyranometer cable wires are properly connected to the readout equipment.
2. Check the power supply (12 VDC recommended).
3. Check that the instrument has a unique Modbus® address.
4. Compare the digital and analogue outputs to see if the problem is in one output only.
5. Check the instrument location. Are there any obstructions that cast a shadow on the instrument by blocking the direct sun during some part of the day?
6. Check the dome, it should be clear and clean. If condensation is deposited on the inside, please change the desiccant. If too much water is deposited internally the drying cartridge should be removed and the instrument warmed to dry it and then replace with new desiccant. It may take several days for the sensitivity to fully recover to the original value.
7. For analogue outputs check the data logger or integrator input offset such that a signal of 0 Volt or 4 mA (as appropriate) gives a 'zero' reading.
8. Check levelling. The bubble should be at least half inside the marked ring of the level.
9. If water, frost or ice is deposited on the dome, clean it. Probably water droplets will evaporate in less than one hour under sunlight.

Any malfunction or visible damage should be reported to your Kipp & Zonen representative, who will suggest the appropriate action.

8.2 Frequently Asked Questions

The most frequently asked questions are listed below. For an update or further information refer to our website at **www.kippzonen.com**

Q: Negative output during night-time measurements?

A: This error is related to Zero Offset Type A. Normally this zero offset is present when the inner dome has a different temperature from the cold junctions of the sensor (the instrument housing). Practically this is always the case when there is a clear sky. Because of the low effective sky temperature (< 0 °C) the Earth's surface emits roughly 100 W/m² of long-wave infrared radiation upwards. The outer glass dome of a pyranometer also has this emission and is cooling down several degrees below air temperature (the emissivity of glass for the particular wavelength region is nearly 1).

The emitted heat is attracted from the body by conduction in the domes, by wind and from the domes through infrared radiation. The heat flow is opposite to the heat flow when absorbing solar radiation and causes the well-known zero depression at night. This negative zero offset is also present on a clear day but is hidden in the solar radiation signal.

Zero Offset Type A can be checked by placing a light and IR reflecting cap over the pyranometer. The response to solar radiation will decay with the response time of the instrument, but the dome temperature will go to equilibrium with a time constant of several minutes. So after about half a minute the remaining signal is mainly Zero Offset Type A.

Good ventilation of the domes and housing minimises zero offsets and increases stability. Using the Kipp & Zonen CVF 3 ventilation unit can reduce Zero Offset Type A by about 50 %.

Q: Maximum and minimum irradiation quantities?

A: Due to reflection from certain types of clouds the global irradiance at sea level can rise above the extra-terrestrial direct irradiance (the Solar Constant) of 1367 W/m² at the top of the atmosphere (WMO 1982). Values up to 1500 W/m² have been reported. Because the clouds move, this irradiance value mostly appears as short events of a few minutes duration.

Q: What is the primary entry point for humidity?

A: The SMP3 is fully sealed, but this also means that it is not serviceable. The construction of the SMP11 allows servicing, such as dome replacement, but this means that there are seals in the construction that are waterproof, but not gastight. Therefore, water vapour can slowly enter due to temperature and pressure changes.

Q: Is the pyranometer calibration affected by the length of the signal cable?

A: With longer cable lengths the impedance increases, however it does not affect the radiometer sensitivity for the following reason. For the SMP3/11-V the impedance of the voltage measurement device is at least 1000 times more than the impedance of the pyranometer plus cable. Therefore the current that goes through the readout cable is negligible and won't generate an offset.

For the SMP3/11-A current versions the cable length is limited by the power supply voltage and voltage drop over the cable. However the low cable impedance (80 Ω/km) and normally high impedance of the read-out unit / logger is normally no limitation.

The digital RS-485 output can operate over cable lengths up to 1000 m, depending on the baud-rate used.

9. Customer support

If you require any support for your Kipp & Zonen product please contact your local representative in the first instance. The information can be found in the 'Contact' section (home tab) of our website at **www.kippzonen.com**

Alternatively, you can contact us directly at **www.kippzonen.com/support**

Please include the following information:

- Instrument model
- Instrument serial number
- Details of the fault or problem
- Examples of data files
- Readout device, data acquisition system and operating system
- Interfaces and power supplies
- History of any previous repairs or modifications
- Pictures of the installation
- Overview of the local environment conditions

Kipp & Zonen guarantees that your information will not be shared with other organisations.

10. Keyword index

Term	Explanation
Albedo	The portion of incoming radiation which is reflected by a surface
Azimuth angle	Angle in horizontal direction (0 to 360 °) normally referred to North
Angle of incidence	Incident angle from zenith (0° is vertical, 90° is horizontal)
Cosine response	Radiometer directional response according to the cosine law
Diffuse horizontal irradiance	Solar radiation, scattered by water vapour, dust and other particles as it passes through the atmosphere falling on a horizontal surface (DHI)
Direct normal irradiance	Radiation that has travelled in a straight path from the sun falling on a surface normal to the beam (DNI)
Global horizontal irradiance	Total irradiance falling on a horizontal surface (GHI) Global = Diffuse + (Direct x cos α); α is the solar zenith angle
Irradiance	Radiant flux density (W/m^2)
Long-wave radiation	Radiation with wavelengths from 4 μm to more than 40 μm
Pyranometer	Radiometer for measuring short-wave global radiation
Pyrgeometer	Radiometer for measuring long-wave radiation
Pyrheliometer	Radiometer for measuring direct short-wave radiation
Short-wave radiation	Radiation with wavelengths from approximately 300 nm to 4000 nm (4 μm)
Thermopile	Thermal detector made up of many thermocouple junctions
WMO	World Meteorological Organisation, Geneva, Switzerland
WRC	World Radiation Centre, Davos, Switzerland
WRR	World Radiometric Reference (standard radiation scale) at WRC
WSG	World Standard Group of radiometer at WRC
Zenith angle	Angle from zenith (0 ° is vertical)

Appendices

A. Modbus®

A.1 Modbus® commands

The commands are all according to the Modbus RTU protocols described in the document: ‘Modbus® over serial line V1.02’ and ‘MODBUS application protocol V1.1b’ available from the Modbus® organization (www.modbus.org). The commands can be tested using software tools, such as the program ‘Modbus Poll’ from www.modbustools.com.

The following commands are implemented:

Function	Sub function	Description
0x01	N/A	Read Coils
0x02	N/A	Read Discrete Inputs
0x03	N/A	Read Holding Registers
0x04	N/A	Read Input Register
0x05	N/A	Write Single Coil
0x06	N/A	Write Holding Register
0x10	N/A	Write multiple Registers

The SMP does not make a difference between a ‘coil’ and a discrete input. The only difference is that a discrete input is read only.

The SMP does not make a difference between a holding register and an input register. The only difference is that an input register is read only.

A.2 Input registers

Input registers are read only

Real-time Processed Data

Register	Parameter	R/W	Type	Mode	Description
0	IO_DEVICE_TYPE	R	U16	All	Device type of the sensor
1	IO_DATAMODEL_VERSION	R	U16	All	Version of the object data model 100=this version
2	IO_OPERATIONAL_MODE	R	U16	All	Operational mode: Normal, Service, Calibration and so on
3	IO_STATUS_FLAGS	R	U16	All	Device status flags
4	IO_SCALE_FACTOR	R	S16	All	Range and scale factor sensor data (1)
5	IO_SENSOR1_DATA	R	S16	N,S	Temperature compensated data sensor 1 in W/m²
6	IO_RAW_SENSOR1_DATA	R	S16	N,S	Sensor data sensor 1 in W/m²
7	IO_STDEV_SENSOR1	R	S16	N,S	Standard deviation sensor 1 in 0.1 W/m²
8	IO_BODY_TEMPERATURE	R	S16	N,S	Body temperature in 0.1 °C
9	IO_EXT_POWER_SENSOR	R	S16	N,S	External power voltage in 0.1 V
10 to 15	FACTORY USE ONLY				
16	IO_DAC_OUTPUT_VOLTAGE	R	U16	N,S	DAC output voltage (actual voltage)
17	IO_SELECTED_DAC_INPUT	R	U16	N,S	DAC selected input data

(1) The scale factor defines the format and number of decimal places

Real-time Data A/D Counts

Register	Parameter	R/W	Type	Mode	Description
18	IO_ADC1_COUNTS	R	S32	All	Input voltage sensor 1 in 0.01 µV
19					(R18=MSB, R19=LSB)
20	IO_ADC2_COUNTS	R	S32	All	Not supported, always 0
21					
22	IO_ADC3_COUNTS	R	S32	All	Input voltage body temperature sensor in 0.01 µV
23					(R22=MSB, R23=LSB)
24	IO_ADC4_COUNTS	R	S32	All	Input voltage power sensor in 0.01 µV
25					(R24=MSB, R25=LSB)

Error reports

Register	Parameter	R/W (2)	Type	Mode	Description
26	IO_ERROR_CODE	R	U16	All	Most recent/ actual error code
27	IO_PROTOCOL_ERROR	R	U16	All	Protocol error/communication error
28	IO_ERROR_COUNT_PRIO1	R	U16	All	Error code priority 1
29	IO_ERROR_COUNT_PRIO2	R	U16	All	Error count priority 2
30	IO_RESTART_COUNT	R	U16	All	Number of controlled restarts
31	IO_FALSE_START_COUNT	R	U16	All	Number of uncontrolled restarts
32	IO_SENSOR_ON_TIME	R	U16	All	On time in seconds (MSB word)
33	IO_SENSOR_ON_TIMEL	R	U16	All	On time in seconds (LSB word)
41	IO_BATCH_NUMBER	R	U16	All	Production batch number
42	IO_SERIAL_NUMBER	R	U16	All	Serial number
43	IO_SOFTWARE_VERSION	R	U16	All	Software version
44	IO_HARDWARE_VERSION	R	U16	All	Hardware version
45	IO_NODE_ID	R	U16	All	(MODBUS®/SMA) device address RS-485

(2) Writing any value to input registers 26-33 will reset the contents of the registers

Legend

Register	Modbus® register	Modbus® register 0 is the first register.	
Parameter	Name	Name of the register	
R/W	Read write	**R**	Read only
		R/W	Read/write
Type	Type and size	**U16**	16 bit unsigned integer
		S16	16 bit signed integer
		S32	32 bit signed integer (MSB first, LSB last)
Mode	Operation mode	**N**	available in normal mode
		S	available in service mode
		C	available in calibration mode (not for users)
		F	available in factory mode (not for users)
		All	available in all modes

A.3 Holding registers

Device Control					
Register	Parameter	R/W	Type	Mode	Description
34	IO_DEF_SCALE_FACTOR	R/W	S16	All	Default scale factor
35 to 40	Factory use only				

A.4 Read input register

Many of the registers and controls are for remote diagnostics. In this chapter only the most interesting registers and controls are described.

Register 0 IO_DEVICE_TYPE

The device typed defines which device is connected. The default values are:

601 = CMP 3 603 = CMP 11

This register can be used to check the type of the connected device.

Register 1 IO_DATAMODEL_VERSION

The data-model describes the functions supported by the smart sensor. This document is valid for data-model version: '100' and '101'. A different implementation of the Modbus® protocol (with new features) could result in a different data model 'that is' or 'that is not' compatible with the older version.

The value of this register must be '100' or '101'. If you receive another value then you should read an updated version of this document and check the differences.

Register 2 IO_OPERATIONAL_MODE

The operation mode defines the state of the smart sensor. The operational modes are 1 = Normal Mode, 2 = Service Mode, 3 = Calibration Mode, 4 = Factory Mode and 5 = Error mode. The standby mode (mode 0) is not supported.

After power on the operation mode (1) is set. When the **IO_CLEAR_ERROR** is set then the smart sensor always returns to the normal mode. When the Error mode (5) is set, then there is a fatal error.

Register 3 IO_STATUS_FLAGS

This register defines the status of the smart sensor and the validity of the data. Each bit has a special meaning. Bit 0 is the first (least significant) bit.

Bit 0	Quality of the signal	see IO_VOID_DATA_FLAG
Bit 1	Overflow	see IO_OVERFLOW_ERROR
Bit 2	Underflow	see IO_UNDERFLOW_ERROR
Bit 3	Error flag	see IO_ERROR_FLAG
Bit 4	ADC Error	see IO_ADC_ERROR
Bit 5	DAC Error	see IO_DAC_ERROR
Bit 6	Calibration Error	see IO_CALIBRATION_ERROR
Bit 7	Update EEPROM error	see IO_UPDATE_FAILED

Register 4 IO_SCALE_FACTOR

The scale factor defines the number of fractional digits, the range and the position of the decimal point for the following registers: **IO_SENSOR1_DATA**, **IO_SENSOR2_DATA**, **IO_RAW_SENSOR1_DATA** and **IO_RAW_SENSOR2_DATA**. The scale factor is read only. The default value of the scale factor is set during calibration mode or it can be changed during operation (see register **IO_DEF_SCALE_FACTOR** and coil **IO_AUTO_RANGE**).

If the register **IO_SCALE_FACTOR** is not set to 0 then you must multiply or divide the data of register (X), whereas X is one of the above mentioned registers.

Scale factor = 2	(floating point) result = (integer) register (X) / 100.0
Scale factor = 1	(floating point) result = (integer) register(X) / 10.0
Scale factor = 0	(floating point) result = (integer) register(X)
Scale factor = -1	(floating point) result = (integer) register(X) * 10.0

The default value of register **IO_SCALE_FACTOR** is 0. However, this value can be set to a different value if the coil **IO_AUTO_RANGE** is set or a different value is written to the register **IO_DEF_SCALE_FACTOR** (set default scale factor).

Register 5 IO_SENSOR1_DATA

This register holds the actual data (solar radiation) measured by the sensor. The solar radiation is measured in W/m².

If the register **IO_SCALE_FACTOR** is not set to 0 then you must multiply or divide the data as described under register 4.

The raw data from the sensor is calibrated, linearized; temperature compensated and filtered using 2 different kinds of filters (See **IO_FAST_RESPONSE** and **IO_TRACKING_FILTER**).

Register 6 IO_RAW_SENSOR1_DATA

The raw sensor data is calibrated but not linearized and temperature compensated. If the register **IO_SCALE_FACTOR** is not set to 0 then you must multiply or divide the data as described under register 4, **IO_SCALE_FACTOR**.

Register 7 IO_STDEV_SENSOR1

This register is used to calculate the standard deviation over the signal. When the register is read the data is sent to the computer and at the same time a new calculation is started. The next time register 7 is read the standard deviation over the last period is sent to the computer and a new calculation is started. If the poll frequency is quite high (for example 1 poll per second) then the standard deviation will be zero or almost zero, but if the poll frequency is very low then the standard deviation can be quite high, indicating that the data in register 5 or 6 changed dramatically since the last poll. The standard deviation is measured in 0.1 W/m². To convert the data to a floating point, make the following calculation:

(floating point) result = (integer) register (IO_STDEV_SENSOR1) / 10.0

Register 8 IO_BODY_TEMPERATURE

The body temperature sensor measures the temperature of the body in 0.1°C.

The convert the data to a floating point number, make the following calculation:

(floating point) result = (integer) register (IO_BODY_TEMPERATURE) / 10.0

Register 9 IO_EXT_POWER_SENSOR

The Ext power sensor measured the external voltage applied to the sensor in 0.1 Volt.

The convert the data to a floating point number, make the following calculation:

(floating point) result = (integer) register (IO_EXT_POWER_SENSOR) / 10.0

Example

Read registers: 'operational mode to external power' from Modbus® device with address 1.

Tx transmitted data to the smart sensor
Rx received data from the smart sensor

SendModbusRequest (0x04, 1, IO_OPERATIONAL_MODE, 8);
Tx 01 04 00 02 00 08 50 0C
Rx 01 04 10 00 01 00 00 00 00 03 E5 03 E5 00 00 00 F8 00 EA 66 12

Explanation of the received bytes:
01 = MODBUS address
04 = read input registers
10 = number of received data bytes
00 01 = operational mode (mode 1)
00 00 = status flags (none)
00 00 = scale factor = 0 = 1x
03 E5 = 997 decimal = sensor 1 data in W/m²
03 E5 = 997 decimal = raw sensor 1 data in W/m²
00 00 = 0 = standard deviation sensor 1
00 F8 = 248 = 24.8°C.
00 EA = 234 = 23.4 Volt
66 12 = MODBUS checksum (CRC16)

A.5 Discrete inputs

A discrete input can be true or false. A discrete input is read only; a coil can be read or written.

Status indicators

Input	Parameter	R/W	Def.	Mode	Description
0	IO_FALSE	R	0	All	Always false (for testing only)
1	IO_TRUE	R	1	All	Always true (for testing only)
2	IO_VOID_DATA_FLAG	R	*	All	Void signal, 1=unstable signal, temperature too low or too high
3	IO_OVERFLOW_ERROR	R	*	All	Overflow, signal out of range
4	IO_UNDEFLOW_ERROR	R	*	All	Underflow signal out of range
5	IO_ERROR_FLAG	R	*	All	General hardware error (set if one of the H/W error flags is set)
6	IO_ADC_ERROR	R	*	All	Hardware error A/D converter
7	IO_DAC_ERROR	R	*	All	Hardware error D/A converter
8	IO_CALIBRATION_ERROR	R	*	All	Calibration checksum error
9	IO_UPDATE_FAILED	R	*	All	Update calibration parameters failed

Legend

Input	Discrete input	Modbus® discrete input 0 is the first discrete input	
Coil	Modbus Coil	A coil can be read or written.	
Parameter	Name	Name of the register	
R/W	Read write	**R**	Read only
		R/W	Read/write
Def	Default value	default value at power on (0, 1or *) * = undefined	
Mode	operation mode	**N**	available in normal mode
		S	available in service mode
		C	available in calibration mode (not for users)
		F	available in factory mode (not for users)
		All	available in all modes

Inputs can be read in all modes but some coils can't be written in normal mode or service mode.

A.6 Coils

Device control

Coil	Parameter	R/W	Def.	Mode	Description
10	IO_CLEAR_ERROR	R/W	0	All	Select normal operation and clear error (1=clear error)
11 to 17	FACTORY USE ONLY				
18	IO_RESTART_MODBUS	R/W	0	All	Restart the device with modbus® protocol
19	FACTORY USE ONLY				
20	IO_ROUNDOFF	R/W	1	S,N	Enable rounding of sensor data
21	IO_AUTO_RANGE	R/W	0	S,N	Enable auto range mode (0=no auto range)
22	IO_FASTRESPONSE	R/W	0	S,N	Enable fast response filter (0=no filter)
23	IO_TRACKING_FILTER	R/W	1	S,N	Enable tracking filter (0=no filter)

Note The default values of the device options are stored in non-volatile memory. The default values can be overruled during operation. However, at power-on the default values are restored and the smart sensor will start up with the default values stored in the non-volatile memory.

ADC CONTROL					
Coil	Parameter	R/W	Def.	Mode	Description
24 to 34	Factory use only				

A.7 Read write holding registers

Register 34 **IO_DEF_SCALE_FACTOR**

The default scale factor is set in the factory mode or service mode and is stored in non-volatile memory. The default scale factor stored in non-volatile memory is always set after a power-on. However it is possible to change the default setting during operation by writing a value to the register 34.

Note This value is not stored in non-volatile memory and is overwritten with the default value at power on.

The following values are valid:
Scale factor = 2
Scale factor = 1
Scale factor = 0
Scale factor = -1
Scale factor 0 is the default value. See also input register 4 **IO_SCALE_FACTOR**.

A.8 Read discrete inputs

Discrete input 0 **IO_FALSE** This discrete input is always false
Discrete input 1 **IO_TRUE** This discrete input is always true
Discrete input 2 **IO_VOID_DATA_FLAG**

The void data flag is raised when the data in register **IO_SENSOR1_DATA** or **IO_RAW_SENSOR1_DAT**A is not valid, because the body temperature of the sensor is too low or too high, when there is an internal overflow condition, because a calculation is out of range or a division by zero occurred, the reference voltage of the ADC is not stable or the digital filter is not stable. When the **IO_VOID_DATA_FLAG** is set, bit 0 in the **IO_STATUS_FLAGS** is also set.

The **IO_VOID_DATA_FLAG** and bit 0 of the **IO_STATUS_FLAGS** are cleared when the **IO_VOID_DATA_FLAG** is read by the computer.

Discrete input 3 **IO_OVERFLOW_ERROR**

This discrete input is raised when an out of range condition occurs and the sensor data (see **IO_SENSOR1_DATA**) is above the maximum value specified by the calibration program or above 29,999. The typical maximum value is 4000 W/m².

When the **IO_OVERFLOW_ERRO**R is set, bit 1 in the **IO_STATUS_FLAGS** is also set.

The **IO_OVERFLOW_ERROR** and bit 1 of the **IO_STATUS_FLAGS** are cleared when the **IO_OVERFLOW_ERROR** is read by the computer.

Discrete input 4 **IO_UNDERFLOW_ERROR**

This discrete input is raised when an underflow condition occurs and the sensor data (see **IO_SENSOR1_DATA**) is below the minimum value specified by the calibration program or below -29,999. The typical minimum value is -400 W/m².

When the **IO_UNDERFLOW_ERROR** is set, bit 2 in the **IO_STATUS_FLAGS** is also set.

The **IO_UNDERFLOW_ERROR** and bit 2 of the **IO_STATUS_FLAGS** are cleared when the **IO_UNDERFLOW_ERROR** is read by the computer.

Discrete input 5 IO_ERROR_FLAG

The error flag is raised when there is a (fatal or correctable) hardware error or software error such as: ADC error, DAC error, calibration error or when the update of the calibration data failed. When the **IO_ERROR_FLAG** is raised the error code is copied to the register **IO_ERROR_CODE** (see register 26).

The error flag is cleared when a true condition is written to the coil: **'IO_CLEAR_ERROR**'. This has no effect when the error is fatal or not resolvable such as a calibration error.

The error flag is always set after a power up, this is to indicate the power went off, or a restart occurred. The computer should raise the **IO_CLEAR_ERROR** in order to reset the error flag.

Discrete input 6 IO_ADC_ERROR

This flag is raised when the A/D converter responsible for the conversion of the analogue signals to digital signals detected a failure (hard or software).

The ADC error flag is cleared when a true condition is written to the coil: **'IO_CLEAR_ERROR'** and the error produced by the ADC, is not fatal.

Discrete input 7 IO_DAC_ERROR

This flag is raised when the D/A converter responsible for the conversion of the digital signal to the analogue output signal detected a failure (hard or software).

The DAC error flag is cleared when a true condition is written to the coil: **'IO_CLEAR_ERROR'** and the error produced by the DAC, is not fatal.

Discrete input 8 IO_CALIBRATION_ERROR

The calibration error flag is raised when the sensor was not calibrated or a checksum error was detected in the calibration data. This flag can't be cleared unless the sensor is sent back to the manufacturer or dealer for a re-calibration.

Discrete input 9 IO_UPDATE_FAILED

The update failed is raised when data is written to the non-volatile memory and the update failed. This can happen in calibration mode when calibration data in written to non-volatile memory or in the service mode when device options are written to the non-volatile memory.

If this error is set you should retry the last update action. If the error does not disappear then there could be a hardware problem with the non-volatile memory (EEPROM).

A.9 Read write discrete coils

Coil 10 IO_CLEAR_ERROR

Setting this coil will clear the error only when the error is a non-fatal error. Reading this coil will always return a 0. The coil **IO_CLEAR_ERROR** can be used to select the normal mode (see **IO_OPERATIONAL_MODE**).

The smart sensors will always start-up in the normal mode.

Note Use **IO_CLEAR_ERROR** to return to the normal mode.

Coil 20 IO_ROUNDOFF

Setting this coil enables rounding of the data presented in **IO_SENSOR1_DATA** and **IO_RAW_SENSOR1_DATA**.

If not set then the customer should round off the received data before processing the data.

The default value after power on is ON.

If **IO_ROUNDOFF** is cleared, then the sensor is not calibrated and could produce more digits, than there are significant digits.

Coil 21 IO_AUTO_RANGE

Setting this coil enables the auto-range feature. The auto-range feature increases the number of digits for small signals

The default value after power on is OFF.

If **IO_AUTO_RANGE** is set then the sensor is not calibrated and could produce more digits, than there are significant digits.

Coil 22 IO_FASTRESPONSE

Setting this coil enables the fast response filter. This filter increases the step response of the sensor. Disabling the fast response give the SMP pyranometers the same response time as the CMP equivalents.

The default value after power on is ON.

Coil 23 IO_TRACKING_FILTER

Setting to this coil enables the tracking filter. The tracking filter reduces the noise of the signal. However, when the filter is on, the step response on a sudden signal change is decreased. The smart sensor uses variable filter constants to minimize the effect on the step response.

The default value after power on is OFF.

A.10 Requesting serial number

Register 41 IO_BATCH_NUMBER

The batch number defines the production year of the smart sensor, 11 = 2011, 12=2012 etc.

Register 42 IO_SERIAL_NUMBER

Register 42 defines the 4 digits serial number of the smart sensor. Only the combination of the batch number and serial number is unique.

A.11 Simple demonstration program

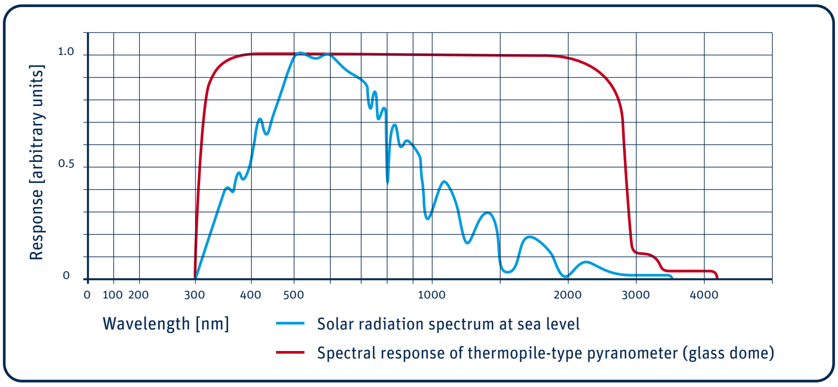
The simple ‘C’ program below will show how to read the sensor data and how to deal with errors. The program will read the registers: ‘operational mode, status flags, scale factor, and sensor data’ from Modbus® device with address 2 into registers uOperationMode, uStatusFlags, iScaleFactor and iSensorData. Then the program will check the operation mode (must be ‘normal’) and if there are no errors flags set in iStatusFlags. If there is an error then set the **IO_ERROR_FLAG**.

```
UInt16      uOperationalMode = 0;
UInt16      uStatusFlags = 0;
Int16       iScaleFactor = 0;
Int16       iSensorData = 0;
float       fSensorData = 0;

int main (void)
{
            while (true)
            {
                        // Send MODBUS request 0x04 Read input registers to slave 2
                        // Get modus data will wait for the answer and copies the data to registers
                        // uOperationalMode, uStatusFlags, iScaleFactor and iSensorData

                        SendModbusRequest (0x04, 2, IO_OPERATIONAL_MODE, 4);
                        WaitModbusReply ();
                        GetModbusData ();

                        If (uOperationalMode != 1)
                        {
                                    // Send MODBUS request 0x05 write single coil to slave 2
                                    SendModbusRequest (0x05, 2, IO_CLEAR_ERRROR, true);
                                    WaitModbusReply ();
                        }
                        else if (uStatusFlags != 0)
                        {
                                    SendModbusRequest (0x05, 2, IO_CLEAR_ERRROR, true);
                                    WaitModbusReply ();
                        }
                        switch (iScaleFactor)
                        {
                                    case 2: fSensorData = (float)(iSensorData) / 100.0;
                                    case 1: fSensorData = (float)(iSensorData) / 10.0;
                                    case 0: fSensorData = (float)(iSensorData);
                                    case -1: fSensorData = (float)(iSensorData) * 10.0;
                                    default: fSensorData = 0.0;
                        }
                        // wait 1 second
                        Delay (1000);
            }
}
```

B. Pyranometer physical properties

B.1 Spectral range

The spectrum of the solar radiation reaching the Earth's surface is in the wavelength range between 280 nm and 4000 nm, extending from ultraviolet (UV) to the far infrared (FIR). Due to the excellent physical properties of the glass dome and black absorber paint, Kipp & Zonen SMP series radiometers are equally sensitive in a wide spectral range. 97 - 98 % of the total energy will be absorbed by the thermal detector.



B.2 Sensitivity

For the SMP series pyranometers the physical sensitivities are converted to a digital output that is identical for all sensors. The SMP-V versions all have an analogue output of 0 to 1 Volt for -200 to 2000 W/m². The SMP-A outputs are 4 to 20 mA for 0 to 1600 W/m².

B.3 Response time

Any measuring device requires a certain time to react to a change in the parameter being measured. The radiometer requires time to respond to changes in the incident radiation. The response time is normally quoted as the time for the output to reach 95 % (sometimes 1/e, 63 %) of the final value following a step-change in irradiance. It is determined by the physical properties of the thermopile and the radiometer construction. SMP series radiometers are set to digitally accelerate the physical response.

B.4 Non-linearity

The non-linearity of a pyranometer is the percentage deviation in the sensitivity over an irradiance range from 0 to 1000 W/m² compared to the sensitivity calibration irradiance of 500 W/m². The non-linear effect is due to convective and radiative heat losses at the black absorber surface which make the conditional thermal equilibrium of the radiometer non-linear.

B.5 Tempearture dependence

The sensitivity change of the radiometer with ambient temperature change is related to the thermo-dynamics of the radiometer construction. The temperature dependence is given as percentage deviation with respect to the calibrated sensitivity at +20 °C. The SMP series pyranometers have an integrated temperature sensor and use a fourth-order polynomial function to actively correct for temperature errors over a -40 °C to +70 °C range.

B.6 Tilt error

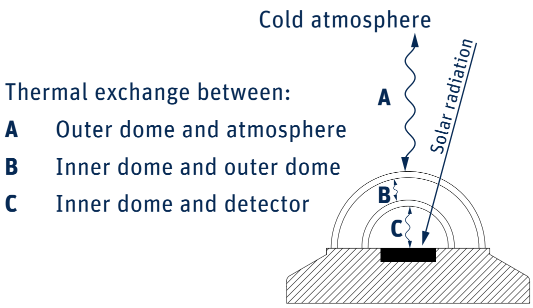
This is the deviation from the sensitivity at 0° tilt (exactly horizontal) over the range from 0° to 90° tilt under 1000 W/m² normal incidence irradiance. The tilt response is proportional to the incident radiation. The error could be corrected for, in applications where it is necessary to install the pyranometer on an inclined surface, but is usually insignificant.

B.7 Zero offset type A

By physical laws any object having a certain temperature will exchange radiation with its surroundings. The domes of upward facing radiometers will exchange radiation primarily with the relatively cold atmosphere. In general, the atmosphere will be cooler than the ambient temperature at the Earth's surface. For example, a clear sky can have an effective temperature up to 50 °C cooler, whereas an overcast sky will have roughly the same temperature as the Earth's surface.

Due to this the pyranometer dome will 'lose' energy to the colder atmosphere by means of radiative transfer. This causes the dome to become cooler than the rest of the instrument. This temperature difference between the detector and the instrument housing will generate a small negative output signal which is commonly called Zero Offset Type A. This effect is reduced by using an inner dome. This inner dome acts as a 'radiation buffer'.

This offset can be minimized by applying appropriate ventilation of the instrument. The CVF 3 ventilation unit can be used with the SMP11, no ventilation unit is available for the SMP3.



B.8 Zero offset type B

Proportionally to the ambient temperature the instrument temperature varies and causes heat currents inside the instrument. This will cause an offset commonly called Zero Offset Type B. It is quantified as the response in W/m^2 to a 5 K/hr change in ambient temperature.

B.9 Operating temperature

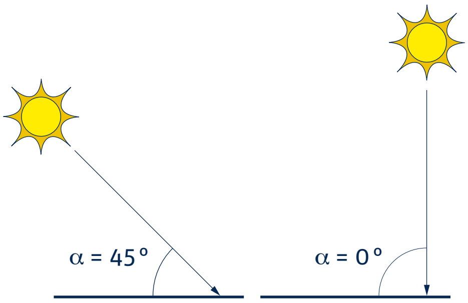
The operating temperature range of the radiometer is determined by the physical properties of the individual parts. Within the specified temperature range Kipp & Zonen radiometers can be operated safely. Outside this temperature range special precautions should be taken to prevent any physical damage or performance loss of the radiometer. Please contact your Kipp & Zonen representative for further information regarding operation in unusually harsh temperature conditions.

B.10 Field of view

The field of view is defined as the unobstructed open viewing angle of a radiometer. ISO and WMO require that a pyranometer for the measurement of global solar radiation has a field of view of 180 ° in all directions (i.e. a hemisphere). The inherent field of view of the instrument should not be confused with the clear field of view of the installation location.

B.11 Directional response

Radiation incident on a flat horizontal surface originating from a point source with a defined zenith position (such as the sun) will have an intensity value proportional to the cosine of the zenith angle of incidence. This is sometimes called the 'cosine-law' or 'cosine-response' and is illustrated below.



Ideally a pyranometer has a directional response which is exactly the same as the cosine-law. However, in a pyranometer the directional response is influenced by the detector and by the quality, dimensions and construction of the dome(s). The maximum deviation from the ideal cosine-response of the pyranometer is given up to 80° angle of incidence with respect to 1000 W/m^2 irradiance at normal incidence (0° zenith angle).

B.12 Maximum irradiance

The maximum irradiance is defined as the total irradiance level beyond which the output is no longer linear and out of specifications. The analogue output for the SMP's is set to 2000 W/m^2, which is sufficient under normal atmospheric conditions. For special applications (environmental test rooms) the SMP11 can be set higher, up to 4000 $W/^2$.

B.13 Non-stability

This is the percentage change in sensitivity over a period of one year. This effect is mostly due to degradation by UV radiation of the black absorber coating on the thermopile surface.

Kipp & Zonen recommends recalibration every two years. However, for quality assurance purposes some institutes, companies or networks may require more or less frequent recalibration. Please read the chapter on the calibration procedure for pyranometers for more information.

B.14 Spectral selectivity

Spectral selectivity is the variation of the dome transmittance and absorption coefficient of the black detector coating with wavelength and is commonly specified as % of the mean value.

B.15 Environmental

The SMP series are intended for outdoor use under all expected weather conditions. The radiometers comply with IP 67 and their solid mechanical construction is suitable to be used under all environmental conditions within the specified ranges.

B.16 Uncertainty

The measurement uncertainty of a pyranometer can be described as the maximum expected hourly or daily uncertainty with respect to the 'absolute truth'. The confidence level is 95%, which means that 95% of the data-points lie within the given uncertainty interval representing the absolute value. Kipp & Zonen empirically determine uncertainty figures based on many years of field measurements for typical operating conditions.

When a pyranometer is in operation, the performance of it is correlated to a number of parameters, such as temperature, level of irradiance, angle of incidence, etc. If the conditions differ significantly from calibration conditions, uncertainty in the calculated irradiances must be expected.

For a 'High Quality' pyranometer the WMO expects maximum uncertainty in the hourly radiation totals of 3%. In the daily total an uncertainty of 2% is expected, because some response variations cancel each other out if the integration period is long. See the WMO 'Guide to Meteorological Instruments and Methods of Observation' Seventh Edition, 2008. ISO 9060:1990 does not refer to hourly or daily uncertainties.

Many years of experience has shown that pyranometer performance can be improved concerning zero offset type A by using a well-designed ventilation system. The Kipp & Zonen CVF 3 ventilation unit is recommended for the SMP11 to minimise this small error.

C. Pyranometer classification to ISO 9060:1990 (E)

Ref. No.	Specification	SMP11	SMP3	Pyranometer Category		
		Secondary Standard	Second Class	Secondary Standard	First Class	Second Class
1	Response time (95% response)	< 2 s	< 12 s	< 15 s	< 30 s	< 60 s
2	Zero off-set (a) Response to 200 W/m² net thermal radiation (ventilated) (b) Response 5 K/hr change in ambient temperature	< 7 W/m² < 2 W/m²	< 15 W/m² <4 W/m²	± 7 W/m² ± 2 W/m²	± 15 W/m² ± 4 W/m²	± 30 W/m² ± 8 W/m²
3a	Non-stability (change per year, percentage of full scale)	< 0.5 %	< 1 %	± 0.8 %	± 1.5 %	± 3.0 %
3b	Non-linearity (percentage deviation from the responsivity at 500 W/m² due to any change of irradiance within the range 100 to 1000 W/m²)	< 0.2 %	< 1 %	± 0.5 %	± 1 %	± 3 %
3c	Directional response for beam radiation (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 1000 W/m²) Commonly defined as up to 80° zenith angle	< 10 W/m²	< 20 W/m²	± 10 W/m²	± 20 W/m²	± 30 W/m²
3d	Spectral selectivity (percentage of deviation of the product of spectral absorptance and spectral transmittance from the corresponding mean within 0.35 μm and 1.5 μm)	< 3 %	< 3%	± 3 %	± 5 %	± 10 %
3e	Temperature response (percentage deviation due to change in ambient temperature within an interval of 50 K)	< 1 % -20°C to +50°C	< 3 % (70 K interval)	2 %	4 %	8 %
3f	Tilt response (percentage deviation from the responsivity at 0° tilt, horizontal, due to change in tilt from 0° to 90° at 1000 W/m² irradiance)	< 0.2 %	< 1 %	± 0.5 %	± 2 %	± 5 %

KIPP & ZONEN
SINCE 1830

Our customer support remains at your disposal for any maintenance or repair, calibration, supplies and spares.

Für Servicearbeiten und Kalibrierung, Verbrauchsmaterial und Ersatzteile steht Ihnen unsere Customer Support Abteilung zur Verfügung.

Notre service 'Support Clientèle' reste à votre entière disposition pour tout problème de maintenance, réparation ou d'étalonnage ainsi que pour les accessoires et pièces de rechange.

Nuestro servicio de atención al cliente esta a su disposición para cualquier actuación de mantenimiento, reparación, calibración y suministro de repuestos.

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