



# DPA953.1

Secondary standard pyranometer  
with Modbus RTU

**User manual**

## Revisions list

<i>Issue</i>	<i>Date</i>	<i>Description of changes</i>
Origin	01/06/2023	

## Cautionary statements

Cautionary statements are subdivided into four categories: danger, warning, caution and notice according to the severity of the risk.

### **⚠ DANGER**

**Failure to comply with a danger statement will lead to death or serious physical injuries.**

### **⚠ WARNING**

**Failure to comply with a warning statement may lead to risk of death or serious physical injuries.**

### **⚠ CAUTION**

**Failure to comply with a caution statement may lead to risk of minor or moderate physical injuries.**

### **NOTICE**

**Failure to comply with a notice may lead to damage to equipment or may compromise reliable operation of the instrument.**

## Table of contents

Cautionary statements .....	3
Table of contents .....	4
List of symbols .....	7
Introduction .....	8
1 Ordering and checking at delivery .....	13
1.1 Included items .....	13
2 Instrument principle and theory .....	14
2.1 Why a “spectrally flat” pyranometer? .....	17
2.2 Operating modes: heating and ventilation .....	19
2.3 Overview of remote diagnostics .....	20
2.4 Use of the tilt sensor .....	20
3 Specifications of DPA953.1 .....	21
3.1 Specifications of DPA953.1 .....	21
3.2 Dimensions of DPA953.1 .....	27
4 Standards and recommended practices for use .....	28
4.1 Classification standards .....	28
4.2 General use for solar radiation measurement .....	28
4.3 Specific use for outdoor PV system performance testing .....	29
4.4 Specific use in meteorology and climatology .....	29
4.5 General use for sunshine duration measurement .....	30
5 Installation of DPA953.1 .....	31
5.1 Site selection and mechanical installation .....	31
5.2 Installation of the sun screen .....	33
5.3 Installation of optional mounts .....	34
5.3.1 Levelling mount .....	34
5.3.2 Tube levelling mount .....	36
5.4 Electrical installation .....	37
5.1 Internal protection .....	38
5.2 Connecting to an RS-485 network .....	39
5.2.1 RS-485 network .....	39
5.3 Electrical isolation, grounding and shield connection .....	41
5.3.1 Spatially extended installations (total cable lengths >5 m) .....	41
5.3.2 Spatially compact installations (total cable lengths ≤5 m) .....	42

---

5.4	Cabling requirements .....	42
5.5	Connecting to a PC.....	44
6	Communication with DPA953.1 .....	45
6.1	Network communication: getting started .....	45
6.2	Changing the device address and serial communication settings.....	46
7	Use of remote diagnostics .....	48
7.1	Recommendations.....	48
7.2	Sensor body temperature.....	48
7.3	Tilt angle .....	49
7.4	Internal relative humidity .....	49
7.5	Heater current .....	49
7.6	Ventilator current.....	49
7.7	Ventilator speed .....	50
8	Making a dependable measurement .....	51
8.1	The concept of dependability.....	51
8.2	Reliability of the measurement .....	52
8.3	Speed of repair and maintenance .....	53
8.4	Uncertainty evaluation .....	53
8.4.1	Evaluation of measurement uncertainty under outdoor conditions .....	53
8.4.2	Calibration uncertainty.....	55
9	Maintenance and trouble shooting.....	56
9.1	Recommended maintenance and quality assurance .....	56
9.2	Trouble shooting.....	57
9.3	Calibration and checks in the field .....	59
9.4	Data quality assurance .....	60
10	Handling.....	60
11	Storage, packaging, preservation, delivery, disposal .....	60
12	Safety.....	60
13	Appendices .....	61
13.1	Appendix on tools for DPA953.1 .....	61
13.2	Appendix on spare parts for DPA953.1 .....	61
13.3	Appendix on the ventilator.....	61
13.4	Appendix on standards for classification and calibration .....	62
13.5	Appendix on calibration hierarchy .....	62
13.6	Appendix on meteorological radiation quantities.....	64
13.7	Appendix on ISO and WMO classification tables .....	65

---

13.8	Appendix on ISO 9060:1990 classification no longer valid.....	67
13.9	Appendix on definition of pyranometer specifications.....	68
13.10	Appendix on terminology / glossary.....	70
13.11	Appendix on function codes, register and coil overview .....	71
13.12	Appendix on electromagnetic compatibility (EMC) testing.....	75

## List of symbols

Quantities	Symbol	Unit
Sensitivity	S	V/(W/m <sup>2</sup> )
Temperature	T	°C
Solar irradiance	E	W/m <sup>2</sup>
Plane of Array irradiance	G <sub>i</sub>	W/m <sup>2</sup>
Solar radiant exposure	H	W·h/m <sup>2</sup>
Time in hours	h	h
Tilt angle relative to horizontal	θ <sub>h</sub>	°
Relative humidity	RH	%
Pressure	p	bar
Temperature coefficient	a	1/°C <sup>2</sup>
Temperature coefficient	b	1/°C
Temperature coefficient	c	-

(see also appendix 10.6 on meteorological quantities)

### Subscripts

extended RS-485 common mode range	V <sub>cm, max</sub>
DC isolation voltage (instrument body to signal ground)	V <sub>iso</sub>
heater power	P <sub>heater</sub>

### Acronyms

ASTM	American Society for Testing and Materials
CRC	Cyclic Redundancy Check
GHI	Global Horizontal Irradiance
IEC	International Electrotechnical Commission
ISO	International Organization for Standards
LSW	Least-Significant Word
MSW	Most-Significant Word
POA	Plane of Array
PV	Photovoltaic
RPM	Rounds-per-Minute
SCADA	Supervisory Control And Data Acquisition
WMO	World Meteorological Organization

Modbus® is a registered trademark of Schneider Electric, licensed to the Modbus Organization, Inc.

## Introduction

Welcome to the next level in solar radiation monitoring! The all-digital heated DPA953.1 pyranometer offers the highest accuracy and highest data availability: using Recirculating Ventilation and Heating (RVH™) technology, DPA953.1 outperforms pyranometers equipped with traditional ventilation systems. DPA953.1 is the ideal instrument for use in PV system performance monitoring and meteorological networks.

DPA953.1 measures the solar radiation received by a plane surface, in  $W/m^2$ , from a 180 ° field of view angle. DPA953.1 is an ISO 9060 spectrally flat Class A (previously “secondary standard”) pyranometer. It is employed where the highest measurement accuracy is required. DPA953.1 offers several advantages over competing pyranometers:

- Heated for best data availability: RVH™ technology outperforms traditional pyranometer ventilation
- The first pyranometer compliant in its standard configuration with the IEC 61724-1:2017 requirements for Class A PV monitoring systems
- Low cost of ownership: remote diagnostics and supported by a worldwide calibration organisation
- Spectrally flat: WMO compliant, also suitable for Plane of Array, diffuse, and albedo measurement



**Figure 0.1** DPA953.1 digital spectrally flat Class A pyranometer with heating and tilt sensor

### NOTICE

**This manual supports model DPA953.1, the successor of DPA953.  
Need support for the discontinued DPA953? Please refer to its separate manual.**



DPA953.1 offers several advantages over competing pyranometers:

### Heated for high data availability, featuring new RVH™ technology

High data availability is attained by heating of the outer dome using ventilation between the inner and outer dome. This space forms a closed circuit together with the instrument body; ventilated air is not in contact with ambient air. RVH™ – Recirculating Ventilation and Heating – technology, developed by LSI Lastem, suppresses dew and frost deposition and is as effective as traditional ventilation systems, without the maintenance hassle and large footprint.

- low power consumption: DPA953.1 requires less than 3 W, compared to 10 W for traditional ventilation systems
- low maintenance: DPA953.1 does not require filter cleaning

RVH™ uses DPA953.1's built-in heater and ventilator. The dome of DPA953.1 pyranometer is heated by ventilating the space between the inner and outer dome. RVH™ is much more efficient than traditional ventilation, where most of the heat is carried away with the ventilation air. Recirculating ventilation is as effective in suppressing dew and frost deposition at less than 3 W as traditional ventilation is at 10 W. RVH™ technology keeps domes and sensor in perfect thermal equilibrium, which Plane of Array leads to a reduction of zero offsets.

### Compliant with IEC 61724-1: 2017, Class A and B

IEC 61724-1: Photovoltaic System Performance Monitoring – Guidelines for Measurement, Data Exchange and Analysis – requires ventilation and heating for Class A monitoring. Only DPA953.1 offers both, without the need for additional accessories. Most competing pyranometers do not even comply with Class B, which requires heating.

### "Spectrally flat" as required for PV monitoring and meteorology

The new ISO 9060:2018 version defines pyranometer classes A, B and C. The standard also adds a new subclass, called "spectrally flat". The vast majority of users needs to use instruments of the spectrally flat subclass; only spectrally flat instruments measure with high accuracy, also when a cloud obscures the sun, or when the irradiance includes reflected radiation. These situations occur for example when you measure Global Horizontal irradiance (GHI) under partly or fully cloudy skies, when you measure Plane of Array (POA), albedo or net-radiation. Normal instruments, just of class A, B or C, and not spectrally flat, only measure accurately under clear sunny skies.

Using "spectrally flat" instruments is essential because this ensures:

- you can measure accurately not only horizontally under clear-blue-sky but also general GHI, POA, albedo and net radiation
- you comply with WMO requirements
- you can use the normal standardised ISO and WMO calibration procedures
- you can also measure separately the diffuse component only (creating a diffusometer) with a shadow ring or shading ball, using the same instrument model
- you can perform uncertainty evaluations with negligible (zero) spectral errors

See Section 2.1 in this manual for a more detailed explanation.

### Low cost of ownership

DPA953.1 is an affordable spectrally flat Class A instrument and is designed for low cost of ownership, which is mainly determined by costs of installation, on-site inspections, servicing and calibration:

- low demand on infrastructure, DPA953.1's RVH™ requires less than 3 W power, compared to 10 W for traditional ventilation systems
- reduction of unnecessary on-site inspection by remote diagnostics
- designed for efficient servicing; easy local diagnostics
- supported by an efficient calibration and maintenance organisation. LSI Lastem offers local support in the main global economies: USA, EU, China, India, SE Asia, Japan and Brazil. Recalibration is recommended every 2 years, which is good practice in the industry.

### Liabilities covered: test certificates

As required by ISO 9060 for Class A classification, each DPA953.1 is supplied with test results for the individual instrument:

- sensitivity
- directional response
- temperature response
- tilt sensor gains, offsets and temperature coefficients

### Improved electronics

Model DPA953.1 is the successor of the DPA953. DPA953.1 offers improved electronics design over its predecessor DPA953.

### Remote sensor diagnostics

Besides solar radiation, DPA953.1 outputs sensor diagnostics, including:

- tilt angle
- sensor body temperature
- internal humidity
- internal pressure
- ventilator speed (RPM)
- ventilator current
- heater current

Remote diagnostics permits real-time status monitoring, reducing the need for (un)scheduled field inspections.

### Suggested use

Suggested use for DPA953.1:

- PV system performance monitoring
- scientific meteorological observations

### Diffuse radiation measurement

With its outstanding zero offset specifications, DPA953.1 is also the instrument of choice for high-accuracy diffuse radiation measurement.

### DPA953.1 design

DPA953.1 pyranometer employs a state-of-the-art thermopile sensor with black coated surface, two domes and an anodised aluminium body. DPA953.1 offers a digital output via Modbus RTU over 2-wire RS-485. The pyranometer dome is heated by ventilating the space between the inner and outer dome using RVH™ - Recirculating Ventilation and Heating - technology.

### Operating modes: heating and ventilation

The standard operating mode of DPA953.1 is with heater and ventilator both [ON]. The power consumption then is < 3 W. Alternatives are operation in medium power mode and in low power mode. Heating and ventilation may be switched on and off by digital control. If the heater is switched [OFF], DPA953.1 operates in medium power mode. Operation at < 0.1 W, in the low power mode, is possible by switching both the ventilator and heater [OFF]. Although zero offset will then increase slightly, overall performance will still comply with the spectrally flat class A classification. In case there is no danger of deposition of dew or frost, the medium power mode offers the most accurate measurement.

### Options for mounting and levelling

There are several mounting options available for DPA953.1: a levelling mount and a tube levelling mount. They allow for simplified mounting, levelling and instrument exchange on either a flat surface or a tube.



**Figure 0.5** *Optional levelling mount (picture on the left); a practical spring-loaded mount for easy mounting, levelling and instrument exchange on flat surfaces, and the optional tube mount (picture on the right) including spring-loaded levelling upper clamp, lower clamp for tube mounting and two sets of bolts*

### Spring-loaded levelling

When opting for one of the levelling mounts, DPA953.1 is easily mounted and levelled using the mount's spring-loaded centre bolt and DPA953.1's adjustable levelling feet.



**Figure 0.6** *Optional levelling mount allows spring-loaded levelling*

The standard cable length is 5 m. Optionally cables of 10 and 20 m are supplied. It is good practice to keep cables as short as possible; see chapter on cabling requirements.



**Figure 0.7** DPA953.1 standard cable with M12-A female connector on sensor end. On the opposite end (not visible), the cable is terminated with removed sheath over 0.15 m; stranded copper conductors with plastic insulators, stripped ends with ferrules. Its length is 5 metres standard and it is available in 10 and 20 metres too.

DPA953.1 is designed for use in SCADA (Supervisory Control And Data Acquisition) systems, supporting Modbus RTU (Remote Terminal Unit) protocol over RS-485. In these networks the sensor operates as a Modbus RTU slave. SCADA systems are often implemented in photovoltaic solar energy (PV) systems and meteorological networks. Using DPA953.1 in a network is easy. Once the Modbus address and communication settings have been configured and is connected to a power supply, the instrument can be used in RS-485 networks. The user should have sound knowledge of the Modbus communication protocol when installing sensors in a network.

The instrument should be used in accordance with the recommended practices of ISO, WMO and ASTM.

The recommended calibration interval of pyranometers is 2 years. The registers containing the applied sensitivity and the calibration history of DPA953.1 are fully accessible for users. This allows the user to choose his own local calibration service. The same feature may be used for remotely controlled re-calibration of pyranometers in the field. Ask LSI Lastem for information on this feature and on ISO and ASTM standardised procedures for field calibration.

## 1 Ordering and checking at delivery

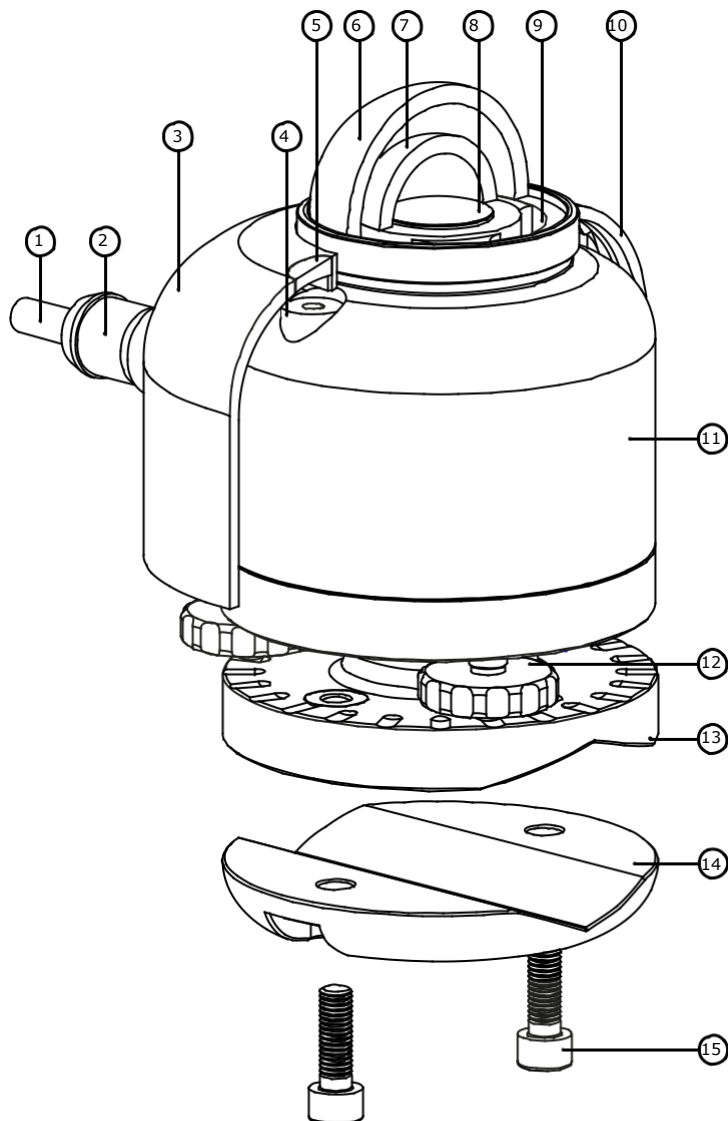
### 1.1 Included items

Arriving at the customer, the delivery should include:

- pyranometer DPA953.1
- sun screen
- cable of the length as ordered
- product certificate matching the instrument serial number, including:
  - calibration certificate
  - temperature response test report
  - directional response test report
  - tilt sensor test report
- any other options as ordered

Please store the certificates in a safe place.

## 2 Instrument principle and theory



**Figure 2.0.1** Overview of DPA953.1:

- (1) cable (standard length 5 metres, optional longer cable)
- (2) connector
- (3) sun screen
- (4) bubble level
- (5) bubble level window
- (6) outer dome
- (7) inner dome
- (8) thermal sensor with black coating
- (9) internal ventilation vents
- (10) quick release system of sun screen
- (11) instrument body
- (12) levelling feet
- (13) optional spring-loaded levelling mount
- (14) optional tube mount
- (15) screws included with tube mount

DPA953.1's scientific name is pyranometer. A pyranometer measures the solar radiation received by a plane surface from a 180 ° field of view angle. This quantity, expressed in  $W/m^2$ , is called "hemispherical" solar radiation. The solar radiation spectrum extends roughly from (285 to 3000)  $\times 10^{-9}$  m. By definition a pyranometer should cover that spectral range with a spectral selectivity that is as "flat" as possible.

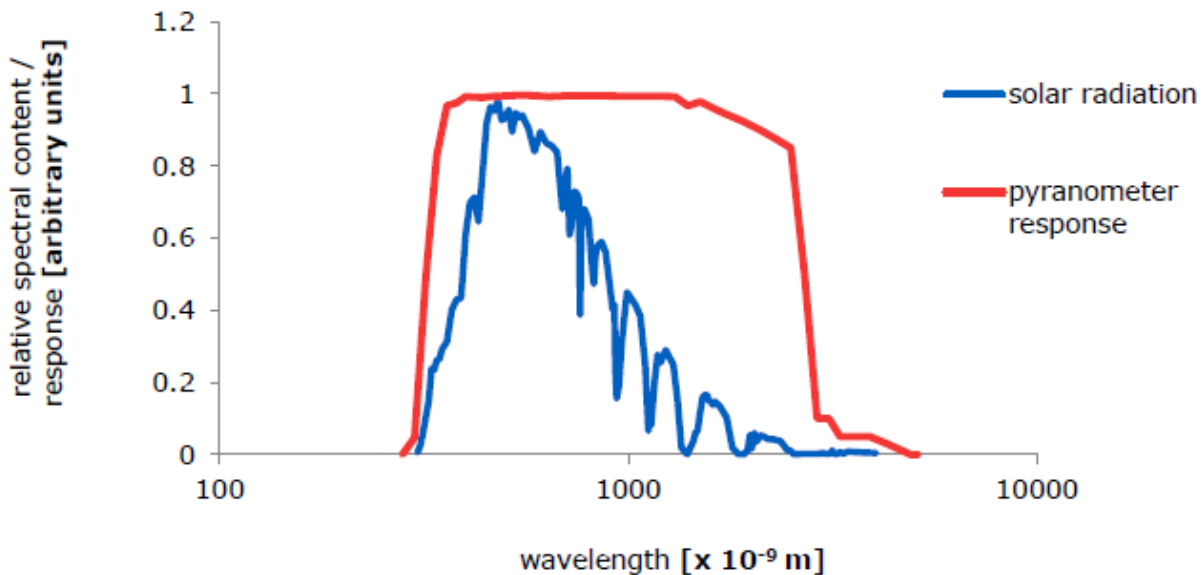
In an irradiance measurement by definition the response to "beam" radiation varies with the cosine of the angle of incidence; i.e. it should have full response when the solar radiation hits the sensor perpendicularly (normal to the surface, sun at zenith, 0 ° angle of incidence), zero response when the sun is at the horizon (90 ° angle of incidence, 90 ° zenith angle), and 50 % of full response at 60 ° angle of incidence. A pyranometer should have a so-called "directional response" that is as close as possible to the ideal cosine characteristic (older documents mention the term "cosine response" instead).

In order to attain the proper directional and spectral characteristics, DPA953.1's main components are:

- a thermal sensor with black coating. It has a flat spectrum covering the (200 to 50 000)  $\times 10^{-9}$  m range, and has a near-perfect directional response. The coating absorbs all solar radiation and, at the moment of absorption, converts it to heat. The heat flows through the sensor to the sensor body and from the sensor body to the environment. The thermopile sensor generates a voltage output signal that is proportional to the solar irradiance.
- in case of DPA953.1, the analogue thermopile voltage is converted by the instrument electronics to a digital signal. In this process the temperature dependence of the thermopile is compensated. DPA953.1 uses high-end conversion electronics with a very small temperature dependence and excellent long-term stability.
- a glass dome. This dome limits the spectral range from (285 to 3000)  $\times 10^{-9}$  m (cutting off the part above 3000  $\times 10^{-9}$  m), while preserving the 180 ° field of view angle. Another function of the dome is that it shields the thermopile sensor from the environment (convection, rain).
- a second (inner) glass dome: For a spectrally flat Class A pyranometer, two domes are used, and not one single dome. This construction provides an additional "radiation shield", resulting in a better thermal equilibrium between the sensor and inner dome, compared to using a single dome. The effect of having a second dome is a strong reduction of instrument thermal offsets.
- a heater and ventilator: in order to reduce dew deposition and frost on the outer dome surface, DPA953.1 has a built-in heater and ventilator. The heater is attached to the sensor body. The ventilation air circulates inside the body and between the domes. The combination of ventilation and heating keeps the domes in thermal equilibrium with the thermopile sensor and above dew point. When ventilation is [ON], zero offsets are very low.
- a tilt sensor: this sensor measures tilt with a  $\pm 1$  ° uncertainty and a short-term resolution, or detection limit, of 0.1 °. This is sufficient to monitor incidents that change the instrument tilt.

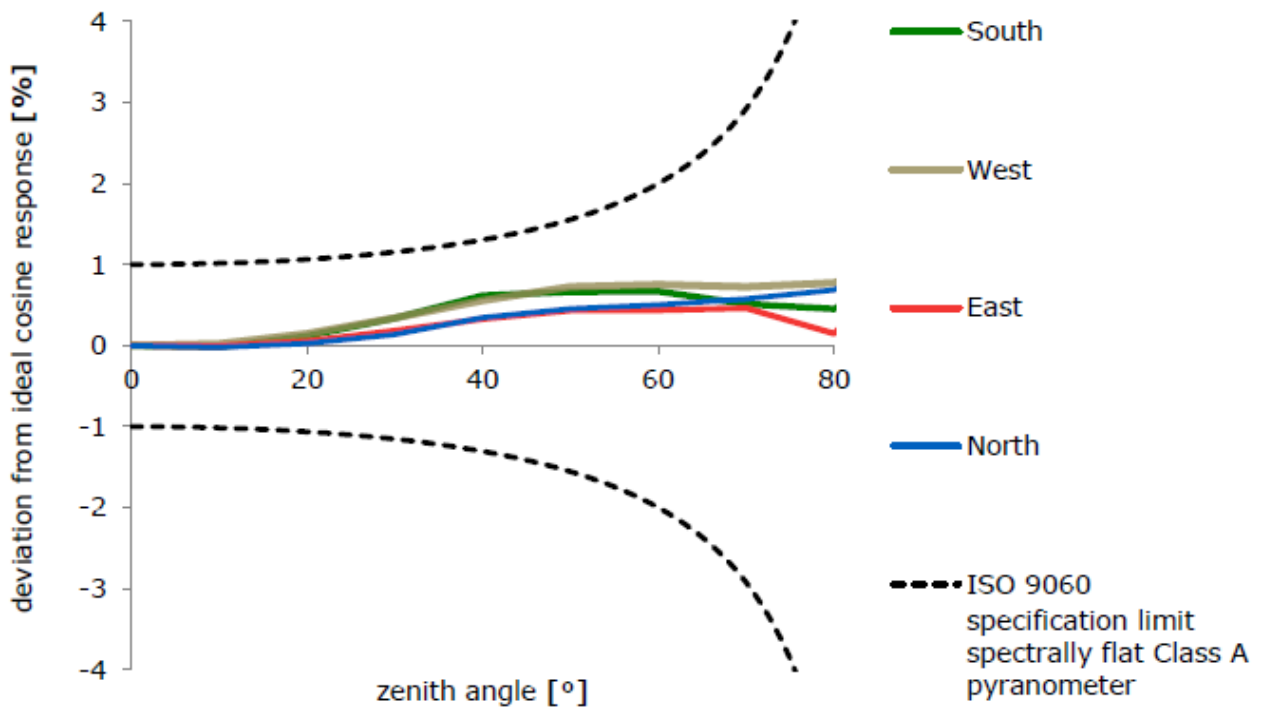
Pyranometers can be manufactured to different specifications and with different levels of verification and characterisation during production. The ISO 9060:2018 standard, “Solar energy - specification and classification of instruments for measuring hemispherical solar and direct solar radiation”, distinguishes between 3 classes; spectrally flat Class A (highest accuracy), Class B (second highest accuracy) and Class C (third highest accuracy).

From class C to class B and from class B to class A, the achievable accuracy improves roughly by a factor 2.



**Figure 2.0.2** Spectral response of the pyranometer compared to the solar spectrum. The pyranometer only cuts off a negligible part of the total solar spectrum.





**Figure 2.0.3** Directional response of an DPA953.1 pyranometer of 4 azimuth angles, compared to secondary standard limits.

## 2.1 Why a “spectrally flat” pyranometer?

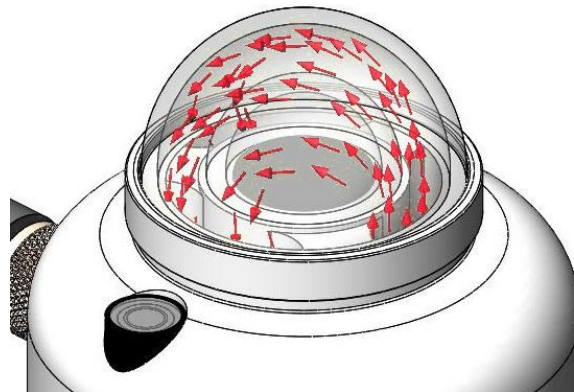
ISO 9060:2018 defines classes A, B and C. The standard also defines a subclass, called "spectrally flat". The vast majority of users needs to use instruments of the spectrally flat subclass; only spectrally flat instruments measure with high accuracy, also when a cloud obscures the sun, or when the irradiance includes reflected radiation. These situations occur when measuring Global Horizontal Irradiance (GHI) under partly or fully cloudy skies, Plane of Array (POA) and albedo or net-radiation. Instruments of class A, B or C that are not spectrally flat only measure accurately under clear sunny skies in a horizontal position.

Compliance with the spectrally flat subclass also means the instrument complies with WMO guide and keeps continuity with the 1990 version of ISO 9060. The classification "spectrally flat" may be added to the name of the class if the instrument fulfils spectral criteria as in the WMO guide and ISO 9060:1990 (the preceding version of the same standard dating from 1990) secondary standard pyranometers (i.e. spectral selectivity  $(350 \text{ to } 1500) \times 10^{-9} \text{ m}$ :  $< \pm 3 \%$  with  $2 \%$  guard band).

The spectral error of ISO 9060:2018 is defined as "Clear sky global horizontal irradiance spectral error". This error is valid under a clear sky on a sunny day. This is not the common spectrum in normal application in solar renewable energy and it is also not the common spectrum in meteorological application. Even for frequently occurring situations, for example when a cloud obscures the direct sun or under a cloudy sky, the measurement error with a normal class A, B or C pyranometer is undefined. This is why almost all users need a "spectrally flat" pyranometer, for which this error is negligible.

To conclude, specifying "spectrally flat" is essential because this ensures:

- you can measure accurately not only clear-blue-sky (with direct solar radiation) GHI in a horizontal position, but also when a cloud obscures the sun, blue sky diffuse only, cloudy sky diffuse, reflected, Plane of Array, POA, for Photovoltaic solar panels, albedo or net radiation for meteorology.
- you comply with WMO: spectrally flat Class A and B instruments comply with the WMO spectral requirements of high quality pyranometers as well as with the WMO network requirement to measure not only global horizontal but also reflected radiation. Normal Class A and B instruments do not comply with WMO requirements.
- you can use the normal standardised ISO and WMO calibration procedures, and can benefit from relatively low-cost indoor calibrations. For normal class A, B and C instruments this is not possible.
- you comply with the WMO *Guide to Meteorological Instruments and Methods of Observation*, and the preceding ISO 9060 version of 1990, attain continuity of performance and specifications.
- you can also measure separately the diffuse component only (creating a diffusometer) for example with a shadowring or shading ball, using the same instrument model.
- you can perform uncertainty evaluations with negligible (zero) spectral errors under all conditions, because they are calibrated out.



**Figure 2.2.1** *Recirculating ventilation and heating between the inner- and outer dome is much more power-efficient than traditional ventilation systems.*

## 2.2 Operating modes: heating and ventilation

A unique feature of DPA953.1 is its built-in heater and ventilator. In practice, this is as effective against dew and frost deposition as using traditional ventilation systems.

The heater is attached to the sensor body. Heat is generated inside the sensor body. The ventilator circulates air inside the body and between the domes. The combination of ventilation and heating keeps the domes in thermal equilibrium with the sensor and the entire instrument above dew point. When ventilation is [ON], zero offsets are very low.

There are 3 operation modes: standard, medium power and low power mode. In standard operating mode, both heater and ventilator are [ON], in medium power mode, only the ventilator is [ON], in low power mode both are [OFF]. Table 2.1.1 gives an overview of these settings and our recommendations for use.

**Table 2.1.1** Possible user scenarios for the heater and ventilator

Operating mode	heater status	ventilator status	power use (at 12 VDC)	comment
standard	[ON]	[ON]	< 3.0 W	factory default recommended settings
N/A	[ON]	[OFF]		do not use these settings, spectrally flat Class A specifications will not be met
medium power	[OFF]	[ON]	< 0.65 W	this mode offers the most accurate measurement results because the sensitivity to thermal fluctuations of the environment is smaller recommended over the [OFF] [OFF] setting, because it reduces the thermal sensor offset
low power	[OFF]	[OFF]	< 0.1 W	spectrally flat Class A performance is also guaranteed with these settings

Heating when used in combination with ventilation does not affect the classification specifications and the measurement accuracy.

When using the heater without ventilation spectrally flat Class A specifications will not be met, because of a heating-induced offset.

In case that there is no danger of deposition of dew or frost, the medium power mode (using the ventilator but not the heater) offers the most accurate measurements over short time intervals. Averages on the minute time scale produce the same result as in the standard operating mode. The measurement in medium power mode is less sensitive to thermal shocks (rapid changes of the sensor body temperature) and is less noisy.

The nominal ventilator power is about 0.5 W and the heater power is 1.5 W, see section 7.5 for more detail. With around 0.1 W power to the electronics and efficiency variations over temperature and operating voltage the total operation power consumption is < 3 W.

### NOTICE

**Do not use DPA953.1 with heater [ON] and ventilator [OFF].  
This is not a valid operating mode. ISO 9060:2018 spectrally flat class A specifications will not be met in this operating mode.**

## 2.3 Overview of remote diagnostics

Besides the digital output measuring irradiance in  $W/m^2$ , DPA953.1 has several internal sensors providing outputs which may be used for remote diagnostics. Remote monitoring of the instrument's condition helps improve the accuracy and reliability of the measurement. It also allows to improve preventive maintenance and effective trouble shooting. Chapter 7 gives recommendations on how to use these diagnostics. Chapter 6 contains details on the register structure, needed for reading the remote diagnostics output.

A brief overview of the diagnostic signals:

- tilt angle
- sensor body temperature
- internal humidity
- internal pressure
- ventilator speed
- ventilator current
- heater current

## 2.4 Use of the tilt sensor

DPA953.1 is equipped with an internal tilt sensor. The tilt measurement serves to monitor slow, long-term changes as well as incidents that cause the instrument to move. The absolute accuracy of the sensor depends on temperature and is not as high as that of the bubble level. The bubble level remains the reference for horizontal installation. The short-term resolution, or detection limit, of the tilt sensor is sufficiently high for monitoring possible incidents. Table 2.4.1 gives recommendations for using the tilt sensor.

**Table 2.3.1** Recommendations for use of the tilt sensor

Application	Required accuracy	Reference	Remarks
Tilted installation	$\pm 1^\circ$	tilt sensor	tilt measurement is sufficiently accurate
Horizontal installation	$\pm 0.1^\circ$	bubble level	tilt measurement is not sufficiently accurate
Short-term incident monitoring	$\pm 0.1^\circ$	tilt sensor output, immediately after installation	after levelling with the bubble level, store "tilt angle average" register. This stored measurement is the reference for monitoring incidents. for short-term incident monitoring, mark changes or generate a warning if the tilt sensor measurement exceeds $0.2^\circ / \text{min}$ .
Long term monitoring	$\pm 1^\circ$	tilt sensor output, immediately after installation	for long term monitoring, mark changes or generate a warning if the tilt sensor measurement exceeds $1^\circ$ .

## 3 Specifications of DPA953.1

### 3.1 Specifications of DPA953.1

DPA953.1 measures the solar radiation received by a plane surface from a 180 ° field of view angle. This quantity, expressed in  $W/m^2$ , is called “hemispherical” solar radiation. DPA953.1 offers irradiance in  $W/m^2$  as a digital output. DPA953.1 must be used in combination with a suitable power supply and a data acquisition system which uses the Modbus RTU communication protocol over an RS-485 connection. When operated in one of the valid operating modes the instrument is classified as spectrally flat Class A according to ISO 9060 and compliant with IEC 61724-1 requirements for use in Class A monitoring systems.

**Table 3.1.1** Specifications of DPA953.1 (continued on next pages)

<b>DPA953.1 CLASSIFICATIONS</b>	
ISO classification (ISO 9060:2018)	spectrally flat Class A pyranometer
ISO classification (ISO 9060:1990)	secondary standard pyranometer
WMO performance level (WMO-No. 8, seventh edition 2008)	high quality pyranometer
<b>LIST OF CLASSIFICATION CRITERIA OF ISO 9060*</b>	
Response time (95 %)	3 s
Zero offset a (response to 200 $W/m^2$ net thermal radiation)	
- in standard operating mode	< 2 $W/m^2$
- in medium power mode	< 2 $W/m^2$
- in low power mode	< 5 $W/m^2$
Zero offset b (response to 5 K/h change in ambient temperature)	< $\pm 2 W/m^2$
Zero offset c (total zero offset)	zero offset a + zero offset b + 1 $W/m^2$
- in standard operating mode	< 5 $W/m^2$
- in medium power mode	< 5 $W/m^2$
- in low power mode	< 8 $W/m^2$
Non-stability	< $\pm 0.5$ % change per year
Non-linearity	< $\pm 0.2$ % (100 to 1000 $W/m^2$ )
Directional response	< $\pm 10 W/m^2$
Directional response test of individual instrument	report included for 0 to 95° angle of incidence
Spectral selectivity	< $\pm 3$ % ((0.35 to 1.5) $\times 10^{-6}$ m)
Clear sky global irradiance spectral error	< $\pm 0.5$ %
Temperature response	< $\pm 0.4$ % (-30 to +50 °C)
Temperature response test of individual instrument	report included
Tilt response	< $\pm 0.2$ % (0 to 90 ° at 1000 $W/m^2$ )
Additional signal processing error	none (signal processing errors are included in other specifications)
<b>IEC 61724-1:2017 COMPLIANCE</b>	
IEC 61724-1:2017 compliance	meets Class A and B PV monitoring system requirements

\*For the exact definition of pyranometer ISO 9060 specifications see the appendix.

**Table 3.1.1** Specifications of DPA953.1 (continued on next pages)

NOTICE	
<b>This manual supports model DPA953.1, the successor of DPA953. Need support for the discontinued DPA953? Please refer to its separate manual.</b>	
DPA953.1 ADDITIONAL SPECIFICATIONS	
Spectral range (20 % transmission points)	(285 to 3000) x 10 <sup>-9</sup> m
Field of view angle	180 °
Technology employed	Recirculating Ventilation and Heating (RVH™)
Heating	included
Ventilation	included
Standard operating mode	heater and ventilator [ON]
Max. power consumption	< 3.0 W at 12 VDC
Output definition	running average over 4 measurements, refreshed every 0.1 s
Recommended data request interval	1 s, storing 60 s averages
Measurement range	-400 to 4000 W/m <sup>2</sup>
Zero offset steady state	< ± 1 W/m <sup>2</sup> (-40 to + 80 °C)
<b>Measurand</b>	hemispherical solar radiation
Measurand in SI radiometry units	irradiance in W/m <sup>2</sup>
Irradiance resolution	0.05 W/m <sup>2</sup>
Uncertainty of the measurement	statements about the overall measurement uncertainty can only be made on an individual basis. see the chapter on uncertainty evaluation
WMO estimate on achievable accuracy for daily sums (see appendix for a definition of the measurement conditions)	2 %
WMO estimate on achievable accuracy for hourly sums (see appendix for a definition of the measurement conditions)	3 %
<b>Optional measurand</b>	sunshine duration
Measurement function / optional programming for sunshine duration	programming according to WMO guide paragraph 8.2.2
<b>Measurand</b>	sensor body temperature
Sensor temperature measurement uncertainty	± 0.5 °C
Sensor temperature resolution	7.8 x 10 <sup>-3</sup> °C
<b>Measurand</b>	sensor tilt angle
Tilt measurement uncertainty	± 1 ° (0 to 90 °)
Tilt measurement range	0 to 180 °

**Table 3.1.1 Specifications of DPA953.1 (started on previous pages)**

Tilt sensor detection limit	< 0.1 ° (smallest meaningfully detectable change in a time interval of < 10 min)
Tilt sensor characterisation of individual instrument	report included
Levelling (see options)	bubble level and adjustable levelling feet are included
Levelling accuracy	< 0.1 ° bubble entirely in ring
Instrument tilt measurement uncertainty	± 1 ° (0 to 90 °)
<b>Measurand</b>	sensor internal relative humidity
Humidity sensor accuracy	± 3 % RH (for RH between 0 and 80 %)
Humidity sensor hysteresis	± 1 % RH
<b>Measurand</b>	sensor internal pressure
sensor uncertainty	± 4 mbar
<b>Measurand</b>	heater current
<b>Measurand</b>	ventilator current
<b>Measurand</b>	ventilator speed in RPM
Standards governing use of the instrument	IEC 61724-1; Photovoltaic system performance monitoring – guidelines for measurement, data exchange and analysis ISO/TR 9901:1990 Solar energy -- Field pyranometers -- Recommended practice for use ASTM G183 - 15 Standard Practice for Field Use of Pyranometers, Pyrhemimeters and UV Radiometers
<b>MECHANICAL</b>	
Chassis connector	M12-A male connector, 5-pole
Mounting (see options)	2 x M5 bolt at 46 mm centre-to-centre distance on north-south axis, requires 4 mm hex key 1x M6 bolt, centered
Desiccant	two bags of silica gel, 2 x 1 g
Desiccant replacement	< 5 year interval, typically replaced during calibration, ask the manufacturer for instructions
Ventilator replacement	< 5 year interval, ask the manufacturer for instructions
Body material	anodised aluminium
Dome material	optical glass, N-BK7
Gross weight including 5 m cable	approx. 1 kg
Net weight including 5 m cable	approx. 0.5 kg
<b>ENVIRONMENT</b>	
Rated operating temperature range	-40 to +80 °C
IP protection class	IP67
<b>HEATING AND VENTILATION</b>	
Heater voltage	5 V (independent of supply voltage)
Rated heater current range	0.250 to 0.375 A
Nominal heater resistance	17 Ω
Nominal heater power	1.5 W
Rated ventilator speed	5000 to 10 000 RPM (uncontrolled)

**Table 3.1.1 Specifications of DPA953.1 (started on previous pages)**

<b>STANDARD OPERATING MODE</b>	
Operating mode	heater [ON] and ventilator [ON]
Zero offset a	< 2 W/m <sup>2</sup>
Supply voltage range	8 to 30 VDC
Power consumption	< 3.0 W at 12 VDC
<b>MEDIUM POWER OPERATING MODE</b>	
Operating mode	heater [OFF] and ventilator [ON]
Zero offset a	2 W/m <sup>2</sup>
Supply voltage range	8 to 30 VDC
Power consumption	< 0.65 W at 12 VDC
<b>LOW POWER OPERATING MODE</b>	
Operating mode	heater [OFF] and ventilator [OFF]
Zero offset a	5 W/m <sup>2</sup>
Supply voltage range	5 to 30 VDC
Power consumption	< 0.1 W at 12 VDC
<b>CALIBRATION</b>	
Calibration traceability	to WRR
Calibration hierarchy	from WRR through ISO 9846 and ISO 9847, applying a correction to reference conditions
Calibration method	indoor calibration according to ISO 9847, Type Iic
Calibration uncertainty	< 1.2 % (k = 2)
Calibration certificate	LSI Lastem issues calibration certificates with content limited as per ISO/IEC 17025-7.8.1.3. Such a certificate contains the calibration result, an uncertainty, a description of the calibration procedure and the traceability. As an option, a certificate including name and contact information of the customer may be ordered
Recommended recalibration interval	2 years
Reference conditions	20 °C, normal incidence solar radiation, horizontal mounting, irradiance level 1000 W/m <sup>2</sup> , heater and ventilator [ON]
Validity of calibration	based on experience the instrument sensitivity will not change during storage. During use under exposure to solar radiation the instrument "non-stability" specification is applicable.
Adjustment after re-calibration	sensitivity adjustment and writing the calibration history data via a PC using the LSI Lastem Sensor Manager software. Please refer to the LSI Lastem Sensor Manager manual for instructions.
<b>DIGITAL COMMUNICATION</b>	
Digital output	irradiance in W/m <sup>2</sup> instrument body temperature in °C instrument internal humidity in % instrument internal pressure in Pa instrument tilt angle in ° ventilator speed in RPM ventilator current in A heater current in A
Hardware interface	2-wire (half-duplex) RS-485



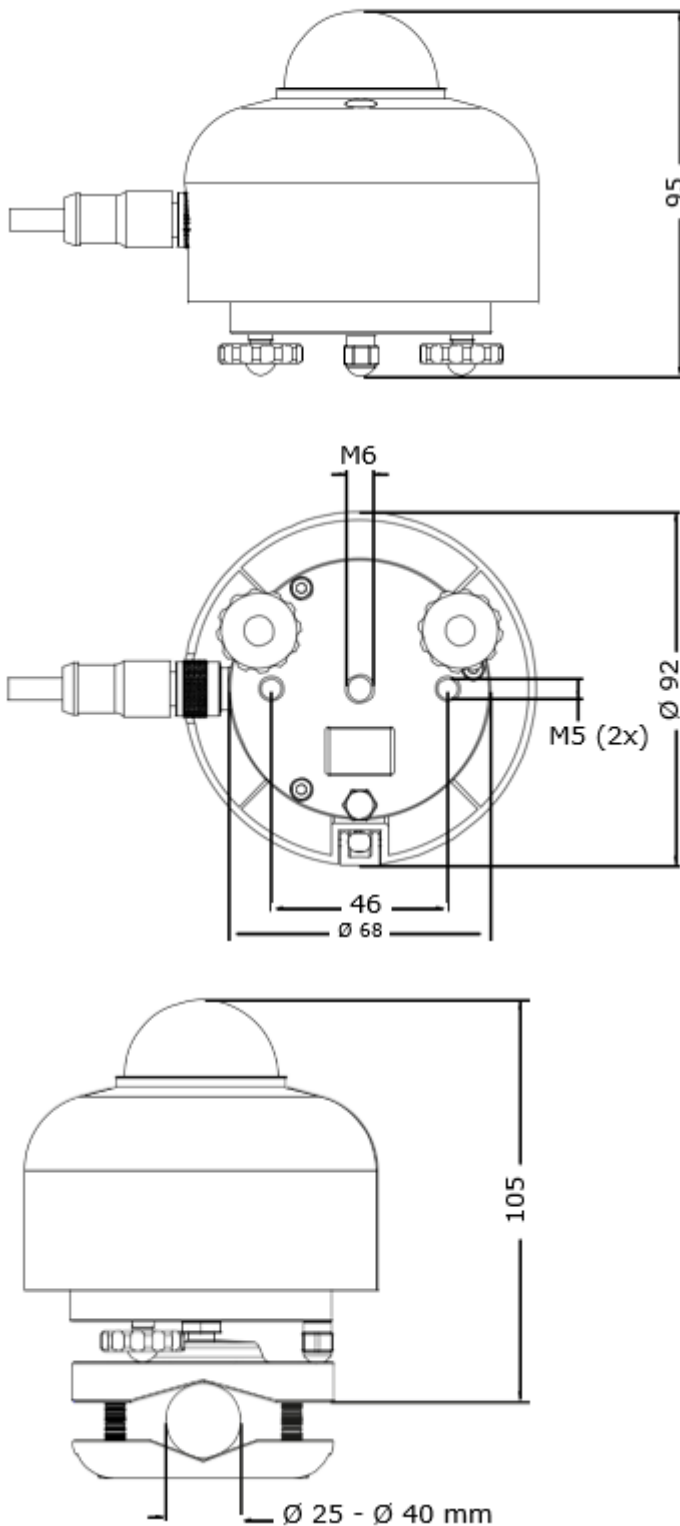
**Table 3.1.1** Specifications of DPA953.1 (started on previous pages)

Communication protocol	Modbus
Transmission mode	RTU
BAUD rate settings	9600, 19200, 38400, 115200
Data bits	Eight
Parity bits	None, even, odd
Stop bits	One
Default serial settings	19200 bits/s, eight data bits, even parity, one stop bit (19200 8E1)
Default device address	1
RS-485 common mode range	$\pm 25$ V
<b>INTERNAL PROTECTION MEASURES</b>	
Power supply surge protection (VDC[+] to VDC[-])	TVS diodes
Power supply TVS surge protection stand-off voltage	+ 30 V
Power supply TVS surge protection peak pulse power capability	600 W
Power supply reverse polarity protection	included
RS-485 surge protection ([data+]/[data-] to signal ground)	TVS diodes
RS-485 TVS surge protection standoff voltage	$\pm 24$ V
RS-485 TVS surge protection peak pulse power capability	350 W
Pyranometer body DC isolation voltage (instrument body to signal ground, $V_{iso}$ )	400 V
<b>CABLE REQUIREMENTS</b>	
Recommended cable length	$\leq 5$ m
Maximum cable length	20 m
<b>CABLE SPECIFICATIONS</b>	
Standard cable length (see options)	5 m
Standard cable conductors	5 $\times$ 24 AWG
Cable diameter	$4.8 \times 10^{-3}$ m
Cable connector	M12-A straight female connector, 5-pole
Connector protection class	IP67
Cable termination	removed sheath over 0.15 m; stranded copper conductors with plastic insulators, stripped ends with ferrules
Cable replacement	replacement cables with connector can be ordered separately from LSI Lastem

**Table 3.1.1** Specifications of DPA953.1 (started on previous pages)

<b>OPTIONS</b>	
Longer cable: 10 or 20 metre length Cable with M12-A female connector on one end and stripped on other end (conductors stripped over 0.15 m with ferrules)	option code = total cable length
Cable with connector pair, 20 m length Cable with male and female M12-A connectors	option code = C07E-20 for 20 metres
calibration certificate including name and contact information of the customer	
<b>ACCESSORIES</b>	
Levelling mount, for spring-loaded levelling and mounting DPA953.1 on a surface	mountable on flat surface allowing tilt adjustment to 3.4 ° requires 4 mm hex key or 10 mm spanner for connecting to DPA953 requires two M5 bolts and hex key for mounting to a surface (not included) 2 x M5 at $46 \times 10^{-3}$ m centre to centre distance option code = LM01
Tube levelling mount, for spring-loaded levelling and mounting DPA953.1 on a tube	mountable on tubes $\varnothing$ 25 to $\varnothing$ 40 mm one spring-loaded levelling mount, one clamp for tube mounting and two sets of bolts (two M5x30 and two M5x45) included allowing tilt adjustment to 3.4 ° requires 4 mm hex key for mounting and 4 mm hex key or 10 mm spanner for connecting to DPA953.1 option code = TLM01
Other mounting options	PMF series mounting fixtures

### 3.2 Dimensions of DPA953.1



**Figure 3.2.1** Dimensions of DPA953.1 in  $\times 10^{-3}$  m. Mounts are optional

## 4 Standards and recommended practices for use

Pyranometers are classified according to the ISO 9060 standard and the WMO-No. 8 Guide. In any application the instrument should be used in accordance with the recommended practices of ISO, IEC, WMO and / or ASTM.

### 4.1 Classification standards

**Table 4.1.1** Standards for pyranometer classification. See the appendix for definitions of pyranometer specifications, and a table listing the specification limits.

STANDARDS FOR INSTRUMENT CLASSIFICATION		
ISO STANDARD	EQUIVALENT ASTM STANDARD	WMO
ISO 9060:2018 Solar energy -- specification and classification of instruments for measuring hemispherical solar and direct solar radiation	Not available	WMO-No. 8; Guide to Meteorological Instruments and Methods of Observation, chapter 7, measurement of radiation, 7.3 measurement of global and diffuse solar radiation

### 4.2 General use for solar radiation measurement

**Table 4.2.1** Standards with recommendations for instrument use in solar radiation measurement.

STANDARDS FOR INSTRUMENT USE FOR HEMISPHERICAL SOLAR RADIATION		
ISO STANDARD	EQUIVALENT ASTM STANDARD	WMO
ISO/TR 9901:1990 Solar energy -- Field pyranometers -- Recommended practice for use	ASTM G183 - 15 Standard Practice for Field Use of Pyranometers, Pyrheliometers and UV Radiometers	WMO-No. 8; Guide to Meteorological Instruments and Methods of Observation, chapter 7, measurement of radiation, 7.3 measurement of global and diffuse solar radiation

### 4.3 Specific use for outdoor PV system performance testing

Pyranometers are used for monitoring PV power plant efficiency, in order to measure incoming solar radiation independently from the PV system. Pyranometers can be placed in two positions:

- Plane of Array (POA), parallel to the PV panels, for measurement of the in-plane irradiance (also noted as  $G_i$  in IEC 61724-1)
- horizontally, for measurement of the global horizontal irradiance (E, also noted as GHI in IEC 61724-1)

**Table 4.3.1** Standards with recommendations for instrument use in PV system performance testing

STANDARDS ON PV SYSTEM PERFORMANCE TESTING	
IEC / ISO STANDARD	EQUIVALENT ASTM STANDARD
IEC 61724-1; Photovoltaic system performance monitoring – guidelines for measurement, data exchange and analysis DPA953.1 complies, in its standard configuration, with the IEC 61724-1:2017 requirements of Class A and Class B PV monitoring systems  COMMENT: Allows pyranometers or reference cells according to IEC 60904-2 and -6. Pyranometer reading required accuracy better than 5 % of reading (Par 4.1)  COMMENT: equals JISC 8906 (Japanese Industrial Standards Committee)	ASTM E2848-13; Standard Test Method for Reporting Photovoltaic Non-Concentrator System Performance  COMMENT: confirms that a pyranometer is the preferred instrument for outdoor PV testing. Specifically recommends a “first class” (now spectrally flat class B in ISO 9060:2018) pyranometer (paragraph A 1.2.1.)

### 4.4 Specific use in meteorology and climatology

The World Meteorological Organization (WMO) is a specialised agency of the United Nations. It is the UN system's authoritative voice on the state and behaviour of the earth's atmosphere and climate. WMO publishes WMO-No. 8; Guide to Meteorological Instruments and Methods of Observation, in which a table is included on “level of performance” of pyranometers. Nowadays WMO conforms itself to the ISO classification system.

In case there is no danger of deposition of dew and frost, the medium power mode (using the ventilator but not the heater) offers the most accurate measurements over short time intervals. Averages on the minute time scale produce the same result as in the standard operating mode. The measurement is less sensitive to rapid changes of the instrument temperature (thermal shock) resulting in less noise on the irradiance reading.

## 4.5 General use for sunshine duration measurement

According to the World Meteorological Organization (WMO, 2003), sunshine duration during a given period is defined as the sum of that sub-period for which the direct solar irradiance exceeds  $120 \text{ W/m}^2$ . WMO has approved the “pyranometric method” to estimate sunshine duration from pyranometer measurements (*Guide to Meteorological Instruments and Methods of Observation, Part I: Measurement of Meteorological Variables*; WMO-No.8; 2008; chapter 8). This implies that a pyranometer may be used, in combination with appropriate software, to estimate sunshine duration. Ask for our application note.

**Table 4.5.1** Standards with recommendations for instrument use in sunshine duration measurement

---

<b>STANDARDS FOR INSTRUMENT USE FOR SUNSHINE DURATION</b>
WMO <i>Guide to Meteorological Instruments and Methods of Observation, Part I: Measurement of Meteorological Variables</i> ; WMO-No. 8; 2008; chapter 8, measurement of sunshine duration, section 8.2.2 Pyranometric Method

---

## 5 Installation of DPA953.1

### 5.1 Site selection and mechanical installation

**Table 6.1.1** Recommendations for installation of pyranometers (continued on next page)

Location	the horizon should be as free from obstacles as possible. Ideally, there should be no objects between the course of the sun and the instrument.
Mechanical mounting / thermal insulation	preferably, use the optional spring-loaded levelling mount for mounting to a flat surface, or use the optional tube mount.  if not using the optional tube mount, use connection by bolts to the bottom plate of the instrument. A pyranometer is sensitive to thermal shocks, i.e. rapid changes of the sensor body temperature. Do not mount the instrument with the body in direct thermal contact to the mounting plate (so always use the levelling feet also if the mounting is not horizontal), do not mount the instrument on objects that become very hot (black coated metal plates).
Instrument mounting with 2 bolts (without optional levelling mount)	2 x M5 bolt at $46 \times 10^{-3}$ m centre to centre distance on north-south axis, connection from below under the bottom plate of the instrument.
Instrument mounting with one bolt (without optional levelling mount)	1 x M6 bolt at the centre of the instrument, connection from below under the bottom plate of the instrument.
Performing a representative measurement	the pyranometer measures the solar radiation in the plane of the sensor. Some measurements require the pyranometer to be installed in a tilted or inverted position. The sensor bottom plate is parallel to the black sensor surface and should be mounted parallel to the plane of interest. In case a pyranometer is not mounted horizontally or in case the horizon is obstructed, the representativeness of the location becomes an important element of the measurement. See the chapter on uncertainty evaluation.
Levelling	in case of horizontal mounting, use the bubble level and levelling feet. after levelling horizontally (using the bubble level) immediately store the tilt sensor output, and use this value as the reference for monitoring both short-term and long-term changes.

**Table 6.1.1** Recommendations for installation of pyranometers (started on previous page)

Cable lengths	Do not directly connect cables longer than 20 meters to DPA953.1. Whenever connection to a longer cable is required, connect the instrument to that cable through a suitable isolated interface (i.e. power and signal isolation, e.g. through an isolated DC-DC converter and an optically isolated RS-485 interface).
Cable ducts	Use grounded metal cable ducts whenever possible, however, do not run the cabling in a cable duct with high-power or noise emitting cabling. If possible, use a signal cable duct.
Electrical design, grounding of the body and cable shield	Mechanical installation cannot be separated from electrical installation; pay special attention to electrically grounding the body and cable shield of the instrument, see next sections.
Tilted installation	in most cases, for tilted installation, the tilt sensor provides a sufficiently accurate measurement. The register “tilt angle” can be used for verification of the tilt angle.
Instrument orientation	<p>When installing in a horizontal orientation, by convention: with the cable exit pointing to the nearest pole, so the cable exit should point north in the northern hemisphere, south in the southern hemisphere.</p> <p>When installing in a tilted orientation; keep the connector pointing down to minimise humidity ingress.</p>
Installation height	in case of inverted installation, WMO recommends an installation height above the surface between 1 and 2 m, reducing the effect of shadows and in order to obtain good spatial averaging (see also: <i>Guide to Instruments and Methods of Observation: Volume I: Measurement of Meteorological Variables</i> ; WMO No.8; 2018 edition; Section 7.3.3.4; p.266)



## 5.2 Installation of the sun screen

The quick release system of DPA953.1's sun screen allows for easy and secure mounting and removal of the sun screen on the sensor. DPA953.1's bubble level can be inspected at all times, even with the sun screen installed: a small window allows to see the bubble level. Installation and removal of the connector can be done after removal of the sun screen.

The quick release system consists of a spring loaded lever opposite the bubble level window of the DPA953.1 sun screen. The bottom of the handle can be pulled out gently. Once the handle is pulled out and fully released, as shown in the figure below, the sun screen can be lifted off manually for removal. Installing the sun screen is easy too: pull out the bottom of the quick release system handle so it is fully released, place the screen on DPA953.1 and, once it is positioned properly, press the handle of the quick release system until it is locked.



**Figure 6.2.1** DPA953.1's sun screen with its quick release system and bubble level window



**Figure 6.2.2** Installation of DPA953.1's sun screen

## 5.3 Installation of optional mounts

### 5.3.1 Levelling mount

The optional levelling mount, for simplified mounting and levelling of DPA953.1 on a flat surface such as a platform or bracket, is easy to use. It can be fitted to DPA953.1 using the mount's spring-loaded centre bolt and a 4 mm hex key or a 10 mm spanner. It can be mounted on a flat surface by inserting two M5 bolts (not included) in the designated holes.



**Figure 6.3.1.1** *Optional spring-loaded levelling mount for DPA953.1*

The preferred way to connect the mount to DPA953.1 and lock its connection, is by using a 4 mm hex key via the bottom part of the levelling mount (see Figure 5.3.1.2). If the bottom part is not accessible, the connection between DPA953.1 and the mount can be made by using a 10 mm spanner (see Figure 5.3.1.3). The spanner may be used as well to lock, or unlock, when DPA953.1 is already fitted to the mount (See Figure 5.3.1.4). In all cases, ensure the legs of DPA953.1 fit into one of the small ledges of the levelling mount. Locking is in place, when the nut of the spring-loaded centre bolt is turned all the way towards DPA953.1's bottom panel.



**Figure 6.3.1.2** *bottom of DPA953.1 levelling mount. Preferred (un)locking with 4 mm hex key*



**Figure 6.3.1.3** DPA953.1 levelling mount seen from above: (un)locking with a 10 mm spanner



**Figure 6.3.1.4** DPA953.1 levelling mount seen from the side: (un)locking with a 10 mm spanner

The levelling mount is spring-loaded. Once DPA953.1 is connected and locked to the levelling mount, DPA953.1 can be levelled by the user, judging the bubble level. Levelling is done by fastening or loosening DPA953.1's two adjustable levelling feet by hand. DPA953.1's static foot remains fixed. Fasten or loosen both legs so that the instrument is level, judging by the bubble level.



**Figure 5.3.1.5** DPA953.1 locked on its optional levelling mount: by fastening (on the left) or loosening (on the right) DPA953.1's two adjustable feet, DPA953.1 can be levelled, judging by the bubble level. DPA953.1's static foot remains fixed. In all cases, ensure the legs of DPA953.1 fit into one of the small ledges of the levelling mount. Locking is in place, when the nut is turned all the way against the bottom plate of DPA953.1

### 5.3.2 Tube levelling mount

DPA953.1 may also be mounted on a tube or a mounting rod using DPA953.1's optional tube mount.



**Figure 6.3.2.1** DPA953.1 mounted with its optional tube levelling mount on a tube

The tube mount option includes the levelling mount, described in the previous paragraph, a lower clamp for tube mounting and two sets of bolts for tube diameters 25 to 40 mm (tube not included). Installation requires a 4 mm hex key.



**Figure 6.3.2.2** Optional tube levelling mount; installation requires a 4 mm hex key

## 5.4 Electrical installation

For reliable operation it is important to follow the installation instructions and recommendation in this section carefully.

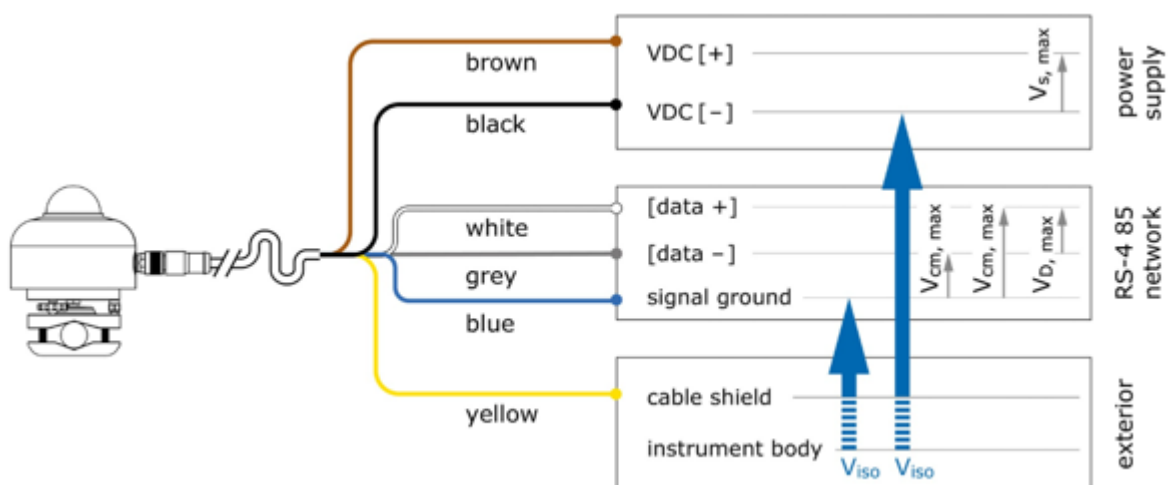
The wiring of DPA953.1 is explained in Figures 5.4.1 and 5.4.2 and Table 5.4.1. On a coarse level DPA953.1 can be viewed as having three electrical ports: a DC power port, a signal port and an enclosure port. The DC power port consists of the VDC [+] and VDC [-] connections used to power the instrument. The signal port consists of the RS-485 [data+], [data-] and signal ground connections used for communication with the sensor. The enclosure port consists of the sensor body and the cable shield connection. An installation that is robust to electromagnetic interference aims to electrically isolate two of these three ports. In addition, refer to Appendix 10.12 for a list of all EMC testing performed.

A cable shield protects the conductors from electromagnetic interference and provides an electrical connection to the instrument body. The instrument body is made of aluminium and is electrically conducting. By mounting the instrument on a grounded conducting platform, the instrument can be grounded. Since the shield is connected to the body, this also means that the shield is connected to the same ground. The instrument should preferably be grounded at a single reference point. For more details please refer to the sections on “Internal protection” and “Electrical isolation, grounding and shield connection”.

Internally the instrument electronics are isolated from the body and the shield. To reduce the effect of electrical interference on the sensor signal the electronics is capacitively attached to the body. This capacitive coupling limits the maximum rated isolation voltage between the electronics and the body, or, equivalently, between the cable shield and the power supply and RS-485 wiring. The rated maximum isolation voltage is listed in the “Specifications” chapter.

The instrument must be powered by an external power supply that provides an operating voltage in the specified range and that can source sufficient current to power the instrument.

To communicate with the instrument, the instrument must be connected to an RS-485 network. The connection consists of two differential signal wires (white and grey) and a signal ground wire (blue). See the “Connecting to an RS-485 network” section for more details on how to setup an RS-485 network.

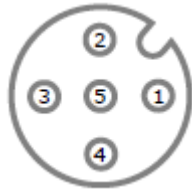


**Figure 5.4.1** Electrical connections of DPA953.1

**Table 6.5.1** Cable and connector connections of DPA953.1

PIN*	WIRE	DPA953.1
1	Brown	VDC [+]
4	Black	VDC [-]
3	Blue	RS-485 signal ground
2	White	RS-485 [data+], B' or B
5	Grey	RS-485 [data-], A' or A
-	Yellow	cable shield / body

\*Numbering as indicated in Figure 5.4.2



**Figure 6.5.1:** Connector layout of DPA953.1, indicating the PIN numbers (viewed from cable side)

## 5.1 Internal protection

DPA953.1 electronics are internally protected to improve reliability and reduce the risk of damage. See the Specifications chapter for the full list of protection levels. The following protection measures are in place on the power supply wiring:

- overvoltage protection
- reverse polarity protection
- surge protection (against voltage spikes)

and on the RS-485 signal wiring:

- overvoltage protection
- extended common mode range ( $V_{cm, max}$ , with respect to the RS-485 specification)
- surge protection (against voltage spikes)

### NOTICE

**The RS-485 interface is not internally isolated from the power supply. Voltage levels must not exceed the rated voltage to avoid damage.**

Internally the instrument body is capacitively coupled to the instrument electronics to reduce noise on the measurement signal. Please refer to the Specification chapter for the maximum rated DC isolation voltage between the instrument body and the instrument electronics ( $V_{iso}$ ).

## 5.2 Connecting to an RS-485 network

DPA953.1 has an RS-485 hardware interface and uses the Modbus RTU protocol to handle the data communication. The RS-485 standard, officially known as TIA/EIA-485, describes the electrical interface (signal levels, timing, etc.) for a data communication system. This section explains how to integrate the DPA953.1 in a RS-485 network, starting with a general overview, followed by installation advice.

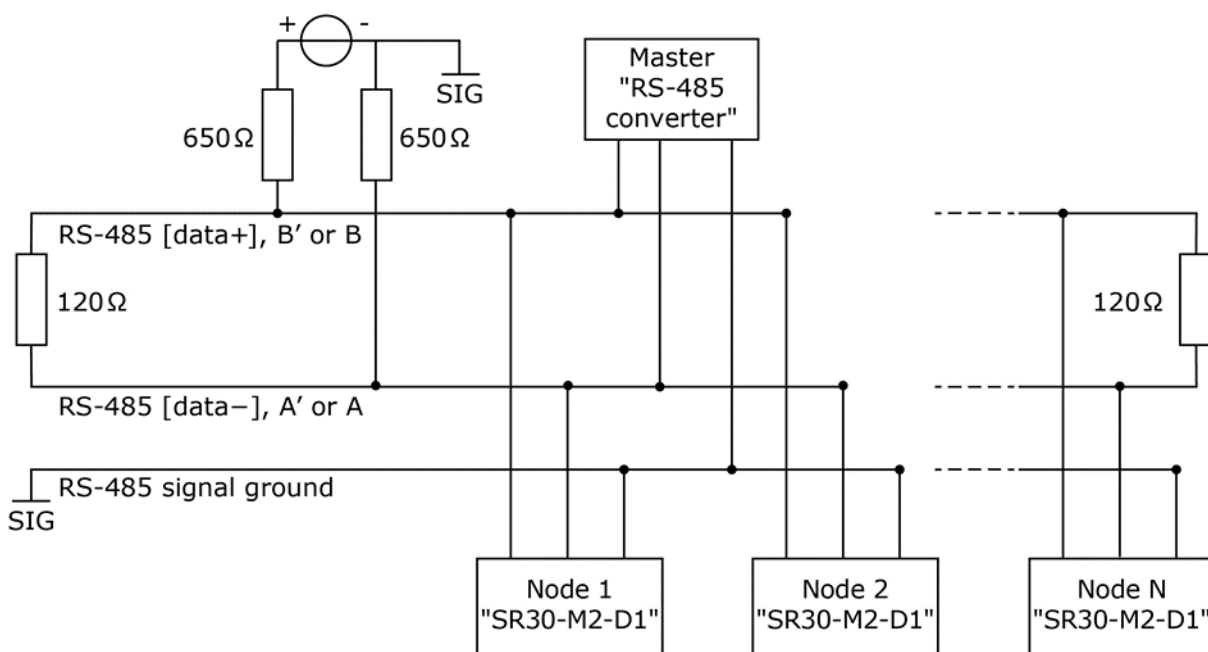
### 5.2.1 RS-485 network

DPA953.1 is designed for use in a two-wire (half-duplex) RS-485 network. In such a network, DPA953.1 acts as a slave device, responding to data requests from the master device. An RS-485 network (or bus), consists of a twisted wire pair for data transmission plus a signal ground wire. The three channels are known as:

- RS-485 [data+], B' or B
- RS-485 [data-], A' or A
- RS-485 signal ground

RS-485 uses differential signalling for data transmission. This means that the logic states are encoded in the electrical potential difference between the [data+] and [data-] lines, whereas on a single-ended interface it would be encoded in the potential of the data line with respect to the signal ground. When designed and installed correctly RS-485 provides a robust reliable communication channel in electrically noisy environments.

An example of the topology of an RS-485 2-wire network is shown in Figure 5.6.1.1. The network has a linear setup with side branches, called stub lines, to the connected devices (nodes) and line termination resistors at each end to reduce the effect of reflecting signals.



**Figure 5.6.1.1** Typical topology of a two-wire (half-duplex) RS-485 network. Figure adapted from: *Modbus over serial line specification and implementation guide v1.02* ([www.modbus.org](http://www.modbus.org)). Neither the power supply nor any isolators that might be required are shown in this figure.

Line termination must be installed at both ends of the bus between the [data+] and

[data-] lines. According to the RS-485 standard, termination resistors have a value of 120  $\Omega$  and no more and no less than two line termination resistors should be installed in a single network. Failure to install line termination resistors may lead to signal reflections which could compromise signal integrity. Placing more than two line termination resistors causes excessive loads on the RS-485 bus which may compromise signal integrity and may lead to damage to equipment.

#### NOTICE

**Line termination is required at both ends of the bus between the [data+] and [data-] lines. Two, and no more and no less than two termination resistors should be placed (see also: *MODBUS over serial line specification and implementation guide v1.02, section 3.4.5, page 27*).**

To minimise noise on the network when no transmission is occurring, a so-called fail-safe biasing circuit can be installed. To do so pull-up and pull-down resistors have to be installed on the [data+] and [data-] lines, respectively. For some devices the use of failsafe biasing is required for the devices to work. Typical values for both resistors are in the range from 650 to 850  $\Omega$ . On the [data+] line this resistor is connected to a +5 VDC supply and on the [data-] line to the signal ground. This will keep the data lines in a welldefined state when none of the connected devices is controlling the bus.

#### NOTICE

**Fail-safe biasing (line polarization) may be required to minimize noise (see also: *MODBUS over serial line specification and implementation guide v1.02, section 3.4.6, page 28*).**

Stub lines in the network should be avoided or kept as short as possible to avoid signal reflection in these un-terminated line elements. The lower the BAUD rate of the serial communication, the longer any stub lines can be without causing problems. Never use stub lines longer than 20 metres.

#### NOTICE

**Do not use stub lines (derivations) longer than 20 metres (see also: *MODBUS over serial line specification and implementation guide v1.02, section 3.4.3, page 27*).**



### 5.3 Electrical isolation, grounding and shield connection

Pyranometers are sensitive equipment. Electrical isolation and grounding need careful consideration when installing and operating DPA953.1. The appropriate choice of electrical isolation and grounding of the pyranometer depends on the local situation. It is the users' responsibility to evaluate their situation and choose the best possible way of isolating and grounding the instrument. Failure to do so may lead to damage to equipment or unreliable operation.

When designing the installation, the following should be taken into account:

- DPA953.1 has limited or no on-board electrical isolation between the instrument power supply (DC power port), signal wiring (signal port) and body (enclosure port)
- the cable shield (yellow wire) is electrically connected to the DPA953.1 body
- the DPA953.1 metal body is anodised. This forms a thin insulating encapsulation of the metal. As a consequence, the instrument may or may not become electrically connected to its mounting platform. Furthermore, corrosion, build-up of debris, etc. may deteriorate the quality of the grounding connection over time. It is important to verify that the instrument is electrically connected to its mounting platform when the application requires this. The user must verify the state of the electrical connection between the instrument and the mounting platform immediately after installation and later on at regular intervals.
- the levelling mount and tube levelling mount are anodised. When mounting DPA953-M2D1 to a mounting platform using the levelling or tube levelling mount the instrument may or may not become electrically connected to its mounting platform. The user must verify the state of the electrical connection between the instrument and the mounting platform through the levelling or tube levelling mount immediately after installation and later on at regular intervals.

#### **⚠ WARNING**

**The DPA953.1 instrument body, levelling mount and tube levelling mount are anodised. When mounting DPA953.1 to a mounting platform the instrument may or may not become electrically connected to that mounting platform. The user must verify the state of the electrical connection.**

#### **⚠ WARNING**

**Grounding or isolation of the instrument may deteriorate over time. Verify grounding or isolation of the instrument according to the installation requirements after installation and set up an inspection and maintenance plan with a regular inspection interval.**

#### 5.3.1 Spatially extended installations (total cable lengths >5 m)

To avoid exposure of the DPA953.1 to large electrical currents or voltages caused by ground potential differences, electrical isolation and grounding is an important point of attention in the installation design. Since there is limited or no on-board electrical isolation between the instrument power supply, signal wiring and body these can be considered to be electrically connected

for grounding purposes. The cable shield is connected to the instrument body through the connector housing. In general, but in particular when DPA953.1 is installed in a spatially extended network (distances between nodes greater than 5 m), it is strongly recommended to use a single point of reference for grounding and other wiring.

Whenever DPA953.1 is installed in a spatially extended network, preferably the instrument body is electrically connected to protective earth by bolting it to a grounded mounting platform, while the instrument is powered from a suitable isolated power supply and connected to the RS-485 network via a suitable optical isolator. The isolated power supply and the optical isolator should be installed within 20 metres from the instrument. In this case the cable shield (yellow wire) should be left disconnected as it is connected to the mounting platform via the sensor body. Do not directly connect cables longer than 20 metres to DPA953.1. If longer cables are required, always electrically isolate the power supply and RS-485 interface.

#### NOTICE

**Do not directly connect cables longer than 20 metres to DPA953.1. If longer cables are required always electrically isolate the instrument from that cable.**

#### NOTICE

**Ground potential differences may compromise reliable operation of the instrument. Take special care of grounding and installation when installing DPA953.1 in spatially extended networks.**

### 5.3.2 Spatially compact installations (total cable lengths $\leq 5$ m)

Preferably, the installation should be designed such that it is spatially compact (total cable lengths/maximum distance between nodes less than 5 m) and the mounting platform is directly connected to the pyranometer. In that case it is recommended to install the pyranometer, the power supply and the RS-485 interface on a single dedicated mounting platform and use this platform to ground all components. Use cable ties or an electrically conductive, grounded cable duct to fix the cable to the mast in order to minimize the impact of electromagnetic disturbances. An example is a point-to-point network where a single DPA953.1 is directly connected to a data-logger using the standard 5 m cable supplied with the pyranometer, with no other nodes on the network.

## 5.4 Cabling requirements

Whenever using cables longer than 5 metres are used, e.g. 10 metres or 20 metres cables, an isolated interface (power and signal isolation) must be used at the end of the cable.

Do not directly connect cables longer than 20 metres to DPA953.1. Whenever connection to a longer cable is required, connect the instrument to that cable through a suitable isolated interface (i.e. power and signal isolation, e.g. through an isolated DC-DC converter and an optical isolator).

Preferably use short cables with a length of 5 m or less. When extending cables is unavoidable the following must be considered:

- The wire gauge (AWG) of the power wires, the corresponding electrical resistance of those wires and the resulting voltage drop. If the voltage drop is too large proper sensor operation may be impaired.
- The use of longer cables results in more pick-up and thus more noise on the RS-485 network, which can cause communication to fail. To reduce this effect, use well shielded cables with twisted wire pairs.
- Ground potential differences must be considered. Refer to Section 5.7 for more information on grounding.

Cables must be suitable for outdoor use.

## 5.5 Connecting to a PC

DPA953.1 can be accessed and controlled using a Personal Computer (PC). In this case communication with the sensor is most easily done through the user interface supplied with the instrument: the LSI Lastem Sensor Manager software. Alternatively, third-party software which supports the Modbus RTU protocol can be used.

The easiest way to connect to the RS-485 interface is to use a USB-to-RS-485 converter. On MS Windows these converters are usually auto-configured and a virtual serial port becomes available on the system. This port can be used by the controlling software to communicate with the instrument. Two recommended RS-485 converter models to use with DPA953.1 are:

- Advantech, Adam-4561, 1-port Isolated USB to RS-232/422/485 Converter
- Moxa, UPort 1150I, 1-port RS-232/422/485 USB-to-serial converters with optical isolation protection

### NOTICE

**When using the popular RS-485 converter solutions manufactured by the FTDI company, e.g. model USB-RS485-WE-1800-BT using the FT232R chipset, please use so-called fail-safe biasing resistors as the idle state of these converters is undefined and is likely to cause communication problems.**

## 6 Communication with DPA953.1

### 6.1 Network communication: getting started

Once the desired device address and serial communication settings have been set, DPA953.1 can be connected to an RS-485 network and a power supply (see Chapter 5). Installing an DPA953.1 in an RS-485 network also requires configuring the Modbus communication for this new Modbus RTU device. This usually consists of defining one or more requests that can be broadcast by the master. To read the irradiance the Modbus registers holding the temperature compensated irradiance (register address 0x0002 and 0x0003) must be read. See Table 6.2.1.

**Table 6.2.1:** Key registers for making a measurement

MODBUS REGISTERS				
REGISTER ADDRESS	PARAMETER	DESCRIPTION OF CONTENT	ACCESS	FORMAT OF DATA
2 + 3	Irradiance (temperature compensated signal)	Temperature compensated signal in $\times 0.01 \text{ W/m}^2$	R	S32

For diagnostic purposes the Modbus registers containing the sensor body temperature, tilt angle, internal relative humidity, heater (electrical) current, ventilator (electrical) current and ventilator speed can be read, see Table 6.2.2. For more details on how to use these diagnostic values, please refer to Chapter 7.

**Table 6.2.2:** Key registers for sensor diagnostics

MODBUS REGISTERS				
REGISTER ADDRESS	PARAMETER	DESCRIPTION OF CONTENT	ACCESS	FORMAT OF DATA
6	Sensor body temperature	In $\times 0.01 \text{ }^\circ\text{C}$	R	S16
98	Humidity	In $\times 0.01 \text{ } \%$	R	U16
194	Tilt angle	In $\times 0.01 \text{ }^\circ$	R	U16
196	Fan speed RPM	In $\times 1 \text{ RPM}$	R	U16
198	Heater current	In $\times 1 \text{ mA}$	R	U16
199	Fan current	In $\times 1 \text{ mA}$	R	U16

Typical operation requires the master to request the irradiance data in registers 0x0002 and 0x0003, sensor temperature in register 0x0006, and the sensor serial number in register 0x0040 every 1 second, and store the 60 second averages. The data format of register 0x0002 and 0x0003 combined is a signed 32 bit integer and the temperature in register 0x0006 is a signed 16 bit integer.

A maximum of five 16 bit Modbus registers may be read in a single request. In case six or more registers are read in one request, DPA953.1 will not respond. If the user needs the content of six or more registers, multiple request cycles must be performed.

A complete list of supported Modbus function codes and Modbus registers and coils can be found in Appendix 10.12. For more information about the Modbus protocol please refer to the “Modbus protocol specification” and “Modbus Serial Line Protocol and Implementation Guide” available at [www.modbus.org](http://www.modbus.org).

#### NOTICE

**32 bit parameters located in two 16 bit Modbus registers must be read in a single Modbus request to guarantee coherence of these two registers.**

#### NOTICE

**The sensor does not distinguish between input registers and holding registers, nor does it distinguish between coils and discrete inputs.**

#### NOTICE

**Each device on the RS-485 network should have the same serial communication settings.**

#### NOTICE

**Each Modbus device on the RS-485 network should have a unique device address.**

## 6.2 Changing the device address and serial communication settings

Setting the device address and serial communication settings (BAUD rate and parity) can be done in different ways:

- by connecting the sensor to a PC and using the LSI Lastem Sensor Manager;
- by connecting the sensor to a PC and using another Modbus testing tool. There are links to different solutions available at [www.modbus.org](http://www.modbus.org);
- by using the available network user interface software.

To set the device address and serial communication settings using the LSI Lastem Sensor Manager, see the “LSI Lastem Sensor Manager” manual.

The registers containing the device address and serial communication settings are listed in Table 6.3.1. The serial communication settings are listed in Table 6.3.2.

**Table 6.3.1:** Registers containing the device address and serial communication settings.

### MODBUS REGISTERS

REGISTER ADDRESS	PARAMETER	DESCRIPTION OF CONTENT	ACCESS	FORMAT OF DATA
0	Device address	Sensor address in Modbus network, default = 1	R/W	U16
1	Serial communication settings	Sets the serial communication, see table 6.3.2, default = 5	R/W	U16

**Table 6.3.2:** Specification of the serial communication settings in register 0x0001

<b>SERIAL COMMUNICATION SETTINGS</b>				
SETTING NUMBER	BAUD RATE	DATABITS	STOPBITS	PARITY
1	9600	8	1	none
2	9600	8	1	even
3	9600	8	1	odd
4	19200	8	1	none
5 (= default)	19200	8	1	even
6	19200	8	1	odd
7	38400	8	1	none
8	38400	8	1	even
9	38400	8	1	odd
10	115200	8	1	none
11	115200	8	1	even
12	115200	8	1	odd

## 7 Use of remote diagnostics

Remote monitoring of the sensor condition helps improve the accuracy and reliability of the measurement. It also allows to improve preventive maintenance and effective trouble shooting. The following remote diagnostics signals are part of the digital output. It is up to the user whether or not to use these diagnostics.

Chapter 6 contains details on the register structure, needed for reading the remote diagnostics output.

### 7.1 Recommendations

For remote diagnostics, we recommend to:

- measure and store internal sensor humidity, ventilator speed, ventilator current, heater current and tilt angle at 24:00 local time.
- monitor short term changes of the sensor tilt, and generate a warning in case of changes  $> 0.2^\circ / \text{min}$ , after levelling horizontally (using the bubble level) or at a tilt (using the tilt sensor), immediately store the tilt sensor output, and use this value as the reference for monitoring both short-term and long-term changes.
- monitor long-term changes of the sensor tilt, and generate a warning in case of changes  $> 1^\circ$  from the stored value.
- check the sensor temperature against the dewpoint or ambient temperature. The sensor temperature should normally be higher than the ambient temperature and dewpoint. Whenever the sensor body temperature is below the dewpoint, water condensation may form on the outside of the pyranometer, including the outer dome, which can affect the irradiance measurement.
- monitor internal humidity trends on a yearly scale, using nighttime values only, and generate a warning if the relative humidity is consistently  $> 50\%$  at body temperatures  $< 20^\circ\text{C}$ .
- monitor ventilator speed and generate a warning if the speed is below 5000 RPM.
- monitor heater current and generate a warning if the current is below 1.0 A.

### 7.2 Sensor body temperature

DPA953.1's low temperature dependence and wide rated operating temperature range makes it ideal for use under a broad range of temperatures from very cold to very hot conditions. Measurement of the sensors' temperature is done using a digital sensor temperature sensor. The sensor signal serves to externally monitor the DPA953.1 temperature and, at the same time, is used by the internal electronics for temperature correction of the measurands. The temperature dependence of the irradiance signal of every individual instrument is tested. Temperature correction of the irradiance signal is programmed into each sensor and is taken care of fully automatically by the internal electronics. The remaining very small deviation from ideal behaviour is shown on the test certificate. In combination with a dewpoint measurement, the temperature measurement can also be used to check that the sensor remains above dewpoint. Whenever the sensor body temperature is below the dewpoint, water condensation on the outside of the pyranometer should be expected and irradiance data may have to be discarded. When operating



DPA953.1 in standard operating mode (heater [ON] and ventilator [ON]) this should not normally occur. When operating DPA953.1 in low or medium power operating mode, water condensation can occur.

### 7.3 Tilt angle

To allow remote monitoring of the instrument tilt and to assist in the tilted installation of the instrument, the DPA953.1 features a digital tilt sensor. The tilt sensor measures the gravitational acceleration on three axes and calculates the corresponding zenith tilt angle of the pyranometer. For an accurate, absolute measurement of the tilt angle with respect to horizontal, the sensor is factory-calibrated relative to the bubble level and using an independent tilt measurement. Temperature correction coefficients of the tilt measurement are programmed during production and provided for each individual sensor on the product certificate. The tilt sensor has an absolute accuracy of  $\pm 1^\circ$  between  $0^\circ$  and  $90^\circ$  tilt angle. This accuracy is sufficient for use in PV performance monitoring and installation in Plane of Array.

### 7.4 Internal relative humidity

When the DPA953.1 accumulates too much moisture, the internals of the sensor will get damaged. Therefore, it is advised to take regular measurements of the internal relative humidity of the sensor. These measurements are made available in the "humidity" register. We recommend taking regular measurements of the internal humidity of the sensor. The long-term (yearly) trend in relative humidity will show the slow saturation of the internal desiccant. The desiccant replacement interval is  $< 5$  years. The relative humidity levels in the sensor depend both on the absolute temperature and the level of saturation of the desiccant and the type of desiccant. The desiccant releases absorbed water as a function of temperature and saturation level. Because of these effects, the short-term relative humidity measurement is not a good indicator of the desiccant condition. The relative humidity levels are preferably measured at low temperatures; we recommend to store measurements taken around midnight (24:00 local time) and monitor changes on a yearly basis. The combined accuracy of the relative humidity sensor is approximately 5 % of the reading.

### 7.5 Heater current

The heater current measurement is an indicative, unverified measurement. Using the heater current reading, an estimation of the heater power can be made. Because the voltage across the heating element is 5.0 Volt, the heater power is given by:

$$P_{\text{heater}} [\text{W}] = 5.0 [\text{V}] \times \text{"heater current"} [\text{A}]$$

Please note that even though the power delivered by the heater is the largest contributor, dissipation by the ventilator and the electronic circuitry also contribute to heating of the sensor.

### 7.6 Ventilator current

The rotation speed of the ventilator can vary significantly with temperature. This variation will also be reflected in the ventilator current. Apart from this, the ventilator current measurement is an unverified measurement. For these reasons the ventilator current reading should only be

used as a binary [ON]/[OFF] indicator, solely to determine the actual ventilator state independently.

## **7.7 Ventilator speed**

The fan speed gives the actual rotation frequency of the fan in RPM (revolutions per minute), irrespective of whether it is switched on or off. The nominal ventilator speed is 7400 RPM at 20 °C. Depending on operating conditions the speed may vary. Especially at temperatures below -10 °C ventilator speed may be significantly lower. When the speed consistently falls below 5000 RPM, maintenance is required, and replacement of the ventilator may be needed. The ventilator replacement interval is < 5 years.

## 8 Making a dependable measurement

### 8.1 The concept of dependability

A measurement with a pyranometer is called “dependable” if it is reliable, i.e. measuring within required uncertainty limits, for most of the time and if problems, once they occur, can be solved quickly.

The requirements for a measurement with a pyranometer may be expressed by the user as:

- required uncertainty of the measurement (see following paragraphs)
- requirements for maintenance and repairs (possibilities for maintenance and repair including effort to be made and processing time)
- a requirement to the expected instrument lifetime (until it is no longer feasible to repair)

It is important to realise that the uncertainty of the measurement is not only determined by the instrument but also by the way it is used.

In case of pyranometers, the measurement uncertainty as obtained during outdoor measurements is a function of:

- the instrument class
- the calibration procedure / uncertainty
- the duration of instrument employment under natural sunlight (involving the instrument stability specification)
- the measurement conditions (such as tilting, ventilation, shading, instrument temperature)
- maintenance (mainly fouling)
- the environmental conditions\*

Therefore, ISO 9060 says, “statements about the overall measurement uncertainty under outdoor conditions can only be made on an individual basis, taking all these factors into account”.

\* defined by LSI Lastem as all factors outside the instrument that are relevant to the measurement such as the cloud cover (presence or absence of direct radiation), sun position, the local horizon (which may be obstructed) or condition of the ground (when tilted). The environmental conditions also involve the question whether or not the measurement at the location of measurement is representative of the quantity that should be measured.

## 8.2 Reliability of the measurement

A measurement is reliable if it measures within required uncertainty limits for most of the time. We distinguish between two causes of unreliability of the measurement:

- related to the reliability of the pyranometer and its design, manufacturing, calibration (hardware reliability).
- related to the reliability of the measurement uncertainty (measurement reliability), which involves hardware reliability as well as condition of use.

Most of the hardware reliability is the responsibility of the instrument manufacturer. The reliability of the measurement however is a joint responsibility of instrument manufacturer and user. As a function of user requirements, taking into account measurement conditions and environmental conditions, the user will select an instrument of a certain class, and define maintenance support procedures.

In many situations there is a limit to a realistically attainable accuracy level. This is due to conditions that are beyond control once the measurement system is in place. Typical limiting conditions are:

- the measurement conditions, for instance when working at extreme temperatures when the instrument temperature is at the extreme limits of the rated temperature range.
- the environmental conditions, for instance when installed at a sub-optimal measurement location with obstacles in the path of the sun.
- other environmental conditions, for instance when assessing PV system performance and the system contains panels at different tilt angles, the pyranometer measurement may not be representative of irradiance received by the entire PV system.

The measurement reliability can be improved by maintenance support. Important aspects are:

- dome fouling by deposition of dust, dew, rain or snow. Fouling results in undefined measurement uncertainty (sensitivity and directional error are no longer defined). This should be solved by regular inspection and cleaning.
- sensor instability. Maximum expected sensor aging is specified per instrument as its non-stability in [% change / year]. In case the sensor is not recalibrated, the uncertainty of the sensitivity gradually will increase. This is solved by regular recalibration.

Another way to improve measurement reliability is to introduce redundant sensors.

- the use of redundant instruments allows remote checks of one instrument using the other as a reference, which leads to a higher measurement reliability.
- in PV system performance monitoring, in addition to instruments measuring in the Plane of Array, horizontally placed instruments are used for the measurement of global radiation. Global irradiance data enable the user to compare the local climate and system efficiency between different sites. These data can also be compared to measurements by local meteorological stations.

## 8.3 Speed of repair and maintenance

Dependability is not only a matter of reliability but also involves the reaction to problems; if the processing time of service and repairs is short, this contributes to the dependability.

The main maintenance actions are:

- cleaning of dome
- replacement of desiccant
- replacement of cabling
- replacement of ventilator

For optimisation of dependability a user should:

- design a schedule of regular maintenance
- design a schedule of repair or replacement in case of defects

When operating multiple instruments in a network, LSI Lastem recommends keeping procedures simple and having a few spare instruments to act as replacements during service, recalibrations and repair.

## 8.4 Uncertainty evaluation

The uncertainty of a measurement under outdoor or indoor conditions depends on many factors, see paragraph 1 of this chapter. It is not possible to give one figure for pyranometer measurement uncertainty. The work on uncertainty evaluation is a continuous effort. There are several groups around the world participating in standardisation of the method of calculation. The consensus is that measurement uncertainty should be evaluated according to the "Guide to Expression of Uncertainty in Measurement" or GUM).

### 8.4.1 Evaluation of measurement uncertainty under outdoor conditions

LSI Lastem actively participates in the discussions about pyranometer measurement uncertainty; we also provide spreadsheets, reflecting the latest state of the art, to assist our users in making their own evaluation. The input to the assessment is summarised:

- 1) The formal evaluation of uncertainty should be performed in accordance with ISO 98-3 Guide to the Expression of Uncertainty in Measurement, GUM.
- 2) The specifications of the instrument, acceptance interval plus guard band, according to the list of ISO 9060 classification of pyranometers and pyrhemometers are entered as limiting values of possible errors, to be analysed as type B evaluation of standard uncertainty per paragraph 4.3.7. of GUM. A priori distributions are chosen as rectangular.
- 3) A separate estimate has to be entered to allow for estimated uncertainty due to the instrument maintenance level.
- 4) The calibration uncertainty has to be entered. Please note that LSI Lastem calibration uncertainties are lower than those of alternative equipment. These uncertainties are entered in measurement equation (equation is usually Formula 0.1:  $E = U/S$ ), either as an uncertainty in E (zero offsets, directional response) in U (voltage readout errors) or in S (tilt error, temperature dependence, calibration uncertainty).
- 5) In uncertainty analysis for pyranometers, the location and date of interest is entered. The course of the sun is then calculated, and the direct and diffuse components are estimated, based on a model; the angle of incidence of direct radiation is a major factor in the uncertainty.

- 6) In uncertainty analysis for modern pyrhemometers: tilt angle dependence often is so low that one single typical observation may be sufficient.
- 7) In case of special measurement conditions, typical specification values are chosen. These should for instance account for the measurement conditions (shaded / unshaded, ventilated/ unventilated, horizontal / tilted) and environmental conditions (clear sky / cloudy, working temperature range).
- 8) Among the various sources of uncertainty, some are “correlated”; i.e. present during the entire measurement process, and not cancelling or converging to zero when averaged over time; the off-diagonal elements of the covariance matrix are not zero. Paragraph 5.2 of GUM.
- 9) Among the various sources of uncertainty, some are “uncorrelated”; cancelling or converging to zero when averaged over time; the off-diagonal elements of the covariance matrix are zero. Paragraph 5.1 of GUM.
- 10) Among the various sources of uncertainty, some are “not included in analysis”; this applies for instance to non-linearity for pyranometers, because it is already included in the directional error, and to the tilt response for pyranometers when measuring global horizontal irradiance.

**Table 8.4.1.1** *Estimates of achievable uncertainties of measurements with pyranometers. The estimates are based on the ISO 9060:2018 specification limits, (tolerance intervals including guard bands) and a calibration uncertainty of 1.5 %, for sunny, clear sky days and well maintained stations, without uncertainty loss due to lack of maintenance and due to instrument fouling. The table specifies expanded uncertainties with a coverage factor of 2 and confidence level of 95 %. Estimates are based on 1 s sampling. IMPORTANT NOTE: there is no international consensus on uncertainty evaluation of pyranometer measurements, so this table should not be used as a formal reference.*

<b>Pyranometer class ( ISO 9060)</b>	<b>season</b>	<b>latitude</b>	<b>uncertainty minute at solar noon</b>	<b>uncertainty totals hourly solar noon</b>	<b>uncertainty totals at daily totals</b>
spectrally flat Class A (DPA953)	summer	mid-latitude	1.8 %	1.8 %	2.3 %
		equator	1.8 %	1.8 %	2.3 %
		pole	2.5 %	2.5 %	3.3 %
	winter	mid-latitude	3.5 %	3.6 %	5.1 %
spectrally flat Class A	summer	mid-latitude	3.0 %	3.1 %	3.9 %
		equator	3.1 %	3.1 %	3.8 %
		pole	4.0 %	4.0 %	5.2 %
	winter	mid-latitude	5.5 %	5.5 %	8.1 %
spectrally flat Class B	summer	mid-latitude	5.3 %	5.4 %	6.9 %
		equator	5.4 %	5.4 %	6.7 %
		pole	7.1%	7.1 %	9.2 %
	winter	mid-latitude	9.7 %	9.9 %	14.6 %
spectrally flat Class C	summer	mid-latitude	11.7 %	11.8 %	14.1 %
		equator	11.8 %	11.8 %	13.7 %
		pole	13.8 %	13.8 %	16.7 %
	winter	mid-latitude	17.4 %	17.6 %	25.1 %

#### 8.4.2 Calibration uncertainty

New calibration procedures were developed in close cooperation with PMOD World Radiation Center in Davos, Switzerland. The latest calibration method results in an uncertainty of the sensitivity of less than 1.2 %, compared to typical uncertainties of higher than 1.7 % for this pyranometer class. See the appendix for detailed information on calibration hierarchy.

## 9 Maintenance and trouble shooting

### 9.1 Recommended maintenance and quality assurance

DPA953.1 can measure reliably at a low level of maintenance in most locations. Usually unreliable measurements will be detected as unreasonably large or small measured values. As a general rule this means that regular visual inspection combined with a critical review of the measured data, preferably checking against other measurements, is the preferred way to attain a reliable measurement.

The IEC 61724-1 standard covering PV system performance monitoring and the WMO manual covering meteorological network operation, have stricter requirements than those in table 9.1.1. IEC recommends weekly cleaning and inspection for its Class A systems, and yearly pyranometer re-calibration. WMO recommends daily inspection and cleaning of pyranometers used in meteorological networks.

**Table 9.1.1** Recommended maintenance of DPA953.1. If possible, the data analysis and cleaning (1 and 2) should be done on a daily basis. (continued on next page)

<b>MINIMUM RECOMMENDED PYRANOMETER MAINTENANCE</b>			
	INTERVAL	SUBJECT	ACTION
1	1 week	data analysis	compare measured data to maximum possible / maximum expected irradiance and to other measurements nearby (redundant instruments). Also historical seasonal records can be used as a source for expected values. Analyse nighttime signals. These signals may be negative (down to - 5 W/m <sup>2</sup> on clear windless nights), due to zero offset a. In case of use with PV systems, compare daytime measurements to PV system output. Look for any patterns and events that deviate from what is normal or expected. check tilt, internal humidity, internal pressure, ventilator speed and heater current according to the recommendations in the chapter about remote diagnostics
2	2 weeks	cleaning	use a soft cloth to clean the dome of the instrument, persistent stains can be treated with soapy water or alcohol
3	6 months	inspection	inspect cable quality, inspect connectors, inspect mounting position, inspect cable, clean instrument, clean cable, inspect levelling, change instrument tilt angle in case this is out of specification, inspect mounting connection electrically (for isolation or conduction), inspect interior of dome for condensation



**MINIMUM RECOMMENDED PYRANOMETER MAINTENANCE (continued)**

INTERVAL	SUBJECT	ACTION	
5	2 years	recalibration	recalibration by side-by-side comparison to a higher standard instrument in the field according to ISO 9847. For sensitivity adjustment and writing the calibration history data via a PC using the LSI Lastem Sensor Manager software, please refer to the LSI Lastem Sensor Manager manual for instructions. Typically during calibration desiccant is replaced. Ask the manufacturer for directions.
6	Lifetime assessment		judge if the instrument should be reliable for another 2 years, or if it should be replaced
7	< 5 years	Desiccant replacement	When necessary have desiccant replaced (see also section 7.4). Contact manufacturer for servicing options.
8	< 5 years	Ventilator replacement	When necessary have ventilator replaced (see also sections 7.6 and 7.7). Contact manufacturer for servicing options
9	Parts replacement		if applicable / necessary, replace the parts that are most exposed to ageing and weathering; cable, connector, sun screen. NOTE: use LSI Lastem approved parts only.

## 9.2 Trouble shooting

**Table 9.2.1** *Trouble shooting for DPA953.1 (continued on next page)*

General	<p>Inspect the instrument for any damage.</p> <p>Inspect if the connector is properly attached.</p> <p>Check the condition of the connectors (on chassis as well as the cable).</p> <p>Inspect if the sensor receives DC voltage power in the working range.</p> <p>Inspect the connection of the shield.</p> <p>Inspect the connection of the sensor power supply.</p> <p>Inspect the connection of the RS-485 signal ground to the RS-485 interface. Read out the internal humidity Modbus register. If the reading is &gt; 50 % at 20 °C for at least 24 hours, the sensor may be leaking, or the desiccant may be saturated. If internal humidity is stored, look at the long-term trend. To investigate leakage, the user may also read out the internal pressure sensor and see if the internal pressure correlates (the pressure divided by the temperature should be approximately constant) with body temperature. This is a sign that the construction is closed, not leaking.</p> <p>Please contact the factory to discuss diagnostics and possible action.</p>
Prepare for indoor testing	<p>Install the Sensor Manager software on a PC. Equip the PC with RS-485 communication. Put DC voltage power to the sensor and establish communication with the sensor. At power-up the signal may have a temporary output level different from zero; an offset. Let this offset settle down.</p>

<p>Not able to communicate with the sensor</p>	<p>Check all physical connections to the sensor and try connecting to the sensor again.          Check the cable for broken/damaged wires by measuring the electrical resistance from pins to cable ends. The electrical resistance should be &lt; 10 Ω. In case of doubt, try a new cable.          Make sure that all device addresses on the bus are unique.          Check if the correct device address and serial communication settings are being used. Default settings upon delivery are listed in section 3.1. If settings are not known use the LSI Lastem Sensor Manager. Connect sensor to a PC and perform a search operation with the Sensor Manager to determine the pyranometer's device address and serial communication settings. Note that this may take up to 30 minutes, depending on the search range. If all physical connections are correct, and communication with the sensor still cannot be established, please contact the factory to send the sensor to the manufacturer for diagnosis and service.</p>
<p>Does not respond to a request for 6 or more registers</p>	<p>It is not possible to request more than five 16 bit registers in one request. In case of requesting six or more registers in just one request, the sensor will not respond. If six or more registers are to be read, use multiple requests: the sensor will respond as expected.</p>
<p>The irradiance signal is unrealistically high or low</p>	<p>Note that night-time signals may be negative (down to -5 W/m<sup>2</sup> on clear windless nights in standard operating mode), due to zero offset a.          Check if the pyranometer has clean domes.          Check the location of the pyranometer; are there any obstructions that could explain the measurement result.          Check the orientation / levelling of the pyranometer.          Check if the irradiance signal responds to light: expose the sensor to a strong light source, for instance a 100 W light bulb at 0.1 m distance. The signal should read &gt; 100 W/m<sup>2</sup> now. Darken the sensor either by putting something over it or switching off the light. The instrument voltage output should go down and within one minute approach 0 W/m<sup>2</sup>.          Check if the sensitivity programmed into the pyranometer corresponds to the sensitivity on the calibration certificate.          Check if the correct Modbus registers are being read (see section 6.2).          Check if the correct multiplication factor is used in the data processing (irradiance registers are in 0.01 W/m<sup>2</sup>).          Check that the most-significant word (MSW) and least-significant word (LSW) of the irradiance registers are being read in a single Modbus request.          Check the data acquisition by replacing the sensor with a spare sensor with the same Modbus device address.</p>
<p>The sensor signal shows unexpected variations</p>	<p>Check the presence of strong sources of electromagnetic radiation (radar, radio).          Check the condition and connection of the shield.          Check the condition of the sensor cable.          Check if the cable is not moving during the measurement.          Check the condition of the connectors (on chassis as well as the cable)</p>
<p>The outer dome shows Internal condensation</p>	<p>In case there is a minor layer of moisture that is hardly visible: replace the desiccant and wait a few days to see if the situation improves. Ask the manufacturer for instructions.</p>
<p>The inner dome shows internal condensation</p>	<p>Arrange to send the sensor to the manufacturer for diagnosis and service.</p>

### 9.3 Calibration and checks in the field

Recalibration of field pyranometers is typically done by comparison in the field to a reference pyranometer. The applicable standard is ISO 9847 "International Standard- Solar Energy- calibration of field pyranometers by comparison to a reference pyranometer". At LSI Lastem an indoor calibration according to the same standard is used.

LSI Lastem recommendation for re-calibration: if possible, perform calibration indoor by comparison to an identical reference instrument, under normal incidence conditions.

The recommended calibration interval of pyranometers is 2 years. The registers containing the applied sensitivity and the calibration history of DPA953.1 are accessible for users. This allows the user to choose his own local calibration service. The same feature may be used for remotely controlled re-calibration of pyranometers in the field. Ask LSI Lastem for information on ISO and ASTM standardised procedures for field calibration. For sensitivity adjustment and writing the calibration history data via a PC using the LSI Lastem Sensor Manager software, please refer to the LSI Lastem Sensor Manager manual for instructions.

In case of field comparison; ISO recommends field calibration to a higher class pyranometer. LSI Lastem suggests also allowing use of sensors of the same model and class, because inter-comparisons of similar instruments have the advantage that they suffer from the same offsets. It is therefore just as good to compare to pyranometers of the same brand and type as to compare to an instrument of a higher class. ISO recommends to perform field calibration during several days; 2 to 3 days under cloudless conditions, 10 days under cloudy conditions. In general this is not achievable. In order to shorten the calibration process LSI Lastem suggests to allow calibration at normal incidence, using hourly totals near solar noon.

LSI Lastem main recommendations for field intercomparisons are:

- 1) to take normal incidence as a reference and not the entire day.
- 2) to take a reference of the same brand and type as the field pyranometer or a pyranometer of a higher class, and
- 3) to connect both to the same electronics, so that electronics errors (also offsets) are eliminated.
- 4) to mount all instruments on the same platform, so that they have the same body temperature.
- 5) to analyse radiation values at normal incidence radiation (possibly tilting the radiometers to approximately normal incidence), if this is not possible to compare 1 hour totals around solar noon for horizontally mounted instruments.
- 6) for spectrally flat Class C radiometers, to correct deviations of more than  $\pm 10\%$ . Lower deviations should be interpreted as acceptable and should not lead to a revised sensitivity.
- 7) for spectrally flat Class B pyranometers, to correct deviations of more than  $\pm 5\%$ . Lower deviations should be interpreted as acceptable and should not lead to a revised sensitivity.
- 8) for spectrally flat Class A instruments, to correct deviations of more than  $\pm 3\%$ . Lower deviations should be interpreted as acceptable and should not lead to a revised sensitivity.

## 9.4 Data quality assurance

Quality assurance can be done by:

- analysing trends in solar irradiance signal
- plotting the measured irradiance against mathematically generated expected values
- comparing irradiance measurements between sites
  
- monitoring statistics on the data communication quality, e.g. the number of failed communication events (Modbus CRC fails) per unit time

The main idea is that one should look out for any unrealistic values. There are programs on the market that can semi-automatically perform data screening.

## 10 Handling

Avoid the introduction of electrostatic discharge (ESD). The product, or part of it, is fragile, avoid mechanical shocks, abrasions or scratches on the surface and dome.

## 11 Storage, packaging, preservation, delivery, disposal

For storage, respect the humidity (10÷100% non-condensing) and temperature (-40÷80 °C) limits. Avoid direct sun exposure.

For delivery and storage, use the packaging supplied with the product.

For preservation, it is recommended to respect the environmental limits of humidity (10÷100% non-condensing) and temperature (-30÷60 °C).

Upon receipt of the material, visually check the package for signs of crushing or perforation; in the presence of these signs, check the integrity of the product inside.



This item is a highly electronic scientific device. In accordance with the standards of environmental protection and collection, LSI LASTEM advises to handle the product as waste of electrical and electronic equipment (WEEE). It is therefore not to be collected with any other kind of waste.

LSI LASTEM is liable for the compliance of the production, sales and disposal lines of the product, safeguarding the rights of the consumer. Unauthorized disposal will be punished by the law. Dispose of the dead batteries according to the regulations in force.

Recycle or dispose of the packaging material according to local regulations.

## 12 Safety

For safety regulations please refer to manual INSTUM\_05290.

## 13 Appendices

### 13.1 Appendix on tools for DPA953.1

**Table 10.1.1** Specifications of tools for DPA953.1

tooling required for opening of the sensor bottom	T10 torx key
tooling required for mounting and levelling DPA953.1 with the optional (tube) levelling mount	4 mm hex key and (alternatively) 10 mm spanner

### 13.2 Appendix on spare parts for DPA953.1

- levelling feet (set of 2)
- static foot
- sun screen for DPA953.1. Specify SCR05
- cable for DPA953.1, with female M12-A connector at sensor end, conductors stripped over 0.15 m with ferrules (5, 10, 20 m). Specify cable length
- cable for DPA953.1, 20 m length, with male and female M12-A connectors (order number C07E-20)
- levelling mount for DPA953.1, for spring-loaded levelling and mounting DPA953.1 on a surface (order number LM01)
- tube levelling mount for DPA953.1, for spring-loaded levelling and mounting DPA953.1 on a tube (order number TLM01)
- lower clamp for tube mount
- pair of M5x30 bolts for tube mount
- pair of M5x45 bolts for tube mount

NOTE: Outer dome, bubble level, thermopile sensor and internal sensors of DPA953.1 cannot be supplied as spare parts. In case of damage to the DPA953.1, after repair the instrument must be tested to verify performance within specification limits. This is required by ISO 9060. Testing involves verification of the directional response after dome, printed circuit board and thermal sensor replacement; verification of the temperature response after thermal sensor and internal sensors replacement and tilt sensor calibration after internal sensors replacement.

### 13.3 Appendix on the ventilator

The nominal ventilator speed is 7400 RPM at 20 °C. Depending on operating conditions the speed may vary. The normal startup time is less than 10 seconds. At temperatures below -10 °C the startup time may increase to several minutes and the ventilator speed may drop. The slow startup does not affect the lifetime in of the ventilator. Variations of the fan speed do not affect the instrument performance. The ventilator life expectancy  $L_{10\%}$  is 70,000 hours and the MTBF (Mean Time Between Failure) is 350,000 hours when continuously operated at 40 °C. Therefore a lifetime < 5 years is specified for the ventilator under typical operating conditions.

The recommended operation is either continuously [ON] or continuously [OFF]. Switching [ON] and [OFF] frequently (for example daily) reduces the ventilator lifetime. In case the ventilator

speed is < 5000 RPM at 20 °C consistently, there may be a problem and fan replacement may be needed. Factors that may negatively impact the fan life time are:

- long operation at elevated temperatures, especially above +70 °C
- frequently (re-)starting the ventilator
- excessive mechanical shocks and vibrations

### 13.4 Appendix on standards for classification and calibration

Both ISO and ASTM have standards on instrument classification and methods of calibration. The World Meteorological Organisation (WMO) has largely adopted the ISO classification system.

**Table 10.4.1** *Pyranometer standardisation in ISO and ASTM*

STANDARDS ON INSTRUMENT CLASSIFICATION AND CALIBRATION	
ISO STANDARD	EQUIVALENT ASTM STANDARD
ISO 9060:2018 Solar energy -- Specification and classification of instruments for measuring hemispherical solar and direct solar radiation	not available Comment: work is in progress on a new ASTM equivalent standard
ISO 9846:1993 Solar energy -- Calibration of a pyranometer using a pyrhelimeter	ASTM G167 - 15 Standard Test Method for Calibration of a Pyranometer Using a Pyrhelimeter
ISO 9847:1992 Solar energy -- Calibration of field pyranometers by comparison to a reference pyranometer	ASTM E824 -10 Standard Test Method for Transfer of Calibration from Reference to Field Radiometers
	ASTM G207 - 11 Standard Test Method for Indoor Transfer of Calibration from Reference to Field Pyranometers
ISO 9059:1990 Solar energy -- Calibration of field pyrhelimeters by comparison to a reference pyrhelimeter	ASTM E816-15 Standard Test Method for Calibration of Pyrhelimeters by Comparison to Reference Pyrhelimeters

### 13.5 Appendix on calibration hierarchy

The World Radiometric Reference (WRR) is the measurement standard representing the SI unit of irradiance. Use of WRR is mandatory when working according to the standards of both WMO and ISO. ISO 9874 states under paragraph 1.3: the methods of calibration specified are traceable to the WRR. The WMO manual states under paragraph 7.1.2.2: the WRR is accepted as representing the physical units of total irradiance.

The worldwide homogeneity of the meteorological radiation measurements is guaranteed by the World Radiation Center in Davos Switzerland, by maintaining the World Standard Group (WSG) which materialises the World Radiometric Reference.

See [www.pmodwrc.ch](http://www.pmodwrc.ch).

The LSI Lastem standard is traceable to an outdoor WRR calibration. Some small corrections are made to transfer this calibration to the LSI Lastem standard conditions: sun at zenith and 1000

W/m<sup>2</sup> irradiance level. During the outdoor calibration the sun is typically at 20 to 40 ° zenith angle, and the total irradiance at a 700 W/m<sup>2</sup> level.

**Table 10.5.1** Calibration hierarchy for pyranometers

---

**WORKING STANDARD CALIBRATION AT PMOD / WRC DAVOS**

---

Calibration of working standard pyranometers:

Method: outdoor calibration using the “continuous sun-and-shade method. This working standard has an uncertainty “uncertainty of standard”. The working standard has been calibrated under certain “test conditions of the standard”. The working standard has traceability to WRR world radiometric reference.

---

**CORRECTION OF (WORKING) STANDARD CALIBRATION TO STANDARDISED REFERENCE CONDITIONS**

---

Correction from “test conditions of the standard” to “reference conditions” i.e. to 20 °C, normal incidence, horizontal mounting and an irradiance level of 1000 W/m<sup>2</sup>:

Using known working standard pyranometer properties: temperature response, directional response, non-linearity, tilt response).

---

**INDOOR PRODUCT CALIBRATION**

---

Calibration of products, i.e. pyranometers:

Method: according to ISO 9847, Type IIc, which is an indoor calibration. This calibration has an uncertainty associated with the method.

---

**CALIBRATION UNCERTAINTY CALCULATION**

---

ISO 98-3 Guide to the Expression of Uncertainty in Measurement, GUM Determination of combined expanded uncertainty of calibration of the product, including uncertainty of the working standard, uncertainty of correction, uncertainty of the method (transfer error). The coverage factor must be determined; at LSI Lastem we work with a coverage factor  $k = 2$ .

---

## 13.6 Appendix on meteorological radiation quantities

A pyranometer measures irradiance. The time integrated total is called radiant exposure. In solar energy radiant exposure is often given in  $W \cdot h/m^2$ .

**Table 10.6.1** Meteorological radiation quantities as recommended by WMO (additional symbols by LSI Lastem Thermal Sensor). POA stands for Plane of Array irradiance. The term originates from ASTM and IEC standards.

SYMBOL	DESCRIPTION	CALCULATION	UNITS	ALTERNATIVE EXPRESSION	
$E_{\downarrow}$	downward irradiance	$E_{\downarrow} = E_{g\downarrow} + E_{l\downarrow}$	$W/m^2$		
$H_{\downarrow}$	downward radiant exposure for a specified time interval	$H_{\downarrow} = H_{g\downarrow} + H_{l\downarrow}$	$J/m^2$		
$E_{\uparrow}$	upward irradiance	$E_{\uparrow} = E_{g\uparrow} + E_{l\uparrow}$	$W/m^2$		
$H_{\uparrow}$	upward radiant exposure for a specified time interval	$H_{\uparrow} = H_{g\uparrow} + H_{l\uparrow}$	$J/m^2$	$W \cdot h/m^2$	Change of units
$E$	direct solar irradiance normal to the apparent solar zenith angle		$W/m^2$	DNI	Direct Normal Irradiance
$E_0$	solar constant		$W/m^2$		
$E_{g\downarrow h}$	global irradiance; hemispherical irradiance on a specified, in this case horizontal surface.*	$E_{g\downarrow} = E \cos \theta_h + E_{d\downarrow}$	$W/m^2$	GHI	Global Horizontal Irradiance
$E_{g\downarrow t}$	global irradiance; hemispherical irradiance on a specified, in this case tilted surface.*	$E_{g\downarrow} = E \cdot \cos \theta_t + E_{d\downarrow t} + E_{r\uparrow t}$ ***	$W/m^2$	POA	Plane of Array
$E_{d\downarrow}$	downward diffuse solar radiation		$W/m^2$	DHI	Diffuse Horizontal Irradiance
$E_{l\uparrow}, E_{l\downarrow}$	upward / downward longwave irradiance		$W/m^2$		
$E_{r\uparrow}$	reflected solar irradiance		$W/m^2$		
$E^*$	net irradiance	$E^* = E_{\downarrow} - E_{\uparrow}$	$W/m^2$		
$T_{\downarrow}$	apparent surface temperature**		$^{\circ}C$ or $K$		
$T_{\uparrow}$	apparent sky temperature**		$^{\circ}C$ or $K$		
SD	sunshine duration		h		

$\theta$  is the apparent solar zenith angle  $\theta_h$  relative to horizontal,  $\theta_t$  relative to a tilted surface

g = global, l = long wave, t = tilted \*, h = horizontal\*

\* distinction horizontal and tilted from LSI Lastem

\*\* T symbols introduced by LSI Lastem,

\*\*\* contributions of  $E_{d\downarrow t}$  and  $E_{r\uparrow t}$  are  $E_{d\downarrow}$  and  $E_{r\uparrow}$  both corrected for the tilt angle of the surface



## 13.7 Appendix on ISO and WMO classification tables

**Table 10.7.1** Valid classification table for pyranometers per ISO 9060:2018 and WMO. NOTE: WMO specification of spectral selectivity is different from that of ISO. LSI Lastem conforms to the ISO limits. WMO also specifies expected accuracies. ISO finds this not to be a part of the classification system because it also involves calibration. Please note that WMO achievable accuracies are for clear days at mid latitudes and that the uncertainty estimate does not include uncertainty due to calibration\*. Continued on next page.

<b>ISO 9060:2018 CLASSIFICATION** TABLE</b>			
ISO ACCURACY CLASS	CLASS A	CLASS B	CLASS C
Specification acceptance interval (guard band)			
Response time (95 %)	10 s (1 s)	20 s (1s)	60 s (1 s)
Zero offset a (response to 200 W/m <sup>2</sup> net thermal radiation)	± 7 W/m <sup>2</sup> (2 W/m <sup>2</sup> )	± 15 W/m <sup>2</sup> (2 W/m <sup>2</sup> )	± 30 W/m <sup>2</sup> (3 W/m <sup>2</sup> )
Zero offset b (response to 5 K/h in ambient temperature)	± 2 W/m <sup>2</sup> (0.5 W/m <sup>2</sup> )	± 4 W/m <sup>2</sup> (0.5 W/m <sup>2</sup> )	± 8 W/m <sup>2</sup> (1 W/m <sup>2</sup> )
Total zero offset	± 10 W/m <sup>2</sup> (2 W/m <sup>2</sup> )	± 21 W/m <sup>2</sup> (2 W/m <sup>2</sup> )	± 41 W/m <sup>2</sup> (3 W/m <sup>2</sup> )
Non-stability (change per year)	± 0.8 % (0.2 %)	± 1.5 % (0.25 %)	± 3 % (0.5 %)
Non-linearity (100 to 1000 W/m <sup>2</sup> )	± 0.5 % (0.2 %)	± 1 % (0.2 %)	± 3 % (0.5%)
Directional response	± 10 W/m <sup>2</sup>	± 20 W/m <sup>2</sup>	± 30 W/m <sup>2</sup>
For spectrally flat subcategory only: Spectral selectivity (350 to 1 500 x 10 <sup>-9</sup> m) (WMO 300 to 3 000 x 10 <sup>-9</sup> m)	± 3 % (2 %)	± 3 % (2 %)	± 3 % (2 %)
Clear sky global horizontal irradiance spectral error	± 0.5 % (0.1%)	± 1 % (0.5 %)	± 5 % (1%)
Temperature response (interval -10 to + 40° C relative to 20 °C)**	± 1 % (0.2 %)	± 2 % (0.2 %)	± 4 % (0.5 %)
Tilt response (0 to 180 ° at 1000 W/m <sup>2</sup> )	± 0.5 % (0.2 %)	± 2 % (0.5 %)	± 5 % (0.5 %)
Additional signal processing errors	± 2 W/m <sup>2</sup> (2 W/m <sup>2</sup> )	± 5 W/m <sup>2</sup> (2 W/m <sup>2</sup> )	± 10 W/m <sup>2</sup> (2 W/m <sup>2</sup> )
Conformity testing**	Temperature and directional test for every individual instrument	group compliance	group compliance
For fast response subclass only: Response time (95 %)	0.5 s	0.5 s	0.5 s

**ADDITIONAL WMO SPECIFICATIONS**

WMO CLASS	HIGH QUALITY	GOOD QUALITY	MODERATE QUALITY
WMO: achievable accuracy for daily sums*	2 %	5 %	10 %
WMO: achievable accuracy for hourly sums*	3 %	8 %	20 %
WMO: achievable accuracy for minute sums*	not specified	not specified	not specified
WMO: resolution (smallest detectable change)	1 W/m <sup>2</sup>	5 W/m <sup>2</sup>	10 W/m <sup>2</sup>

\* WMO 7.2.1: The estimated uncertainties are based on the following assumptions:

- a) instruments are well-maintained, correctly aligned and clean;
- b) 1 min and 1 h figures are for clear-sky irradiances at solar noon;
- c) daily exposure values are for clear days at mid-latitudes. WMO 7.3.2.5: Table 7.5 lists the expected maximum deviation from the true value, excluding calibration errors.

\*\* ISO 9060: 2018: an instrument is subject to conformity testing of its specifications. The classification of pyranometers may be applied to individual instruments or to groups (particular types) of instruments, depending on the category. A pyranometer type (pyranometers of identical design) may be claimed to be of a particular class even without individual tests depending on the class if the appropriate quality control has shown that pyranometers of this type comply with the respective specifications. For the classification of a pyranometer in the highest class a, individual tests of temperature response and directional response are required. A specification is fulfilled if:

- a) the value of the respective test result lies in the corresponding acceptance interval given in Table 1 for the specific class of instrument; and if
- b) the sum of the absolute amounts of the expanded uncertainty of the test and the test result is less or equal to the absolute amount of the limit of the tolerance interval (guarded acceptance) — the tolerance interval is determined by the acceptance interval and the guard bands from iso 9060: 2018 table 1 (same as 10.8.1). Reference: JCGM 106 and ISO /IEC Guide 98-4 Uncertainty of measurement — Part 4: Role of measurement uncertainty in conformity assessment

## 13.8 Appendix on ISO 9060:1990 classification no longer valid

**Table 10.8.1** Former classification table for pyranometers per ISO 9060:1990 and WMO. ISO 9060:1990 has been superseded by ISO 9060:2018, see appendix 10.7.

*NOTE: WMO specification of spectral selectivity is different from that of ISO. LSI Lastem conforms to the ISO limits. WMO also specifies expected accuracies. ISO finds this not to be a part of the classification system because it also involves calibration. Please note that WMO achievable accuracies are for clear days at mid latitudes and that the uncertainty estimate does not include uncertainty due to calibration\*.*

<b>FORMER ISO 9060:1990 CLASSIFICATION TABLE (SUPERSEDED BY ISO 9060:2018)</b>			
ISO CLASS	SECONDARY STANDARD	FIRST CLASS	SECOND CLASS
Specification limit			
Response time (95 %)	15 s	30 s	60 s
Zero offset a (response to 200 W/m <sup>2</sup> net thermal radiation)	+ 7 W/m <sup>2</sup>	+ 15 W/m <sup>2</sup>	+ 30 W/m <sup>2</sup>
Zero offset b (response to 5 K/h in ambient temperature)	± 2 W/m <sup>2</sup>	± 4 W/m <sup>2</sup>	± 8 W/m <sup>2</sup>
Non-stability (change per year)	± 0.8 %	± 1.5 %	± 3 %
Non-linearity (100 to 1000 W/m <sup>2</sup> )	± 0.5 %	± 1 %	± 3 %
Directional response	± 10 W/m <sup>2</sup>	± 20 W/m <sup>2</sup>	± 30 W/m <sup>2</sup>
Spectral selectivity (350 to 1 500 x 10 <sup>-9</sup> m) (WMO 300 to 3 000 x 10 <sup>-9</sup> m)	± 3 %	± 5 %	± 10 %
Temperature response (interval of 50 K)**	2 %	4 %	8 %
Tilt response (0 to 90 ° at 1000 W/m <sup>2</sup> )	± 0.5 %	± 2 %	± 5 %
<b>ADDITIONAL WMO SPECIFICATIONS</b>			
WMO CLASS	HIGH QUALITY	GOOD QUALITY	MODERATE QUALITY
WMO: achievable accuracy for daily sums*	2 %	5 %	10 %
WMO: achievable accuracy for hourly sums*	3 %	8 %	20 %
WMO: achievable accuracy for minute sums*	not specified	not specified	not specified
WMO: resolution (smallest detectable change)	1 W/m <sup>2</sup>	5 W/m <sup>2</sup>	10 W/m <sup>2</sup>
<b>CONFORMITY TESTING***</b>			
ISO 9060	individual instrument only: all specs must comply	group compliance	group compliance

\* WMO 7.2.1: The estimated uncertainties are based on the following assumptions: (a) instruments are well-maintained, correctly aligned and clean; (b) 1 min and 1 h figures are for clear-sky irradiances at solar noon; (c) daily exposure values are for clear days at mid-latitudes. WMO 7.3.2.5: Table 7.5 lists the expected maximum deviation from the true value, excluding calibration errors.

\*\* At LSI Lastem the expression ± 1 % is used instead of a range of 2 %.

\*\*\* ISO 9060:1990 an instrument is subject to conformity testing of its specifications. Depending on the classification, conformity compliance can be proven either by group- or individual compliance. A specification is fulfilled if the mean value of the respective test result does not exceed the corresponding limiting value of the specification for the specific category of instrument.

## 13.9 Appendix on definition of pyranometer specifications

**Table 10.9.1** Definition of pyranometer specifications (continued on next page)

SPECIFICATION	DEFINITION	SOURCE
Response time (95 %)	time for 95 % response. The time interval between the instant when a stimulus is subjected to a specified abrupt change and the instant when the response reaches and remains within specified limits around its final steady value. The response time is a measure of the thermal inertia inherent in the stabilization period for a final reading.	ISO 9060:2018 WMO 1.6.3
Zero offset a: (200 W/m <sup>2</sup> net thermal radiation)	response to 200 W/m <sup>2</sup> net thermal radiation (ventilated). LSI Lastem assumes that unventilated instruments have to specify the zero-offset in unventilated – worst case – conditions. Zero offsets are a measure of the stability of the zeropoint. Zero offset a is visible at night as a negative offset, the instrument dome irradiates in the far infra red to the relatively cold sky. This causes the dome to cool down. The pyranometer sensor irradiates to the relatively cool dome, causing a negative offset. Zero offset a is also assumed to be present during daytime.	ISO 9060:2018
Zero offset b: (5 K/h in ambient temperature)	response to 5 K/h change in ambient temperature. Zero offsets are a measure of the stability of the zeropoint.	ISO 9060:2018
Total zero offset	Including the effects of zero offset a and b and other sources	ISO 9060:2018
Non-stability (change per year)	percentage change in sensitivity per year. The dependence of sensitivity resulting from ageing effects which is a measure of the long-term stability.	ISO 9060:2018
Non-linearity (100 to 1000 W/m <sup>2</sup> )	percentage deviation from the sensitivity at 500 W/m <sup>2</sup> due to the change in irradiance within the range of 100 W/m <sup>2</sup> to 1000 W/m <sup>2</sup> .  Non-linearity has an overlap with directional response, and therefore should be handled with care in uncertainty evaluation.	ISO 9060:2018
Directional response	the range of errors caused by assuming that the normal incidence sensitivity is valid for all directions when measuring from any direction (with incidence angle of up to 90 ° or even from below the sensor) a beam radiation whose normal incidence irradiance is 1000 W/m <sup>2</sup> . Directional response is a measure of the deviations from the ideal "cosine behaviour" and its azimuthal variation. Appendix A5: measurement should be made at least at the following directions: incidence angles of 40°, 60°, 70°, 80° and 95° at four azimuth angles (e.g. 0°, 90°, 180°, 270°).	ISO 9060:2018
Spectral selectivity (350 to 1500 x 10 <sup>-9</sup> m) (WMO 300 to 3000 x 10 <sup>-9</sup> m)	percentage deviation of the product of spectral absorptance and spectral transmittance from the corresponding mean within 350 x 10 <sup>-9</sup> m to 1500 x 10 <sup>-9</sup> m and the spectral distribution of irradiance. Spectral selectivity is a measure of the spectral selectivity of the sensitivity.	ISO 9060:2018

Clear sky global horizontal irradiance spectral error	maximum spectral error observed for a set of global horizontal irradiance clear sky spectra defined in this document ISO 9060:2018	ISO 9060:2018
Temperature response (interval of 50 K)	percentage deviation of the sensitivity due to change in ambient temperature within the interval of - 10 °C to + 40 °C relative to °20 C.	ISO 9060:2018
Tilt response (0° to 180° at 1000 W/m <sup>2</sup> )	percentage deviation from the sensitivity at 0° tilt (horizontal) due to change in tilt from 0 ° to 180 ° at 1000 W/m <sup>2</sup> irradiance. Tilt response describes changes of the sensitivity due to changes of the tilt angle of the receiving surface.	ISO 9060:2018
Additional signal processing errors	The additional signal processing errors contain data acquisition and analogue to digital conversion that might be carried out in the instrument and all other processing steps carried out within the instrument that are not covered by the other specifications	ISO 9060:2018
Sensitivity	the change in the response of a measuring instrument divided by the corresponding change in the stimulus.	WMO 1.6.3
Spectral range	the spectral range of radiation to which the instrument is sensitive. For a normal pyranometer this should be in the 0.3 to 3 x 10 <sup>-6</sup> m range. Some pyranometers with coloured glass domes have a limited spectral range.	LSI Lastem

## 13.10 Appendix on terminology / glossary

**Table 10.10.1** Definitions and references of used terms (continued on next page)

TERM	DEFINITION (REFERENCE)
Solar energy or solar radiation	solar energy is the electromagnetic energy emitted by the sun. Solar energy is also called solar radiation and shortwave radiation. The solar radiation incident on the top of the terrestrial atmosphere is called extra-terrestrial solar radiation; 97 % of which is confined to the spectral range of $290$ to $3\,000 \times 10^{-9}$ m. Part of the extra-terrestrial solar radiation penetrates the atmosphere and directly reaches the earth's surface, while part of it is scattered and / or absorbed by the gas molecules, aerosol particles, cloud droplets and cloud crystals in the atmosphere. The former is the direct component, the latter is the diffuse component of the solar radiation. (ref: WMO, LSI Lastem)
Hemispherical solar radiation	solar radiation received by a plane surface from a $180^\circ$ field of view angle (solid angle of $2\pi$ sr).(ref: ISO 9060)
Global solar radiation	the solar radiation received from a $180^\circ$ field of view angle on a horizontal surface is referred to as global radiation. Also called GHI. This includes radiation received directly from the solid angle of the sun's disc, as well as diffuse sky radiation that has been scattered in traversing the atmosphere. (ref: WMO) Hemispherical solar radiation received by a horizontal plane surface. (ref: ISO 9060)
Plane of Array irradiance	also POA: hemispherical solar irradiance in the plane of a PV array. (ref: ASTM E2848-11 / IEC 61724)
Direct solar radiation	radiation received from a small solid angle centred on the sun's disc, on a given plane. (ref: ISO 9060)
Terrestrial or Longwave radiation	radiation not of solar origin but of terrestrial and atmospheric origin and having longer wavelengths ( $3\,000$ to $100\,000 \times 10^{-9}$ m). In case of downwelling $E_i \downarrow$ also the background radiation from the universe is involved, passing through the "atmospheric window". In case of upwelling $E_i \uparrow$ , composed of long-wave electromagnetic energy emitted by the earth's surface and by the gases, aerosols and clouds of the atmosphere; it is also partly absorbed within the atmosphere. For a temperature of $300$ K, 99.99 % of the power of the terrestrial radiation has a wavelength longer than $3\,000 \times 10^{-9}$ m and about 99 per cent longer than $5\,000 \times 10^{-9}$ m. For lower temperatures, the spectrum shifts to longer wavelengths. (ref: WMO)
World Radiometric Reference (WRR)	measurement standard representing the SI unit of irradiance with an uncertainty of less than $\pm 0.3$ % (see the WMO Guide to Meteorological Instruments and Methods of Observation, 1983, subclause 9.1.3). The reference was adopted by the World Meteorological Organization (WMO) and has been in effect since 1 July 1980. (ref: ISO 9060)
Albedo	ratio of reflected and incoming solar radiation. Dimensionless number that varies between 0 and 1. Typical albedo values are: $< 0.1$ for water, from 0.1 for wet soils to 0.5 for dry sand, from 0.1 to 0.4 for vegetation, up to 0.9 for fresh snow.
Angle of incidence	angle of radiation relative to the sensor measured from normal incidence (varies from $0^\circ$ to $90^\circ$ ).
Zenith angle	angle of incidence of radiation, relative to zenith. Equals angle of incidence for horizontally mounted instruments
Azimuth angle	angle of incidence of radiation, projected in the plane of the sensor surface. Varies from $0^\circ$ to $360^\circ$ . 0 is by definition the cable exit direction, also called north, east is $+90^\circ$ . (ASTM G113-09)

Sunshine duration	sunshine duration during a given period is defined as the sum of that sub-period for which the direct solar irradiance exceeds 120 W/m <sup>2</sup> . (ref: WMO)
-------------------	------------------------------------------------------------------------------------------------------------------------------------------------------------------

### 13.11 Appendix on function codes, register and coil overview

**Table 10.11.1** Supported Modbus function codes

SUPPORTED MODBUS FUNCTION CODES	
FUNCTION CODE (HEX)	DESCRIPTION
0x01	Read Coils
0x02	Read Discrete Inputs
0x03	Read Holding Registers
0x04	Read Input Register
0x05	Write Single Coil
0x06	Write Single Holding Register
0x0F	Write Multiple Coils
0x10	Write Multiple Registers

#### NOTICE

**Depending on processing by the network master, your data request may need an offset of +1 for each DPA953.1 register address. Example: DPA953.1 register address 7 + master offset = 7 + 1 = master register address 8. Consult the manual of the local network master.**

DPA953.1 does not distinguish between holding registers and input registers. Therefore both function code 0x03 and 0x04 may be used to read registers.

Up to five 16 bit registers can be read in one request. If six or more registers are to be read, multiple requests must be used. Whenever a 32 bit parameter is being read (S32, U32 or FLOAT) both 16 bit Modbus registers must be read in a single Modbus request. When reading the 16 bit registers separately, the parameter value may be updated in between read requests (may become incoherent), which can lead to false readings.

**Table 10.11.2** Modbus registers 0 to 199 (continued on next pages)

MODBUS REGISTERS 0-199				
REGISTER ADDRESS	PARAMETER	DESCRIPTION OF CONTENT	ACCESS	FORMAT OF DATA
0	Device address	Sensor address in Modbus network, default = 1	R/W	U16
1	Serial communication settings	Sets the serial communication, default = 5	R/W	U16
2 + 3	Irradiance (temperature compensated signal)	Temperature compensated signal in $\times 0.01 \text{ W/m}^2$	R	S32
4 + 5	Irradiance (uncompensated signal)	Uncompensated signal in $\times 0.01 \text{ W/m}^2$	R	S32
6	Sensor body temperature	In $\times 0.01 \text{ }^\circ\text{C}$	R	S16
7	Sensor electrical resistance	In $\times 0.1 \text{ } \Omega$	R	U16
8	Scaling factor irradiance	Default = 100	R	U16
9	Scaling factor temperature	Default = 100	R	U16
10 + 11	Sensor voltage output	In $\times 10^{-9} \text{ V}$	R	S32
12 to 31	Factory use only			
32 to 35	Sensor model	Part one of sensor description	R	String
36 to 39	Sensor model	Part two of sensor description	R	String
40	Sensor serial number		R	U16
41 + 42	Sensor sensitivity	In $\times 10^{-6} \text{ V}/(\text{W/m}^2)$	R	Float
43	Response time as measured during calibration	In $\times 0.1 \text{ s}$	R	U16
44	Sensor resistance as measured during calibration	In $\times 0.1 \text{ } \Omega$	R	U16
45	Reserved	Always 0	R	U16
46 + 47	Sensor calibration date	Calibration date of the sensor in YYYYMMDD	R	U32



MODBUS REGISTERS 0 – 199, continued				
REGISTER ADDRESS	REGISTER ADDRESS	REGISTER ADDRESS	REGISTER ADDRESS	REGISTER ADDRESS
48 to 60	Factory use			
61	Firmware version		R	U16
62	Hardware version		R	U16
63 + 64	Sensor sensitivity history 1	In $\times 10^{-6}$ V/(W/m <sup>2</sup> ) Default value is 0	R	Float
65 + 66	Calibration date history 1	Former calibration date of the sensor in YYYYMMDD Default value is 0	R	U32
67 + 68	Sensor sensitivity history 2	See register 63 + 64	R	Float
69 + 70	Calibration date history 2	See register 65 + 66	R	U32
71 + 72	Sensor sensitivity history 3	See register 63 + 64	R	Float
73 + 74	Calibration date history 3	See register 65 + 66	R	U32
75 + 76	Sensor sensitivity history 4	See register 63 + 64	R	Float
77 + 78	Calibration date history 4	See register 65 + 66	R	U32
79 + 80	Sensor sensitivity history 5	See register 63 + 64	R	Float
81 + 82	Calibration date history 5	See register 65 + 66	R	U32
83 - 86	Factory use			

MODBUS REGISTERS 0 – 199, continued				
REGISTER ADDRESS	PARAMETER	DESCRIPTION OF CONTENT	ACCESS	FORMAT OF DATA
87 + 88	Polynomial temperature coefficient a		R	Float
89 + 90	Polynomial temperature coefficient b		R	Float
91 + 92	Polynomial temperature coefficient c		R	Float
93 - 97	Factory use only			
98	Humidity	In x 0.01 %	R	U16
99	Factory use			
100-137	Factory use			
138	Pressure average	In x (1/32) mbar	R	U16
139 - 193	Factory use			
194	Tilt angle	In x 0.01 °	R	U16
195	Factory use			
196	Fan speed RPM	In x 1 RPM	R	U16
197	Factory use			
198	Heater current	In x 1 mA	R	U16
199	Fan current	In x 1 mA	R	U16

### NOTICE

**Depending on processing by the network master device, your data request may need an offset of +1 for each DPA953.1 register address. If so, this offset applies to coils as well. Consult the manual of the network master device.**

**Table 10.11.3** Coils

COILS				
COIL	PARAMETER	DESCRIPTION	TYPE OF	OBJECT TYPE
0	Restart	Restart the sensor	W	Single bit
1	Heater	Turn heater on/off	W	Single bit
2	Check	Measure sensor electrical resistance	W	Single bit
3	Fan	Turn fan on/off	W	Single bit

## 13.12 Appendix on electromagnetic compatibility (EMC) testing

EMC testing has been performed according to the following standards:

- Emission IEC/EN 61326-1 (2013)
- Immunity IEC/EN 61326-1 (2013)

**Table 10.12.1** Immunity test descriptions and basic test standards used for EMC testing

DESCRIPTION	BASIC STANDARD
Conducted emission, test with a LISN	IEC/EN 55011 (2009) + A1 (2010)
Radiated emission up to 1 GHz (in a semi-anechoic chamber)	IEC/EN 55011 (2009) + A1 (2010)
Electrostatic discharge (ESD)	IEC/EN 61000-4-2 (2009)
Radiated Immunity	IEC/EN 61000-4-3 (2006) + A1 (2008) + A2 (2010)
Electrical fast transient (EFT)	IEC/EN 61000-4-4 (2012)
Surge*	IEC/EN 61000-4-5 (2014) + A1 (2017)
Conducted Immunity	IEC/EN 61000-4-6 (2014)

\* Only tested up to 500 V line-to-ground

Note: All emission testing has been performed under a lamp at about 200 W/m<sup>2</sup> and all immunity testing has been performed at about 200 W/m<sup>2</sup> and is repeated at 300 W/m<sup>2</sup>.



[www.lsi-lastem.com](http://www.lsi-lastem.com)

---