RAMSES

Hyperspectral radiometer

manual

Rel. 1.1

TriOS Optical Sensors

TriOS Mess- und Datentechnik GmbH
Bürgermeister-Brötje-Str. 25
D-26180 Rastede
Germany

fon: +49 (0) 4402 69670-0
fax: +49 (0) 4402 69670-20
info@trios.de
www.trios.de

Introduction

Measurement of solar radiation in the water column is a well-known method in marine science. The *in situ* light field is influenced by absorption and scattering of different substances and life-forms like phytoplankton, yellow substance, suspended matter, contaminants and by the water itself (Jerlov, Morel and many other).

In biology works PAR (**P**hotosynthetically **A**vailable **R**adiation), as the integral value of the irradiance from 400 to 700 nm, is most commonly used to characterise the conditions for photosynthesis of phytoplankton communities. Due to the individual pigment composition of different species the usefulness of a given light field for photosynthesis is not a simple function of the total intensity of PAR. It depends also on the spectral distribution of quanta, especially with regard to the absorption spectrum (Fig.1) of the phytoplankton. To account for this Morel (1978) introduced the concept of PUR (**P**hotosynthetically **U**sable **R**adiation), which is a modified PAR obtained by weighting it across the spectrum with the specific absorption spectra of phytoplankton.

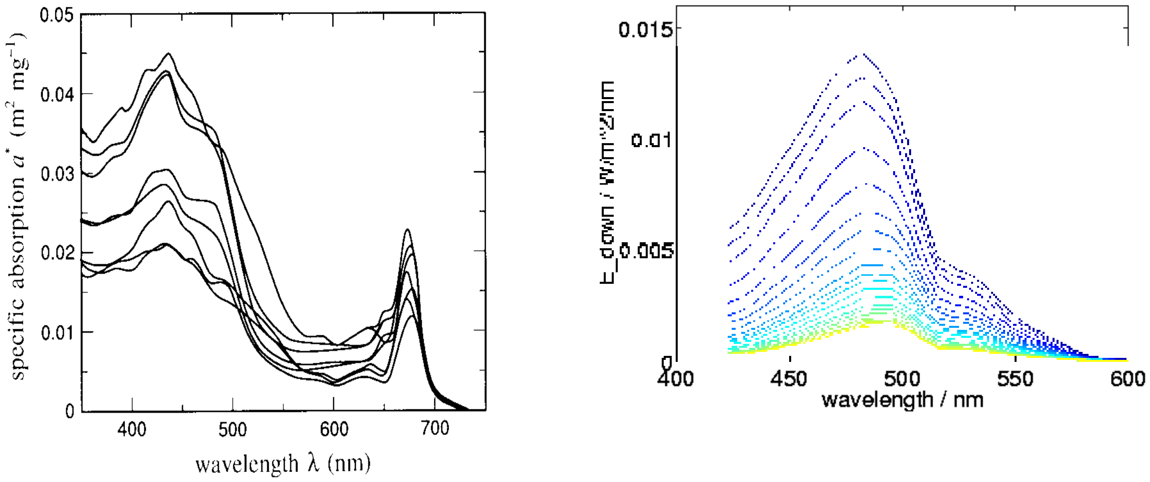


Fig.1: (a) Specific absorption spectra of the main phytoplankton classes (after Mobley, 1994); (b) Down-welling irradiance at water depths between 40 and 70 m with 2 m intervals at a station in the western Arabian sea taken in May 1997 on board RV *Sonne*.

Fig. 2 a-b shows the spectral distribution and the vertical decrease at two selected wavelengths of the down-welling irradiance in the presence of a deep chlorophyll maximum at different water depths at a station in the western Arabian sea. Fig. 2 c represents the chlorophyll fluorescence which has been measured simultaneously to the irradiance. The bold lines in Fig’s. 2 a and b represent the curve calculated for the absence of chlorophyll. The figures clearly shows the spectral selective light absorption by the phytoplankton and therefore the necessity of hyperspectral radiation measurements.

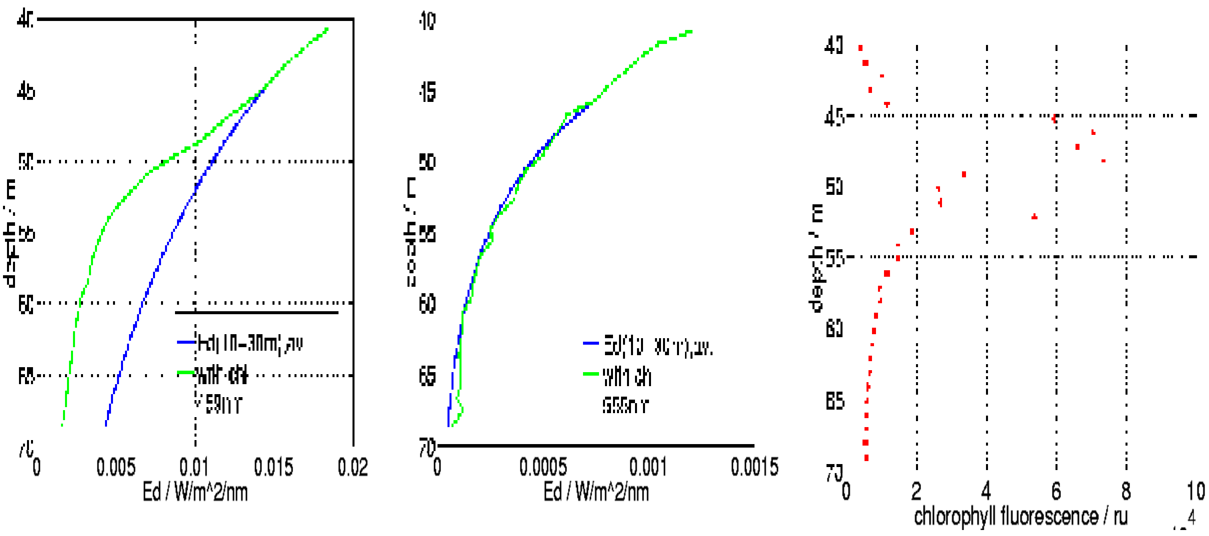


Fig.2: Down-welling irradiance at 469 nm (a) and 555 nm (b) from 40 to 70 m taken from the same profile as shown in Fig 1b. The full lines are the calculated values for a situation without a deep chlorophyll maximum between 40 and 50 m (according to values from 10-30 m). (c) distribution of *in situ* chlorophyll fluorescence measured simultaneously with the radiation.

Studies of the behaviour of different life-forms on ultraviolet radiation shows non-repairable damages. In view of increasing ultraviolet radiation due to decreasing ozone in the atmosphere, it becomes more and more interesting to extend the spectral light measurements from the visible to the UV-A and UV-B parts of the spectrum.

Beside the described applications in biology, hyperspectral radiometers are playing a major role in the validation and calibration of satellite data. With the availability of several environmental satellites for colour measurements (SeaWIFS, MERIS, etc), more and more reference measurements are required, even in coastal areas. In this field, hyperspectral radiometers offers much more flexibility then radiometers with discrete band filters, which are normally only useable for one specific satellite due to the slightly different detection wavelengths.

Setups for this application are normally including one irradiance and one or two radiance sensors.

To meet these different requirements, TriOS has introduced a hyperspectral radiometer series with a modular concept. The performance of these instruments includes:

- high resolution hyperspectral detection in the UV and UV/VIS from 280 - 950 nm
- more than 200 sensors in a single system
- easy combination with other TriOS sensors like fluorometers, transmissiometers, etc.
- specialized UV-B/UV-A detection modules

- sensors with different detection characteristics for the measurement of different parameters (radiance, irradiance, scalar irradiance)
- low power consumption to make the instrument suitable for handheld and moored applications
- modular setup for customized sensor configurations
- operation down to 300m
- wide range of accessories (datalogger, power supplies, frames, calibration units, and many others)

Instrument Description

This manual describes the use and the principles of operation of the hyperspectral radiometers of the RAMSES family for radiance, irradiance and scalar irradiance measurement in-air and in-water.

All RAMSES units have a RS232 interface. They can be operated as stand-alone units as well as part of instruments packages. An easy integration can be done other TriOS sensors, like transmissometer, fluorometers, UV-nitrate analysers and many others. A wide range of available accessories offers the most possible flexibility for a wide range of applications.

A built-in microcontroller allows various different integration times, either set manually or automatically by the instrument itself, to guarantee an optimised measurement in all situations.

Using TriOS MSDA software packages, devices and their actual settings will be automatically identified.

Principle of Operation

RAMSES hyperspectral radiometers are based on a highly miniaturized monolithic spectrometer module from ZEISS (MMS or MMS1 series). The principle optical layout is shown in Fig.1.

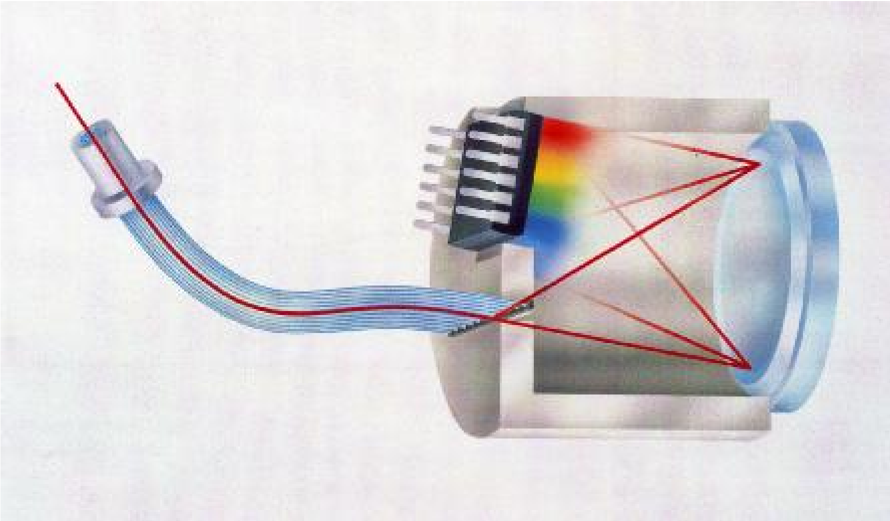


Fig.1 Principle optical layout of TriOS Radiometer

The light is detected by an optical fibre bundle with 30 single fibres giving a total diameter of 0.5mm. These fibres are arranged in a linear order on the entrance side of the polychromator. The entered light is separated into its single colours by a holographic grid mounted on the bottom of the module and detected by a 256 channel photodiode array.

Fig.2 MMS spectrometer without mounted photodiode array

All required signals for controlling the photodiode array and data read-out are generated and controlled within highly miniaturised electronic boards, developed by TriOS. Special emphasis was put on an ultra-low power consumption, to allow long-term operations powered by batteries. A low-power microcontroller builds the digital interface and the central controlling unit. A built-in command controller, implemented in all TriOS sensors, allows user setting of sensor configuration, baud-rate, power management and many others. Via a query command, the software (MSDA_XE) can identify the serial number and the sensor type of the connected unit.

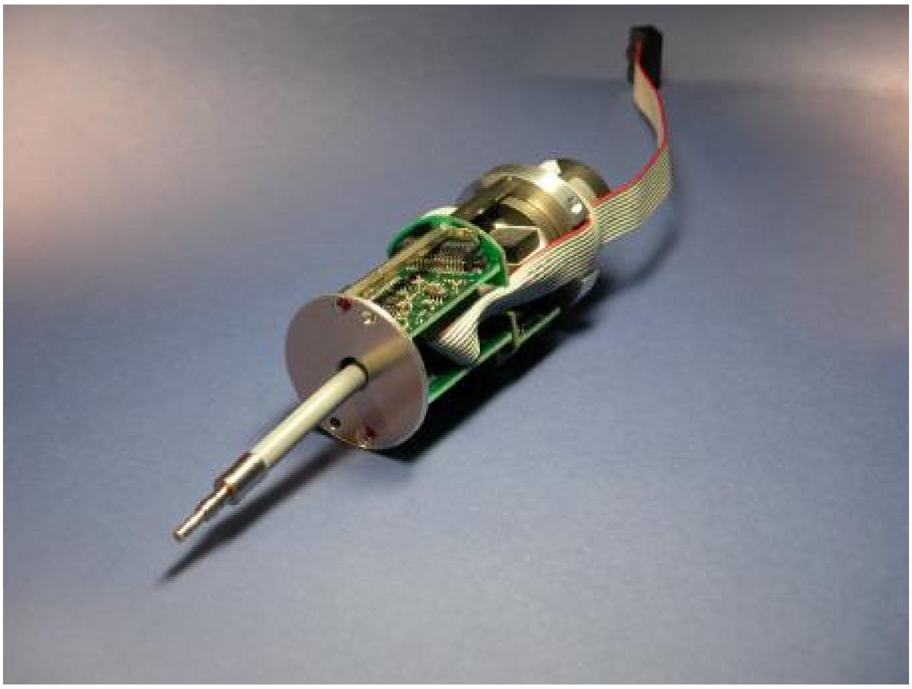


Fig.3 miniSpec-VIS: spectrometer with operation electronic

Dark current handling

An essential point for a precise measurement of light in the nature is an accurate handling of the dark current of the detectors, which is in normal operational conditions mostly influenced by temperature and the actual selected integration time. Additionally care has to be taken on the temperature behaviour of the connected electronics.

The most common way of handling this, is the use of a shutter in front of the fibres to perform in a certain time intervals dark spectra. Beside the sampling time required for this 'extra' spectra, the main disadvantage is the shutter itself. As this is a moving part inside the sensor, it represents a source of malfunctioning on a long-term scale.

A more effective way to monitor the dark currents and electronic drifts is the use of 'blacked' diodes. This means, that during the manufacturing process of the spectrograph a couple (e.g. 20-30 diodes, depending on the type of the spectrograph) of the 256 photodiodes (pixel) are predicted from light detection by a black sheet in front of them. The VIS version of the RAMSES hyperspectral radiometers are using the infrared part of the spectrum (above 950nm) for this purpose.

Typical observed dark current spectra are shown in Fig.4 for all available integration times of the RAMSES sensors. The 'spectral' signature on the dark currents is due to small variations in the active area of the single diodes in the array caused in the production process. As this is constant, it can be used as a 'fingerprint' of the individual spectrograph, which stays stable with time and ambient conditions. The effect of the 'blacked' pixels (further on named 'dark pixel') on a raw spectrum taken from a halogen light source is shown in Fig. 5. The structure of the spectrum is caused by the holographic grid.

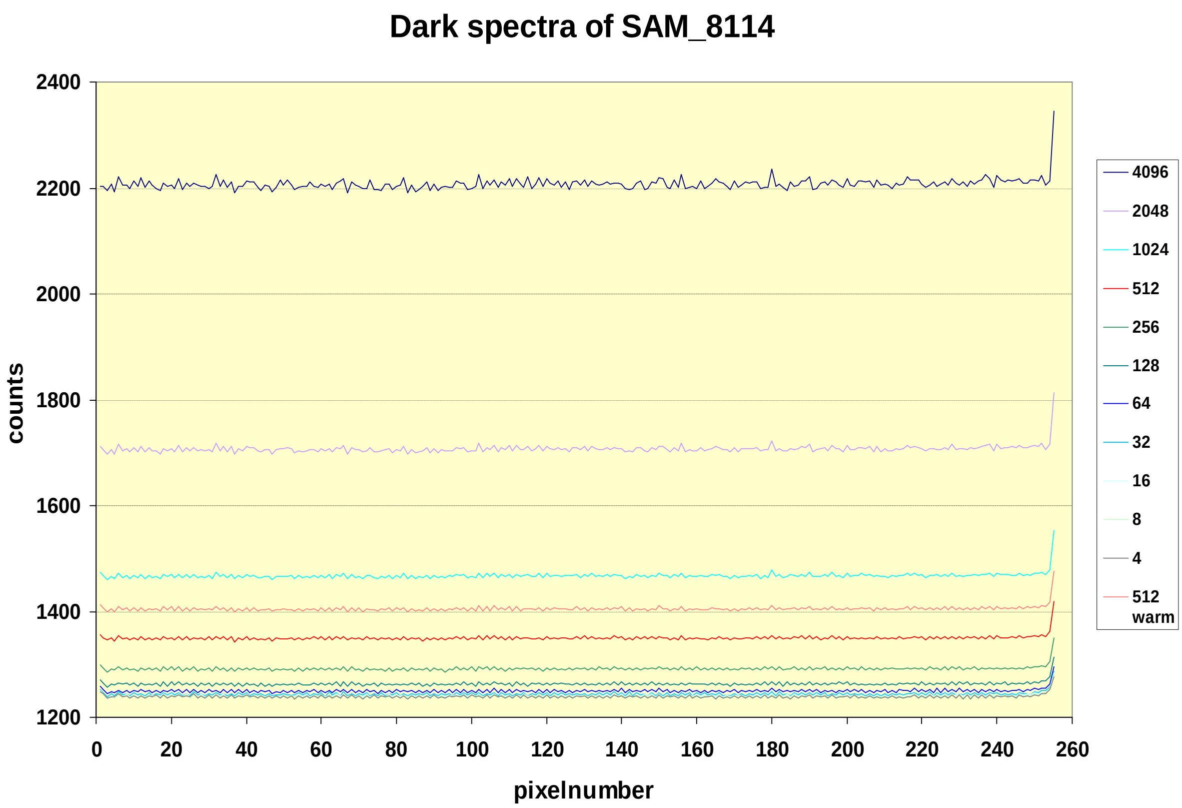


Fig.4: dark current spectra for various integration times from 4ms to 4,096 ms. The 512ms spectra is shown for two different temperatures to demonstrate the effect of ambient temperature on the readings.

The relation between dark current and integration time shows a linear behaviour. In total, the use of dark pixel in combination with the knowledge of the fingerprint and the linear behaviour against the integration time, a proper dark current subtraction can be done within every sample. Both required information are measured during the calibration process and are delivered together with the spectral sensitivity information (ref. data processing/calibration) as device files with the instruments.

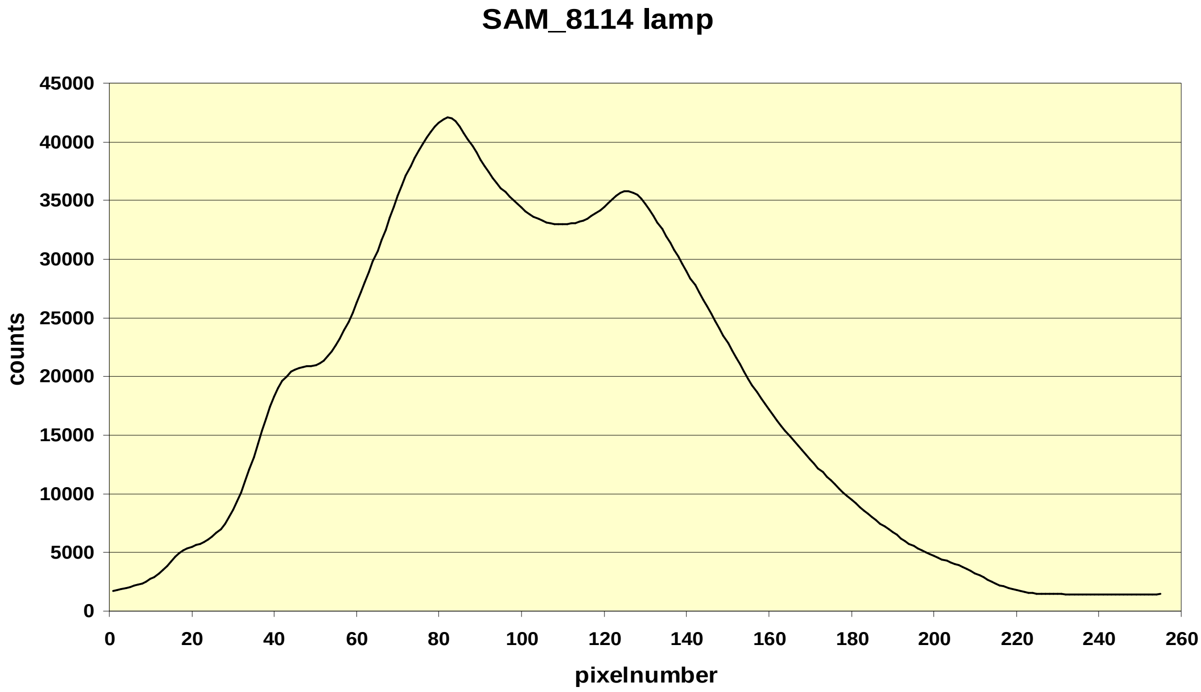


Fig. 5 Raw spectrum of a halogen lamp. Pixels above 230 are 'dark pixel'.

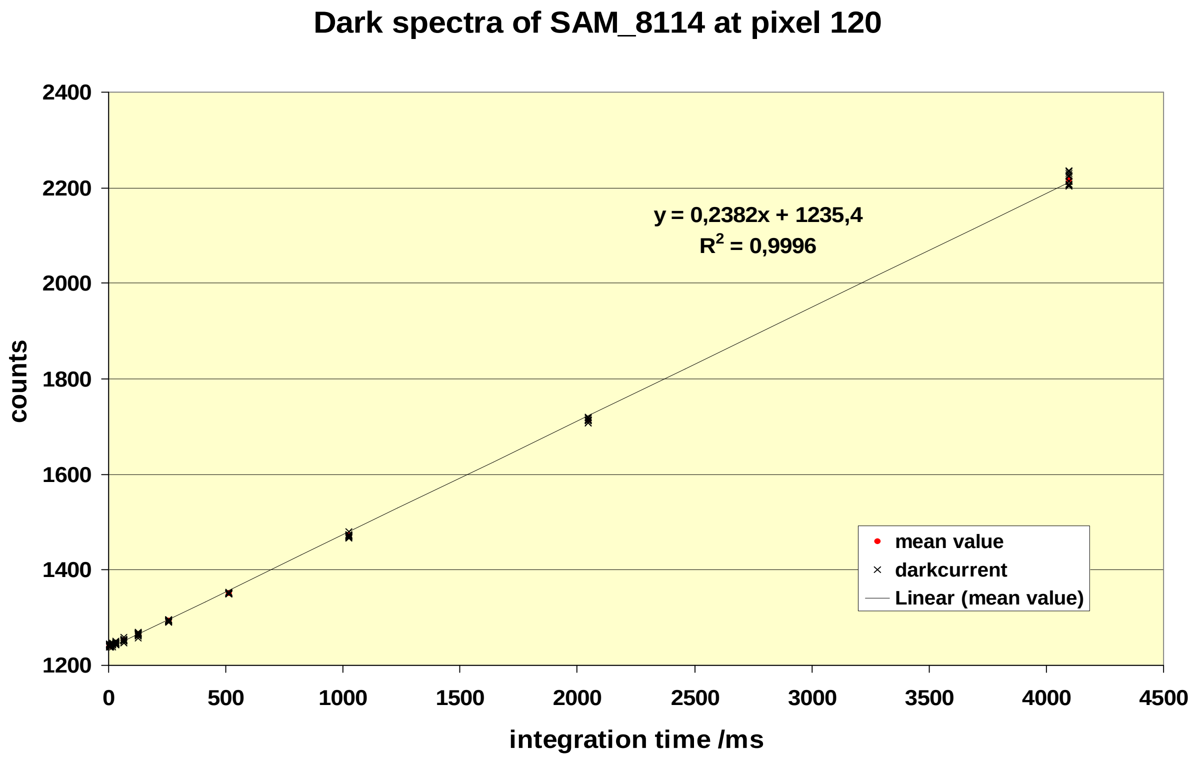


Fig. 6 Linear behaviour of dark current versus integration time for a single pixel

Wavelength relation

The wavelength is calibrated by Carl Zeiss Jena GmbH during the manufacturing process of the spectrograph. It is given as a function of pixel number N=1 to 255, respectively. The function λ (N+1) is fitted by polynomials of 3rd order:

$$\lambda\,(N+1) = C0s + C1s \cdot (N+1) + C2s \cdot (N+1)^2 + C3s \cdot (N+1)^3$$

Data Processing

Data conversion and normalization

The binary data from the sensor are 16-bit unsigned integer data of the interval [0..65535].

They are divided by 65535 to get floating point data from the interval [0.0 .. 1.0]. These are called "raw data" in the following processing steps.

Offset subtraction

The background data and electronical offset are subtracted from the raw data. The background data is supplied together with the sensor in the file BACK_SAM_xxxx.dat. The electronical offset is determined from blackened pixels at the end of the diode array.

The background data file either can contain one single data column B or alternatively two data columns B_0 and B_1. In the second case the background is calculated according to the equation

$$B = B_0 + t/t_0 \cdot B_1$$

whereas t is the integration time derived from the range setting (4 ms .. 8192 ms) and t_0 = 8192 ms is a normalisation factor.

Range scaling

Data are normalised to a range setting of t_0, i.e. data are scaled by a factor $k = t_0 / t$ (<range>)

Spectral calibration

The spectrum is divided by the sensitivity function of the sensor and data is converted to physical units (Power scale / quanta scale), either mW / (m^2 nm) respectively µmol / (s m^2 nm) for the irradiance sensors or mW / (sr m^2 nm) respectively µmol / (s sr m^2 nm) for the radiance sensors.

The sensitivity function is derived from measurements with a calibrated lamp and supplied together with the sensor in the file CAL_SAM_xxxx.dat

Summary for MSDA_XE data processing step 1..3

I (n)	n=1..256	16-bit unsigned integer data from the sensor
M (n)	n=1..256	Floation point raw data [0.0 .. 1.0] (exported Raw Data)
B (n)	n=0..255	Background data file (one data column, BACK_SAM_xxxx.dat by default)
B_0(n), B_1(n)	n=0..255	alternatively: Background data file (two data columns, BACK_SAM_xxxx.dat by default)
S (n)	n=0..255	Sensitivity data file (CAL_SAM_xxxx.dat by default)
t		Integration time t = $2^{range+1}$ ms, range= M(0) i.e. [1..12] <=> t = 4 ms .. 8192 ms
t_0		8192 ms

Data conversion and normalisation

M(n) := I(n) / 65535

Background subtraction

C(n) := M(n) - B(n) n=1..256, if 2 column background data are available: $B = B_0 + t/t_0 \cdot B_1$

Determination of offset from dark pixels

Offset = Mean(C(i),i=n_1..n_2),

n_1 and n_2 are device properties.

Shift of the spectrum

D(n) := C(n) - Offset n=1..255

Normalization for the integration time

E(n) := D(n) · t_0 / t n=1..255

Sensitivity calibration

$F(n) := E(n) / S(n)$ $\qquad$ $n=1..255$

where $F(n)$ are spectral data calibrated in physical units

Up to this point all data processing have been performed for each sensor element of the detector array.

RAMSES-ARC: hyperspectral radiance

The optical system of the RAMSES-ARC sensor is built by the optical fibre and a lens (fused silica). The field of view (FOV) is defined by the position of the fibre in relation to the focal point of lens. In a standard setup the fibre is fixed in a position closer to the lens then the focal length, in a way giving 7° FOV (full angle) in air. Other FOVs can be realized due to customer requirements during the manufacturing process.

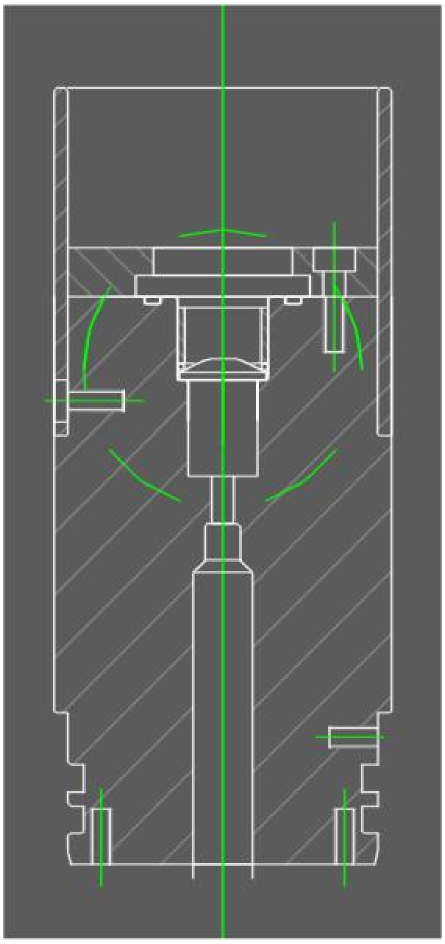


Fig.7 Optical layout of the RAMSES-ARC radiance sensor

The cap in front of the instrument is designed to reduce the influence of spray water for above water measurements. It has no influence on the optical properties of the sensor. For in-water use the cap should be removed.

Note: Remove the spray protection cap for in-water use of the RAMSES-ARC by removing the 3 screws mounted from the side of the cap. Otherwise air bubbles might be staying in front of the window.

RAMSES-ACC: hyperspectral irradiance

Light is collected by a plane diffuser and detected by the fibre. The optical setup is designed in a way, that the angular detection characteristic is following a cosine function. Typical results for various wavelengths are given in Fig. 9. The sensor can be used in-air and in-water. For in-water use, the immersion effect has to take into account. Therefore RAMSES-ACC sensors are delivered with two sensitivity calibration files (one for air and one for water).

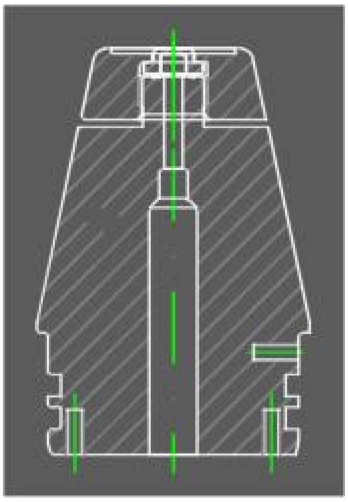


Fig. 8 Optical layout of the RAMSES-ACC irradiance sensor

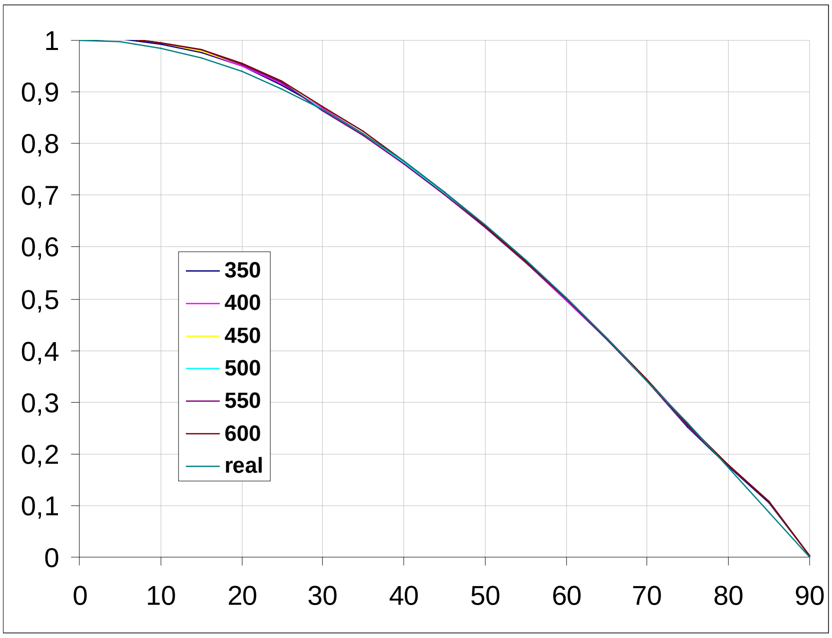


Fig. 9 Typical cosine characteristic of RAMSES-ACC irradiance sensor for various wavelengths and the theoretical function.

Note: The cosine collector is made out of a special fused silica. Take care of mechanical damages, as this is a brickle material. The collector is resistant against the most known solvents used for cleaning (like acetone).

RAMSES-ASC: hyperspectral scalar irradiance

The RAMSES-ASC uses a spherical diffuser instead of the planar one of the RAMSES-ACC. Therefore the detection characteristic is not a function of the incident angle of the light. The simultaneous use of 2 RAMSES-ASC sensors, one in upward and one in downward orientation results in a precise 4Pi scalar irradiance detection.

Operation

All RAMSES radiometer are delivered with a SUBCONN-5pin underwater connector. To use, plug the interface cable's (PUR-SUB-M8/xx m) in-line connector into the bulkhead connector on the RAMSES by carefully aligning pins of the bulkhead connector with the sockets on the in-line connector.

Fig.10 Mounting of the underwater connector

Next turn the locking-sleeve clockwise to tighten in-line connector on the bulkhead connector.

Fig.11 Use of the locking sleeve

Note: When connecting and disconnecting connectors, do not rock connector back and forth. Mate connectors straight and use locking sleeve to tighten pin contact. When disconnecting, hold onto in-line connector and pull straight out.

The connection of the other end of the cable depends on the type of controlling system you are using.

Use with power supply and PC

For every application there a PC can be used as a controlling device e.g. in the lab, the use of a power supply PS101+ (85..265VAC/12VDC) or PS201+ (85..265VAC/24VDC) is a reliable solution. The front panel of the unit includes 3 LEDs. The green one indicates that the system in powered. The other two yellow LEDs are indicating the status of the RS232 lines. The CMD LED monitors the PC connection and activities, the DATA LED monitors the connected sensor line. Both show the following functionality:

- off: no sensor/PC connected, (or maybe a damage or error in the cable)
- half-power: sensor/PC connected, no data transfer
- full-power: data are transmitted

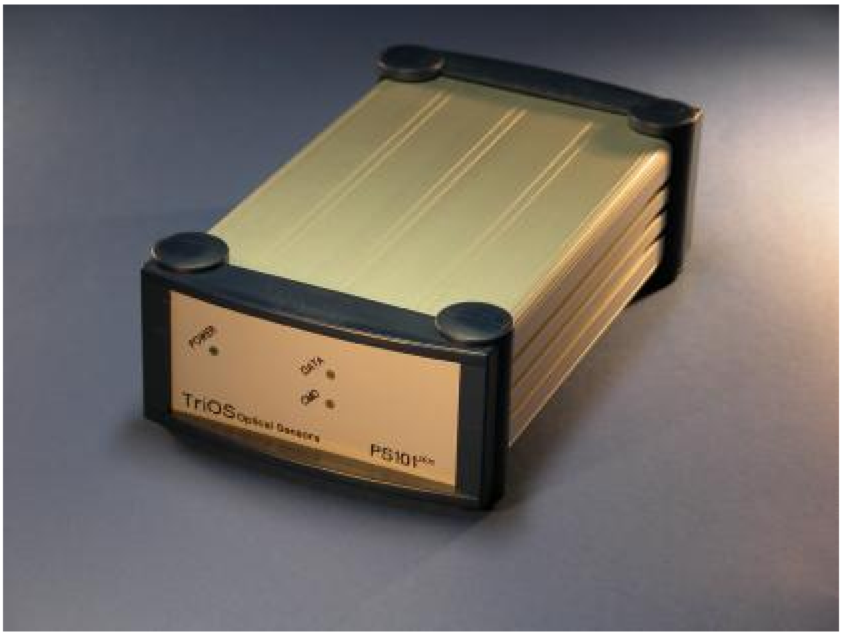


Fig. 12 PS101 power supply

The sensor is connected to the PS101+/PS201+ units via the M8 industrial connector mounted on the sensor connection cable. Take care during the mounting that the pins are aligned with the sockets.

PC connection is done via a RS232 9pin connector. A matching cable is delivered with the power supply. Connect the other side of the cable to the serial port of your PC. Special adapters for USB interfacing are available from TriOS.

Use the delivered line connector to supply line voltage to the unit. All PS101+/PS201+ units have a built-in AC/DC converter. Input voltages between 85..265VAC (50..60Hz) are accepted.

Fig. 13 Connecting the PS101 unit

Install the MSDA-XE software on your PC system. Refer to the MSDA-XE manual for further instructions.

Use with IPS104 and PC

The use with the IPS104 interface and power supply units is very similar to the use with the PS101 single channel unit. IPS units are available either in 2, 3 or 4 channel versions, for simultaneous operation of several sensor. The MSDA-XE software will recognize automatically the actual configuration and the connected sensors.

The CMD-LEDs are here not indicating the connection of the PC, but indicates the operation of the assembled interfaces for the sensors (e.g. CMD-LED of Ch 4 will not be on if you are operating a 2 or 3 channel version). Flashing CMD-LEDs are indicating that commands are send to the sensors by the controlling unit (e.g. PC).

To increase the number of simultaneously connected sensors, IPS104 units can be 'stacked'. This means, that on every sensor channel on an IPS104 unit another IPS104 unit can be connected. This could be repeated for up to 4 levels, allowing to connect more than 200 sensors at once.

Fig. 14 'stacking' of the IPS104 units to increase the number of connected sensors

Use with underwater IPS unit

The underwater IPS unit offers the possibility to use only one long cable to connect several TriOS sensors to the PC in profiling applications. The unit is powered either by a PS101 power supply or an IPS104 unit.

TriBox2 connection

TriBox2 is an on-line display and controlling system for fixed stations, e.g. environmental monitoring stations, industrial plants, etc. It allows the connection of two sensors (in the standard settings), offers data-logging functionality, various type of interfaces (e.g. 4..20mA, network, USB, GSM modem). Please refer to the TriBox2 manual to obtain how to connect the sensor to the interface box. The connector on the TriBox2 side is a M12 industrial connector. The needed cable for the RAMSES connection is PUR-SUB-M12 / xx m.

Mounting

TriOS is offering various frames for different applications. Please refer to our website www.trios.de to select the most suitable one for your application. In other cases, we are suggesting the use of clamps of similar type like the ones shown in Fig. 15 (TriOS ordering codes CL-48 or CL-48R).

Fig.15 Recommended mounting clamps

Note: When submerging the sensor, visually inspect the optical window for bubbles. If bubbles are present, gently rock the instrument from side to side until the bubbles are dislodged.

Cleaning/Servicing

Depending on the actual type of application, a cleaning of the optical window should be performed on a regular basis to obtain reliable readings. Its strongly recommended to rinse the instruments after every use with fresh water to avoid corrosions and damages.

First step of the cleaning process should be to rinse the sensor with freshwater to remove mud and particles. Use a clean tissue to dry the window afterwards.

To prevent the system from damages, we are recommending to use the parts included in the 'optical cleaning set' from TriOS and to follow the supplied instructions. This set includes a proven solvent, optical tissues and a special tool for handling. The use of other solvents might damage the material. Damages caused by an improper cleaning are out of warranty.

In addition to the cleaning, a regular visual inspection of the instruments for damages should be performed by the operator.

Calibration

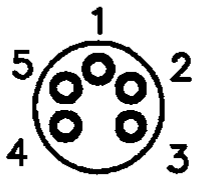
The RAMSES radiometers are delivered with corresponding calibration files (and background files) and a calibration certificate. The factory calibration is performed following the NIST standards. For a more detailed description of the calibration process refer to the corresponding chapter in the RAMSES calibration certificates.

The sensors show an excellent long-term stability. Nevertheless we are strongly recommending a factory re-calibration and check-up once a year to guarantee the specified characteristics.

A user check of the calibration can be done using the TriOS FieldCAL unit with its corresponding software. This is not a replacement for a high-quality re-calibration with a NIST lamp, but allows user check instrument functioning in the field.

Connectors

RAMSES devices are delivered with a SUBCONN-Micro 5 pin male connector (stainless steel or titanium version).

RS 232 interface	
 Male Face View	1. Ground 2. RS232 RX (commands) 3. RS232 TX (data) 4. Power 5. Battery power (only for TriOS DSP data logger and battery pack)

For a proper operation please use only original TriOS connection cables (ordering code: PUR-SUB-M8/xx or similar) and accessories.

Software

Please refer to the MSDA_XE software user manual.

Warranty

Warranty time is 2 years following the date of invoice. Excluded from warranty are all parts of the instrument which are normal consumables, e.g. light sources. Warranty is bounded to a proper use of the instrument and accessories, e.g.

- The instrument and attachments must be installed, powered and operated in compliance with the directions in this manual.
- Damages resulting from contact with incompatible materials, fluids or gases (e.g. corrosive, acid or solvent materials, fluids or gases) is not covered.
- Damage incurred by shipment is not covered.
- Damage by improper treatment by the customer is not covered.

- o Damage by modification of the instrument or mounting improper parts by the customer is not covered.
- o Do not open the instrument!

We strongly recommend a factory check-up and (if required) a re-calibration once per year.

Contact information

We are always working to improve our products. Please check our website for updates.

You have found an error in this instrument/program, or you would like to see some additional features enabled in a future version?

Feel free to contact us at: support@trios.de

General request / sales: info@trios.de

Our website: www.trios.de

TriOS Mess- und Datentechnik GmbH
Bürgermeister-Brötje-Str. 25
D-26180 Rastede
Germany

fon: +49 (0) 4402 69670-0
fax: +49 (0) 4402 69670-20