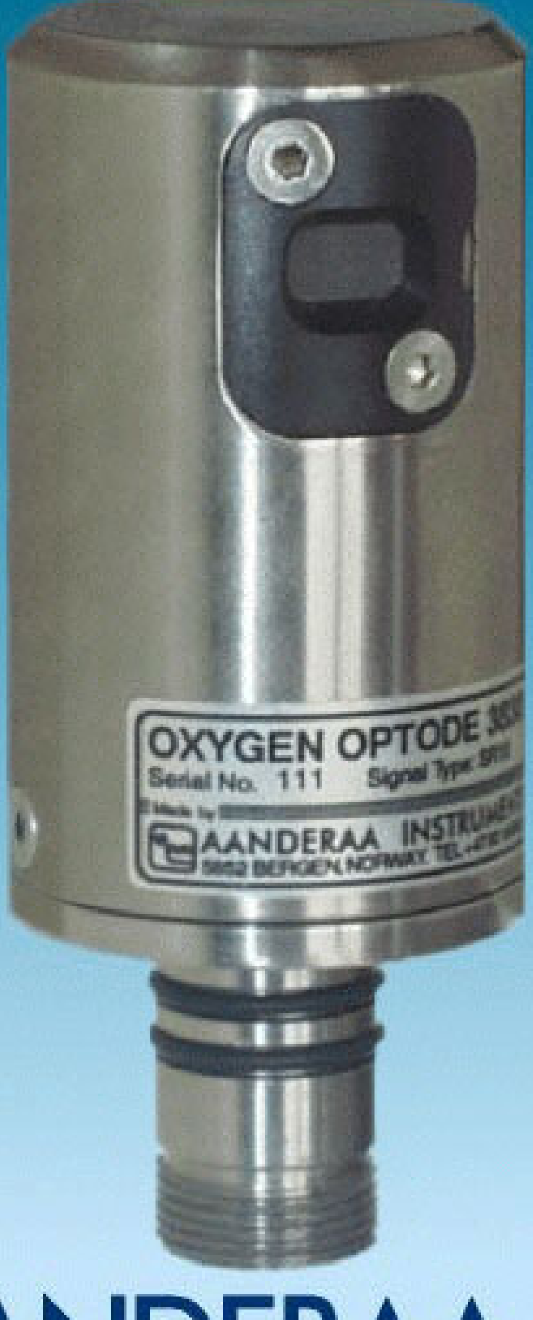
TD 218 Operating Manual
Oxygen Optode 3830 and 3930



AANDERAA
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1st Edition	29	April	2002		
2nd Edition	24	June	2002		
3rd Edition	09	July	2002	*Sensor diameter corrected, was Ø31mm now Ø36mm*	
4th Edition	08	September	2002	*Specifications revised*	
5th Edition	09	September	2002	*CHAPTER 5 Software - After approximately 20seconds …*	
6th Edition	30	January	2003	Oxygen Calculation, RS-232C Protocol, Calibration, Sensing Foil Kit 3853, Communication with the 3930	
7th Edition	08	August	2003	settling time reduced to 7 seconds	
8th Edition	21	August	2003	p.3	new content page
				p.7	new drawing and new text 3rd paragraph
				p.8	new drawing
				p.15	4th paragraph
				p.16	RS-232C Protocol moved to Chapter 5
				p.19	new Chapter 6 Oxygen Calculation 1st equation revised
				p.21	new drawing
				p.22	new drawing V8392 Sensor Foot
				p.33	point 4, revised equation examples of changing foil coefficients
8th Edition	25	August	2003	p.17	new property "*AnCoef" introduced*
				p.18	new section Output Control
				p.34	"Example of changing foil coefficients" corrected
9th Edition	27	August	2003	p.31	updated Test and Specifications Sheet
				p.32	new last paragraph and revised equations
				p.33	new fist paragraph and revised equations
				p.35 - 40	updated Calibration Sheets

CONTENT

INTRODUCTION

Purpose and scope

This document is intended to give the reader knowledge of how to operate, calibrate and maintain the Aanderaa Oxygen Optode 3830 and Oxygen Optode/Temperature Sensor 3830. It also aims to give insight in how the sensors works.

Since oxygen is involved in most of the biological and chemical processes in aquatic environments, it is the single most important parameter needing to be measured. Oxygen can also be used as a tracer in oceanographic studies.

For environmental reasons it is critical to monitor oxygen in areas where the supply of oxygen is limited compared to demand e.g.:

- In shallow coastal areas with significant algae blooms
- In Fjords or other areas with limited exchange of water
- Around fish farms
- In areas interesting for dumping of mine or dredging waste

Document Overview

The document starts by giving a short description of the physical principle behind the Oxygen Optode.

Subsequently a description of the optical, electronic and software design are presented.

An overview of the mechanical design follows, followed by a description of the test and calibration procedures and finally maintenance and an appendix of useful information.

Applicable Documents

V-8278	Assembly Drawing Oxygen Optode 3830
v-8392	Sensor Foot for Optode Sensor
V-8775	Assembly Drawing Oxygen Optode/Temperature Sensor 3930
V-8699	Sensor Cable 3854
V-8700	Sensor Cable 3855
Form 620	Test & Specification Sheet, Oxygen Optode
Form 621	Calibration Certificate, O^2 Sensing Foil 3853
Form 622	Calibration Certificate, Oxygen Optode 3830
D335	Data sheet

References

Garcia and Gordon, Limnology & Oceanography 37(6), 1992,1307-1312

Abbreviations

O_2	Oxygen molecule
LED	Light Emitting Diode
ADC	Analog to Digital Converter
DSP	Digital Signal Processor
EPROM	Erasable Programmable Read Only Memory
ASCII	American Standard Code for Information Interchange
MSB	Most significant bit
UART	Universal Asynchronous Transmitter and Receiver
RTC	Real Time Clock

Fig. 0.01 Oxygen Optode 3830 mounted on an RCM 9 MkII

CHAPTER 1 Short Description and Specifications

Description

Since oxygen is involved in most of the biological and chemical processes in aquatic environments, it is the single most important parameter needing to be measured. Oxygen can also be used as a tracer in oceanographic studies.

For environmental reasons it is critical to monitor oxygen in areas where the supply of oxygen is limited compared to demand e.g.:
· In shallow coastal areas with significant algae blooms
· In Fjords or other areas with limited exchange of water
· Around fish farms
· In areas interesting for dumping of mine or dredging waste

The Oxygen Optode 3830 is based on the ability of selected substances to act as dynamic fluorescence quenchers. The fluorescent indicator is a special platinum porphyrin complex embedded in a gas permeable foil that is exposed to the surrounding water. A black optical isolation coating protects the complex from sunlight and fluorescent particles in the water.

This sensing foil is attached to a sapphire window providing optical access for the measuring system from inside a watertight titanium housing.

The foil is excited by modulated blue light, and the phase of a returned red light is measured (see illustration overleaf). By linearizing and temperature compensating, with an incorporated temperature sensor, the absolute O2 concentration can be determined.

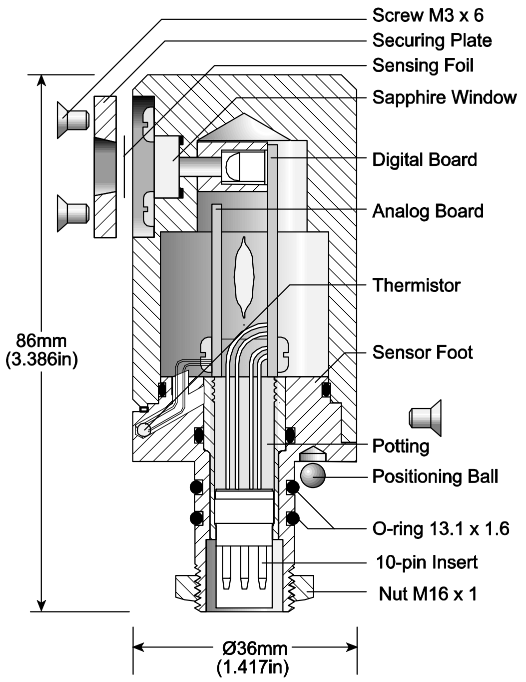
The Optode outputs data in both RS-232C and Aanderaa SR10 format. On the RS-232C output both the absolute oxygen content in micro molar (µM) and the relative air saturation in % are available. The SR10 output can be configured to present oxygen content in µM or air saturation by connecting the sensor to a PC.

The lifetime-based luminescence quenching principle offers the following advantages over electrochemical sensors:

- Not stirring sensitive (it consumes no oxygen)
- Less affected by fouling
- Measures absolute oxygen concentrations without repeated calibrations
- Better long-term stability
- Less affected by pressure
- Pressure behaviour is predictable
- Faster response time.

The sensor is designed to operate down to 6000 meters. It fits directly on to the top end-plate of Recording Current Meters RCM 9, RCM 11 and other Aanderaa instruments.

Specifications Oxygen Optode 3830

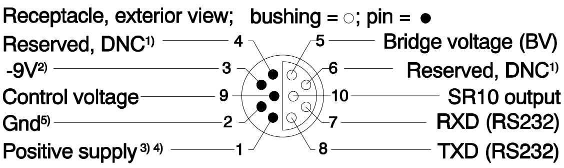


	Output Setting:	
	O_2 Concentration	Air Saturation
Measuring Range:	***0-500 µM [1]***	***0 - 120%***
Resolution:	***< 1 µM***	***< 0.4%***
Accuracy:	***< 8 µM or 5%[2]*** whichever is greater	***< 5%[2]***
Settling Time (63%):	***7 seconds***	
Operating Temperature:	***0 - 40°C (32 - 104°F)***	
Operating Depth:	***0 - 6000m (19,690ft)***	
Sampling Interval:		
SR10 Operation:	***SR10 controlled by Datalogger***	
RS-232C Operation:	***From 2 seconds to 255 minutes***	
Output Formats:	***Aanderaa SR10*** ***RS-232C (9600 baud, 8 data bits, 1 stop bit, No parity, Xon/Xoff Handshake***	
Electrical Connection:	***10-pin receptacle mating plug 3216A***	
Current Consumption:		
SR10 Operation:	***13 mA/T where T is recording interval in minutes***	
RS-232C Operation:	***110mA/S +0.3mA where S is the recording interval in seconds***	
Supply Voltage:		
SR10 Operation:	***-6 to -14 Vdc***	
RS-232C Operation:	***+5 to +14Vdc***	
Dimensions:	***Ø36 x 86 mm (Ø1.42 x 3.386in)***	
Weight:	***0.230kg (8.113oz)***	
Materials:	***Titanium, Hostaform(POM)***	
Warranty:	***Two years against faulty material and workmanship***	
Accessories included:	***Sensor Cable 3854***	
(not included):	***Sensor Cable 3855 to PC*** ***Foil Service Kit 3853 MPST1***	

[1] O_2 concentration in micro Molar = µ mol/l
To obtain mg/l divide by 31.25.
[2] Valid for 0 to 2000m (6562ft) depth, salinity 33-37ppt

Specifications Subject to change without prior notice

PIN CONFIGURATION



[1] *DNC: Do Not Connect*
[2] *Supply for SR10 Operation*
[3] *Ground for SR10 Operation*
[4] *Supply for RS-232C Operation*
[5] *Ground for RS-232C Operation*

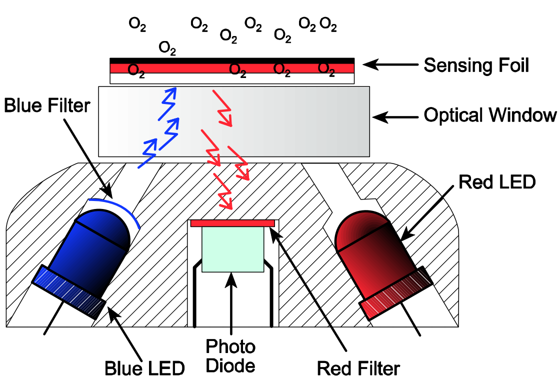
The sensor can be mounted directly on the top end-plate of the Aanderaa RCM 9 or RCM 11 and connected to the Main Control Board (Electronic Board) with a short cable, Sensor Cable 3854.

The Oxygen Optode can also be incorporated into other Aanderaa assemblages such as buoys, handheld profiling systems or hydrological monitoring. For such use a sensor version model 3930 is available.

The 10-pin receptacle in the sensor foot mates with Aanderaa Plug 3216A giving access to RS-232C output. For connection to a Personal computer (PC) the 1.5 meter (4.921ft) Sensor Cable 3855 can be used. It is furnished with a watertight 10-pin plug at the sensor end. An additional USB plug is used for providing power to the sensor.

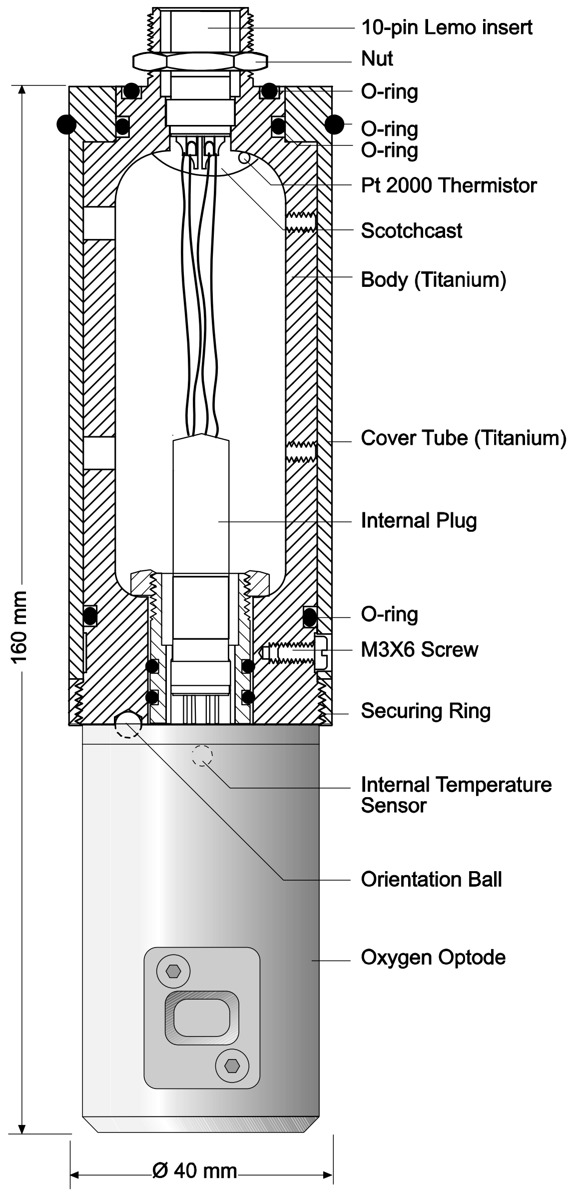
The distance from the PC can be extended to 15 meters by using a Cable Coupler 3472 and a standard Connecting Cable 3282 with watertight titanium plugs.

The Optical System



DATA SHEET D335, AUGUST 2003 **2** ***STATE-OF-THE-ART SCIENTIFIC PRODUCTS***

Specifications Oxygen Optode 3930



	Output Setting:	
O_2: CHANNEL 1	***O_2-Concentration***	***Air Saturation***
Measuring Range:	0-500 µM [1]	0 - 120%
Resolution:	< 1 µM	< 0.4%
Accuracy:	< 8 µM or 5%[2] whichever is greater	< 5%[2]
Settling Time (63%):	7 seconds	
Operating Temperature:	0 - 40°C (32 - 104°F)	

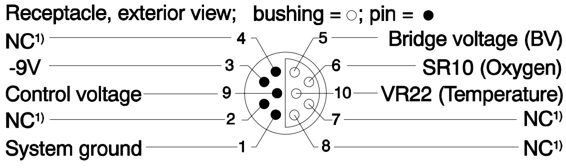
TEMPERATURE: CHANNEL 2	
Range:	– 7.5 to + 41°C
Accuracy:	± 0.1°C
Resolution:	0.05°C
Time Constant (63%):	30s
Operating Depth:	0 - 2000m (6,562ft)
Sampling Interval:	Controlled by Datalogger
Output Formats:	Aanderaa SR10 RS-232C (9600 baud, 8 data bits, 1 stop bit, No parity, Xon/Xoff Handshake (used for configuration and calibration)
Electrical Connection:	10-pin receptacle mating plug 3216A
Current Consumption:	13 mA/T where T is recording interval in minutes
Supply Voltage:	SR10 Operation: –6 to -14Vdc RS-232C Operation:+5 to +14Vdc
Dimensions:	Ø40 x 168mm (OD1.575 x 6.614in)
Weight:	495g (17.5oz)
Materials:	Titanium, Hostaform(POM)
Warranty:	Two years against faulty material and workmanship
Accessories (not included):	Sensor Cable 3855 to PC Foil Service Kit 3853 MPST1

[1] O_2 concentration in micro Molar = µ mol/l
To obtain mg/l divide by 31.25.
[2] Valid for 0 to 2000m (6562ft) depth, salinity 33-37ppt
Specifications Subject to change without prior notice

In order to change settings or calibrating the 3930 Optode Sensor the sensor has to be connected to a PC. To gain access to the Optode's RS-232C signals its cylindrical body must be removed, see the Operating Manual TD218, chapter 9 RS-232C protocol for communicating with the sensor.

PIN CONFIGURATION

Receptacle, exterior view; bushing = ○; pin = ●



[1] *Not connected*

Representatives Stamp

Latest version is on the Internet
PO BOX 160, NESTTUN
5852 BERGEN, NORWAY
NESTTUNBREKKEN 97
5221 NESTTUN, NORWAY
TEL. +47 55 109900
FAX. +47 55 109910
E-MAIL: info@aanderaa.no
WEB: http://www.aanderaa.com

CHAPTER 2 Theory of Operation

The Oxygen Optode is based on a principle called dynamic luminescence quenching.

This phenomenon is the ability of certain molecules to influence the fluorescence of other molecules.

Dynamic Luminescence Quenching

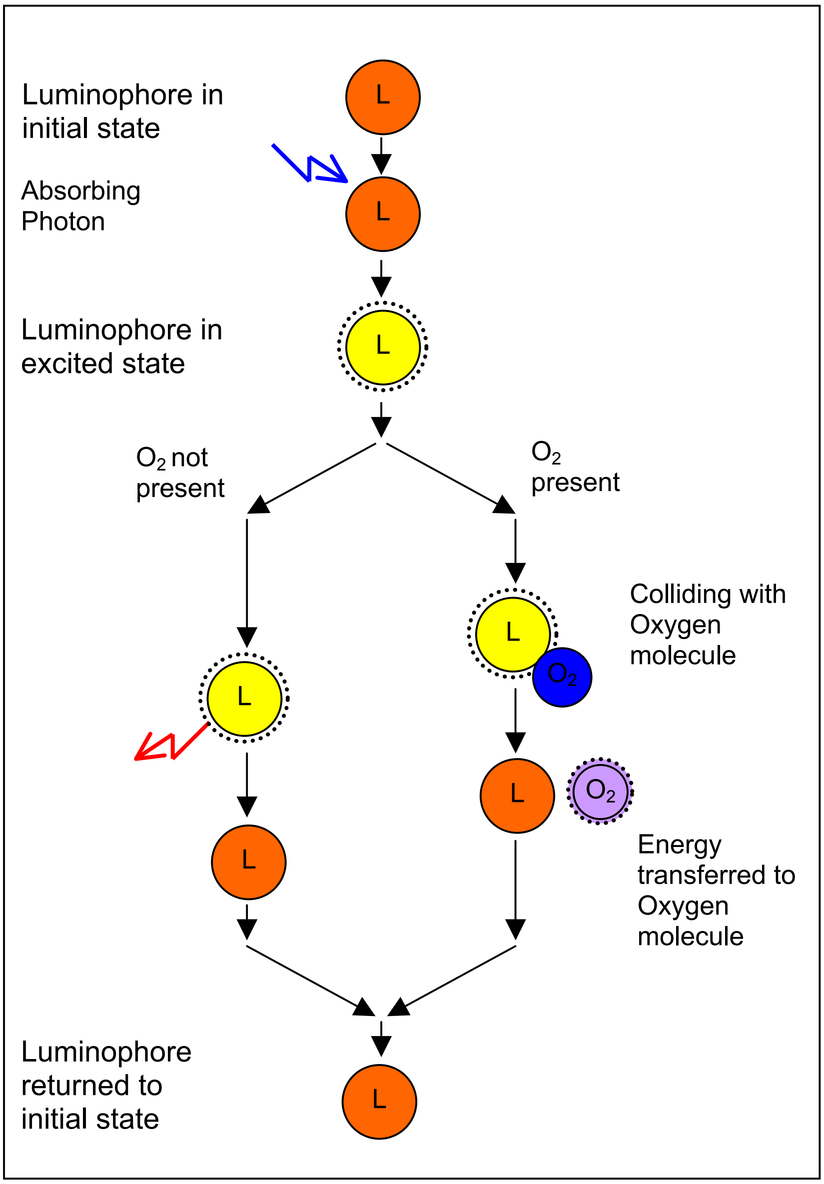


Fig. 2.01 Dynamic Luminescence Quenching

Fluorescence is the ability of a molecule to absorb light of certain energy and later emit light with lower energy.

Such a molecule, called a luminophore, will after absorbing a photon with high enough energy, enter an exited state.

After a while the luminophore will emit a photon of lower energy and return to its initial state.

Some types of luminophores might also return to the initial state when colliding with certain other molecules.

The luminophore will then transfer its excitation energy to the colliding molecule, with the result that no photon is emitted from the luminophore.

This effect is called dynamic luminescence quenching, and in the Oxygen Optode the colliding molecules is O_2.

Sensing Foil

The luminophore used in the Oxygen Optode is a special molecule called platinum porphyrine. These luminophores are embedded in a polymer layer.

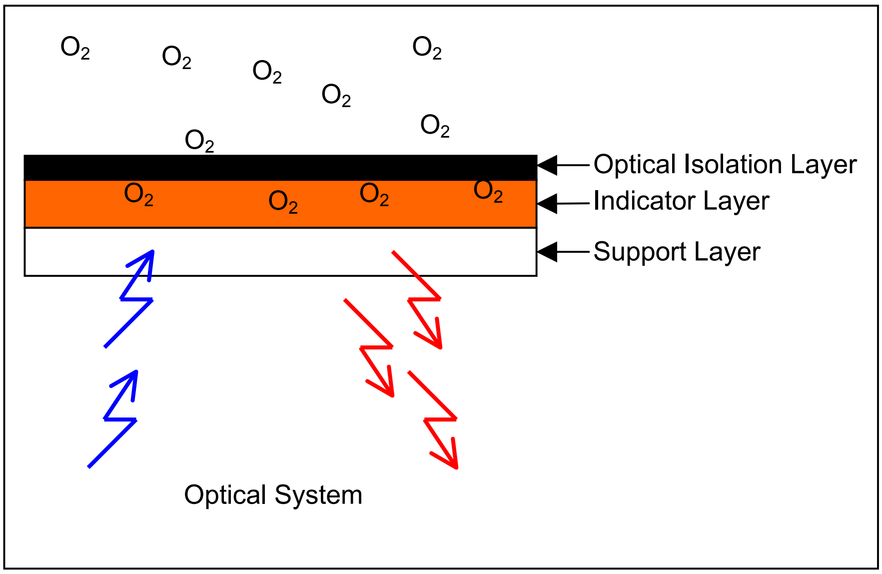


Fig. 2.02 Sensing Foil

This layer, called the indicator layer, is coated on a thin film of polyester support.

To avoid influence from fluorescent material surrounding the sensor or direct incoming sunlight when measuring in the photic zone, the foil is also equipped with gas permeable coating.

The coating gives optical isolation between the indicator layer and the surroundings.

Luminescence Decay Time

Due to its fluorescent behaviour the sensing foil will return a red light when it is excited with a blue-green light (505 nm).

If there is O_2 present this fluorescent effect will be quenched.

The amount of returned light will therefore be dependent on the concentration of O_2 in the foil.

The intensity of the returned light is however not the optimal property to measure since it is dependent on many other factors as i.e. optical coupling or bleaching of the foil.

Since the returned light is delayed with respect to the excitation light, the presence of O_2 will also influence this delay.

This property called luminescence decay time (or lifetime) will also degrease with increasing O_2 concentrations.

The relationship between the O_2 concentration and the luminescence decay time can be described by the Stern-Volmer equation:

$$[O_2] = \frac{1}{K_{sv}} \left\{ \frac{\tau_0}{\tau} - 1 \right\}$$

where:

τ = decay time

τ_0 = decay time in absence of O_2 τ_0

K_{sv} = Stern - Volmer constant (quenching efficiency)

In order to measure this luminescence decay time, the sensing foil is excited with a blue-green light modulated at 5 KHz.

The decay time will then be a function of the phase of the received signal.

In the Oxygen Optode the relationship between the phase and the O_2 concentration is used directly, without calculating the decay time.

The following diagram shows a typical relationship between the phase measurement and O_2 concentration:

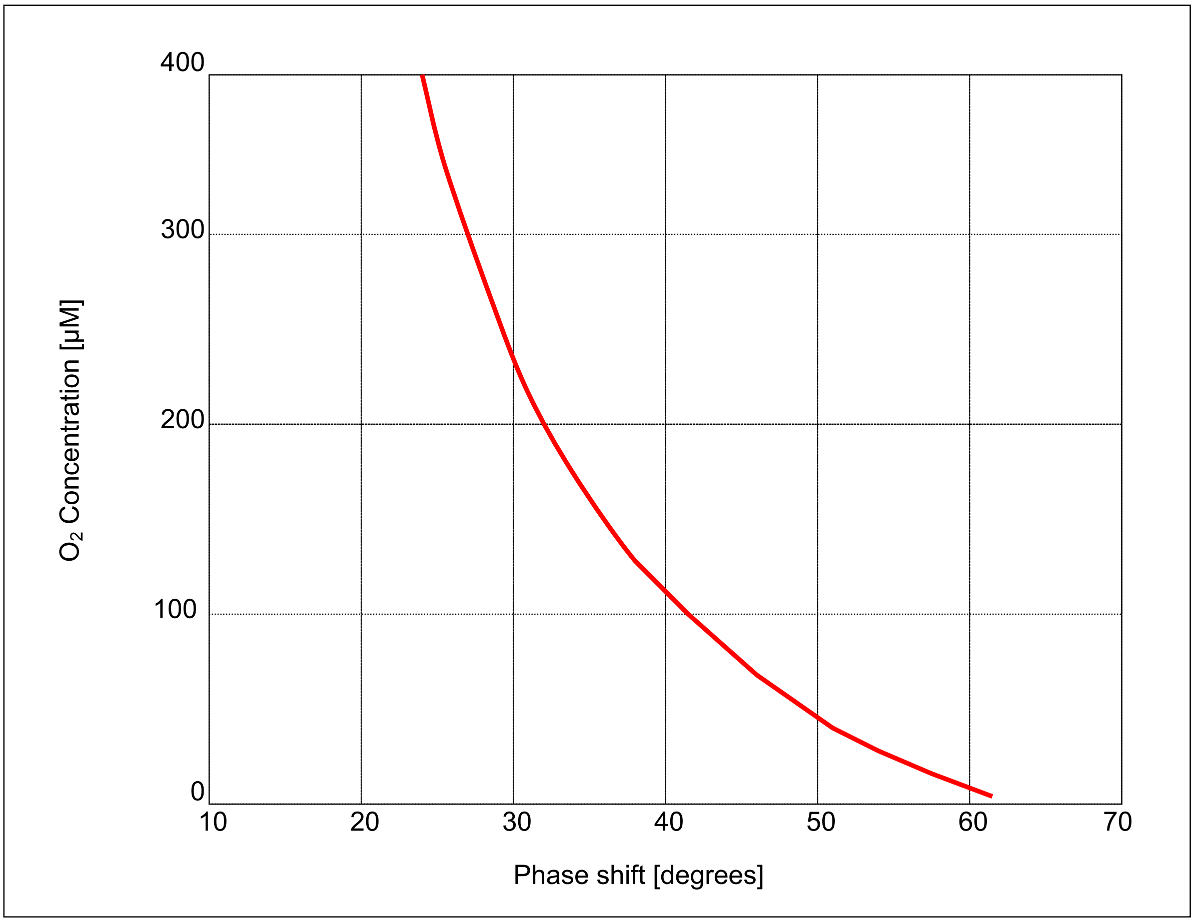


Fig. 2.03 Typical Phase/O_2 response

CHAPTER 3 Optical Design

The sensing foil is mounted outside an optical window, exposed to the surrounding water. On the inside of the window two light emitting diodes (LEDs) and a photodiode is placed. A blue-green LED is used for excitation of the foil and the photodiode is used for sensing the fluorescent light.

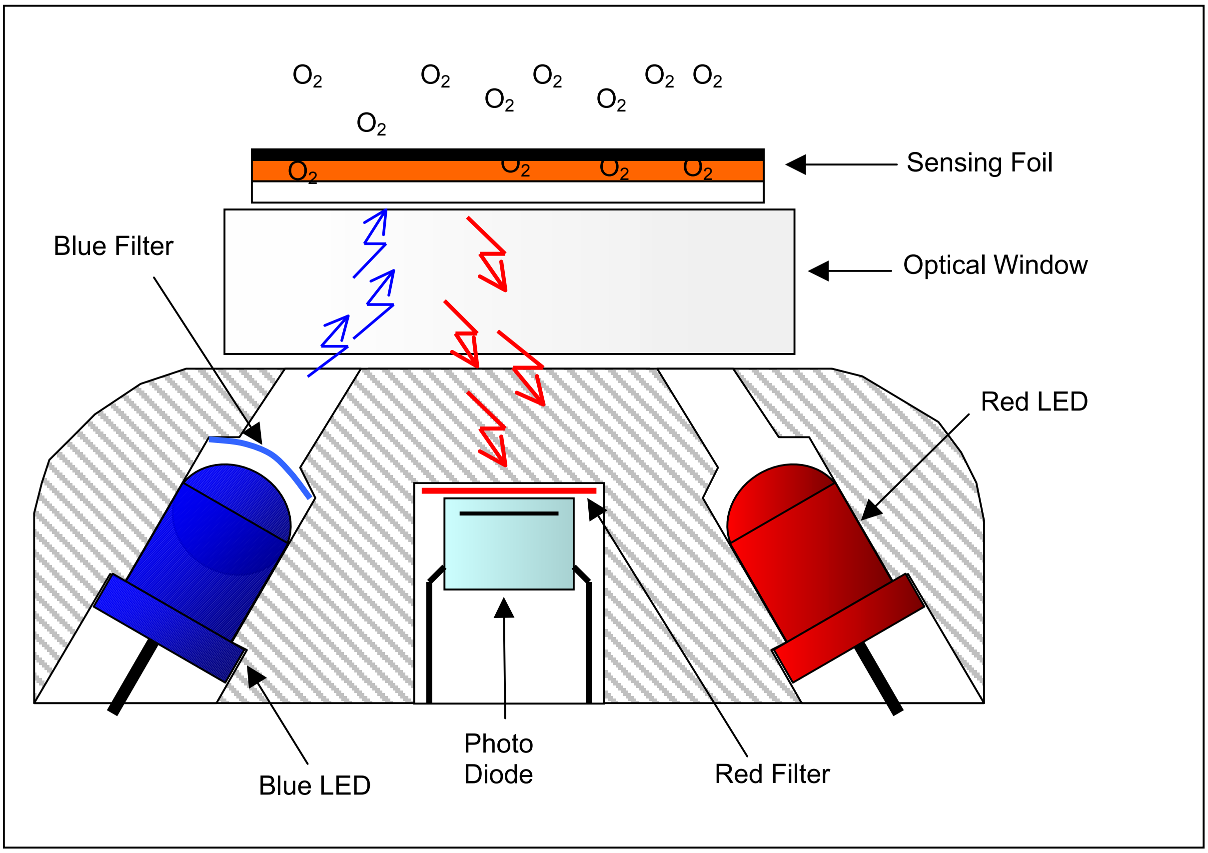


Fig. 3.01 Optical Design

Even thought the sensing foil is highly fluorescent a part of the light will be directly reflected. To minimize the influence of the reflected light the photo diode is equipped with a colour filter that stops light with short wavelengths and the blue-green LED is equipped with a filter that stops light with long wavelengths.

An additional red LED that does not make the foil emit fluorescent light is used to compensating for phase shift in the transmitter and receiver circuit.

The spectral response of the LEDs and the filter are illustrated in the following diagram.

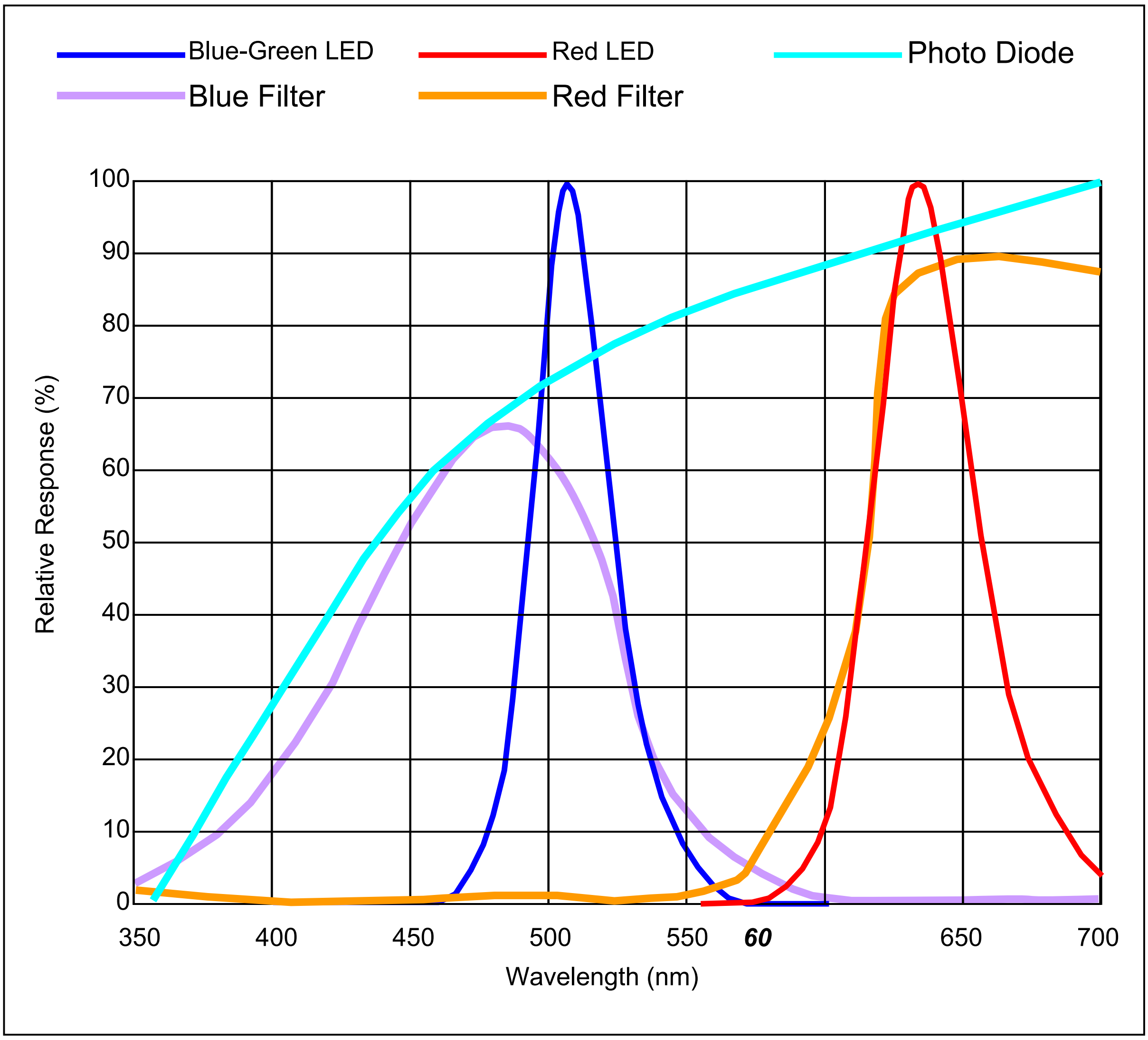


Fig. 3.02 Spectral Response

CHAPTER 4 Electronic Design

To obtain good oxygen measurement; the electronic circuit must be able to measure the phase between the excitation signal and received signal accurately and with good resolution.
The received signal is sampled with a frequency 4 times the excitation frequency. From these samples two signal components with a phase difference of 90 degrees is extracted. The phase of the received signal can then be calculated by an arcos tangents function of the two components.

Linearizing and temperature compensating the phase measurement enables calculation of the oxygen concentration. The result is presented either as an SR10 or an RS-232C output.
A thermistor thermally connected to the sensor body, provides for the temperature measurement.

The following figure illustrates the main functions of the electronics.

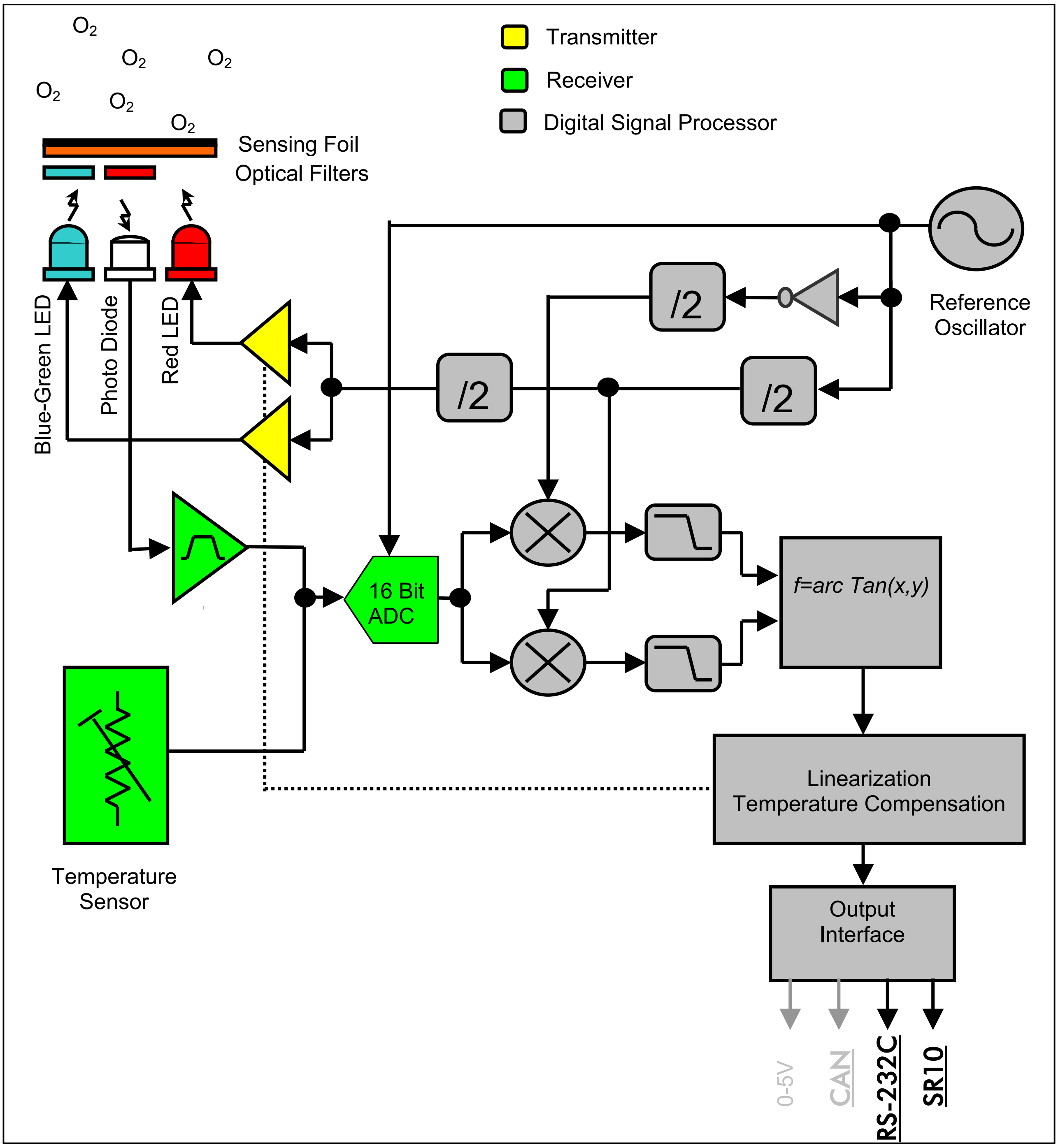


Fig. 4.01 Functional Diagram

CHAPTER 5 Software

The software's main tasks are to control the transmitter, sample the returned signal, extract the phase of this signal, and convert it into oxygen concentration.

All properties that can be changed for each individual sensor, i.e. calibration coefficients, are called sensor properties.

These properties can be displayed and changed using the RS-232C port (see RS-232C Protocol for how to communicate with the sensor).

When powered up; the Oxygen Optode will take an oxygen sample and present the result (within the first 1.5 seconds).

After this, and after each following sample; the RS-232C input buffer is checked for 100 milliseconds.

If the buffer contains any characters the timeout is increased to 1 second and the software starts interpreting the RS-232C input.

If the input buffer is empty the sensor will continue to sample and present data accordingly to the setting of the *Interval* property.

If the *Interval* is set to zero the user can initiate a new sample by use of a **Do_Sample** command. The following drawing illustrates the operation sequence.

After approximately 20 seconds without any valid commando inputs the sensor will enter a sleep mode until the next interval starts.

In sleep mode the sensor will not respond to RS-232C input commands.

However, before entering the sleep mode the sensor stops the host's transmission by sending out a XOFF handshake-control character.

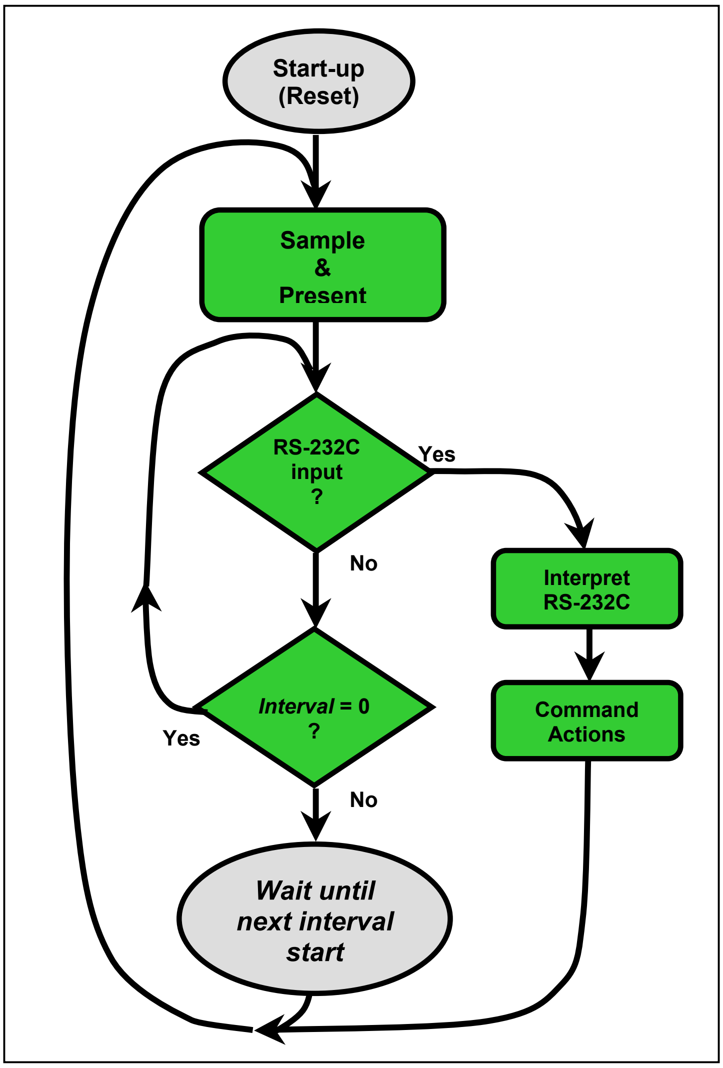


Fig. 5.01 Software, Operation Sequence

After waking up and finishing the next sample, the host transmission is turned on again.

When this handshake method is used the host's output will be buffered until the sensor is ready to receive.

This relieves the host from the need to synchronize the communication with the sensors sampling interval.

When the Optode is connected to a RCM 9 or other Aanderaa Instrument or Logger, the power to the sensor is switched on by the Control Voltage becoming active (initiated by the RCM 9).

The sensor will then take one sample in the start of the recording interval and present this at the SR10 output.

When the logger is finished reading the SR10/VR22 sensors, the Control Voltage is turned off and the Optode sensor is powered down.

RS-232C Protocol

The RS-232C protocol describes how to communicate with the sensor.

For connection to a Personal computer (PC) the 1.5-meter Sensor Cable 3855 can be used.
Most terminal programs, such as the HyperTerminal*) by Hilgraeve Inc (included in Microsoft's operating systems), can be used for manual communication.

The following RS-232C setup should be used:

9600 Baud
8 Data bits
1 Stop bit
No Parity
Xon/Xoff Handshake

*) *Note!*
The options "Send line ends with line feeds" and "Echo line ends with line feeds" in the HyperTerminal setup must be selected.

All communication is ASCII coded with the following rules:

- All inputs to the sensor are given as commands with the following format:
  ***MainCmd**_SubCmd* or ***MainCmd_Property**(Value.., Value)*
- The main command *(MainCmd_SubCmd)* is followed by an optional subcommand *(SubCmd)* or sensor property *(Property).*
- The *MainCmd* and the *SubCmd/ Property* must be separated with the underscore character '_' or a space ' ' character.
- When entering new settings the *Property* is followed by parentheses containing comma-separated values.
- The command string must be terminated by a Line Feed character (ASCII code 10). Termination with Carriage Return followed by Line Feed is also allowed.
- The command string is not case sensitive (UPPER/lower-case).
- A valid command string is acknowledged with the character '#' while character '*' indicates an error. Both are followed by Carriage Return/ Line Feed (CRLF).
  For most errors a short error message is also given subsequent to the error indicator.

The RS-232C protocol describes how to communicate with the sensor. All inputs to the sensor are given as commands with the following format:

The following main commands are available in the Oxygen Optode:

Command	Meaning
Do_*Subcmd*	Execute *Subcmd*
Get_*Property*	Output *Property* value
Get_All	Output all property values
Set_*Property*(*Value*,… *Value*)	Set *Property* to *Value*,… *Value*
Save	Store current settings
Load	Load stored settings
Help	Print help information

In the Oxygen Optode the following subcommands and properties are available:

Subcommand	Function	Write Protection
Sample	Execute an oxygen measurement and presents the result	No
Calibrate	Execute calibration function	Yes
CalAir	Collect calibration data in air	Yes
CalZero	Collect calibration data in zero solution	Yes
Test	Execute a test function and present the result	No

Properties	Type	No. of Elements	Use	Write Protection
Protect	Int	1	Protection of property read and write access	No
PhaseCoef	Float	4	Curve fitting coefficients for the phase measurement	Yes
TempCoef	Float	4	Curve fitting coefficients for the temperature measurement	Yes
FoilNo	Int	1	Foil batch number	Yes
C0Coef	Float	4	Temperature Coefficient in the phase to [O_2] formula	Yes
C1Coef	Float	4	Temperature coefficients in the phase to [O_2] formula	Yes
C2Coef	Float	4	Temperature coefficients in the phase to [O_2] formula	Yes
C3Coef	Float	4	Temperature coefficients in the phase to [O_2] formula	Yes
C4Coef	Float	4	Temperature coefficients in the phase to [O_2] formula	Yes
Salinity	Float	1	Salinity setting	No
CalAirPhase	Float	1	Calibration data in air, phase	Yes
CalAirTemp	Float	1	Calibration data in air, temperature	Yes
CalAirPressure	Float	1	Calibration data in air, pressure	Yes
CalZeroPhase	Float	1	Calibration data in zero solution, phase reading	Yes
CalZeroTemp	Float	1	Calibration data in zero solution, temperature reading	Yes
Interval	Int	1	Sampling Interval in seconds.	No
AnCoef	Float	2	Offset and slope correction coefficients for I2C output to Analog Adaptor	Yes
Output	Char	1	Output setting	Yes

A property may contain one or more equal elements of the type Character, Integer or Float.
The Character type is stored as an 8-bit bit word and may be signed (value –128 to 127) or unsigned (0-256).
The Integer type is stored as a 16-bit word and may be signed (value –32768 to 32767) and unsigned (0 to 65535).
The Float consists of 32-bit and has a range from 1.19209290e–38 to 3.4028235e+38.

The **Get** command is used for reading the value/values of a property.
The command name **Get,** is followed by _*Property* and returns a string on following format:

Property ProductNo SerialNo Value, ..Value

The string starts with the name of the property (*Property*), continues with the product number and serial number of the sensor, and finally the value or values of the property.
All names and numbers are separated by tabulator spacing (ASCII code 9).
The string is terminated by Carriage Return and Line Feed (ASCII code 13 & 10).

Example:

```
         Get_Salinity
Returns: Salinity   3830   116   3.500000E+01
         #
```

A special version, **Get_All**, reads out all available properties in the sensor.

The **Set** command is used for changing a property.

Example:
Set_TempCoef(-124,1.6644E-4, 3.3456E-12,0)
Returns: #

Float values may be entered on normal decimal form or exponential form, either with 'e' or 'E' leading the exponent. Extra "Space" characters in front or after a value are allowed.

When one or more properties are changed, the sensor will start using the new properties.
If the **Save** command is executed the new setting will be stored in the internal EEPROM.
If a **Load** is executed instead, the previous stored setting will be reloaded.

To avoid accidental change, most of the properties are write-protected.
A special property called *Protection* must be set to 1 before changing the value of properties with this write protection.
The *Protection* property always returns to zero after power up or execution of the **Load** or **Save** command.

The **Do_Sample** command or an interval initiated measurement result in one output string containing the obtained data.

Output Control

A property called *Output* controls the presentation of the measured data.

When the *Output* value is different from 0 a comprehensive RS-232C string containing raw data is presented:

```
MEASUREMENT   3830   104   Oxygen:      234.87 Saturation:       104.75
    Temperature:      28.78 DPhase:       7.95 BPhase:        50.37
    RPhase:     38.04  BAmp:        825   RAmp:       4678   RawTem.:   -1146
```

When the *Output* property is set to 0 a normal string with following format is transmitted:

```
MEASUREMENT   3830   104   Oxygen:      234.87 Saturation:       104.75
    Temperature:      28.78
```

If the *Output* is set to 100 or 101 the output string is as for the 0 and 1 setting but with all the text removed.

The leading word, MEASUREMENT, is followed by the sensor's product number and serial number.
All words and numbers are followed by a tabulator spacing (ASCII code 9).
The string is terminated by Carriage Return and Line Feed (ASCII code 13 & 10).

Setting a negative *Output* property value enables either the SR10 outputs or the I2C output to the Analog Adaptor:

Output =	Data on the SR10 output	Unit /scaling coefficients	Data on the Analog Adaptor, Output 1	Data on the Analog Adaptor, Output 2
-1	O_2 Concentration	µM A = 0 B = 0.488281		
-2	O_2 Saturation	% A = 0 B = 0.146484		

-100	Test, fixed reading	777		
-101			O_2 Concentration	Temperature
-102			O_2 Saturation	Temperature
-103			Compensated phase measurement (Dphase)	Temperature
-110			Test, fixed reading 4V/16.8mA	Test, fixed reading 1V/7.2mA
-111			Test, fixed reading 1V/7.2mA	Test, fixed reading 4V/16.8mA

The Analog Adaptor 3966 converts the I2C output to analog 0-5 Volt or 4-20 mA.
The selection between voltage and current output is done by dip switches at the Analog Adaptor board.

All measurements are also presented at the RS-232C port when the analog or the SR10 output is enabled.
After the first sample, additional information about setting and scaling coefficients are presented:

Example:

```
MEASUREMENT   3830      104 Oxygen:           234.87     Saturation:       104.75…....
0-5V  Output 1: Oxygen           1.367 V, use scaling coef. A:= 0.000000E+01 B:= 6.600000E+00
0-5V  Output 2: Temperature      3.766 V, use scaling coef. A:=-5.000000E+00 B:= 8.000000E+00
4-20mA Output 1: Conductivity     6.56 mA, use scaling coef. A:= 1.175000E+01 B:= 2.062500E+00
4-20mA Output 2: Temperature     16.05 mA, use scaling coef. A:=-1.500000E+01 B:= 2.500000E+00
```

Scripting

Often it may be usefully to collect more than one command in a text file. For example the following text can be written in an ordinary text editor and saved as a text file.

// Set sampling interval to 30 seconds
Set_Protect(1)
Set_Interval(30)
Save
Get_All

This file can then be sent to the sensor in one operation. The first line is a comment line that is disregarded by the Conductivity Cell. Strings starting with either '//' or ';' are ignored by the software, and do not produce any errors or acknowledge.

CHAPTER 6 Oxygen Calculation

Oxygen Calculation

The software calculates the engineering values (calibrated oxygen concentrations) based on the sampled raw-data and a set of stored ("flashed") coefficients.

After converting the phase raw data to degrees, a compensated phase difference is calculated as a 3rd-degree polynomial of the difference between the phase measurement with blue light excitation and red light excitation.
The coefficients in this polynomial are called *PhaseCoef.*

The temperature in degrees Celsius (°C) is calculated by use of a similar polynomial with coefficient called *TempCoef*.

The O_2 concentration is calculated in micro Molar (µM) by use of a 4th degree polynominal.

$$[O_2] = C_0 + C_1 P + C_2 P^2 + C_3 P^3 + C_4 P^4$$

where: $C_{0..}C_4$ = temperature dependent coefficients
P = compensated phase difference

Each of the $C_{0..}C_4$ coefficients is calculated by use of a 3-degree polynomial with temperature as argument and the coefficients *C0Coef* and *C4Coef.*

Based on O_2 concentration, temperature and a manual salinity setting, the *Calculate* function also calculates the relative O_2 saturation.

The following formula by Garcia and Gordon [1] gives O_2 solubility (C^*) at standard air mixture and pressure (1013 hPa).

$$\ln(C^*) = A_0 + A_1 T_s + A_2 T_s^2 + A_3 T_s^3 + A_4 T_s^4 + A_5 T_s^5 + S\left(B_0 + B_1 \cdot T_s + B_2 \cdot T_s^2 + B_3 \cdot T_s^3\right) + C_0 S^2$$

where:

$$\text{Ts} = \text{Scaled Temperature} = \ln\left[\frac{298.15 - t}{273.15 + t}\right]$$

t = Temperature in degrees Celsius

S = Salinity (fixed setting)

A_0 = 2.00856	B_0 = -6.24097e-3	C_0 = -3.11680e-7
A_1 = 3.22400	B_1 = -6.93498e-3	
A_2 = 3.99063	B_2 = -6.90358e-3	
A_3 = 4.80299	B_3 = -4.29155e-3	
A_4 = 9.78188e-1		
A_5 = 1.71069		

The relative O_2 saturation in % can then be calculated as:

$$O_{2Sat} = \frac{[O_2] \cdot 2.2414}{C^*}$$

where:

$$[\mathrm{O_2}] = \mathrm{O_2} \ \text{ concentration in } \mu\mathrm{M}$$

$$\mathrm{C}^* = \ \text{Solubility in } \mathrm{cm_3/liter}$$

Salinity Calculation

The O_2 concentration sensed by the Optode is in fact the O_2 concentration in the sensing foil. Since this foil is only permeable by gas and not water, the Optode cannot sense the effect of salt dissolved in the water. In effect this means that the Optode measures as if immersed in fresh water.

If the salinity variation on site is minor, the O_2 concentration can be corrected by setting the internal property *Salinity* to the average salinity there.

On the other hand, if salinity varies significantly and the actual salinity is available a more accurate correction may be applied externally.
The O_2 concentration in µM should then be multiplied by the following factor:

$$e^{S\left(B_0 + B_1 \cdot T_s + B_2 \cdot T_s^2 + B_3 \cdot T_s^3\right) + C_0 S^2}$$

where :

$$S = \text{Salinity in ppt}$$

$$T_s = \text{Scaled Temperature} = \ln\left[\frac{298.15 - t}{273.15 + t}\right]$$

$$t = \text{Temperature in degrees Celsius}$$

B_0 = -6.24097e-3 C_0 = -3.11680e-7
B_1 = -6.93498e-3
B_2 = -6.90358e-3
B_3 = -4.29155e-3

If the salinity setting in the Optode is set to other than zero, the O_2 concentration must also be divided by the above expression substituting *S* with the fixed setting.

Depth Compensation

The response of the sensing foil decreases to some extent with the ambient water pressure. This effect is however totally reversible and easy to compensate for by the following formula:

$$O_{2c} = O_2^* \left(1 + \frac{0.04^* d}{1000}\right)$$ where d is depth in meters

The compensation is not performed within the Optode.

CHAPTER 7 Mechanical Design

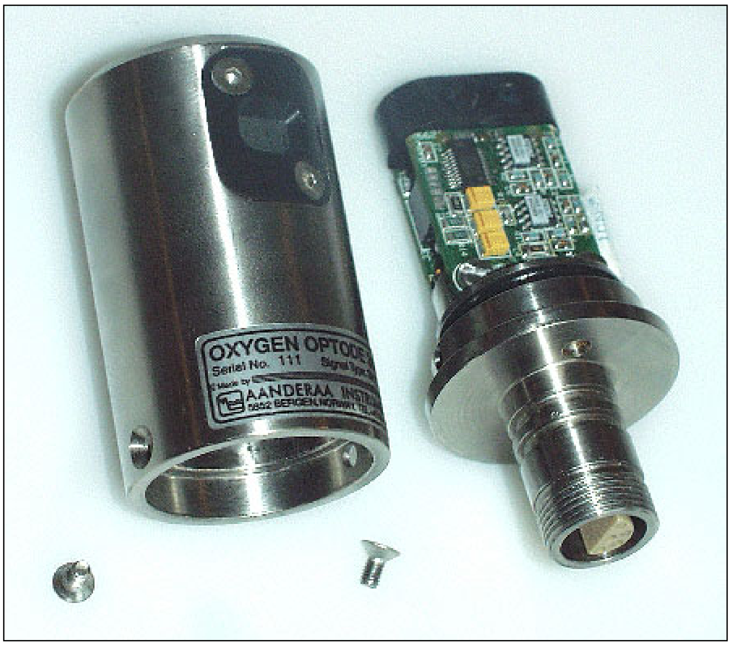


Fig. 7.01 Components
(Note! The sensor housing should not be opened)

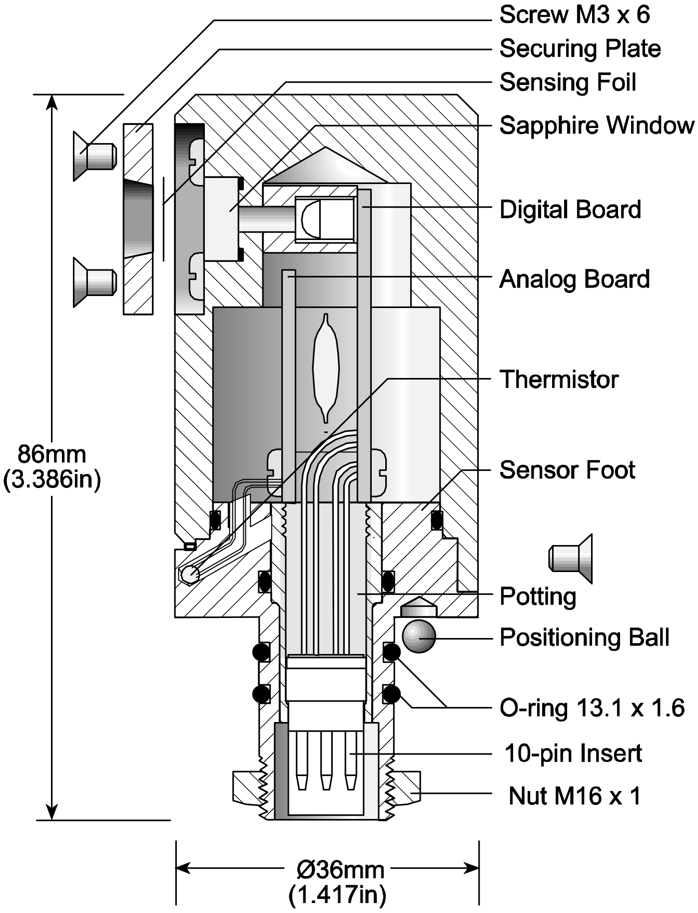


Fig. 7.02 Drawing of Sensor

A cylindrical titanium housing shields the electronics from the surrounding water and high pressure.

A 4 millimetre thick sapphire window provides for the optical connection between the optics inside the sensor and the sensing foil on the outside.

The foil is fixed to the window by securing plate and is easily replaceable.

A 10-pin receptacle in the sensor foot provides all electrical connection to the sensor.

To prevent leakage from the sensor to rest of the measurement system, this receptacle is first moulded inside a receptacle housing.

The sensor can be mounted directly on the top plate of the Aanderaa RCM9 or RCM11.

A short cable called Sensor Cable 3854 is then used for connection between the sensor and the data logger.

See Maintenance for instructions concerning changing Sensing Foil.

Note! The sensor should not be opened! Opening the sensor housing could breach the warranty (see Chapter 8 Maintenance for instructions concerning changing Sensing Foil).

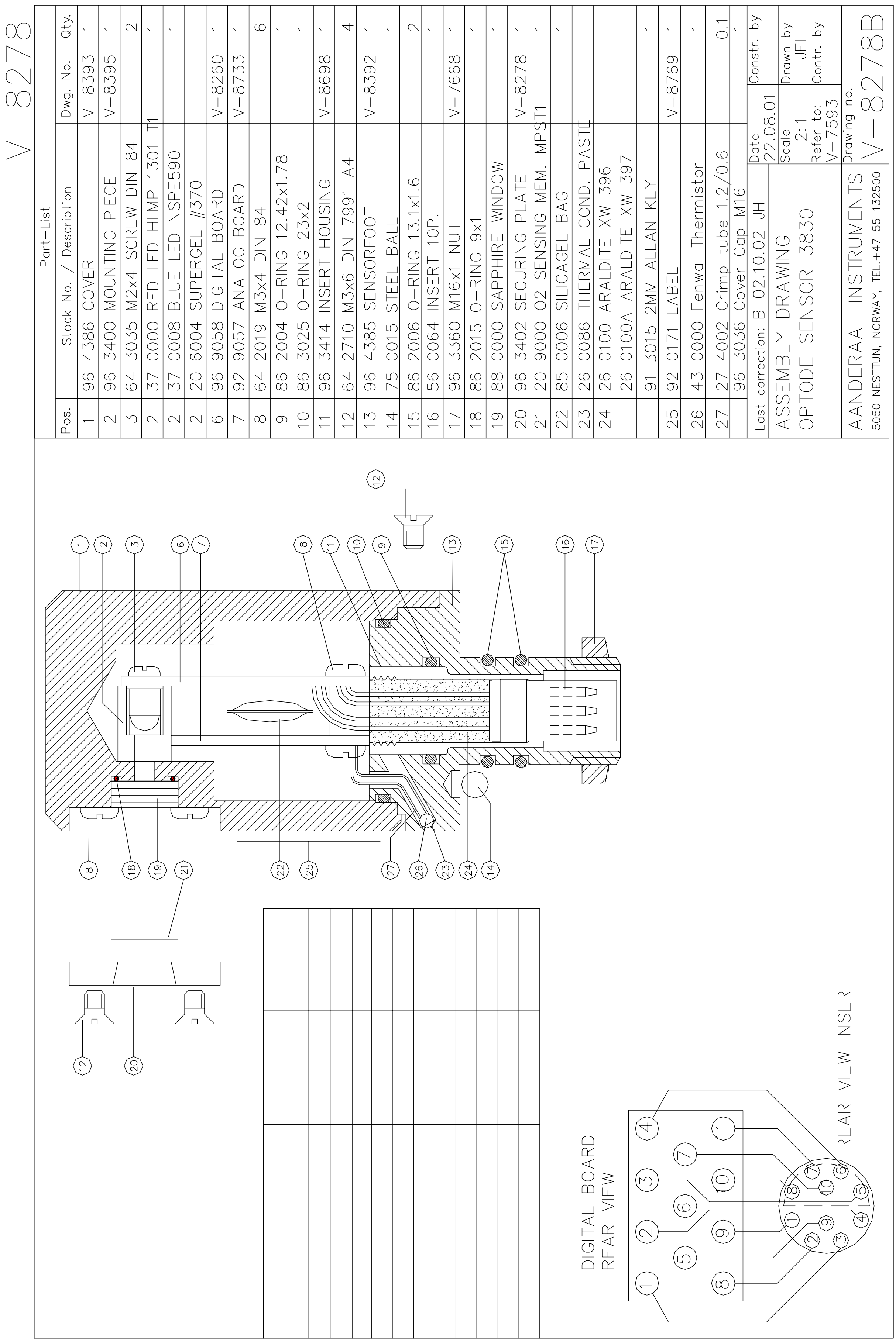


Fig. 7.03 Assembly Drawing Oxygen Optode 3830

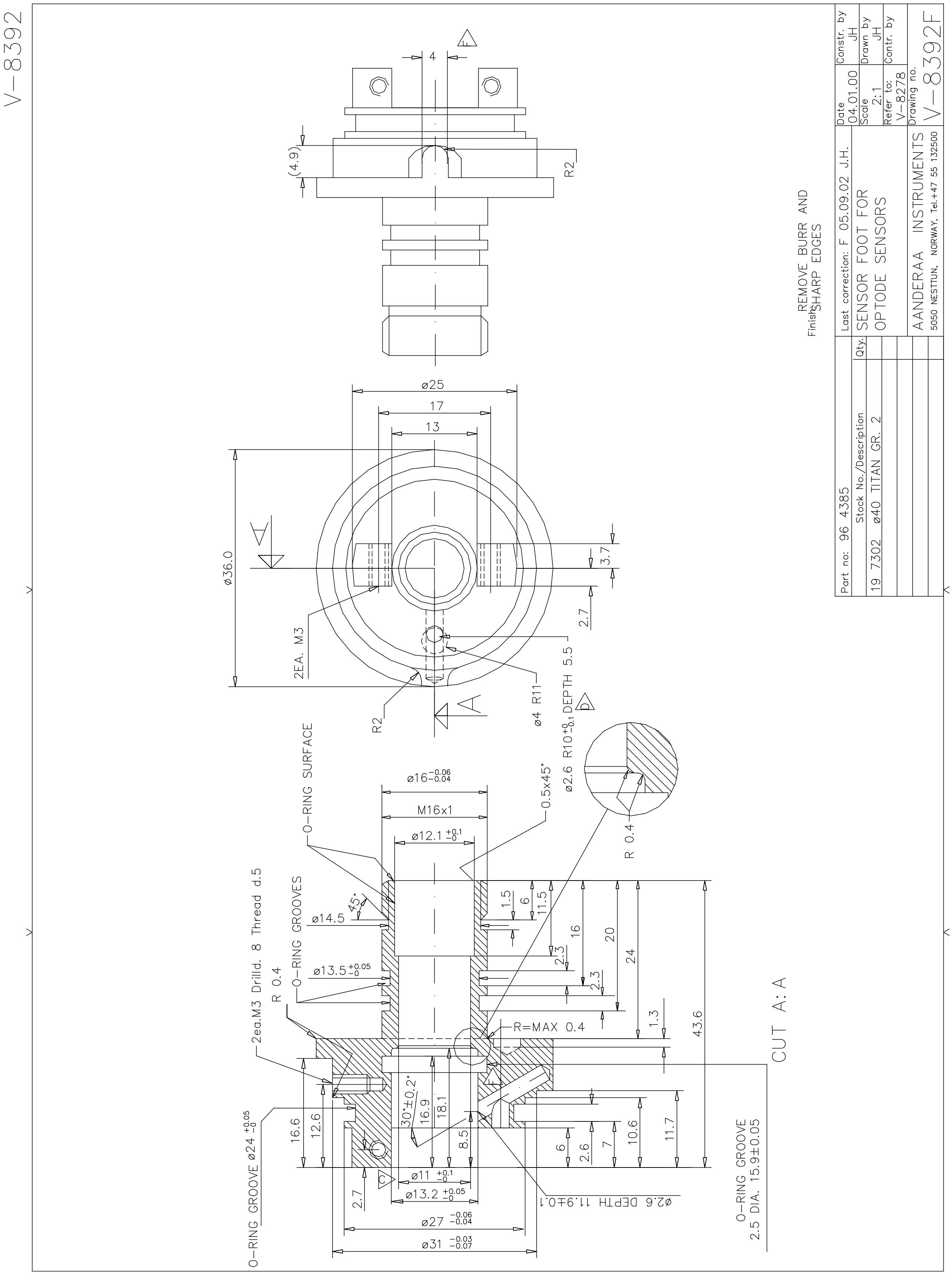
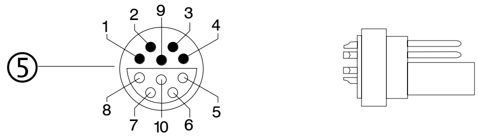
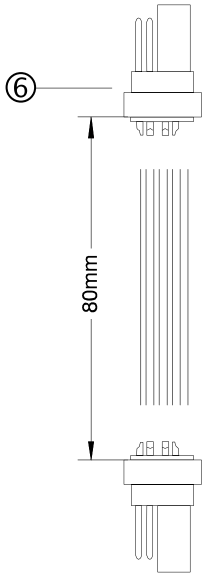


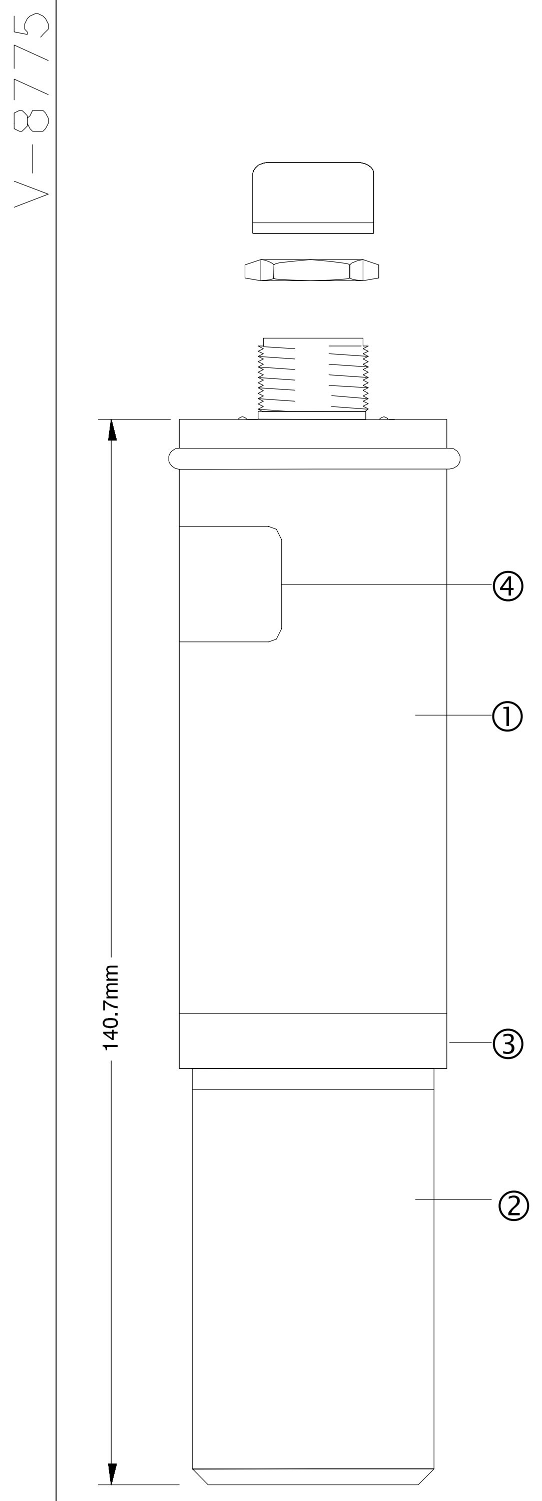
Fig. 7.04 Sensor Foot for Optode Sensors

10-PIN INSERT

Exterior view; bushing = ○ ; pin = ●







SIGNAL NAME	10P PLUG	Pt BRIDGE	10P RECEPTACLE	COLOR
SYSTEM GROUND	8		1	YELLOW
-9V	6		3	WHITE
BRIDGE VOLTAGE	4	RESISTOR	5	BLUE
CH. 1	9		6	BROWN
BRIDGE GROUND		Pt	8	
CONTROL VOLTAGE	10		9	GREEN
CH. 2		MIDTPOINT	10	

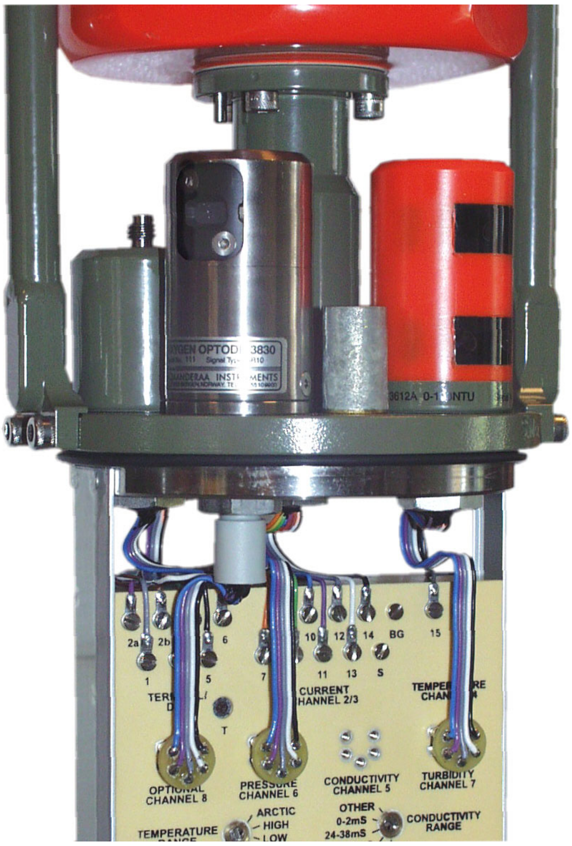
Part-List

Pos.	Stock No. / Description	Dwg. No.	QTY.
1	3714 ADAPTER	V-7967	1
2	3830 OXYGEN OPTODE	V-8278	1
3	96 4357PROTECTING RING	V-7977	1
4	92 1065 LABEL	V-8793	1
5	56 0064 10 PIN INSERT		1
	29 4009 CONDUCTOR, YELLOW		
	29 4005 CONDUCTOR, WHITE		
	29 4011 CONDUCTOR, BLUE		
	29 4003 CONDUCTOR, BROWN		
	29 4008 CONDUCTOR, GREEN		

Last correction. A 17.06.99 G.S.S.	Date 07.01.02	Constr. by JH
OPTODE / TEMPERATURE SENSOR 3930, ASSEMBLY DRAWING	Scale 1:1	Drawn by ERM
	Refer to:	Contr. by
AANDERAA INSTRUMENTS 5852 BERGEN, NORWAY. Tel.+47 55 109900	Drawing no. V – 8775	

Fig. 7.05 Assembly Drawing Oxygen Optode 3930

Electrical Connections



The 10-pin receptacle in the sensor foot mates with an Aanderaa 3216A plug ((Fig. 6.06).).

For connection to a Personal computer (PC) the 1.5 meter Sensor Cable 3855 can be used

This cable has a watertight 10-pin plug at the sensor end, and a 9 pin D-Sub plug at the PC-end (Fig. 6.07).

An additional USB plug is used for providing power to the sensor.

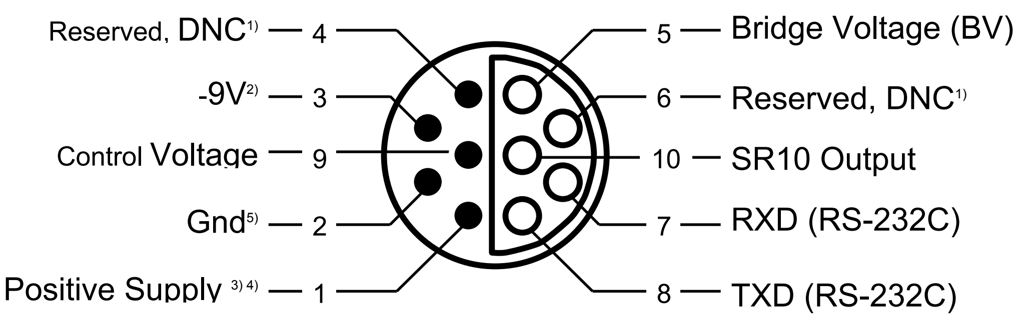
Power may also be connected to an included extension to the USB plug.

A short cable called Sensor Cable 3854 is used for connection between the sensor and Aanderaa Current meters (Fig. 6.04).

The electrical connections of the sensors are given below (Fig. 6.05).

Fig. 7.06 Sensor connected to Electronic Board

Receptacle, exterior view; bushing = ○; pin = ●



[1)] *DNC: Do Not Connect*
[2)] *Supply for SR10 Operation*
[3)] *Ground for SR10 Operation*
[4)] *Supply for RS-232C Operation*
[5)] *Ground for RS-232C Operation*

Figure 7.07 Pin Configuration

Fig. 7.08 Sensor Cable 3854

The sensor can be mounted directly on the top plate of the Aanderaa RCM9 or RCM11 and connected to the Electronic Board using Sensor Cable 3854.

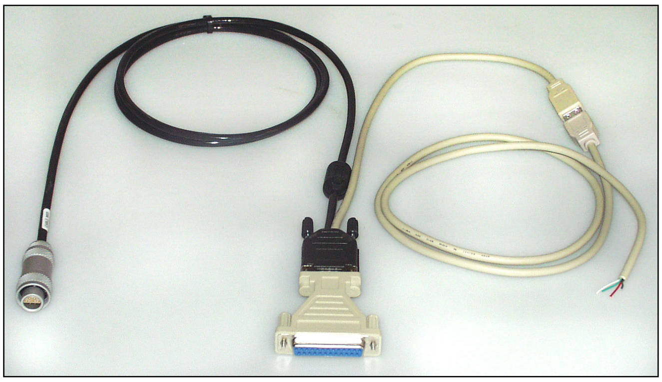


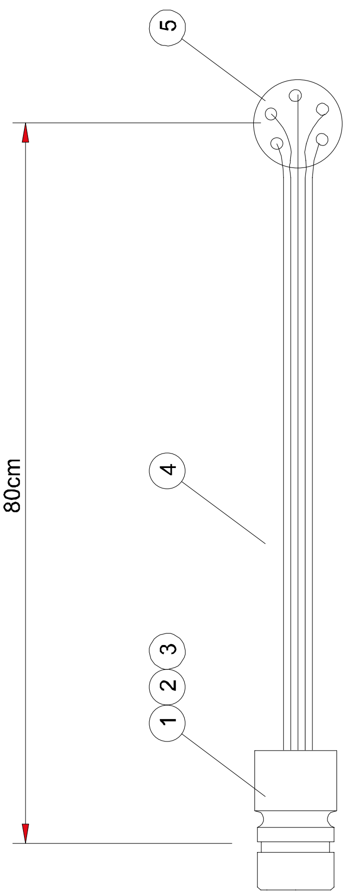
Fig. 7.09 Sensor Cable 3855

A 1.5 meter cable, Sensor Cable 3855, is used for connection between the sensor and the PC. By using a Cable Coupler 3472 and a standard Connecting Cable 3282 this connection can be extended to 15 meters.

Drawings of Sensor Cables 3854 and 3855 follow:

V-8699

Orientation between Lemo Insert and cable must be fixed approx. as indicated below.



Signal name	Color	Optode Plug	Cell Plug
BV	BLUE	4	1
CONTROL VOLTAGE	VIOLET	10	2
POSITIVE SUPPLY	GREY	8	3
-9V	WHITE	6	4
SR10	BLACK	9	5

Part-List

Pos.	Stock No. / Description	Dwg. No.	Qty.
1	96 3415 PLUG HOUSING	V-8710	1
2	56 0064 LEMO INSERT		1
3	26 0044A/B SCOTCHCAST		
4	29 0008 RIBBON CABLE		1m
5	96 9021 RADIAL PLUG		1

Last correction:

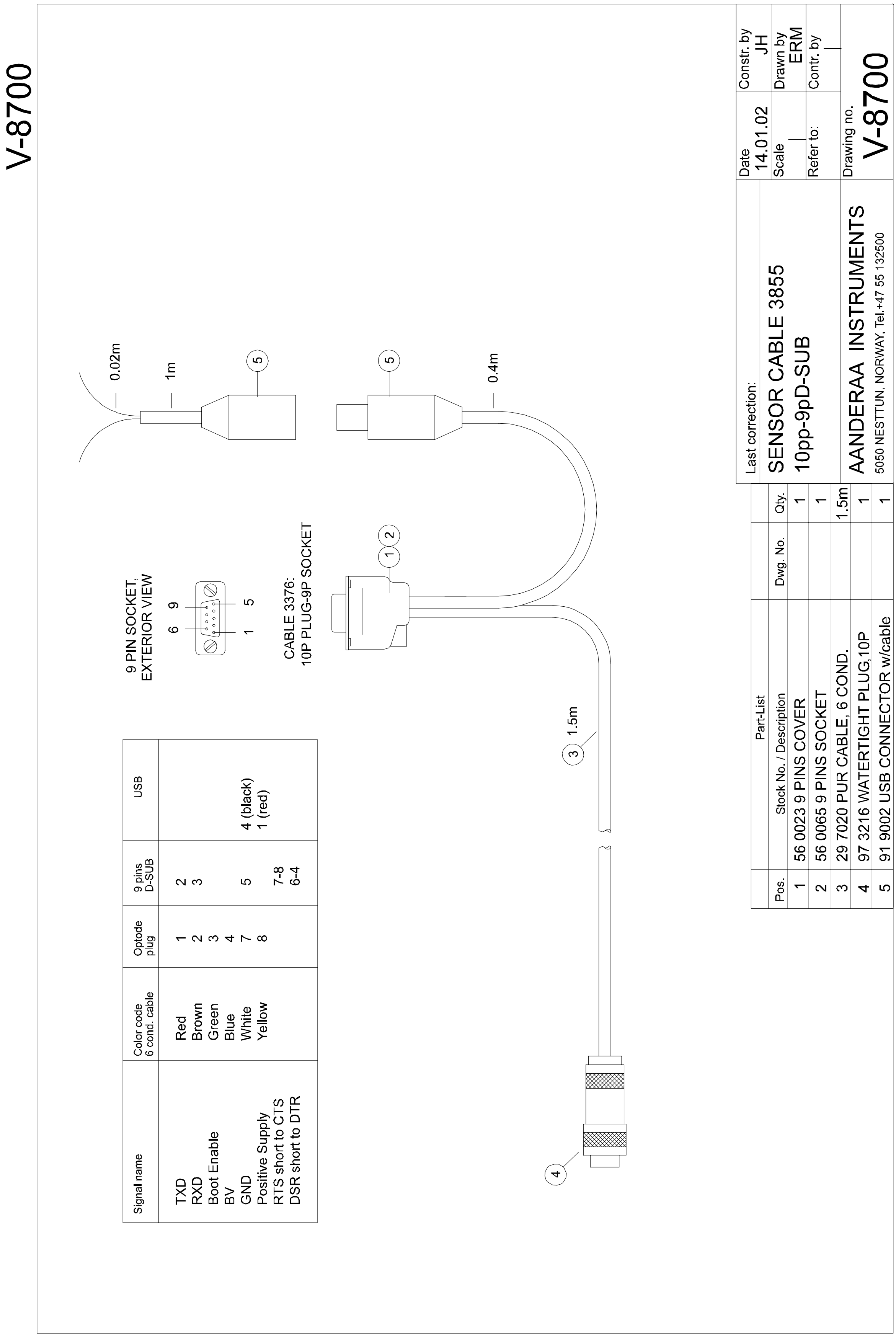
SENSOR CABLE 3854
10pp-RADIAL PLUG

Date 15.01.02 | Constr. by JH
Scale 1:1 | Drawn by ERM
Refer to: | Contr. by

AANDERAA INSTRUMENTS
5852 BERGEN, NORWAY, Tel.+47 55 109900

Drawing no. V-8699

Fig. 7.10 Sensor Cable 3854



Signal name	Color code 6 cond. cable	Optode plug	9 pins D-SUB	USB
TXD	Red	1	2	
RXD	Brown	2	3	
Boot Enable	Green	3		
BV	Blue	4		
GND	White	7	5	4 (black)
Positive Supply	Yellow	8		1 (red)
RTS short to CTS			7-8	
DSR short to DTR			6-4	

Part-List

Pos.	Stock No. / Description	Dwg. No.	Qty.
1	56 0023 9 PINS COVER		1
2	56 0065 9 PINS SOCKET		1
3	29 7020 PUR CABLE, 6 COND.		1.5m
4	97 3216 WATERTIGHT PLUG,10P		1
5	91 9002 USB CONNECTOR w/cable		1

Fig. 7.11 Sensor Cable 3855

CHAPTER 8 Production

Aanderaa Instruments have Proven Reliability.
With over 30 years of producing instruments for the scientific community around the world, you can count on our reputation for designing the most reliable products available.

We are guided by three underlying principles: quality, service, and commitment. We take these principles seriously, for they form the foundation upon which we provide lasting value to our customers. Our unmatched quality is based on a relentless program of continuous monitoring to maintain the highest standards of reliability.

Testing

In order to assure the quality of this sensor, critical properties are tested during production. A special form, named “Test and Specification Sheet” (see Fig. 6.10) lists the required tests and the result of these tests and checkpoints: A special test algorithm provides most of the data for the performance test in paragraph 4,5 and 6.

AANDERAA *Test & Specification Sheet*

Product: Oxygen Optode 3830
Serial No: 318

Layout No: 1308B, 1299C; Circuit Diagram No: V-3947 , V-8731 ; Program Version: 2,63

Visual and Mechanical Checks:

1.1	O-ring surface	☒
1.2	Soldering quality	☒
1.3	Visual surface	☒
1.4	Pressure test (60 MPa)	☒
1.5	Galvanic isolation between housing and electronics	☒

Current Drain and Voltages:

2.1	Average current drain at 0.5 Hz sampling (Max.: 54 mA)	33	mA
2.2	Current drain in sleep (Max.: 300 µA)	220	µA
2.3	Quiescent current drain from –9V (Max.: 5 µA)	0	µA
2.4	DSP voltage, IC5.1 (3.3 ±0.15V)	3,29	V
2.5	Excitation driver voltage, IC1.1 (3.3 ±0.15 V)	3,3	V
2.6	Flash/RS232 driver voltage, IC7.4 (5 ±0.2 V)	5,06	V

Receiver test:

3.1	Average of Receiver readings (0±50mV)	-5	mV
3.2	Standard Deviation of Receiver readings (Max.: 10mV)	3	mV

Performance Test in Air, 0°C Temperature:	**Excitation:**	**BLUE**	**RED**	
4.1 Amplitude measurement (Blue: 220–470 mV, Red: disabled)		270	0	mV
4.2 Phase measurement (Blue: 29±5°, Red: disabled)		27,7	0,00	°
4.3 Standard deviation of Phase measurement: (Max.: 0.02 °, Red: disabled)		0,004	0,000	°
4.4 Temperature measurement: (530±180 mV)		498		mV
4.5 SR10 concentration raw data (800±150)		874		

Performance Test in Air, 20°C Temperature:	**Excitation:**	**BLUE**	**RED**	
5.1 Amplitude measurement (Blue: 290–470 mV, Red: disabled)		386	0	mV
5.2 Phase measurement (Blue: 24±5°, Red: disabled)		23,1	0,0	°
5.3 Standard deviation of Phase measurement: (Max.: 0.02 °, Red: disabled)		0,001	0,000	°
5.4 Temperature measurement: (-120±180 mV)		-224		mV
5.5 SR10 concentration raw data (550±150)		581		

Performance Test in Air, 40°C Temperature:	**Excitation:**	**BLUE**	**RED**	
6.1 Amplitude measurement (Blue: 330–510 mV, Red: disabled)		441	0	mV
6.2 Phase measurement (Blue: 20±5°, Red: disabled)		20,4	0,00	°
6.3 Standard deviation of Phase measurement: (Max.: 0.02 °, Red: disabled)		0,002	0,000	°
6.4 Temperature measurement: (-600±150 mV)		-585		mV
6.5 SR10 concentration raw data (450±150)		477		

Date: 27 August 2003

Sign. Vidar Selsvik
Production Engineer

Form No. 620
August 2003

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SWIFT code: DNBANOKK

Fig. 8.01 Form 620 Test and Specification Sheet Oxygen Optode 3830

CHAPTER 9 Calibration

Each batch of sensing foils is delivered with calibration data describing the behaviour with respect to oxygen concentration and temperature. When changing the sensing foil the following coefficients must be updated:

$C0Coef_{0..3}$
$C1Coef_{0..3}$
$C2Coef_{0..3}$
$C3Coef_{0..3}$
$C4Coef_{0..3}$

These coefficients are found in the Calibration Certificate for the Sensing Foil 3853.

In addition to the above calibration, the phase measurement of individual sensors can be calibrated using the *PhaseCoef* property. This property contains coefficients for a third degree polynomial used prior to the modified Stern-Volmer equation. Even tough the *PhaseCoef* holds coefficients for a 3rd-degree polynomial; a two-point calibration is usually sufficient.

Two controlled oxygen concentrations are relatively easy to obtain, one in air saturated water, and one in a zero-oxygen solution. When measuring in vapour-saturated air the sensor will respond equal to measuring in air-saturated fresh water. The O_2 concentration will in this case be given by the following formula:

$$[O_2] = \left(\frac{p - p_v(t)}{1013}\right) \cdot \frac{100 \cdot R_{o2}}{V_m} \cdot \alpha(t)$$

where:

p = atmospheric pressure in hPa

t = temperature in degrees C

$p_v(t)$ = vapour pressure in hPa $\approx e^{\left(52.57 - \frac{6690.9}{t+273.15} - 4.681 \cdot \ln(t+273.15)\right)}$

α = Bunsen absorption coefficient

$$\approx 48.998 - 1.335t + 2.755 \cdot 10^{-2} t^2 - 3.220 \cdot 10^{-4} t^3 + 1.598 \cdot 10^{-6} t^4$$

R_{02} = volume percentage of O_2 = 20.95 %

V_m = molar volume of O_2 = 22.414 l/mol

By finding the roots of the 4th degree polynominals it is possible to find the ideal phase measurement at zero and 100% oxygen.

$$[O_2] = C_0 + C_1 P_{C1} + C_2 P_{C1}^2 + C_3 P_{C1}^3 + C_4 P_{C1}^4$$
$$[O] = C_0 + C_1 P_{C0} + C_2 P_{C0}^2 + C_3 P_{C0}^3 + C_4 P_{C0}^4$$

where:

P_{C1} = compensated phase in air saturated water
P_{C0} = compensated phase at zero oxygen
f_1, f_2 = temperature independent coefficients, *f1* and *f2* property
$[O_2]$ = oxygen concentration in air saturated water

The $C_0, \ldots C_4$ are temperature dependent coefficients and are calculated by the following 3rd degree polynomial:

$$C_n = A + B \cdot t + C \cdot t^2 + D \cdot t^3$$

Where *t* is the temperature measurement in Celsius, and the *A,B,C,D* coefficients are stored respectively in the *C0Coef*$_{0\text{-}3}$ to *C1Coef*$_{0\text{-}3}$ property.

Then the first two coefficients of the *PhaseCoef* (A and B) can be calculated by ordinary linear curve fitting:

$$\mathrm{B} = \frac{P_{c1} - P_{c0}}{P_1 - P_0} \qquad \mathrm{A} = P_{co} - \left(\frac{P_{c1} - P_{c0}}{P_1 - P_0} \right) P_0$$

where:

P_0 = uncompensated phase measurement calibration at zero oxygen
P_{c0} = compensated phase measurement calibration at zero oxygen
P_1 = uncompensated phase measurement calibration in air
P_{c1} = compensated phase measurement calibration in air

In order to ease this calibration procedure, the above calculation can be performed inside the sensor. The **Do_Calibrate** command starts a function that calculates and stores the above coefficients based on the following properties:

CalAirPhase:	Uncompensated phase measurement at calibration point in air
CalAirTemp:	Temperature measurement in ºC at calibration point in air
CalAirPressure:	Air pressure in hPa at calibration point in air
CalZeroPhase:	Uncompensated phase measurement at calibration point in zero solution
CalZeroTemp:	Temperature measurement in ºC at calibration point in zero solution

These properties may be entered manually or by use of the **Do_AirCal** and the **Do_ZeroCal** commands.

When the readings are stabilized in air the **Do_AirCal** command can be entered to sample and store values in the *CalAirTemp* and *CalAirPressure* property.

Likewise, the **Do_ZeroCal** command is used for sampling and storing value to the *CalZeroPhase* and *CalZeroTemp* property after stabilization in the zero solution.

A subsequent execution of the **Do_Calibrate** command effectuates a new calibration.

Calibration Procedure

1) Prepare a suitable container with fresh water. Aerate (apply bubbling) the water using an ordinary aquarium pump together with an airstone.
2) Prepare a zero oxygen solution by dissolving 5 grams of sodium sulfite (Na_2SO_3) in 500 ml of water.

3) Connect the sensor to a Personal Computer by use of the Sensor Cable 3855.
Start a terminal program, i.e. the HyperTerminal by Hilgraeve Inc (included in Microsoft's operating systems), with following set-up:
9600 Baud
8 Data bits
1 Stop bit
No Parity
Xon/Xoff Handshake

*) *Note! For HyperTerminal*
The "Send line ends with line feeds" and "Echo typed characters locally" options under ASCII setup should be selected.

Control and if necessary update the *C0Coef, C1Coef, C2Coef, C3Coef* and *C4Coef* properties accordingly to the Calibration Certificate for the sensing foil in use (see Chapter 5 Software, RS-

232C Protocol, for communicating with the sensor).

Example of changing foil coefficients:

```
Set_Protect(1)
Set_FoilNo(1403)
Set_C0Coef(3.95439E+03,-1.38606E+02,2.98835E+00,-2.73775E-02)
Set_C1Coef(-2.46937E+02,7.58489E+00,-1.62433E-01,1.50790E-03)
Set_C2Coef(6.32108E+00,-1.67391E-01,3.64539E-03,-3.50274E-05)
Set_C3Coef(-7.61504E-02,1.72586E-03,-3.95623E-05,4.02602E-07)
Set_C4Coef(3.52769E-04,-6.78062E-06,1.70524E-07,-1.86920E-09)
Save
```

4) Submerge the sensor into the aerated water.
   Set the *Interval* property to e.g. 30 seconds.
   Enter the **Save** command and wait until both the temperature and and the phase measurements have stabilized.
5)
6) Set the Protect property to 1, and enter the **Do_CalAir** command to store calibration values.

7) Set the *CalAirPressure* property to the actual air pressure in hPa at the site.
   Note! For maximum accuracy do not compensate the air pressure for height above sea level.

8) Submerge the sensor in the zero solution.
   Make sure that the sensing foil is free for air bobbles.
   Wait until both the temperature and the phase measurements have stabilized.

9) Set the *Interval* property to zero.
   Enter the *Save* command to stop the sampling, and set the Protect property to 1.
   Enter the **Do_CalZero** command to store calibration values.

10) Enter the **Do_Calibrate** command to effectuate the new calibration.

AANDERAA Calibration Certificate

Page 1 of 1

Sensor Type: O2 Sensing Foil PSt3 **Batch No:** 1403

Certificate No: 3853 1403 37789 **Calibration Date:** 17 June 2003

Calibration points and phase readings (degrees)

Temperature (°C)		2.41	10.28	20.09	30.15	39.51
Pressure (hPa)		975.05	975.05	975.05	975.05	975.05
Oxygen (%)	0.00	63.14	62.50	61.68	60.95	60.92
	1.00	59.22	58.10	56.78	55.40	54.48
	2.00	56.05	54.63	52.96	51.27	49.74
	5.00	48.46	46.60	44.45	42.39	40.40
	10.00	40.11	38.06	[illegible]	33.71	31.77
	20.90	30.16	[illegible]	[illegible]	24.42	22.80
	30.00	[illegible]	[illegible]	[illegible]	20.34	18.96

Giving these coefficients [1)]

Index	0	1	2	3
C0 Coefficient	3.95439E+03	-1.38606E+02	2.98835E+00	-2.73775E-02
C1 Coefficient	-2.46937E+02	7.58489E+00	-1.62433E-01	1.50790E-03
C2 Coefficient	6.32108E+00	-1.67391E-01	3.64539E-03	-3.50274E-05
C3 Coefficient	-7.61504E-02	1.72586E-03	-3.95623E-05	4.02602E-07
C4 Coefficient	3.52769E-04	-6.78062E-06	1.70524E-07	-1.86920E-09

1) Ask for Form No 621S when this O_2 Sensing Foil is used in Oxygen Sensor 3830 with Serial Numbers lower than 184.

Date: 27 August 2003

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Form 621, January 2003

Fig. 9.01 Form 621 Calibration Sheet Sensor Foil

AANDERAA Calibration Certificate

Page 1 of 2

Sensor Type: Oxygen Optode 3830 **Serial No:** 118
Certificate No: 3830_118_37504 **Calibration Date:** 14-Apr-2002
Sensing Foil Batch No: 0602

This is to certify that this product has been calibrated using the following instruments:

Tinsley Digital Thermometer model 5885A
Platinium Resistance Thermometer
Calibration Bath model CB 15-45E

Parameter: Internal Temperature
Calibration points and readings

Temperature (°C)	1.21	12.03	24.12	36.01
Reading (mV)	775.32	397.34	-50.00	-454.59

Giving these coefficients

Index	0	1	2	3
TempCoef	2.274820E+01	-2.730850E-02	2.361074E-06	-3.829321E-09

SAMPLE

Date: 05 September 2002 Sign. Tor Ove Kvalvaag
Calibration Manager

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Form 622, February 2003

Fig. 9.02 Form 622 Calibration Sheet Oxygen Optode, page 1

AANDERAA Calibration Certificate

Page 2 of 2

Sensor Type: Oxygen Optode 3830 **Serial No:** 320

Certificate No: 3830 320 37855 **Calibration Date:** 22 August 2003

Sensing Foil Batch No: 1403

Parameter: Oxygen:

	O_2 Concentration		Air Saturation
Range:	0-500 µM [1)]	**Range:**	0 - 120%
Accuracy [1)]**:**	< ±8µM or ±5% whichever is greater	**Accuracy** [1)]**:**	±5%
Resolution:	< 1 µM	**Resolution:**	< 0.4%
Settling Time (63%):	< 7 seconds		

Calibration points and readings [2)]

	Air Saturated Water	Zero Solution (Na_2SO_3)
Phase reading (°)	2.27479E+01	5.92335E+01
Temperature reading (°C)	2.00458E+01	2.04306E+01
Air Pressure (hPa)	9.95320E+02	

Giving these coefficients

Index	0	1	2	3
PhaseCoef	3.92418E+00	9.79979E-01	0.00000E+00	0.00000E+00

[1)] *Valid for 0 to 2000m (6562ft) depth, salinity 33 - 37ppt*

[2)] *The calibration is performed in fresh water and the salinity setting is set to 0*

SR10 Scaling Coefficients:

At the SR10 output the Oxygen Optode 3830 can give either absolute oxygen concentration in **µM** or air saturation in **%**. The setting of the internal property "*Output*"[3)], controls the selection of the unit. The coefficients for converting SR10 raw data to engineering units are fixed.

Output = **-1**	*Output* = **-2**
A = *0*	A = *0*
B = *4.883E-01*	B = *1.465E-01*
C = *0*	C = *0*
D = *0*	D = *0*
Oxygen (µM) = $A + BN + CN^2 + DN^3$	Oxygen (%)= $A + BN + CN^2 + DN^3$

[3)] *The default output setting is set to -1*

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Form 622, August 2003

Fig. 9.03 Form 622 Calibration Sheet Oxygen Optode, page 2

AANDERAA Calibration Certificate

Page 1 of 3

Sensor Type: Oxygen Optode 3930 **Serial No:** 315
Certificate No: 3930 315 37806 **Calibration Date:** 4 July 2003
Sensing Foil Batch No: 1403

This is to certify that this product has been calibrated using the following instruments:

ASL Digital Thermometer model F25 Serial No. 1103-14
Platinum Resistance Thermometer Serial No. B1667A/24
Calibration Bath model Midttun TM-55

Parameter: Temperature **Accuracy:** ± 0.1 °C
Range: -8.0 to 41.5 °C **Time Constant (63%):** Approx 30 seconds
Resolution: 0.05 °C

Calibration points and readings

Temperature (°C)	1.10	12.03	24.09	36.01				
Reading, N	204	439	686	[illegible]				

Giving these coefficients

A = -7.954E+00
B = 4.340E-02
C = 4.832E-06
D = 0

Temperature (°C) = A + BN + CN² + DN³
Where N is the VR22 raw data reading

Date: 27 August 2003

Sign. Roar Sognnes
Calibration Engineer

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Form 626, February 2003

Fig. 9.04 Form 626 Oxygen Sensor 3930 Calibibration Certificate Page 1

AANDERAA Calibration Certificate

Page 2 of 3

Sensor Type: Oxygen Optode 3930
Serial No: 315
Certificate No: 3930 315 37806
Calibration Date: 4 July 2003
Sensing Foil Batch No: 1403

Parameter: Internal Temperature

Calibration points and readings

Temperature (°C)	1.01	11.97	24.06	36.03
Reading (mV)	620.16	257.44	-145.01	-503.25

Giving these coefficients

Index	0	1	2	3
Temp Coef	1.96162E+01	-3.01497E-02	2.81137E-06	-4.15003E-09

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Form 626, August 2003

Fig. 9.05 Form 626 Oxygen Sensor 3930 Calibibration Certificate Page 2

AANDERAA Calibration Certificate

Page 3 of 3

Sensor Type: Oxygen Optode 3930 **Serial No:** 315
Certificate No: 3930 315 37806 **Calibration Date:** 4 July 2003
Sensing Foil Batch No: 1403

Parameter:	Oxygen:		
	O_2 Concentration		**Air Saturation**
Range:	0-500 µM [1]	**Range:**	0 - 120%
Accuracy [1]**:**	< ±8µM or ±5% whichever is greater	**Accuracy** [1]**:**	±5%
Resolution:	< 1 µM	**Resolution:**	< 0.4%
Settling Time (63%):	< 7 seconds		

Calibration points and readings [2]

	Air Saturated Water	Zero Solution (Na_2SO_3)
Phase reading (°)	2.37900E+01	6.06740E+01
Temperature reading (°C)	2.03244E+[illegible]	2.07676E+01
Air Pressure (hPa)	1008[illegible]5E+0[illegible]	

Giving these coefficients

Index	0	1	2	3
PhaseCoef	2.81449E+00	9.74794E-01	0.00000E+00	0.00000E+00

[1] *Valid for 0 to 2000m (6562ft) depth, salinity 33 - 37ppt*

[2] *The calibration is performed in fresh water and the salinity setting is set to 0*

SR10 Scaling Coefficients:

At the SR10 output the Oxygen Optode 3830 can give either absolute oxygen concentration in **µM** or air saturation in **%**. The setting of the internal property "*Output*"[3], controls the selection of the unit. The coefficients for converting SR10 raw data to engineering units are fixed.

Output = **-1**	*Output* = **-2**
A = *0*	A = *0*
B = ***4.883E-01***	B = ***1.465E-01***
C = *0*	C = *0*
D = *0*	D = *0*
Oxygen (μM) = $A + BN + CN^2 + DN^3$	Oxygen (%)= $A + BN + CN^2 + DN^3$

[3] *The default output setting is set to -1*

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Form 626, August 2003

Fig. 9.06 Form 626 Oxygen Sensor 3930 Calibibration Certificate Page 3

CHAPTER 10 Maintenance

Fig. 10.01 After deployment

The Oxygen Optode requires very little maintenance.

When the foils of traditional Oxygen Sensors based on Clark cells are fouled, the ability to diffuse gas decreases. This will influence the measurement directly. Since the Optode consumes no Oxygen, the ability to diffuse gas has no influence on the measurement's accuracy.

However if the fouling is in the form of algae that produce or consume oxygen, the measurement might not reflect the oxygen concentration in the surrounding water correctly. Also the response time of the measurement might increase if the sensing foil is heavily fouled.

To avoid this the sensor should be cleaned at regular intervals from 1 month to a year depending on the required accuracy and the fouling condition at the site.

The body of the Optode can be cleaned using a brush and clean water. Carefully use a wet cloth to clean the sensing foil.

If scratched the sensing foil should be replaced (Sensing Foil Kit 3853) and the sensor recalibrated.

It is recommended that the sensor be recalibrated annually (see CHAPTER 6 Calibration Procedure).

Fig. 10-02 Screws, Securing Plate, Sensing Foil, and Hex Key

Sensing Foil Kit 3853

Consists:

2 ea. Sensing Foil packed in aluminium foil (962203)

Form No. 621 Calibration Sheet for Sensing Foil (each batch of foils is calibrated)

2 ea. Hex countersink screw 3 x 6mm Din 7991 A4 (642710)

1 ea. 2mm Hex Key (913015)

The Sensor Foil is changed by unscrewing the 2 hex screws in the securing plate.
Remove the plate and the old foil.
Clean the window and place the new foil with the black side up.
Square the foil in the window and replace the securing plate.

Communicating with the Oxygen Optode 3930

In order to change settings or calibrating the 3930 Optode Sensor the sensor has to be connected to a PC. To gain access to the Optode's RS-232C signals its cylindrical body must be removed.

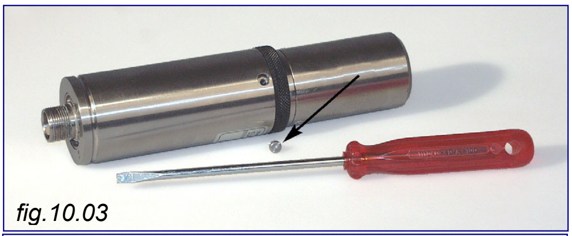

fig.10.03

1. Remove the setscrew, fig. 9.03.

2. Unscrew the black securing ring, fig. 9.04

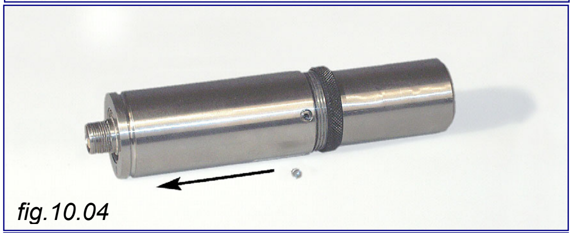

fig.10.04

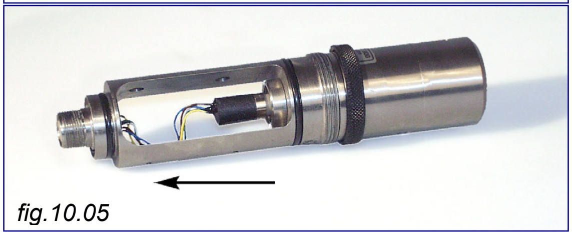

fig.10.05

3. Remove the cylindrical body by pulling upwards towards the sensor receptacle, figs. 9.04 and 9.05.

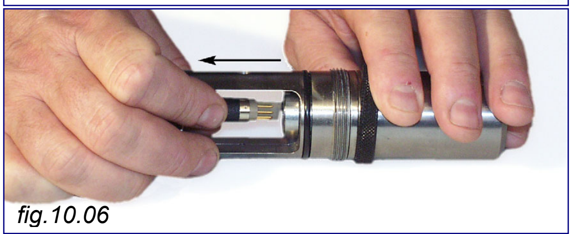

fig.10.06

4. Gently pull out the internal plug connected to the Optode, figs. 9.06 and 9.07.

fig.10.07

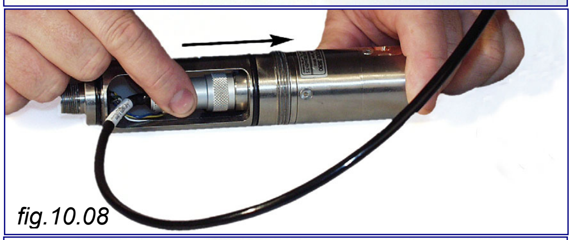

fig.10.08

5. Use Sensor Cable 3855 to carefully connect the Optode to the serial connector of a PC, figs. 9.08, 9.09 and 9.10.

fig.10.09

6. See chapter 9, RS-232C protocol for communicating with the sensor.

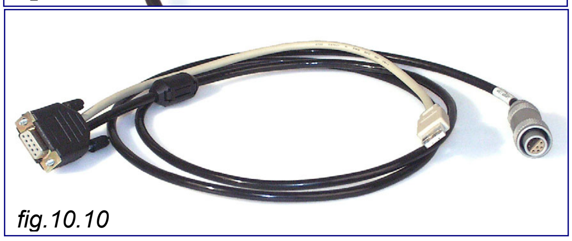

fig.10.10

7. Reassemble the housing in reverse order. Please make sure that the both O-rings in the Optode housing are clean and undamaged. First replace the setscrew and then tighten the plastic ring.

APPENDIX

Oxygen Dynamics in Water

Seawater and Gases

Tabulated physical parameters of interest to people working with microsensors in marine systems.
Presented by: Unisense A/S at:
http://www.unisense.com/support/support.html)

Tables

Gas tables by Niels Ramsing & Jens Gundersen with diffusion coefficients and solubility of oxygen in seawater, density of water versus temperature and salinity and much more (PDF-file) at:
http://www.unisense.com/support/pdf/gas_tables.pdf

Note!
Use tables 1 and 2 for salinities between 0 and 40 ‰ and temperatures between 0 and 40 °C.
The formulas used to calculate these tables are only valid in these intervals.
The formula used in table 3 is less precise in these intervals, but is a good approximation at higher salinities and temperatures.

DATA-TABLE 6 *by Niels Ramsing & Jens Gundersen* **Unisense A/S - www.unisense.com** © Unisense

Oxygen solubility at different temperatures and salinities of seawater

Units: µmol/l

Salinity (‰)	Temperature (°C) 0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0
0.0	456.6	444.0	431.9	420.4	409.4	398.9	388.8	379.2	369.9	361.1	352.6	344.4	336.6	329.1	321.9	314.9	308.3	301.8	295.6	289.7	283.9
1.0	453.5	441.0	429.0	417.6	406.7	396.3	386.3	376.7	367.6	358.8	350.4	342.3	334.5	327.1	319.9	313.0	306.4	300.0	293.9	287.9	282.2
2.0	450.4	438.0	426.1	414.8	404.0	393.6	383.7	374.3	365.2	356.5	348.1	340.1	332.4	325.0	317.9	311.1	304.5	298.2	292.1	286.2	280.6
3.0	447.3	435.0	423.2	412.0	401.3	391.0	381.2	371.8	362.8	354.2	345.9	338.0	330.4	323.0	316.0	309.2	302.7	296.4	290.4	284.5	278.9
4.0	444.2	432.0	420.4	409.2	398.6	388.5	378.7	369.4	360.5	351.9	343.7	335.9	328.3	321.0	314.0	307.3	300.9	294.6	288.6	282.9	277.3
5.0	441.1	429.1	417.5	406.5	396.0	385.9	376.3	367.0	358.2	349.7	341.6	333.7	326.2	319.0	312.1	305.5	299.0	292.9	286.9	281.2	275.7
6.0	438.1	426.1	414.7	403.8	393.3	383.3	373.8	364.6	355.9	347.5	339.4	331.6	324.2	317.1	310.2	303.6	297.2	291.1	285.2	279.5	274.0
7.0	435.1	423.2	411.9	401.1	390.7	380.8	371.3	362.3	353.6	345.2	337.2	329.6	322.2	315.1	308.3	301.7	295.4	289.4	283.5	277.9	272.4
8.0	432.1	420.3	409.1	398.4	388.1	378.3	368.9	359.9	351.3	343.0	335.1	327.5	320.2	313.1	306.4	299.9	293.6	287.6	281.8	276.2	270.8
9.0	429.1	417.5	406.3	395.7	385.5	375.8	366.5	357.6	349.0	340.8	333.0	325.4	318.2	311.2	304.5	298.1	291.9	285.9	280.1	274.6	269.2
10.0	426.1	414.6	403.6	393.0	383.0	373.3	364.1	355.2	346.8	338.6	330.8	323.4	316.2	309.3	302.6	296.2	290.1	284.2	278.5	273.0	267.6
11.0	423.2	411.8	400.8	390.4	380.4	370.8	361.7	352.9	344.5	336.5	328.7	321.3	314.2	307.3	300.8	294.4	288.3	282.5	276.8	271.3	266.1
12.0	420.3	409.0	398.1	387.8	377.9	368.4	359.3	350.6	342.3	334.3	326.7	319.3	312.2	305.4	298.9	292.6	286.6	280.8	275.1	269.7	264.5
13.0	417.4	406.2	395.4	385.2	375.3	366.0	357.0	348.3	340.1	332.2	324.6	317.3	310.3	303.5	297.1	290.8	284.8	279.1	273.5	268.1	262.9
14.0	414.5	403.4	392.7	382.6	372.8	363.5	354.6	346.1	337.9	330.0	322.5	315.3	308.3	301.7	295.2	289.1	283.1	277.4	271.9	266.5	261.4
15.0	411.7	400.6	390.1	380.0	370.4	361.1	352.3	343.8	335.7	327.9	320.5	313.3	306.4	299.8	293.4	287.3	281.4	275.7	270.2	265.0	259.9
16.0	408.8	397.9	387.4	377.4	367.9	358.7	350.0	341.6	333.5	325.8	318.4	311.3	304.5	297.9	291.6	285.5	279.7	274.0	268.6	263.4	258.3
17.0	406.0	395.2	384.8	374.9	365.4	356.4	347.7	339.4	331.4	323.7	316.4	309.4	302.6	296.1	289.8	283.8	278.0	272.4	267.0	261.8	256.8
18.0	403.2	392.5	382.2	372.4	363.0	354.0	345.4	337.2	329.2	321.7	314.4	307.4	300.7	294.2	288.0	282.1	276.3	270.8	265.4	260.3	255.3
19.0	400.4	389.8	379.6	369.9	360.6	351.7	343.1	335.0	327.1	319.6	312.4	305.5	298.8	292.4	286.3	280.3	274.6	269.1	263.8	258.7	253.8
20.0	397.7	387.1	377.0	367.4	358.2	349.3	340.9	332.8	325.0	317.6	310.4	303.5	296.9	290.6	284.5	278.6	273.0	267.5	262.3	257.2	252.3
21.0	394.9	384.5	374.5	364.9	355.8	347.0	338.6	330.6	322.9	315.5	308.4	301.6	295.1	288.8	282.7	276.9	271.3	265.9	260.7	255.7	250.8
22.0	392.2	381.8	371.9	362.4	353.4	344.7	336.4	328.5	320.8	313.5	306.5	299.7	293.2	287.0	281.0	275.2	269.7	264.3	259.1	254.1	249.3
23.0	389.5	379.2	369.4	360.0	351.0	342.4	334.2	326.3	318.7	311.5	304.5	297.8	291.4	285.2	279.3	273.5	268.0	262.7	257.6	252.6	247.9
24.0	386.8	376.6	366.9	357.6	348.7	340.2	332.0	324.2	316.7	309.5	302.6	295.9	289.6	283.4	277.5	271.9	266.4	261.1	256.0	251.1	246.4
25.0	384.1	374.0	364.4	355.2	346.4	337.9	329.8	322.1	314.6	307.5	300.7	294.1	287.8	281.7	275.8	270.2	264.8	259.5	254.5	249.6	244.9
26.0	381.5	371.5	361.9	352.8	344.0	335.7	327.7	320.0	312.6	305.5	298.7	292.2	285.9	279.9	274.1	268.5	263.2	258.0	253.0	248.2	243.5
27.0	378.8	368.9	359.5	350.4	341.7	333.4	325.5	317.9	310.6	303.6	296.8	290.4	284.2	278.2	272.4	266.9	261.6	256.4	251.5	246.7	242.1
28.0	376.2	366.4	357.0	348.0	339.5	331.2	323.4	315.8	308.6	301.6	294.9	288.5	282.4	276.5	270.7	265.3	260.0	254.9	250.0	245.2	240.6
29.0	373.6	363.9	354.6	345.7	337.2	329.0	321.2	313.8	306.6	299.7	293.1	286.7	280.6	274.7	269.1	263.6	258.4	253.3	248.5	243.8	239.2
30.0	371.0	361.4	352.2	343.4	334.9	326.9	319.1	311.7	304.6	297.8	291.2	284.9	278.8	273.0	267.4	262.0	256.8	251.8	247.0	242.3	237.8
31.0	368.5	358.9	349.8	341.1	332.7	324.7	317.0	309.7	302.6	295.9	289.3	283.1	277.1	271.3	265.8	260.4	255.3	250.3	245.5	240.9	236.4
32.0	365.9	356.5	347.4	338.8	330.5	322.5	314.9	307.7	300.7	294.0	287.5	281.3	275.4	269.6	264.1	258.8	253.7	248.8	244.0	239.4	235.0
33.0	363.4	354.0	345.1	336.5	328.3	320.4	312.9	305.6	298.7	292.1	285.7	279.5	273.6	268.0	262.5	257.2	252.2	247.3	242.6	238.0	233.6
34.0	360.9	351.6	342.7	334.2	326.1	318.3	310.8	303.7	296.8	290.2	283.9	277.8	271.9	266.3	260.9	255.7	250.6	245.8	241.1	236.6	232.2
35.0	358.4	349.2	340.4	332.0	323.9	316.2	308.8	301.7	294.9	288.3	282.0	276.0	270.2	264.6	259.3	254.1	249.1	244.3	239.7	235.2	230.9
36.0	355.9	346.8	338.1	329.7	321.7	314.1	306.7	299.7	293.0	286.5	280.3	274.3	268.5	263.0	257.7	252.5	247.6	242.8	238.2	233.8	229.5
37.0	353.5	344.4	335.8	327.5	319.6	312.0	304.7	297.7	291.1	284.6	278.5	272.5	266.8	261.4	256.1	251.0	246.1	241.4	236.8	232.4	228.2
38.0	351.0	342.0	333.5	325.3	317.4	309.9	302.7	295.8	289.2	282.8	276.7	270.8	265.2	259.7	254.5	249.5	244.6	239.9	235.4	231.0	226.8
39.0	348.6	339.7	331.2	323.1	315.3	307.9	300.7	293.9	287.3	281.0	274.9	269.1	263.5	258.1	252.9	247.9	243.1	238.5	234.0	229.7	225.5
40.0	346.2	337.4	329.0	320.9	313.2	305.8	298.7	292.0	285.4	279.2	273.2	267.4	261.8	256.5	251.4	246.4	241.6	237.0	232.6	228.3	224.1

DATA-TABLE 7 *by Niels Ramsing & Jens Gundersen* **Unisense A/S - www.unisense.com** © Unisense

Oxygen solubility at different temperatures and salinities of seawater

Units: µmol/l

Salinity (‰)	Temperature (°C) 20.0	21.0	22.0	23.0	24.0	25.0	26.0	27.0	28.0	29.0	30.0	31.0	32.0	33.0	34.0	35.0	36.0	37.0	38.0	39.0	40.0
0.0	283.9	278.3	273.0	267.8	262.8	257.9	253.2	248.7	244.3	240.0	235.9	231.9	228.0	224.2	220.5	217.0	213.5	210.1	206.7	203.5	200.4
1.0	282.2	276.7	271.4	266.3	261.3	256.5	251.8	247.3	243.0	238.7	234.6	230.6	226.8	223.0	219.4	215.8	212.3	209.0	205.7	202.5	199.3
2.0	280.6	275.1	269.8	264.7	259.8	255.0	250.4	245.9	241.6	237.4	233.3	229.4	225.6	221.8	218.2	214.7	211.2	207.9	204.6	201.4	198.3
3.0	278.9	273.5	268.3	263.2	258.3	253.6	249.0	244.6	240.3	236.1	232.1	228.1	224.3	220.6	217.0	213.5	210.1	206.8	203.6	200.4	197.3
4.0	277.3	271.9	266.7	261.7	256.8	252.1	247.6	243.2	238.9	234.8	230.8	226.9	223.1	219.5	215.9	212.4	209.0	205.7	202.5	199.4	196.3
5.0	275.7	270.3	265.2	260.2	255.4	250.7	246.2	241.8	237.6	233.5	229.5	225.7	221.9	218.3	214.7	211.3	207.9	204.6	201.4	198.3	195.3
6.0	274.0	268.7	263.6	258.7	253.9	249.3	244.8	240.5	236.3	232.2	228.3	224.4	220.7	217.1	213.6	210.2	206.8	203.6	200.4	197.3	194.3
7.0	272.4	267.2	262.1	257.2	252.5	247.9	243.4	239.1	235.0	230.9	227.0	223.2	219.5	215.9	212.4	209.0	205.7	202.5	199.4	196.3	193.3
8.0	270.8	265.6	260.6	255.7	251.0	246.5	242.1	237.8	233.7	229.7	225.8	222.0	218.3	214.8	211.3	207.9	204.7	201.5	198.3	195.3	192.3
9.0	269.2	264.1	259.1	254.2	249.6	245.1	240.7	236.5	232.4	228.4	224.5	220.8	217.2	213.6	210.2	206.8	203.6	200.4	197.3	194.3	191.3
10.0	267.6	262.5	257.6	252.8	248.2	243.7	239.4	235.2	231.1	227.1	223.3	219.6	216.0	212.5	209.1	205.7	202.5	199.4	196.3	193.3	190.3
11.0	266.1	261.0	256.1	251.3	246.7	242.3	238.0	233.8	229.8	225.9	222.1	218.4	214.8	211.3	208.0	204.7	201.4	198.3	195.3	192.3	189.4
12.0	264.5	259.5	254.6	249.9	245.3	240.9	236.7	232.5	228.5	224.6	220.9	217.2	213.7	210.2	206.8	203.6	200.4	197.3	194.2	191.3	188.4
13.0	262.9	257.9	253.1	248.4	243.9	239.6	235.3	231.2	227.3	223.4	219.7	216.0	212.5	209.1	205.7	202.5	199.3	196.2	193.2	190.3	187.4
14.0	261.4	256.4	251.6	247.0	242.5	238.2	234.0	229.9	226.0	222.2	218.5	214.9	211.4	208.0	204.6	201.4	198.3	195.2	192.2	189.3	186.5
15.0	259.9	254.9	250.2	245.6	241.1	236.8	232.7	228.6	224.7	220.9	217.3	213.7	210.2	206.8	203.6	200.4	197.2	194.2	191.2	188.3	185.5
16.0	258.3	253.4	248.7	244.2	239.8	235.5	231.4	227.4	223.5	219.7	216.1	212.5	209.1	205.7	202.5	199.3	196.2	193.2	190.2	187.4	184.6
17.0	256.8	252.0	247.3	242.8	238.4	234.2	230.1	226.1	222.2	218.5	214.9	211.4	208.0	204.6	201.4	198.2	195.2	192.2	189.3	186.4	183.6
18.0	255.3	250.5	245.9	241.4	237.0	232.8	228.8	224.8	221.0	217.3	213.7	210.2	206.8	203.5	200.3	197.2	194.1	191.2	188.3	185.4	182.7
19.0	253.8	249.0	244.4	240.0	235.7	231.5	227.5	223.6	219.8	216.1	212.5	209.1	205.7	202.4	199.2	196.1	193.1	190.2	187.3	184.5	181.7
20.0	252.3	247.6	243.0	238.6	234.3	230.2	226.2	222.3	218.6	214.9	211.4	207.9	204.6	201.3	198.2	195.1	192.1	189.2	186.3	183.5	180.8
21.0	250.8	246.1	241.6	237.2	233.0	228.9	224.9	221.1	217.3	213.7	210.2	206.8	203.5	200.3	197.1	194.1	191.1	188.2	185.4	182.6	179.9
22.0	249.3	244.7	240.2	235.8	231.7	227.6	223.6	219.8	216.1	212.5	209.1	205.7	202.4	199.2	196.1	193.0	190.1	187.2	184.4	181.6	179.0
23.0	247.9	243.2	238.8	234.5	230.3	226.3	222.4	218.6	214.9	211.4	207.9	204.6	201.3	198.1	195.0	192.0	189.1	186.2	183.4	180.7	178.0
24.0	246.4	241.8	237.4	233.1	229.0	225.0	221.1	217.4	213.7	210.2	206.8	203.4	200.2	197.1	194.0	191.0	188.1	185.2	182.5	179.8	177.1
25.0	244.9	240.4	236.0	231.8	227.7	223.7	219.9	216.2	212.5	209.0	205.6	202.3	199.1	196.0	193.0	190.0	187.1	184.3	181.5	178.8	176.2
26.0	243.5	239.0	234.7	230.5	226.4	222.5	218.6	214.9	211.4	207.9	204.5	201.2	198.0	194.9	191.9	189.0	186.1	183.3	180.6	177.9	175.3
27.0	242.1	237.6	233.3	229.1	225.1	221.2	217.4	213.7	210.2	206.7	203.4	200.1	197.0	193.9	190.9	188.0	185.1	182.4	179.6	177.0	174.4
28.0	240.6	236.2	231.9	227.8	223.8	219.9	216.2	212.5	209.0	205.6	202.3	199.0	195.9	192.9	189.9	187.0	184.2	181.4	178.7	176.1	173.5
29.0	239.2	234.8	230.6	226.5	222.5	218.7	215.0	211.4	207.9	204.5	201.2	198.0	194.8	191.8	188.9	186.0	183.2	180.5	177.8	175.2	172.6
30.0	237.8	233.5	229.3	225.2	221.3	217.4	213.7	210.2	206.7	203.3	200.1	196.9	193.8	190.8	187.9	185.0	182.2	179.5	176.9	174.3	171.7
31.0	236.4	232.1	227.9	223.9	220.0	216.2	212.5	209.0	205.5	202.2	199.0	195.8	192.7	189.8	186.9	184.0	181.3	178.6	175.9	173.4	170.9
32.0	235.0	230.7	226.6	222.6	218.7	215.0	211.3	207.8	204.4	201.1	197.9	194.7	191.7	188.7	185.9	183.0	180.3	177.6	175.0	172.5	170.0
33.0	233.6	229.4	225.3	221.3	217.5	213.8	210.1	206.7	203.3	200.0	196.8	193.7	190.7	187.7	184.9	182.1	179.4	176.7	174.1	171.6	169.1
34.0	232.2	228.0	224.0	220.0	216.2	212.5	209.0	205.5	202.1	198.9	195.7	192.6	189.6	186.7	183.9	181.1	178.4	175.8	173.2	170.7	168.2
35.0	230.9	226.7	222.7	218.8	215.0	211.3	207.8	204.3	201.0	197.8	194.6	191.6	188.6	185.7	182.9	180.1	177.5	174.9	172.3	169.8	167.4
36.0	229.5	225.4	221.4	217.5	213.8	210.1	206.6	203.2	199.9	196.7	193.6	190.5	187.6	184.7	181.9	179.2	176.5	173.9	171.4	168.9	166.5
37.0	228.2	224.1	220.1	216.2	212.5	208.9	205.4	202.1	198.8	195.6	192.5	189.5	186.6	183.7	180.9	178.2	175.6	173.0	170.5	168.1	165.7
38.0	226.8	222.7	218.8	215.0	211.3	207.7	204.3	200.9	197.7	194.5	191.4	188.5	185.6	182.7	180.0	177.3	174.7	172.1	169.6	167.2	164.8
39.0	225.5	221.4	217.5	213.8	210.1	206.6	203.1	199.8	196.6	193.4	190.4	187.4	184.5	181.7	179.0	176.3	173.8	171.2	168.7	166.3	164.0
40.0	224.1	220.1	216.3	212.5	208.9	205.4	202.0	198.7	195.5	192.4	189.3	186.4	183.5	180.8	178.1	175.4	172.8	170.3	167.9	165.5	163.1

DATA-TABLE 8 *by Niels Ramsing & Jens Gundersen* **Unisense A/S - www.unisense.com** © Unisense

Oxygen solubility at different temperatures and salinities of seawater

Units: µmol/l

Salinity (‰)	Temperature (°C) 0.0	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0	60.0	65.0	70.0	75.0	80.0	85.0	90.0	95.0	100.0
0.0	456.6	398.9	352.6	314.9	283.9	257.9	235.9	217.0	200.4	185.6	172.2	159.9	148.3	137.2	126.5	115.9	105.5	95.1	84.7	74.5	64.3
5.0	441.1	385.9	341.6	305.5	275.7	250.7	229.5	211.3	195.3	181.0	168.1	156.2	145.0	134.2	123.8	113.6	103.4	93.3	83.2	73.2	63.3
10.0	426.1	373.3	330.8	296.2	267.6	243.7	223.3	205.7	190.3	176.6	164.1	152.6	141.7	131.3	121.2	111.3	101.4	91.6	81.7	71.9	62.2
15.0	411.7	361.1	320.5	287.3	259.9	236.8	217.3	200.4	185.5	172.3	160.2	149.1	138.6	128.5	118.7	109.0	99.4	89.8	80.2	70.7	61.2
20.0	397.7	349.3	310.4	278.6	252.3	230.2	211.4	195.1	180.8	168.0	156.4	145.6	135.5	125.7	116.2	106.8	97.5	88.1	78.8	69.4	60.2
25.0	384.1	337.9	300.7	270.2	244.9	223.7	205.6	190.0	176.2	163.9	152.7	142.3	132.4	123.0	113.7	104.6	95.5	86.4	77.3	68.2	59.2
30.0	371.0	326.9	291.2	262.0	237.8	217.4	200.1	185.0	171.7	159.9	149.0	139.0	129.4	120.3	111.3	102.5	93.6	84.8	75.9	67.0	58.2
35.0	358.4	316.2	282.0	254.1	230.9	211.3	194.6	180.1	167.4	155.9	145.5	135.7	126.5	117.7	109.0	100.4	91.8	83.2	74.5	65.8	57.2
40.0	346.2	305.8	273.2	246.4	224.1	205.4	189.3	175.4	163.1	152.1	142.0	132.6	123.7	115.1	106.7	98.3	90.0	81.6	73.1	64.7	56.3
45.0	334.4	295.8	264.6	238.9	217.6	199.6	184.2	170.8	159.0	148.3	138.6	129.5	120.9	112.6	104.4	96.3	88.2	80.0	71.8	63.5	55.3
50.0	323.0	286.1	256.3	231.7	211.3	194.0	179.2	166.3	154.9	144.7	135.3	126.5	118.2	110.1	102.2	94.3	86.4	78.5	70.5	62.4	54.4
55.0	311.9	276.7	248.2	224.7	205.1	188.5	174.3	161.9	151.0	141.1	132.1	123.6	115.5	107.7	100.0	92.4	84.7	77.0	69.2	61.3	53.5
60.0	301.3	267.7	240.4	217.9	199.1	183.2	169.6	157.7	147.1	137.6	128.9	120.7	112.9	105.4	97.9	90.5	83.0	75.5	67.9	60.2	52.6
65.0	291.0	258.9	232.8	211.3	193.3	178.1	165.0	153.5	143.4	134.2	125.8	117.9	110.4	103.1	95.8	88.6	81.4	74.1	66.6	59.2	51.7
70.0	281.0	250.4	225.5	204.9	187.7	173.0	160.5	149.5	139.8	130.9	122.8	115.2	107.9	100.8	93.8	86.8	79.8	72.6	65.4	58.1	50.8
75.0	271.4	242.2	218.4	198.7	182.2	168.2	156.1	145.6	136.2	127.7	119.9	112.5	105.5	98.6	91.8	85.0	78.2	71.2	64.2	57.1	50.0
80.0	262.2	234.2	211.5	192.6	176.8	163.4	151.9	141.7	132.7	124.6	117.0	109.9	103.1	96.4	89.9	83.3	76.6	69.9	63.0	56.1	49.1
85.0	253.2	226.6	204.8	186.8	171.7	158.8	147.7	138.0	129.3	121.5	114.2	107.3	100.8	94.3	88.0	81.6	75.1	68.5	61.8	55.1	48.3
90.0	244.5	219.1	198.3	181.1	166.7	154.3	143.7	134.4	126.0	118.5	111.5	104.9	98.5	92.3	86.1	79.9	73.6	67.2	60.7	54.1	47.5
95.0	236.2	211.9	192.1	175.6	161.8	150.0	139.8	130.8	122.8	115.6	108.8	102.4	96.3	90.2	84.3	78.2	72.1	65.9	59.6	53.1	46.6
100.0	228.1	205.0	186.0	170.3	157.1	145.8	136.0	127.4	119.7	112.7	106.2	100.0	94.1	88.3	82.5	76.6	70.7	64.6	58.4	52.2	45.8
105.0	220.3	198.2	180.2	165.1	152.5	141.7	132.3	124.0	116.7	109.9	103.6	97.7	92.0	86.3	80.7	75.0	69.3	63.4	57.4	51.2	45.1
110.0	212.7	191.7	174.5	160.1	148.0	137.7	128.7	120.8	113.7	107.2	101.2	95.4	89.9	84.4	79.0	73.5	67.9	62.1	56.3	50.3	44.3
115.0	205.4	185.4	169.0	155.2	143.7	133.8	125.2	117.6	110.8	104.5	98.7	93.2	87.9	82.6	77.3	72.0	66.5	60.9	55.2	49.4	43.5
120.0	198.4	179.3	163.6	150.5	139.5	130.0	121.8	114.5	108.0	102.0	96.4	91.0	85.9	80.8	75.7	70.5	65.2	59.8	54.2	48.5	42.8
125.0	191.6	173.4	158.5	146.0	135.4	126.3	118.4	111.5	105.2	99.4	94.1	88.9	83.9	79.0	74.0	69.0	63.9	58.6	53.2	47.7	42.1
130.0	185.0	167.7	153.4	141.5	131.4	122.8	115.2	108.5	102.5	97.0	91.8	86.9	82.0	77.3	72.5	67.6	62.6	57.5	52.2	46.8	41.3
135.0	178.7	162.2	148.6	137.2	127.6	119.3	112.1	105.7	99.9	94.6	89.6	84.8	80.2	75.6	70.9	66.2	61.3	56.4	51.2	46.0	40.6
140.0	172.6	156.9	143.9	133.1	123.8	115.9	109.0	102.9	97.3	92.2	87.4	82.9	78.4	73.9	69.4	64.8	60.1	55.3	50.3	45.1	39.9
145.0	166.6	151.7	139.4	129.0	120.2	112.7	106.0	100.2	94.9	90.0	85.4	80.9	76.6	72.3	67.9	63.5	58.9	54.2	49.3	44.3	39.2
150.0	160.9	146.7	134.9	125.1	116.7	109.5	103.2	97.5	92.4	87.7	83.3	79.0	74.9	70.7	66.5	62.2	57.7	53.1	48.4	43.5	38.6
155.0	155.4	141.9	130.7	121.3	113.3	106.4	100.3	95.0	90.1	85.6	81.3	77.2	73.2	69.1	65.1	60.9	56.6	52.1	47.5	42.7	37.9
160.0	150.1	137.2	126.5	117.6	110.0	103.4	97.6	92.5	87.8	83.4	79.3	75.4	71.5	67.6	63.7	59.6	55.4	51.1	46.6	42.0	37.2
165.0	144.9	132.7	122.5	114.0	106.7	100.5	94.9	90.0	85.5	81.4	77.4	73.6	69.9	66.1	62.3	58.4	54.3	50.1	45.7	41.2	36.6
170.0	139.9	128.3	118.7	110.5	103.6	97.6	92.3	87.6	83.4	79.4	75.6	71.9	68.3	64.7	61.0	57.2	53.2	49.1	44.9	40.5	36.0
175.0	135.1	124.1	114.9	107.2	100.6	94.9	89.8	85.3	81.2	77.4	73.8	70.2	66.8	63.3	59.7	56.0	52.1	48.2	44.0	39.7	35.3
180.0	130.5	120.0	111.3	103.9	97.6	92.2	87.4	83.1	79.1	75.5	72.0	68.6	65.2	61.9	58.4	54.8	51.1	47.2	43.2	39.0	34.7
185.0	126.0	116.0	107.8	100.8	94.8	89.6	85.0	80.9	77.1	73.6	70.3	67.0	63.8	60.5	57.1	53.7	50.1	46.3	42.4	38.3	34.1
190.0	121.7	112.2	104.3	97.7	92.0	87.0	82.7	78.7	75.2	71.8	68.6	65.4	62.3	59.2	55.9	52.6	49.1	45.4	41.6	37.6	33.5
195.0	117.5	108.5	101.0	94.7	89.3	84.6	80.4	76.7	73.2	70.0	66.9	63.9	60.9	57.9	54.7	51.5	48.1	44.5	40.8	36.9	32.9
200.0	113.5	104.9	97.8	91.8	86.7	82.2	78.2	74.6	71.4	68.3	65.3	62.4	59.5	56.6	53.6	50.4	47.1	43.6	40.0	36.3	32.4