Document N° : MU/3464/EGF/001

OCTANS

Subsea Unit
Models 3000 TI

User's guide

February 2002

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FOREWORD

This document serves as the user’s guide for the subsea versions, model 1000 and 3000, of the Gyrocompass and Motion Sensor Octans developed and manufactured by IXSEA. For any question, contact your nearest IXSEA’s representative or directly IXSEA at:

Our Main Office: **IXSEA S.A.S** 55, Avenue Auguste Renoir 78160 MARLY LE ROI FRANCE	Phone : + 33 (0)1 30 08 98 88 Fax : + 33 (0)1 30 08 88 01 Email: info@ixsea.com
Our Benelux Office: **IXSEA b.v.** A Hofmanweg 5A 2031 BH HAARLEM THE NETHERLANDS	Phone : +31 (0) 23 750 5110 Fax : +31 (0) 23 750 5111 Email : info@ixsea.nl

Version	Date	Commentary
/	January 2002	First diffusion

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WARRANTY

IXSEA provides a warranty covering this product against any defect in materials or manufacture for a period of one (1) year from the date of shipment. In the event that such a defect becomes manifest during the stipulated warranty period, IXSEA undertakes, at its sole discretion, either to repair the defective product, bearing the cost of all parts and labor, or to replace it with an identical product.

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This warranty covers the product hereunder and is provided by IXSEA in place of all and any other warranty whether explicit or implicit. IXSEA does not guarantee the suitability of the product under warranty for sale or any specific use. IXSEA's liability is limited to the repair or replacement of defective products, this being the sole remedy open to Customer in the event the warranty becomes applicable. IXSEA cannot be held liable for indirect, special, subsequent or consequential damage, irrespective of whether IXSEA has or has not received prior notification of the risk of occurrence of such damage.

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- IXSEA S.A.S.
  55, Avenue Auguste Renoir,
  78160 Marly-le-Roi,
  France
  Tel.: + 33 (0)1 30 08 98 88
  Fax: + 33 (0)1 30 08 88 01
  E-mail: info@ixsea.com

For Benelux, please contact directly the Dutch site of

- *IXSEA b.v*
  A. Hofmanweg 5A
  2031 BH Haarlem
  Netherlands
  Tel.: + 31 (0) 23 750 5110
  Fax: + 31 (0) 23 750 5111
  E-mail: info@ixsea.nl

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EXPORTS

OCTANS is free of exportand use worlwide, excpet in the following countries (list dated december 2001):

> *OCTANS cannot be export or re-export in the territory of :*
>
> Afganistan, Angola, Myanar, Cuba, Iran, Iraq, Lybia, North Korea, Sudan, Syria, Serbia Montenegro.

SHIPPING PACK CONTENTS

You have just received your equipment in a protective carton. This contains the following items:

1. A blue shipping case (see photo 1) containing the items listed below. This enables the OCTANS unit to be protected for shipment by air.
2. The OCTANS navigation unit (photo 2).
3. This User Guide.
4. A mains supply module directly connectable to the OCTANS unit (photo 3), enabling conversion of 100/240V AC to 24V DC.
5. A Souriau 851-06J 14-19 S 50 connector (photo 4), enabling connection of analog I/O interfaces.
6. A Souriau 851-06J 20-41 S 50 connector (photo 5), enabling connection of digital I/O interfaces.
7. A cable enabling connection of the OCTANS unit to a local mains supply (photo 6).
8. A cable enabling connection of the OCTANS unit to a PC-compatible computer, to allow the unit to be configured (photo 7).
9. A CD-Rom to be downloaded onto a PC to enable the unit to be configured (photo 8).
10. A half-cable enabling the OCTANS unit to be powered at 24V (photo 9).
11. A calibration certificate signed by the IXSEA Quality Department.
12. The IMO certificate for surface units.

Verification of pack contents

You will find in the shipping case a Packing List detailing all the items referred to above. This Packing List was completed and checked by IXSEA shortly before shipment, and should logically match the contents of the pack you have received.

However, **we recommend that you check the contents of the pack and the equipment immediately on receipt of your OCTANS unit**. Specifically, you should check that all the items referred to above are present on delivery and that none has sustained damage.

If you observe any non-conformity or damage, please inform the carrier and IXSEA without delay by certified mail, describing in detail the nature of the problem.

I- INTRODUCTION

Octans 3000 TI are the members of the Octans family dedicated to underwater applications (down to 3000 m), featuring a specific waterproof housing in Titanium (13 kg total weight in air).

Octans is both a fiber-optic survey-grade IMO-certified gyrocompass and a Motion Reference Unit for marine applications that provides true-heading, roll, pitch, yaw, heave, surge, sway, rates of turn and accelerations even in highly volatile environments. Octans is also certified to meet to the requirements of the International Maritime Organisation (IMO) for gyrocompasses. Its heart consists of a small strapdown Inertial Measurement Unit (IMU), which contains three accelerometers, three fiberoptic gyrometers, and a real-time computer.

The fiberoptic gyrometer is a recent technology generated to meet the requirements of the aeronautical industry. It is totally inert, has no moving parts, and requires neither maintenance nor recalibration. It is capable of a very wide dynamic range and can tolerate extremely demanding mechanical environments without compromise to its performances.

Octans features the benefits of fiberoptic gyrometer technology and therefore shares the advantages of not requiring maintenance or recalibration. Its strapdown IMU structure enables straightforward, effective use with which no traditional mechanical gyrocompass can compete. Octans is insensitive to physical shock, can be carried in a case, and is easy to install. Strapdown equation processing enables the system to find North in less than 5 minutes whatever the sea conditions may be. Notably, it can be powered up at sea, which is impossible with a conventional gyrocompass.

In addition, Octans consumes only a small amount of power and directly outputs binary data to NMEA 0183 standard, which can be reconfigured if desired, in addition to analog data allowing easy interfacing with most available repeaters.

This document briefly describes how a subsea Octans works, and provides in more detail all the possible interfaces which can be configured.

II- TECHNICAL DESCRIPTION

Octans is a strapdown IMU that contains three fiberoptic gyrometers in the 0.05°/hour class, three milli-g accelerometers, and a real-time DSP computer. Figure 1 shows the Octans unit "open".

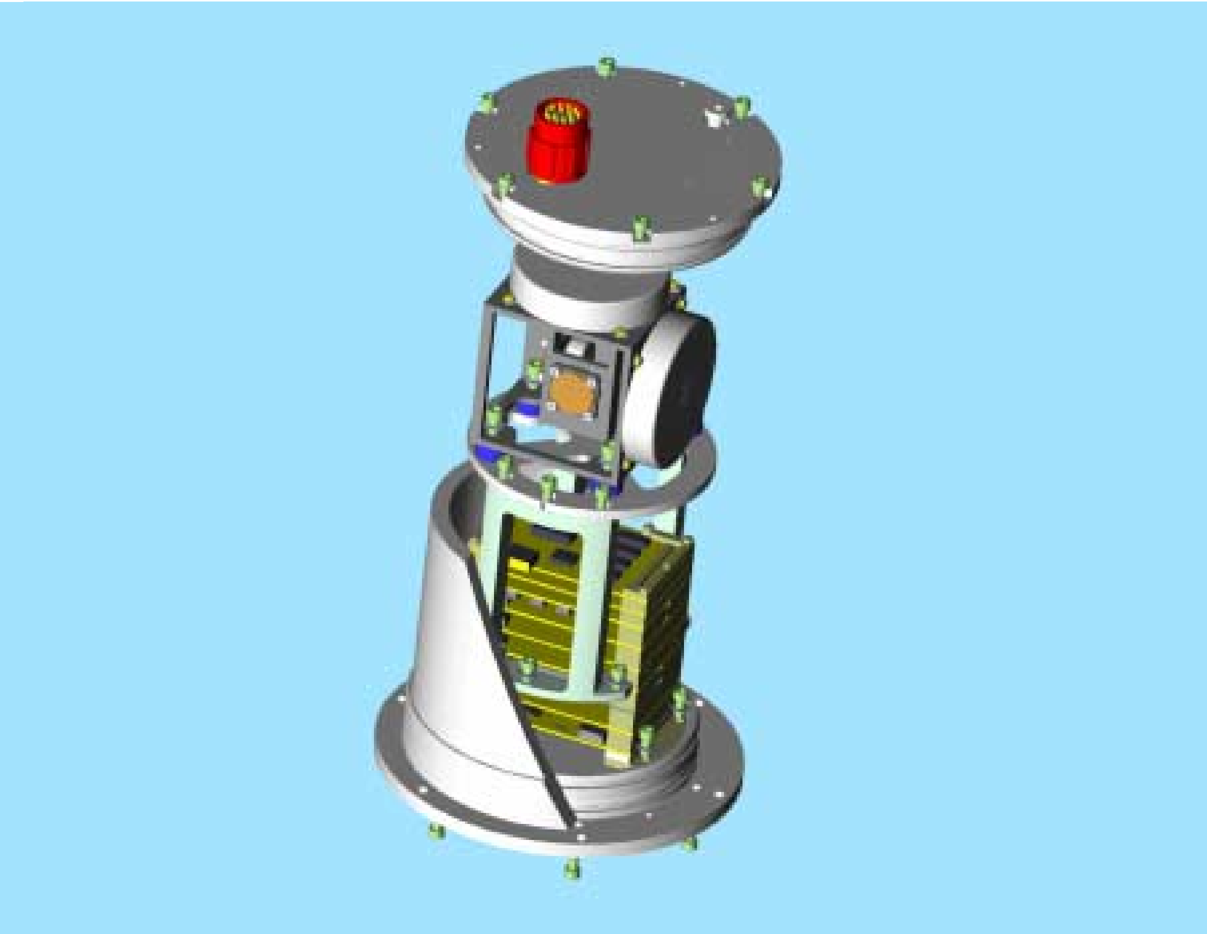


Figure 1 : Subsea Octans unit opened

Dimensions and physical characteristics are given in appendix [A].

II-1 Fiberoptic gyrometer description

The fiberoptic gyrometers contain fiberoptic coils with a length of nearly 800 m and an average diameter of 90 mm.

Typical performance specifications include:

Temperature bias stability:	*± 0.05 deg/hour (-40°C to +80°C)*
In room bias stability:	*0.002 deg/hour*
Random walk:	*0.0025 deg/ hour*
Dynamic range:	*± 500 deg/sec*
Angular resolution:	*≈ 0.2 arc second*
Temperature scale factor:	*30 ppm (-40°C to +80°C)*
Bandwidth:	*5 kHz*

These fiberoptic gyrometers are manufactured by iXSEA and are used for other applications, notably for military and aerospace applications.

II-2 Accelerometer description

The accelerometers are of pendulum type, particularly suited for attitude detection.

Typical performance specifications include:

Bias stability over one year:	*< 500 µg*
In room bias stability :	*10 µg*
Dynamic range:	*± 30 g*
Scale factor over one year:	*< 500 ppm*
Noise :	*15 µg/√Hz*
Resolution:	*≈ 10 µg*
Bandwidth:	*> 300 Hz*

The accelerometers can withstand a severe environment in mechanical and thermal terms:

Physical shock:	*250 g*
Vibration:	*25 g peak, 20 Hz to 2000 Hz*
Temperature:	*-55°C to +95°C*

II-3 Computer description

The unit's computer is a Digital Signal Processor (DSP) chip enabling rapid and complex real-time computation. This computation relates particularly to angle integration using quaternion algebra, a heading search algorithm and Coriolis force correction for vessel speed.

The heading search algorithm is specific to IXSEA and is suited to use with a strapdown IMU. It enables the heading to be sought whether the system is in movement or not and without an external reference point. It is based on (filtered) measurement of shifts in local gravity as the Earth rotates. This is possible because, in relation to an inertial reference frame, local gravity moves within a cone whose axis is related to the direction of the Earth's rotational vector (its North-South axis). Monitoring the movements in local gravity enables the axis of the cone to be determined and therefore the direction of geographical North. More detail on the algorithm used are given in appendix B.

III- MECHANICAL INTERFACE

The Octans 3000 TI is installed using six M6 screws on the base plate of the unit (see figure 2). Alignment is carried out by means of two centering pins located on the bottom plate of the system, enabling precise "point/line" positioning. These pins are located on the Octans 3000 TI centerline as shown by grooves on the base plate of the unit. The mechanical tolerance in the manufacture of Octans bottom plate allows to have 0,01° of accuracy on the centreline of the unit.

NOTE: Useable configuration

All our subsea units are designed as a standard for use on a vertical configuration.
For a subsea use in an horizontal configuration, please *consult IXSEA.*

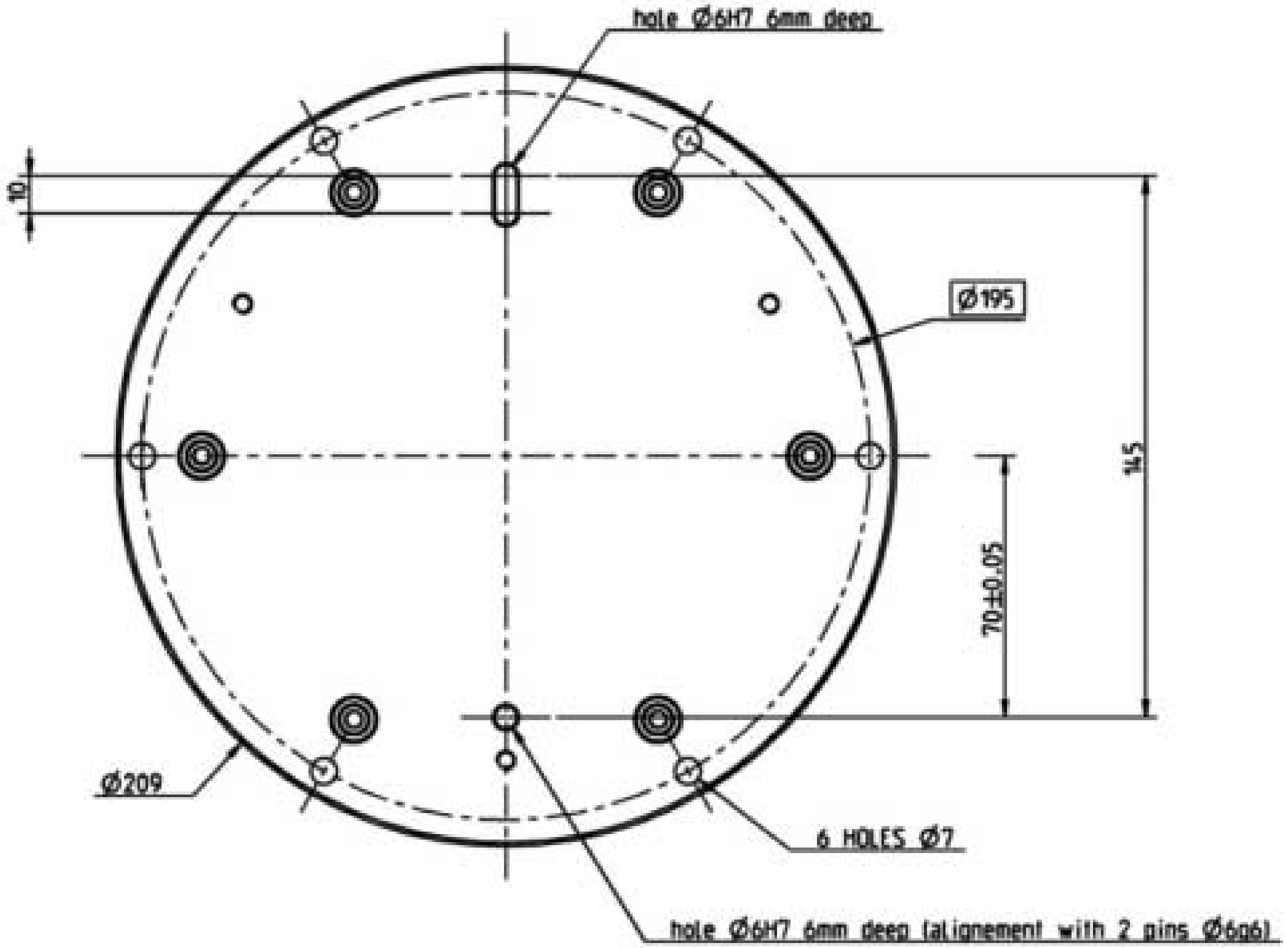


Figure 2 : Subsea Octans bottom plate mounting diagram

IV- ELECTRICAL INTERFACE

IV-1 Description of the top panel

Octans 3000 TI inputs/outputs are arranged via a 13-pin Burton connector. The reference of the connector is 5506 20-13.

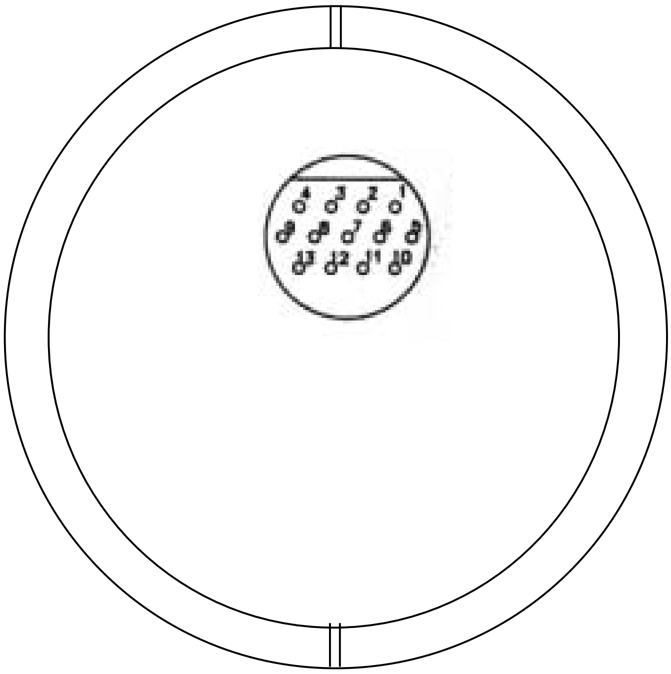


Figure 3 : Subsea Octans top panel

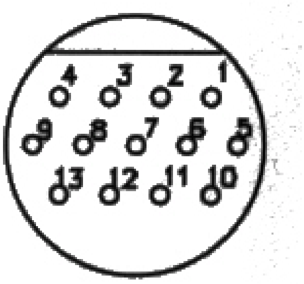
IV-2 Listing of interfaces

The 16-pin connector fitted on subsea octans is used to provide the following:

1. Power supply, described in IV-4,
2. Configuration port, described in IV-5,
3. 1 Analog Outputs described in IV-6,
4. 1 Serial Input/Output RS232/422 user-configurable, described in IV-7,

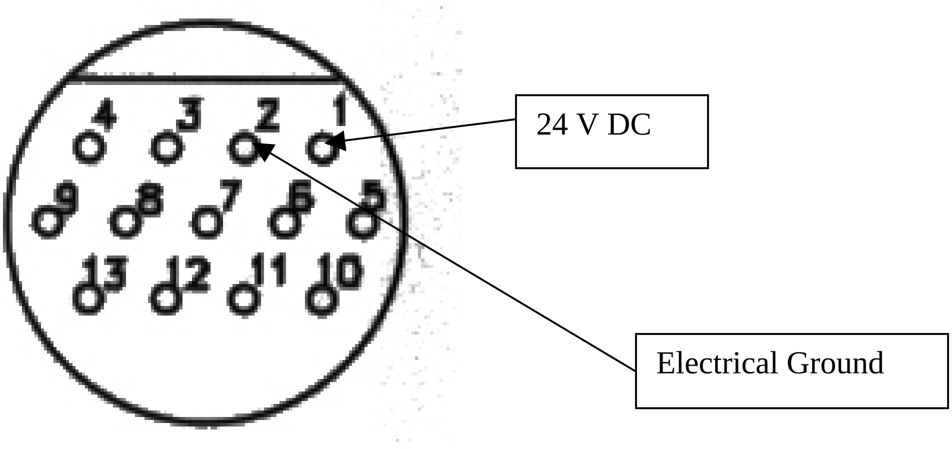
IV-3 Description of the 13-pin connector

The structure of the Octans 3000 TI connector is shown below:



Pin	Signal	Pin	Signal
1	VDC (19 V to 35 V)	9	ConfigOutGnd
2	GROUND	10	SerGnd
3	SerOutV+/232	11	ConfigOutV+
4	SerOutV-	12	ConfigIn-
5	SerInV+	13	ConfigIn+
6	SerInV-		
7	AnaOutASig		
8	AnaOutGnd		

IV-4 Power supply (pins 1, 2)

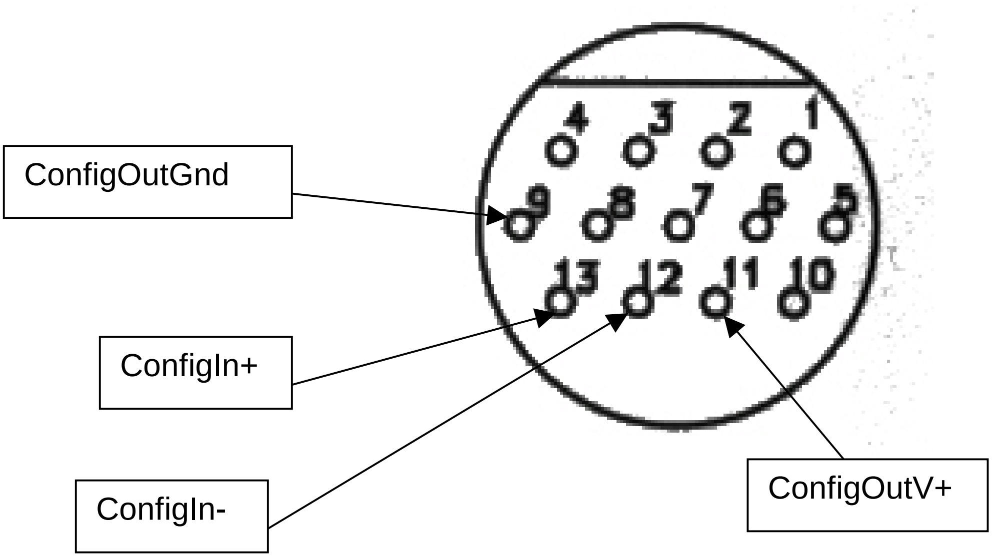


Octans is powered with a standard 24 V DC supply. It is possible however to supply power at any voltage between 19 V and 35 V. Maximal power consumption is 12 W in all cases. Octans does not possess an on/off switch. As soon as it is powered, it begins to seek geographical North.

NOTE: IMPORTANT

Please remember that any interruption of the power supply, even brief, will return the system to its initial condition and it will begin to seek North again.

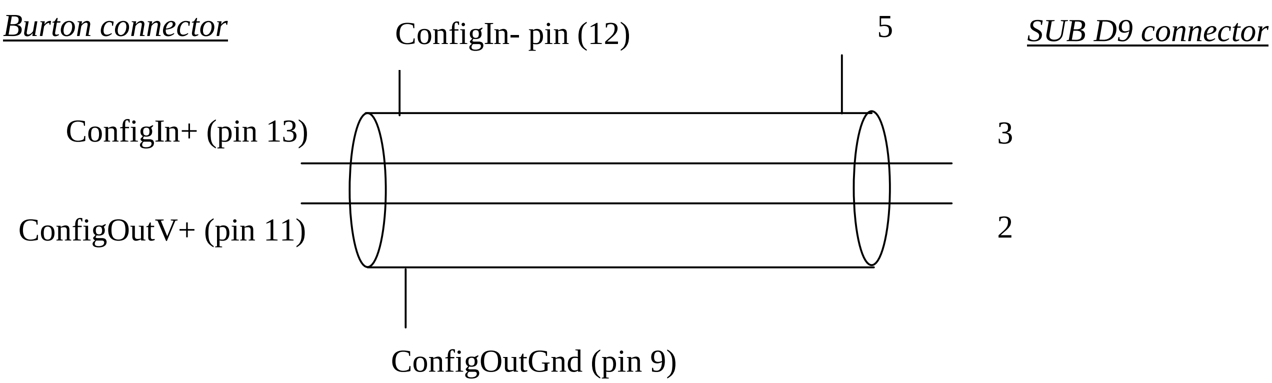
IV-5 IXSEA configuration and display output (pins 9, 11, 12, 13)



The pins 9, 11, 12, 13 are used to link the subsea Octans directly to the IXSEA *Octans Installation and configuration Software*.

In order to install, configure Octans or to use the Display Data, please connect your subsea Octans to a PC using a standard SUB D9 connector.

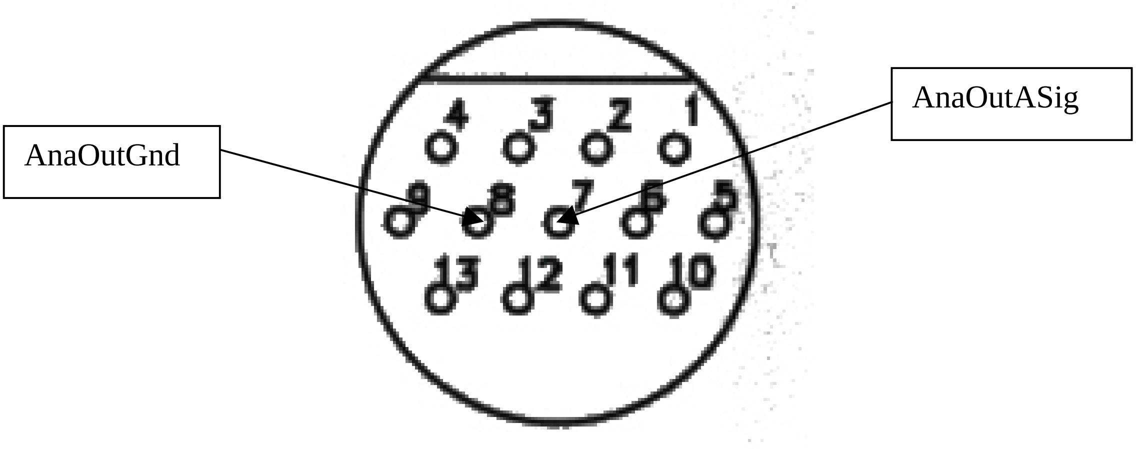
The cable between Octans and the PC has to be as follows :



IV-6 Analog Ouputs (pins 7, 8)

One analog ±10 V outputs are available and can be entirely configured (signal, sampling frequency, and scale factor). For more details, please refer to the *Octans Installation and configuration Software* user's guide.

This output offers 14-bit resolution at 300 Hz and is identified by the signals AnaOutGnd (pin 8) and AnaOutASig (pin 7).



IV-7 Digital Input/Output (pins 3, 4, 5, 6 and 10)

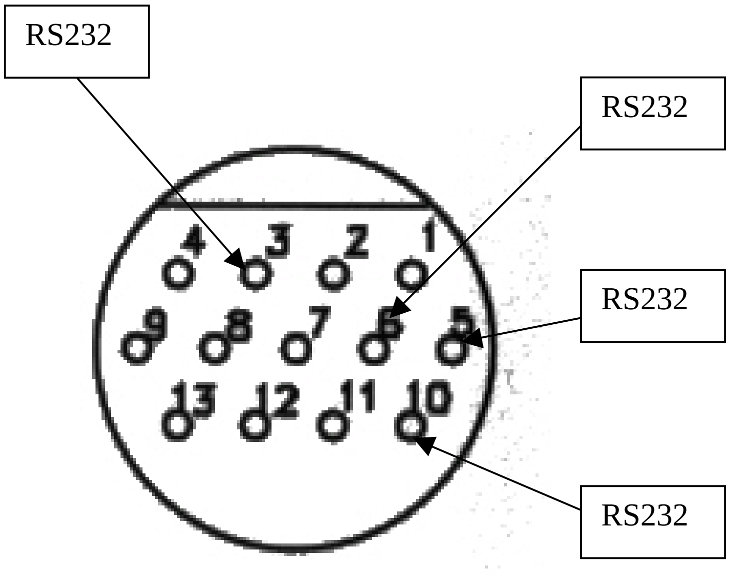
One serial input and one serial output are available on the subsea Octans. These serial I/O can be entirely configured. For more details, please refer to the *Octans Installation and configuration Software* user's guide. **Please note that only the port A is to be used.**

For each I/O, configuration parameters include:

- Electrical levels : RS 232 or 422 (see detailed pinout hereafter),
- Pair, parity: No parity, Even parity or Odd Parity,
- Number of bits: 0.5, 1, 1.5, or 2 stop bits,
- Data transmission rate: from 600 Bauds to 115.2k or from two definable values
- Protocol: 30 protocols based on NMEA 0183, ASCII or Binary,
  Output frequency: 0.1 Hz to 100 Hz.

IV-7.1 RS 232 Input / Ouput

In RS 232, the following pinout is used:



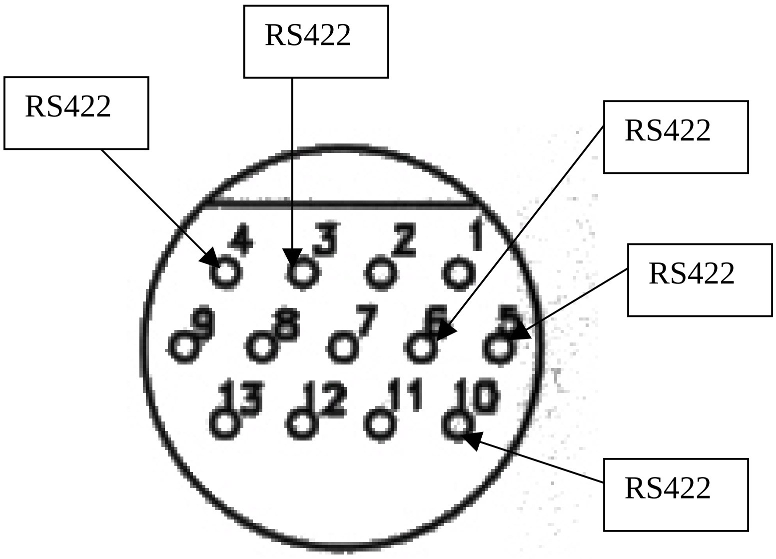
	OutGnd	Out /+232	InGnd	In /+232
A	SerOutGnd (10)	SerOutV+/232 (3)	SerInV- (6)	SerInV+ (5)

Note 1 : It is possible to connect the OutGnd to the InGnd pins to allow the use of 1 single Sub D9 connector for I/O,

Note 2 : SerOutGnd is internally connected to ConfigOutGnd and AnaOutGnd

IV-7.2 RS 422 Input/ Output

In RS 422, the following pinout is used:



	OutGnd / InGnd	Out /+422	Out /-422	In /+422	In /-422
A	SerOutGnd (10)	SerOutV+/232 (3)	SerOutV- (4)	SerInV+ (5)	SerInV- (6)

Note 1 : SerOutGnd is internally connected to ConfigOutGnd and AnaOutGnd

V. POSSIBLE SOURCES OF ERRORS

All gyrocompasses, Octans included, are sensitive to the speed of travel of the vessel and current latitude. However these errors are small and as described below, latitude needs to be entered in Octans only if the ship changes latitude very substantially, and very precise speed measurement is not imperative.

V-1 Heading error due to the speed log

The heading output of all gyrocompasses is sensitive to the speed of travel of the vessel towards North. The international standard (ISO 8728) defines that:

"Course error in degrees for a gyrocompass aligned north-south is determined by the formula V/5 x the secant of the latitude, where V is the North component of the speed in knots".

This speed correction applies whatever the technology used in the gyroscopes: Indeed, the linear speed of a boat travelling on the terrestrial "sphere" produces, with respect to the Earth and therefore with respect to the inertial frame of reference, a rotational speed V/R, where R is the radius of the Earth. This disturbs the measurement of the speed of rotation of the Earth and therefore the detection of North.

Using the above formula, it is easy to compute the speed level at which the heading will begin to demonstrate an error, if the accuracy of the heading measurement is known: Octans has an dynamic accuracy of 0.2 degree x secant of latitude and therefore the speed in knots at which an error greater than this appears is $V\ North_{max}$ = 0.2 x 5 3,2 knots.

Given that this is a relatively low value, it is generally recommended to enter the speed in Octans to allow the unit to compensate automatically and indicate the correct heading. It can be seen from the above formula however that the speed needs to be known only to a few knots. In practice, a log which gives the speed of the vessel in relation to the water without intrinsically taking into account the surface currents is more than satisfactory for such compensation. Since all ships are equipped with GPS, the GPS speed can also be entered.

V-2 Error due to unreliable latitude data

Gyrocompasses are intrinsically sensitive to latitude. Heading error is itself dependent in general terms on the secant of the latitude, which is fairly logical: the error tends theoretically toward infinity when the gyrocompass approaches one of the geographical Poles. However, it is not this error which is considered here, but rather intrinsic system inaccuracy when it has unreliable data for the latitude of the current location.

Octans needs to know the latitude of its location in order to find geographical North rapidly. If the latitude information input is incorrect, Octans will produce an error. **This error is nevertheless very small**: The curve in the figure 4 shows the heading error in degrees multiplied by the secant of the latitude versus the latitude of the current location, assuming that the latitude entered in the Octans unit is incorrect by one degree. In practice, Octans needs to know the latitude only to an accuracy of a 5 degrees or so. Please note that this dependency is slightly more important at low latitudes and it is recommended below 30° to enter the current latitude in the system with at worst a 3° accuracy.

In practice, it is possible to enter the latitude directly to Octans by using a GPS NMEA sentence. You can also manually enter the latitude, please refer to the *Octans Installation Software*.

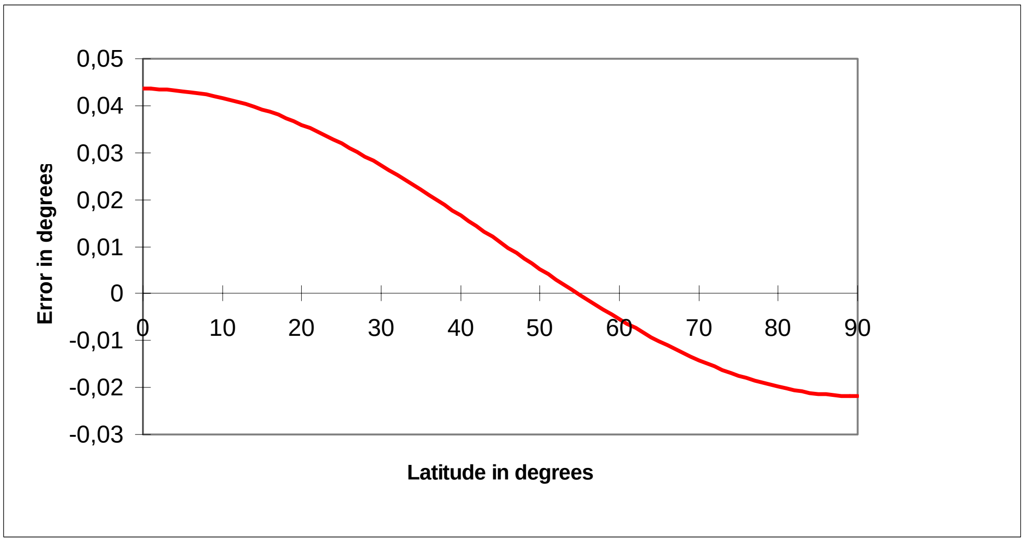


Fig. 4 : Heading error in degrees by secant of latitude for a 1 degree latitude error

<u>Example</u>:
At 40° latitude, an error of 3° in the latitude will cause 3x0,02 = 0,06° sec. Lat error.

VI- COMPUTATION OF HEAVE, SURGE, AND SWAY

VI-1 Definition of heave, surge, and sway

The heave, or vertical motion of the vessel, is determined by the double integration of the vertical acceleration. Unfortunately, the vertical acceleration is measured with small bias due to the physical limitations of the sensors. Because of this bias component, the double integration, which represents vertical position, can diverge to infinity very quickly. The best solution, used in every motion sensor, is to use an high-pass filter, which nulls out the bias component effect. By definition, the vertical amplitude of a movement which is filtered to cut-off the frequency around zero, is called "Heave". Respectively, the two horizontal positions filtered to cut-off the frequency around zero, the *surge* and the *sway*.

VI-2 Axis directions for heave, surge and sway measurements

VI-2.1 General

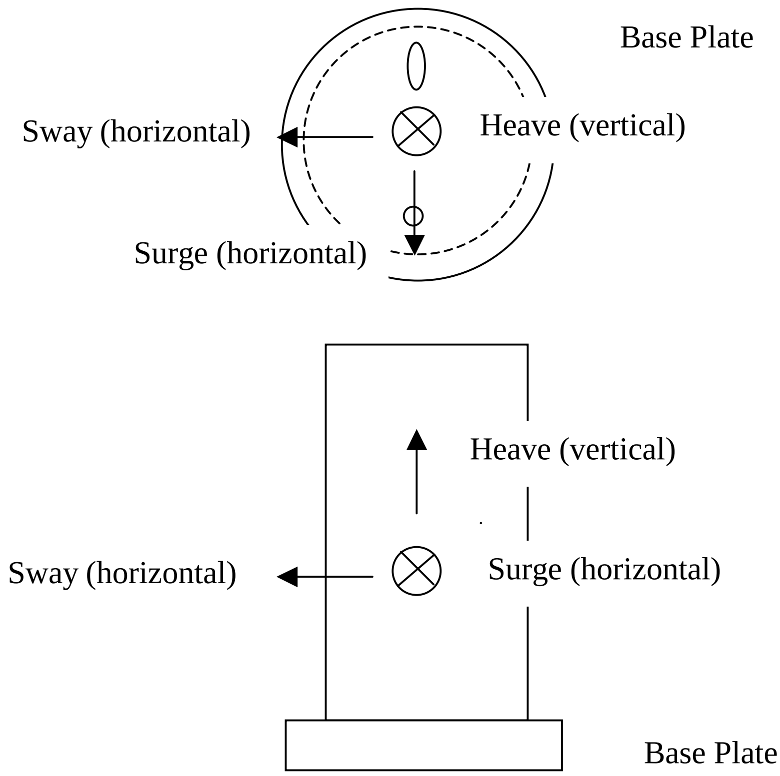


Figure 5 : Axis directions for the heave, surge, and sway measurements

VI-2.2 Sign conventions

The axis directions are defined as follows :

- The heave is default defined positive up on a vertical axis pointing to the direction of the connector.
- The surge is default defined positive on a horizontal axis parallel to the centerline pointing to the direction of the circle located on the base plate.
- The sway is default defined positive on a horizontal axis pointing to the left of the subsea Octans (on the port side of the vehicule, if the unit is "correctly" mounted).

VI-3 Choice of the high-pass filter

VI-3.1 General behaviour of an heave, surge and sway filter

Since the heave (surge and sway) output is high-pass filtered, the output will always return to zero when Octans is static. If Octans is moved over a given vertical distance, the heave output will show a step change in position. If Octans remains static in the new position, the output will gradually return to zero with a certain time constant (which depends upon the adjustment parameter of the filter). If Octans is moved following a sine or a combination of sinus, as usually observed with swell movements, the heave (surge and sway) output will follow this movement, provided that the high-pass filter is adapted to the swell frequency.

The heave, surge, and sway are computed by the double integration of the three accelerations. The frequency response of Octans for the heave measurement, which is the ratio between the measured heave and the exact vertical position, is :

$$H(f)=\left[\frac{j\frac{f}{f_C}}{1+j\frac{f}{f_C}}\right]^3$$

where fc is the cut-off frequency of the high-pass filter.

VI-3.2 Guidance for tuning the filter

For practical and operational reasons, the heave (surge and sway) formula is implemented inside octans as follows:

$$H(f)=\left(\frac{jT_o f}{1+jT_o f}\right)^3$$

Where "To" is the adjustment parameter that the operator can modify in order to adjust the heave behaviour to the sea state. For more detail, please refer to the "Octans Installation Software" or the "Repeater Software".

- **How to choose To, the adjustment parameter ?**

To correctly measure the swell movement using the heave output, it is important to **adjust To to a value quite larger than the longest period of the swell** expected during the operations.

The longer the swell period is, the higher To must be. **However, if To is high, the time to come back to zero in case of a sudden change in altitude increases.** There is therefore a conflict between the need to reduce the effects of errors, and the need for an extended bandwith in order to maximize the operational ability of Octans.

A compromise is found when **To is higher that 5.4 times the longest period of the swell (in that case the amplitude response is 95 %).**

Please refer the application note ‘’HEAVE TOOL’’ file included in the installation and configuration software CD if you wish to assess the effect of different To settings.

VI-4 Use of lever arms for heave computation

VI-4.1 Multiple lever arms

Octans is able to calculate the heave of an external monitoring point. Effective from firmware 4.1, three “secondary” monitoring points have been added. For each one of those secondary monitoring points, data can be outputted with a completely different setting including serial or analog I/O. In particular, at each location, a different protocol can be set. This allows, for instance, to drive a multibeam on one side of a vessel, to drive a single beam echosounder at an other location, to send analog heave info to a sub-bottom profiler.

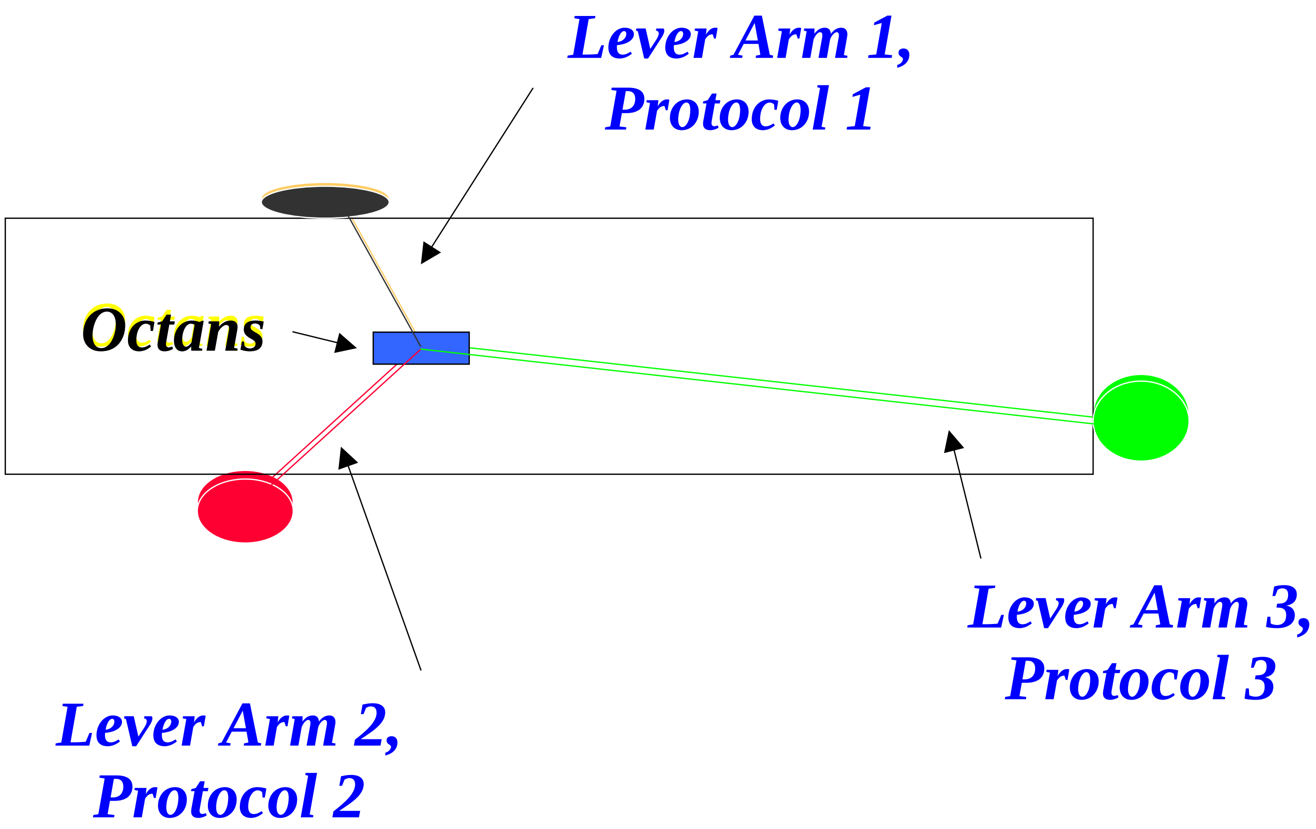


Figure 6: Multiple lever arms monitoring

VI-4.2 Effect of a lever arm on the computation of heave

Octans can be located some distance away from the desired monitoring point. In this case, the heave of the monitoring point can be very different from the one of the subsea Octans, due to the lever arms.

Let us assume for example that the heave of the subsea Octans is null, but there is just a pitch angle. If there is a lever arm between Octans and the desired monitoring point in the direction of the subsea Octans, it is easy to see that the heave of the monitoring point is not null, but equal to the tangent of the pitch angle times the lever arm distance (see figure 7).

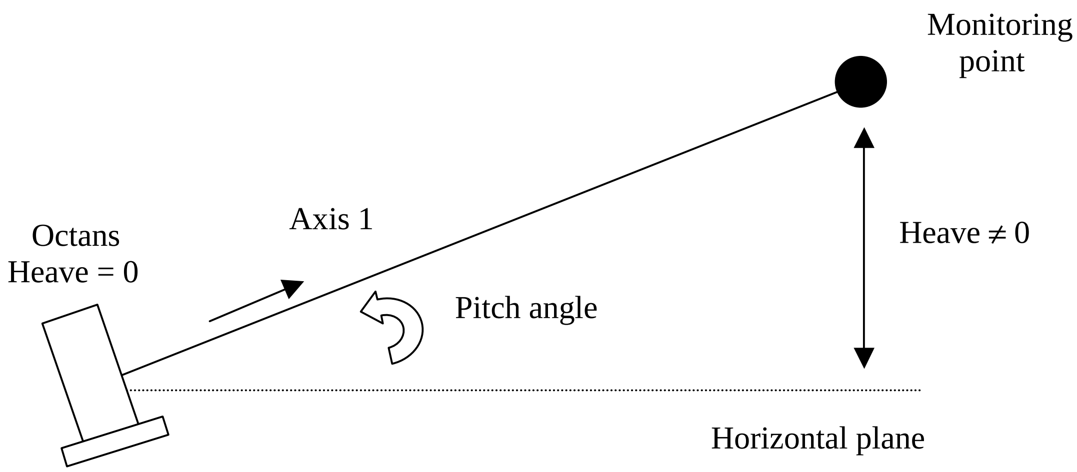


Figure 7 : Effect of lever arms

To avoid this effect, it is recommended to place the subsea Octans as close as possible to the monitoring point.

Otherwise, it is possible to compensate the effects of lever arms by computation. To perform this computation, it is necessary to know the exact place of the monitoring point in the frame of the subsea Octans . It is possible to give the vector (X_1 , X_2 , X_3) to Octans using the *Octans Installation Software*. The definition of this vector follows (see figure 8, next page).

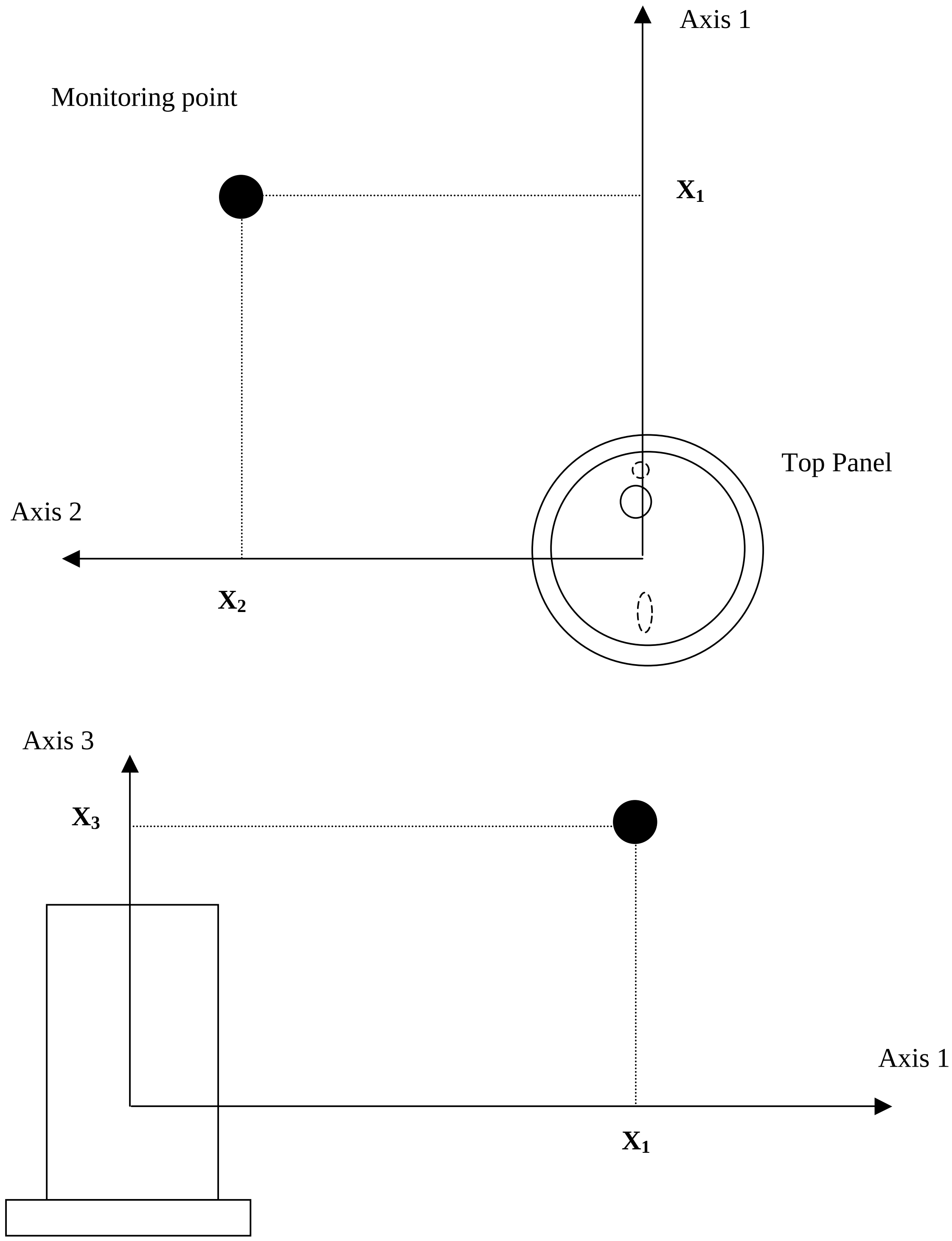


Figure 8 : Definition of the vector (X_1 , X_2 , X_3) for lever arms compensation for heave computation

VII- TRUE HEADING, ROLL AND PITCH

The true heading is the angle between the vertical plane oriented in the North direction and the vertical plane passing through the subsea Octans. The vertical plane passing through Octans is visualized by the centreline, **oriented positive from the oval-shaped hole towards the circular-shape hole located on the bottom plate**.

The orientation of this angle is given in figure 9.

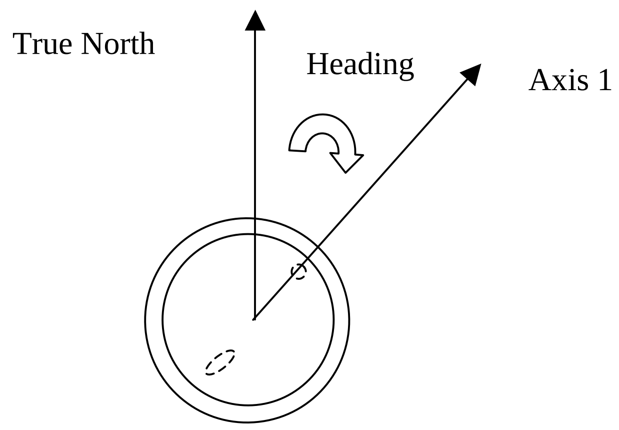


Figure 9 : Definition of true heading

VII-2 Roll

The roll is the angle between the horizontal plane and the axis 2 of the subsea Octans. This angle is default defined positive in the direction of axis 1, i.e. when the vehicle's port side is up.

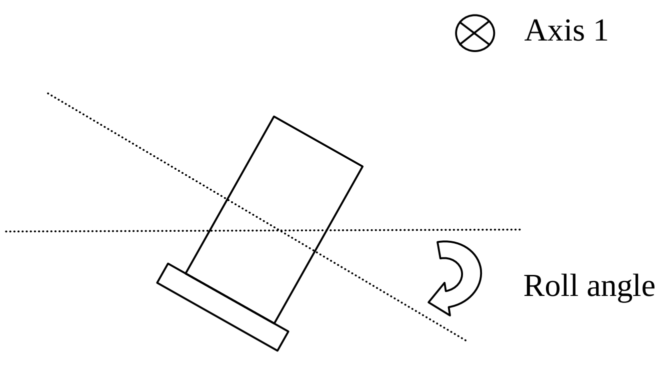


Figure 10 : Definition of roll

VII-3 Pitch

The pitch is the angle between the horizontal plane and the axis 1 of the subsea Octans. This angle is default defined positive in the direction of axis 2, i.e. when the vehicle's bow is down.

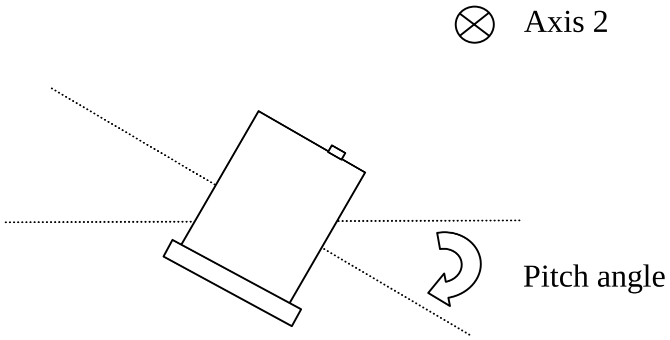


Figure 11 : Definition of pitch

APPENDIX A-SPECIFICATION

1. TECHNICAL DESCRIPTION

Octans in an IMO-compliant survey-grade gyrocompass and an integral motion sensor at the same time.

1.1. Performances

Gyrocompass Technical Performances

Dynamic accuracy (whatever sea-state)	± 0.2° Secant Latitude (*) or 0.1° Rms
Settle point error	± 0.1° Secant Latitude or 0.05° Rms
Settling time (static conditions)	1 Minute
Settling time at sea :	3 Minutes
Repeatability	± 0.025° Secant Latitude
Resolution	0.01°

No Latitude limitation
No speed limitation

(*) Secant Latitude = 1/cosine Latitude

Motion Sensor Technical Performances

Heave, Surge & Sway :

Accuracy	5 cm or 5% (whichever is highest)
Resolution	1 cm
Heave motion periods	0.003 to 100 s (tunable)

Roll, Pitch & Yaw :

Accuracy	0.01°
Range	No limitation
Follow-up speed	Up to 500°/s

Sensor (IMU) Intrinsic Performances

	Accelerometers	***Gyroscopes***
In-room bias stability (rms)	20 µg	0.005 °/h
Bias stability over temperature range (-40°C to +80°C)	± 500 µg	± 0.05 °/h
Resolution	10 µg	0.2Arc second

1.2. Environment

Environmental specifications

Operating temperature :	-40°C to +60°C
Storage temperature :	-40°C to +80°C
Shocks :	30 g in 6 ms (operating)
	50 g in 11 ms (survival)
Vibrations :	1 g sine (5 to 50 Hz)
MTBF	30 000 Hours

:

1.3. Interface

1.3.1 Power Requirement

Input voltage : 19 to 35 V d.c. (24 V nominal)
Power consumption : 12 W (max.)

1.3.2 Outputs

- Serial: 3 independent and configurable digital outputs (Surface Octans)
  Or 1 configurable digital output (Sub-sea Octans)

  To be chosen among a complete set of existing protocols (NMEA 0183, TSS, Seatex, Simrad, Robertson, Tokimec, Anschutz Compatible) or any custom protocol, with RS 232 or RS 422 levels
- Analogue: 4 independent and configurable analogue outputs, 14 bits / ± 10 V, (Surface Octans)
  Or 1 configurable analogue output,14 bits / ± 10 V, (Sub-sea Octans),
- Pulses
- Update rate: up to 300 Hz

1.3.3 Inputs

- Serial: 3 independent and configurable digital inputs (Surface Octans),
  Or 1 configurable digital output (Sub-sea Octans)
- Analogue: 2 independent and configurable analogue inputs, 16 bits / ±15 V,
- Pulses
- Update rate : up to 300 Hz

1.3.4 Installation Software

Octans is delivered with a powerful and easy-to-use installation software, which allows a complete configuration (choice of baud-rates and frequencies, data frame protocols, scale factors for analogue I/O, multiple lever arms, filtering parameters….).

1.4. Housings

1.4.1. Surface unit

OCTANS

Shape :	Rectangular box, splash proof(IP 66)
Dimensions (L x W x H, in mm) :	280 x 136 x 152
Weight in air :	4.5 kg
Material :	Aluminium

1.4.2. Sub-sea units

OCTANS 1000, built in an underwater housing (1000-meter depth rated)

Shape :	Cylinder
Dimensions (Ø x H, in mm) :	209 x 318 (body = 179 x 318)
Weight in air :	10 kg
Weight in water :	2 kg
Material :	Aluminium (hard anodising)

OCTANS 3000, built in an underwater housing (3000-meter depth rated)

Shape :	Cylinder
Dimensions (Ø x H, in mm) :	209 x 318 (body = 179 x 318)
Weight in air :	25 kg
Weight in water :	17 kg
Material :	Stainless steel (duplex)

OCTANS 3000 TI, built in an underwater housing (3000-meter depth rated)

Shape :	Cylinder
Dimensions (Ø x H, in mm) :	209 x 322 (body = 173 x 322)
Weight in air :	13 kg
Weight in water :	5 kg
Material :	Titanium

OCTANS 6000, built in an underwater housing (6000-meter depth rated)

Shape :	Cylinder
Dimensions (Ø x H, in mm) :	209 x 318
Weight in air :	15 kg
Weight in water :	7 kg
Material :	Titanium

1.4.3 Useable configuration

All the Sub-sea units are designed as a standard for use on a vertical configuration. For a sub-sea use in an horizontal configuration, please *consult IXSEA.*

2. CERTIFICATION

Octans complies with the regulations of the International Maritime Organisation resolutions A.424 (XI), A. 694 (17), A.183 (19) for gyrocompasses, with SOLAS 74 as amended (regulations V/12 (d), (i)) and IEC 60945, IEC 61162-1 and ISO 8728.

Octans has been awarded certificate N° 09807/A0 EC from certifying authority N° 0062. A copy of all relevant documentation is available upon request to iXSEA.

APPENDIX B - PHYSICAL PRINCIPLES OF OCTANS

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PHYSICAL PRINCIPLES OF OCTANS

Extract from
‘’highly compact fiber optic gyrocompass for applications at depths up to 3,000 meters,
presented at the Underwater Intervention 2000 show, January 2000’’

1. THE TECHNOLOGY OF FIBER OPTIC GYROSCOPES (FOGs)

FOGs do not use the rapidly spinning top employed in mechanical gyroscopes – in fact, they have no moving parts at all. They do not use the gyroscope effect to measure the rotational speeds of mobiles, but a radically different phenomenon – the so-called “Sagnac Effect”.

1.1. The Sagnac Effect

The Sagnac Effect is a physical phenomenon of relativistic type; understanding it requires a good grasp of Special Relativity [1]. However, it is possible to provide a simplified (although inaccurate) physical interpretation of the effect. Imagine a coil of optical fiber. Optical fiber, as is well known, is a good vector for the propagation of light. This coil will in principle have two exits at the two ends of the fiber. If we inject a light pulse into one end, it will come out at the other after a duration equal to the time the light takes to cover the entire length of the coiled fiber. If we now inject two pulses simultaneously into the two ends of the coil, they will travel in opposite directions, pass each other in the middle and come out at opposite ends of the coil. The time the light takes to travel through the coil will be the same irrespective of its direction of travel, and the two pulses will therefore exit the fiber at the same time. If we now imagine that the coil is rotating around its central axis, this movement will “help” one pulse but “hold back” the other. It can be seen therefore that the two pulses will leave the coil at different times. If we measure this temporal difference, we can deduce from it the speed of rotation.

1.2. FOG description and performance

In practice, this difference is determined in optics using interferometry, which provides a measurement of the phase difference between the two light waves travelling in opposite directions within the coil. The interferometer is created by “closing” the coil on itself using an optoelectronic component called an “Integrated Optical Circuit” (see figure 1).

Figure 1 : The “heart” of a FOG
the optical fiber coil with its integrated optical circuit

The ingenious signal processing which follows requires a large number of optoelectronic components if the information on optical phase, carrying information on rotation, is to be converted into a digital signal useable by a calculator.

In practice, FOG performance gets better as it gets bigger, a fact which can be easily understood in terms of the length of the coiled optical fiber: at any given rotational speed, increased length will make it easier to separate the two light pulses temporally in the way described above.

FOG performance can be measured in terms of many parameters, of which the most important is known as bias stability, which means the stability of the zero point, or the intrinsic accuracy of the measurement of rotational movement. It is usual to express bias stability in degrees per hour (deg/hour), to make comparison easier with the Earth's rotation rate, which is 15 deg/hour (1 revolution in 1 day, 360 degrees in 24 hours, giving 15 degrees per hour). In practice, in order to measure the bias stability of a FOG, we measure the Earth's rotation rate. As an example, at the latitude of Paris, France (48,57°N), a FOG must measure 11.33 deg/hour (i.e. the projection of the rotation of the Earth onto the apparent vertical).

1.3. Inertial Measurement Unit (IMU)

In fact, a single FOG measures the projection of the instantaneous rotation along the main axis of its coil, and three FOGs are necessary to measure the rotation rate vector.

This triad of gyrometers is usually combined with a set of three accelerometers. An accelerometer enables measurement firstly of the instantaneous acceleration along a given axis (and thereby, through successive integrations, speed and position), and secondly, knowledge of apparent local gravity, and thereby the local vertical axis.

The compact assembly formed by the three gyrometers and the three accelerometers is called an "Inertial Measurement Unit" (IMU) and forms the heart of any inertial reference system. When an IMU is coupled to a calculator and an interface, the result is an "inertial reference system".

Octans is an inertial reference system capable of providing complete information on the physical attitude of the mobile. The IMU comprises three FOGs (0.05 deg/hour bias stability) and three accelerometers (± 500μg).

2. THE FIBER OPTIC GYROCOMPASS – UNDERLYING PRINCIPLES

By definition, a gyrocompass is a gyroscope-based system for the measurement of true heading, that is to say, angular measurement of a position in relation to geographical North, whatever the movements made by the object on which the gyrocompass is placed. This means for example, that the gyrocompass must remain relatively insensitive to pitch and roll movements, which may be at high levels on certain ships. In this way, the gyrocompass is to be distinguished from North finders, which need to remain totally immobile in relation to the Earth when the measurement is done.

Gyrocompass types currently in use comprise a gyroscope which aligns its angular moment with that of the Earth and therefore exploit at a basic level the intrinsic properties of rotating solids, and notably the principle of gyroscopic spins. A gyrocompass using FOGs must therefore be based on a radically different concept. It is this concept that we explain below.

2.1. North finders

We can begin by assuming that our initial objective is to produce a “static” indicator of North, that is to say, an indicator without any mechanical system (which means that we cannot rotate a single horizontal-axis gyro in order to find the position which cancels out the signal, which will correspond to the East). In order to measure the rotation vector of the Earth **Ω**, the first thing we need is three gyros for the three spatial axes. However, that is not enough yet to indicate a heading, because we lack information about the horizontality of the assembly. This information can be obtained from a plumb line, electrolytic levels or accelerometers, by making a measurement of the local gravity vector **g**. It then remains to project the Earth rotation vector **Ω** onto the horizontal plane orthogonal to **g** to obtain the direction of geographical North (figure 2). It can be seen that the intrinsic accuracy of this measurement depends on the accuracy of the sensors (the bias of the gyros b_{gyro} and the accelerometers b_{acc} for example) and the latitude L. It can be expressed in radians as:

$$\Delta\Phi = \frac{b_{gyro}}{\Omega} \text{Sec L} + \frac{b_{acc}}{g} \tan \text{L}$$

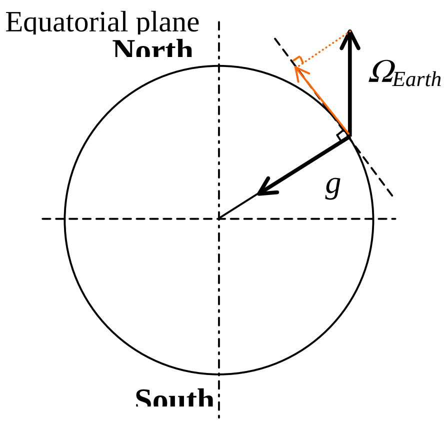

Figure 2: North Finder / basic concept

To achieve a North finder capable of rivalling commercially available conventional gyrocompasses, accurate to a few tenths of a degree of the secant of the latitude, it is necessary to select gyros offering accuracy to at least one-hundredth of terrestrial rotation rate (0.1 °/h), such as the FOG 90 (0.05°/h) produced at IXSEA, and accelerometers precise to one-hundredth of apparent gravity. In practice, the accelerometers used in octans provide better performance than this in order to improve dynamic stability.

2.2. Gyrocompasses

The gyrocompass represents a step up from the above in terms of complexity. At this level, the system has to withstand random movements – which may be violent, such as a ship's pitch and roll. The difficulty is twofold compared with the previous design: firstly, measurement of terrestrial rotation is disturbed by enormously high rotational values (several orders of magnitude greater than the Earth's rotation rate), and secondly, measurement of gravity is disturbed by centrifugal accelerations which may also prove to be relatively high.

The basic idea is therefore to abandon the direct use of the measurement of the Earth's rotation rate related to the gyroscopic frame, in favour of a "fixed" reference frame, which is called the Inertial Space.

Described briefly, the system comprises three gyros and three accelerometers: the three gyros enable the rotation rate of the moving object to be measured at any given instant (including the Earth's rotation rate), and the three accelerometers give the sum of the acceleration and apparent gravity; these measurements are both related to a reference bound to the moving object itself. The angular attitude of the moving object compared to the Inertial space is then computed by integration of the rotation rate. The accelerometer data, which is the sum of the acceleration and gravity, is then expressed within the Inertial Space. After filtering out the acceleration values, it is possible to "observe" the slow drift of apparent gravity due to the rotation of the Earth. In fact, it is easy to show that the apparent gravity expressed within the Inertial Space defines a cone whose main axis is the rotational axis of the Earth (see figure 3). Examination of the movement of **g** can therefore tells us where geographical North is without need of an external reference.

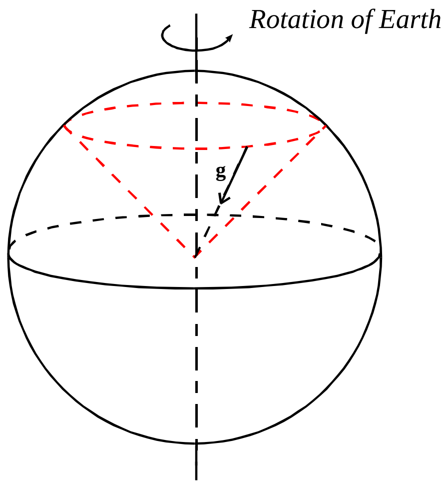

Figure 3: Conical movement of the local gravity g in relation to the Inertial Space