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Institute of Oceanographic Sciences Deacon Laboratory

INTERNAL DOCUMENT No. 347

Attitude sensor for the BRIDGET Deep-Tow

R E Kirk

1995

Natural Environment Research Council

INSTITUTE OF OCEANOGRAPHIC SCIENCES
DEACON LABORATORY

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DOCUMENT DATA SHEET

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PUBLICATION DATE

1995

TITLE

Attitude sensor for the BRIDGET Deep-Tow.

REFERENCE

Institute of Oceanographic Sciences Deacon Laboratory, Internal Document, No. 347, 27pp.
(Unpublished manuscript)

ABSTRACT

This report describes the design, construction and operation of a vehicle attitude and heading sensor system to be used on a deep-towed chemical sensor and sampling vehicle (BRIDGET).

KEYWORDS

ATTITUDE SENSOR
BRIDGE
HEADING SENSOR

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CONTENTS

Page No.

1. INTRODUCTION. 6

2. DESIGN. 8

2.1 Pitch And Roll Sensors. 8
2.2 Clinometer sensor specifications. 9
2.3 Heading Sensor. 10
2.4 KVH C100 Compass Specifications.
12
2.5 Power Supply. 13
2.6 Electronics Chassis And Pressure Case. 13

3. SET UP AND TESTING. 16
3.1 Clinometer, Lab Testing. 16
3.2 Pitch And Roll Sensor Outputs 17
3.3 Compass Set Up 19
3.4 Compass Output 22
3.5 Compass Calibration At Sea. 23

4. OPERATIONAL USE AT SEA. 24
4.1 Conclusions 27

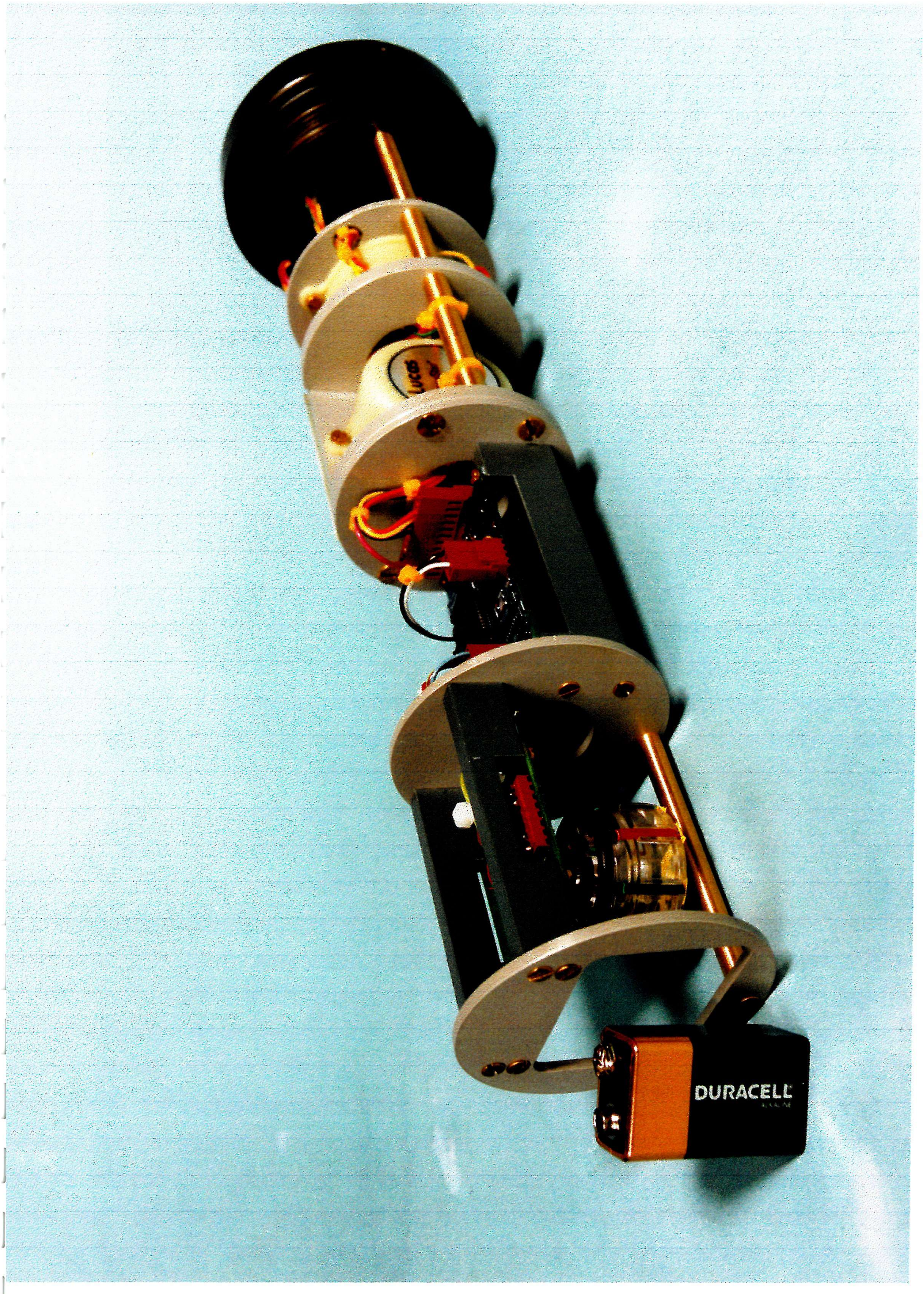
FIGURES

1. Linear Compass Output With Hysteresis. 11
2. Voltage Regulator. 14
3. Component List (Voltage Reg.) 15
4. Attitude Sensor Wiring. 20
5. Att. Sens To PC Conn Lead 21
6. Attitude Sensor Output During Haul 25
7. Attitude Sensor Output During Veer 26

1. INTRODUCTION.

The BRIDGET deep-tow is a multi sensor platform designed specifically to detect, map and sample hydrothermal plumes. Funded by the BRIDGE community research program the construction of this instrument is a collaborative effort involving scientists and engineers from I.O.S. Deacon Laboratory and Cambridge University. The system is attached via a slip ring assembly to the end of a co-axial conducting tow cable. This cable is used to tow the system within 500 metres of the seabed and also carries both power and signals to enable operation and control of sensors and sampling devices.

It was decided that although precise knowledge of the orientation of the deep-tow was not required, some ability to monitor variations in package attitude would be useful. A simple system would show up towing instabilities and indicate corrective design changes may be needed. Acoustic altimeter readings from the vehicle when being towed near-bottom could be treated with more confidence if stable vehicle attitude was indicated by the sensor package. Although commercial attitude sensing packages can be readily purchased, their cost and complexity would not be justified in this application. It was therefore decided that a simple pitch, roll and heading sensor unit should be constructed. This would then be attached to the BRIDGET frame and interfaced to the data gathering system along with other sensor signals and transmitted to the ship for display, monitoring and logging.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DURACELL

2. DESIGN

To construct a pitch, roll and heading sensor to be integrated into a larger instrument platform several things have to be considered. Some parameters are dictated by the envisaged use and operational requirements and others by the design of the rest of the system.

The working depth of the system and the ability to site the attitude sensor on the deep-tow suggested the unit be self contained within a single pressure case. The sensors themselves should be small units so the size of the pressure case could be kept small. A capability of down wire or vehicle mounted battery pack power supply to the sensor suggested that it should be tolerant to wide variations of supply voltage. Signal outputs from the three sensors should be analogue voltages to simplify bulkhead connector arrangement and wiring to the centralised data acquisition unit.

2.1 Pitch And Roll Sensors.

Pitch and roll sensors are two, single axis, Lucas-Schaevitz "Accustar" electronic clinometers. These units have a good specification whilst being both compact and rugged. The linear sensing range and the low cross axis error sensitivity were found to be adequate for our requirements. A capacitance-based gravity sensor with no moving parts the unit provides a linear variation in capacitance, when rotated about it's sensitive axis, which is electronically converted to angular data.

There are three models in the range having, analogue, digital and ratiometric outputs to ease integration into larger systems. For our application a unit with ratiometric output was chosen for pitch and roll sensing. Zero output from the sensors, i.e. no roll or pitch, is at half supply level. Therefore the supply voltage to these units has to be regulated and is set to be +5v. giving zero pitch and roll outputs of +2.5v. Sensitivity is supply voltage dependant and for a +5v. supply the clinometers give an output of 16 millivolts / deg. The output from the pitch sensor increases above 2.5 volts as the nose of the vehicle rises and conversely the output falls below 2.5 volts as the nose drops. Rolling to port increases the sensor output above 2.5 volts and rolling to starboard decreases it. The linear output range of these sensors is + and - 45 degrees from horizontal which should be more than adequate for use on a deep-tow vehicle. Further details and full specification of these units can be found in the following
Section 2.2.

2.2 CLINOMETER SENSOR SPECIFICATIONS.

Performance

Total Range	+/- 60 deg.	
Linear Range	+/- 45 deg.	
Linearity	0 - 10 deg.	0.1 deg.
	10 - 45 deg.	1% angle.
Cross axis error	1% c.a. angle.	
Time constant	0.3 sec.	
Frequency response	0.5 Hertz.	

Electrical - Ratiometric

Voltage supply nominal	+9v.
Voltage supply range reg.	+5v. to +16v. dc.
Current	0.5 ma.
Scale factor to linear range	16 to 52mv. / degree (supply voltage dependant)
Load resistance	10k. ohms

Environmental

Temperature Range

Operating	-40 to +65 deg.C
Storage	-55 to +65 deg.C
Temp coeff. of null	0.008 deg. per deg.C
Temp coeff. of scale	0.1% per deg.C

Electrical connections

Black	Power ground
Red	Regulated supply
Yellow	Signal output

2.3 Heading Sensor.

The heading sensor chosen was a KVH C100 compass engine. This is a stand-alone sensor which is of a compact fluxgate design which can give accurate analogue and digital outputs in various formats. The compass subsystem consists of a printed circuit board with a detachable toroidal fluxgate sensor element. A floating ring core and gimbal arrangement (SE-10 coil option) allows the fluxgate to remain horizontal even if its housing is tilted by a few degrees. Reliable operation at tilt angles of up to +/- 45 degrees is enabled in this way. Microprocessor controlled circuitry allows the unit to be calibrated once it is mounted on the vehicle to compensate for any magnetic disturbances caused by the host itself. These compensation constants are retained in EEPROM memory until the unit is recalibrated.

For use on the BRIDGET an analogue output from the sensor is digitised by the central data gathering system. There are two types of linear output available. Standard output as the name suggests gives a rising voltage from 0 to 359 degrees (5mv. / deg.) which then falls back to the 0 degree level (0.1 volt). This is a very sharp transition and can dither between the two values causing inaccurate readings. It was decided to use the hysteresis output, of the sensor, which has the advantage of producing a jitter free transition from 359 to 0 degrees. FIGURE 1. Linear Output With Hysteresis on the following page illustrates this concept in diagrammatic form.

The serial port on the unit is only used to set the various output options required and to perform calibration of the compass engine sensor when it is mounted on the frame of the vehicle prior to launch. This work is carried out on deck using a portable computer to communicate with the compass engine. Although it would be possible to transmit heading data serially from the unit this would create problems regarding the number of connectors required and cabling complexity.

To house the gimballed fluxgate head in a small diameter pressure case the sensor element is detached from the rest of the circuit card and mounted separately. Electrical connections between the microprocessor circuit card and the sensor element are made by a slightly modified jumper cable provided with the unit.

The sensor coil is mounted at the forward end of the chassis to keep it as far from electronic or magnetic interference sources as is possible in a small pressure case. As the fluxgate coil is gimballed and free to swing during deployment on the vehicle it should be restrained when not in use or in transit to prevent damage. This can be done by removing the end cap of the pressure case and wedging a piece of soft foam sponge between the sensor head and the inside of the pressure case. A hole has been machined in the end bulkhead of the chassis to facilitate this.

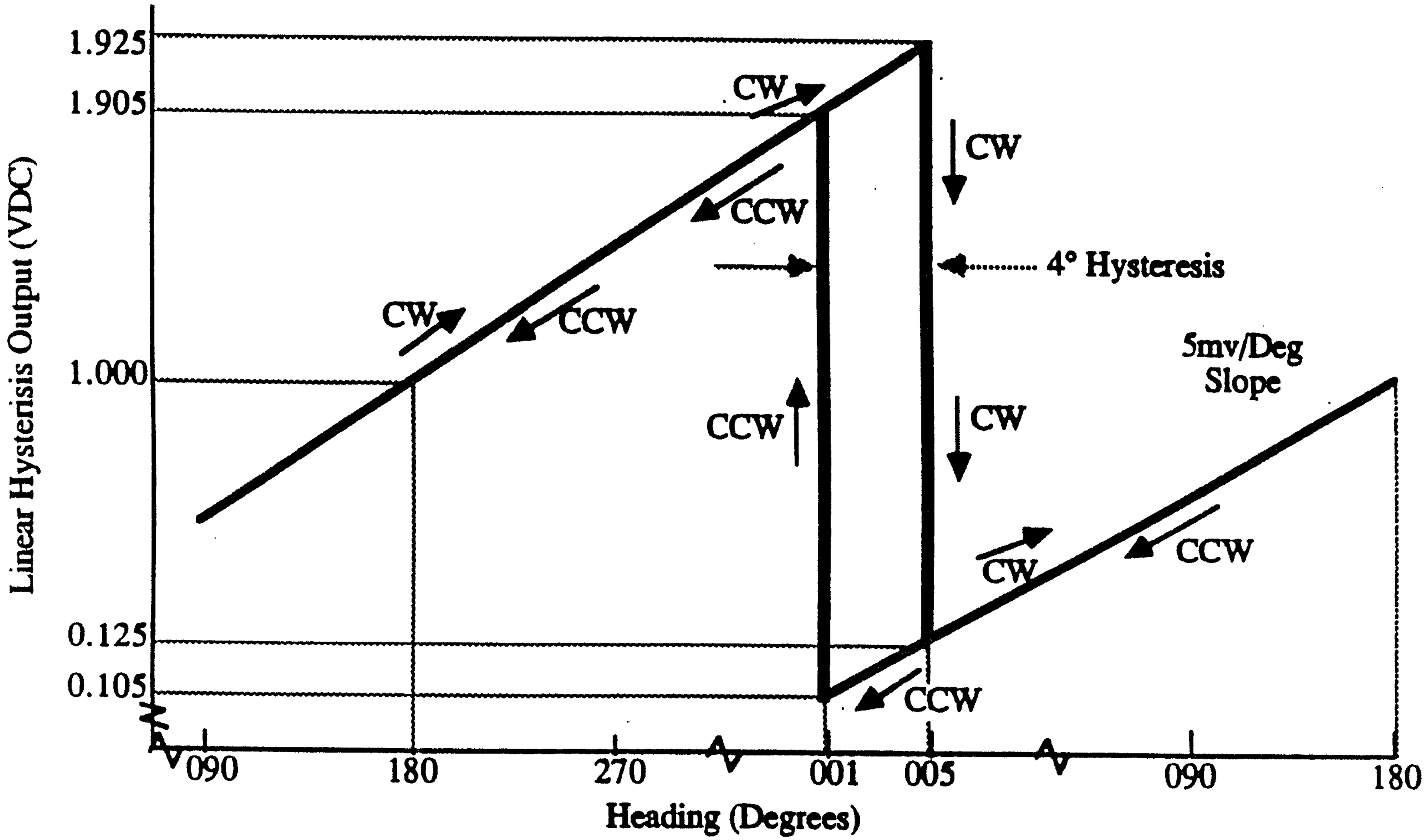


FIGURE 1. LINEAR COMPASS OUTPUT WITH HYSTERESIS.

2.4 KVH C100 Compass (SE-10 Gimballed coil option) Specifications.

Performance

Accuracy	0.5 deg.
Resolution	0.2 deg.
Resolution	0.1 deg.
Dip Angle	Maintains accuracy over +/- 80 deg. magnetic dip angles.
Tilt angle	+/- 45 deg. (SE-10 coil)

Electrical power

Input voltage	+8 to +18v. dc or +18 to + 28v. dc (user selectable)
Current drain	40ma. dc maximum

Offset adjustment

Variation/declination	+/- 180 deg. offset adjustment
Index error offset	+/- 180 deg. range adjustment
Damping	0.1 to 24 seconds (to final value) user selectable

Characteristics

Size	Electronics board	1.8" x 2.8" x 0.4"
	Sensor board	1.8" x 1.58" Gimballed SE-10 coil hangs 1.7" below card.
Weight		2.25 ounces (64gms)

Environmental

Operating temperature	-30 to +50 deg.C
Storage temperature	-57 to +71 deg. C
Reliability	MTBF calculated to exceed 30,000 hrs.

2.5 Power Supply.

The power supply is contained on a single printed circuit board and mounted on the chassis of the attitude sensor. A wide input supply dc-dc converter produces an output of +15v. which is regulated down to +12v. by a linear regulator. The wide input characteristics of the dc-dc converter would enable this unit to be operated with a 12v. battery supply if desired. The +12v. from the linear regulator supplies the KVH compass and a voltage reference device which is used as a voltage regulator to provide a very stable +5v. to the two clinometers. With output sensitivity of the clinometers(16mv./ deg.) being input voltage dependent it is most important that their supply voltage is precise and does not drift. Capacitors provide smoothing. A diagram of the circuitry is shown in FIG. 2 VOLTAGE REG. A list of components used and supplier details is shown in FIG. 3 COMPONENT LIST (Voltage Reg.)

2.6 Electronics Chassis And Pressure Case.

The pressure case used is a standard I.O.S.D.L. unit of 4 1/2" i.d. and 6" o.d. by 16" long. Two end caps with single face "O" seals provide an operational depth capability of 5,000 mtrs. Tube and end caps are produced from high strength aluminium alloy and are anodised after machining to prevent corrosion.

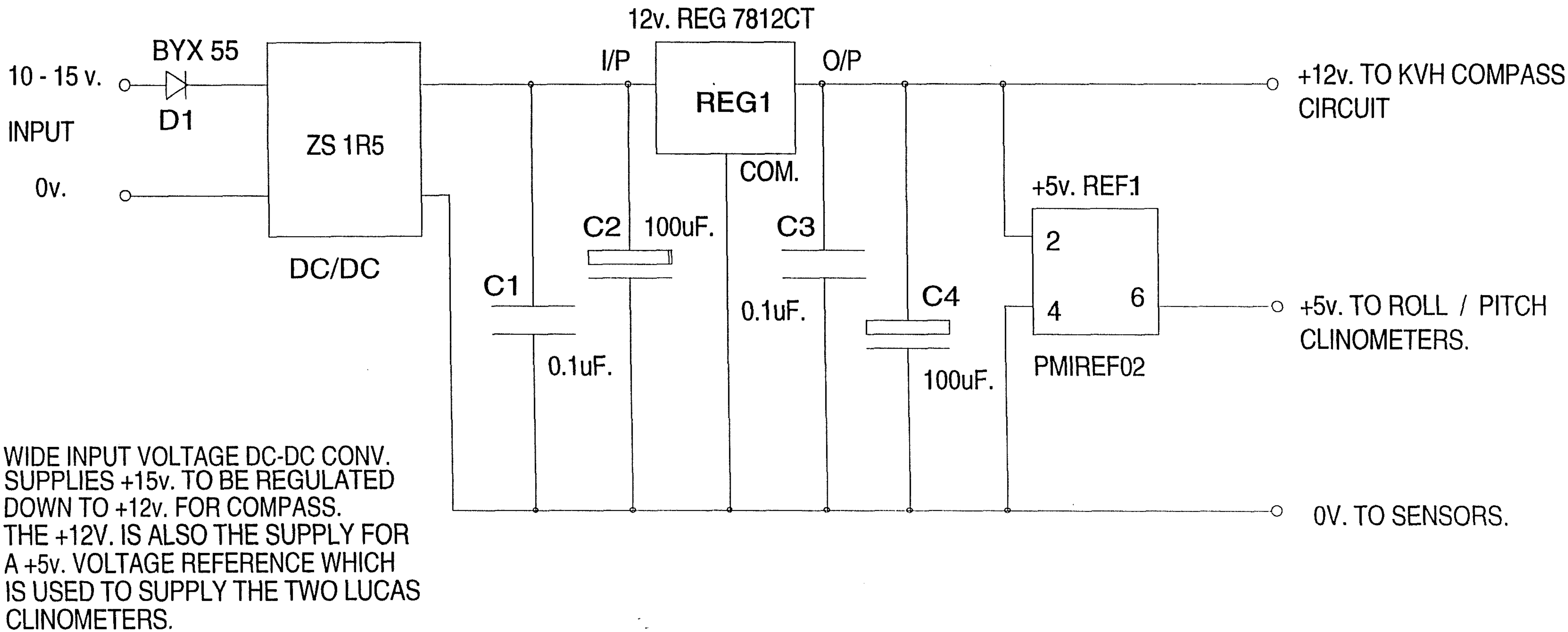
Voltage regulator card, clinometers and compass circuitry are all mounted on a simple chassis. This is constructed from non ferrous materials such as aluminium, brass and plastics. The chassis is fixed to one end-cap of the pressure case. This cap has penetrations for two bulkhead connectors which carry power to the unit and signals from the three sensors to the digitising electronics. Wiring details of the connectors and chassis wiring are shown in FIG. 4 ATTITUDE SENSOR WIRING.

To remove the circuitry and sensors from the pressure case the end cap with the bulkhead connectors should be carefully unscrewed and the complete chassis can then be withdrawn from the tube. Should it be necessary to remove the connectors from the end cap the internal wiring can be disconnected and the miniature plugs can be removed through the end cap holes to enable "O" seals to be inspected and cleaned periodically.

BRIDGET DEEP-TOW ATTITUDE SENSOR VOLTAGE REGULATOR.

See file ATTWIR.SKD (Attitude Sensor Wiring) for further details.

FIGURE 2 VOLTAGE REGULATOR



Institute Of Oceanographic Sciences Deacon Laboratory Brook Rd. Wormley Surrey England Gu8 5ub	Title VOLTAGE REG.	Drawn R.E.KIRK
	Filename VOLREG	Date 24/5/94

FIGURE 3 VOLTAGE REGULATOR CIRCUIT COMPONENTS LIST.

	Component	Value	Type	Supplier
Capacitor	C1	0.1uF		RS Components
	C2	100uF	Electrolytic	"
	C3	0.1uF		"
	C4	100uF		"
Diode	D1		BYX55	"
dc/dc converter	DC/DC		ZS 1R5-1215	XP plc
Voltage Regulator	REG1	+12v.	LM 7812CT	RS Components 641-623
Voltage Reference	REF1	+5v.	PMIREF02	RS Components 652-695

3. SET UP AND TESTING.

The following sections describe the setting up of the attitude sensors after the unit has been assembled. Basic operation of the unit can be checked in the lab and once this is done the unit should be left undisturbed apart from electronic recalibration of the compass aboard ship. Sensors such as clinometers can be statically tested in the lab for zero offset and range however this would be very difficult to do on a moving platform such as a ship.

3.1 Clinometer Lab Testing.

Both pitch and roll clinometers are mounted on the chassis in the vertical plane but at right angles to each other. To set up the sensors the chassis has to be fixed on a workshop surface table or stable bench so that it is vertical in the pitch and roll planes. This can be checked by using a good quality digital protractor.

Once the chassis is aligned power can be applied to the unit and the supply voltage to the clinometers should be accurately measured, using a digital voltmeter, and noted. Next the output from the clinometers is measured whilst the units themselves are moved carefully on their mounting plates. When a voltage equivalent to half the previously measured supply is given by the clinometers then their mechanical fixings can be carefully tightened. A final check of the readings will ensure that the sensors have not been disturbed.

The chassis should then be tilted in both pitch and roll planes at various angles up to + and - 45 degrees from the vertical using the protractor to measure the angles. At each point the output of the clinometers should be recorded to provide a calibration of later readings. There are no electronic adjustment points on these devices.

Capacitance plate design and electronic circuitry of the sensors reduces cross axis errors and filter out high frequency signals. Further tests can be carried out on a motorised tilt table if checking of time constants and frequency response are required.

3.2 Pitch and Roll Sensor Outputs .

Pitch Measurements .

Nose Up

Degrees	Voltage Output	Voltage Error	Degrees Error
35	3.071	+0.011	+0.7
30	3.002	+0.22	+1.4
25	2.911	+0.011	+0.7
20	2.831	+0.011	+0.7
15	2.750	+0.01	+0.6
10	2.671	+0.011	+0.7
5	2.588	+0.008	+0.5
0	2.508	+0.008	+0.5

Nose Down

Degrees	Voltage Output	Voltage Error	Degrees Error
0	2.508	+0.008	+0.5
5	2.427	+0.007	+0.4
10	2.350	+0.01	+0.6
15	2.271	+0.011	+0.7
20	2.191	+0.011	+0.7
25	2.110	+0.01	+0.6
30	2.025	+0.05	+0.3
35	1.950	+0.01	+0.6

Roll Measurements .

Roll To Port

Degrees	Voltage Output	Voltage Error	Degrees Error
35	3.050	-0.1	-0.6
30	2.968	-0.12	-0.75
25	2.885	-0.15	-1.0
20	2.800	-0.2	-1.25
15	2.722	-0.18	-1.12
10	2.638	-0.22	-1.4
5	2.559	-0.21	-1.3
0	2.477	-0.23	-1.4

Roll To Starboard

Degrees	Voltage Output	Voltage Error	Degrees Error
0	2.480	-0.02	-1.25
5	2.390	-0.03	-1.9
10	2.309	-0.031	-1.9
15	2.229	-0.031	-1.9
20	2.147	-0.033	-2.0
25	2.065	-0.035	-2.2
30	1.981	-0.039	-2.4
35	1.904	-0.036	-2.3
40	1.820	-0.04	-2.5

The above tables can be used to correct data readings.

3.3 Compass Set Up.

To check compass operation the whole attitude sensor package, including pressure case, should be set up on a calibrated rotating table in a location of low magnetic disturbance. Power and a portable computer are connected to the unit via the four pin male connector (CONN. 2) as shown on the ATTITUDE SENSOR WIRING diagram FIG. 4.

Details of the wiring of a suitable connecting lead for use with a portable computer are given in the ATT. SENS. TO PC CONN. LEAD diagram FIG. 5.

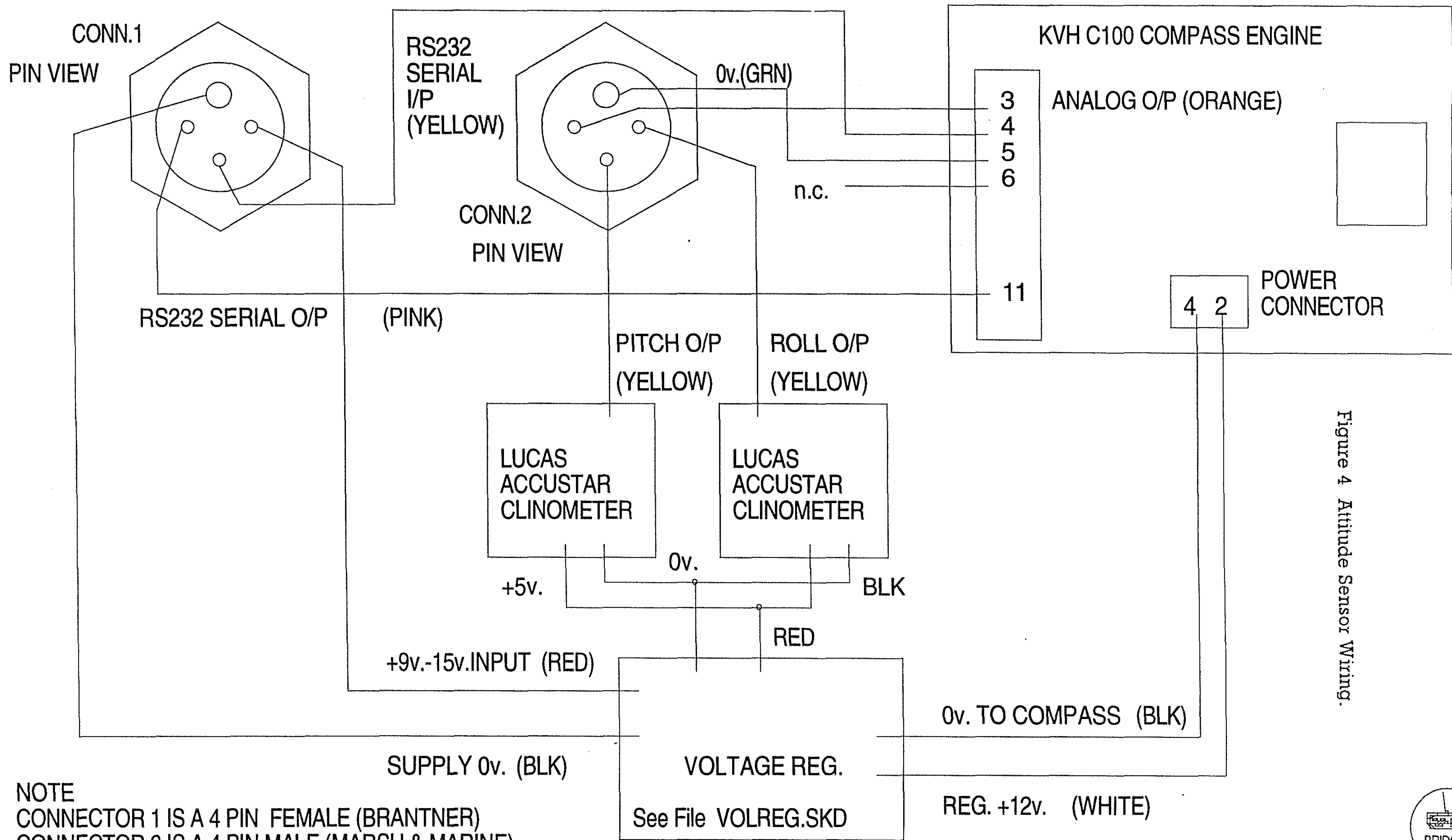
The KVH C100 compass engine is supplied with its own software which can be installed on the hard disc of the computer. The software is menu driven and allows the user to progress sequentially from one menu to the next and set up the required comms. port, baud rate, offsets, power up mode, signal output type etc.

Once set up the program can select terminal mode to allow communication with the compass and readings to be made. These are digital readings transmitted through the serial port. Once the compass is in it's transmit mode the unit can be monitored with any terminal program.

There is a calibrate menu available to allow semi-automatic calibration of the unit. Three different types of calibration available from a sub menu, these are eight point, three point, and circular calibrations. Of these the three point calibration requires very accurate alignment and would therefore not be used. Circular calibration is available if the compass software is of the correct version. Eight point calibration is probably the best to use and once completed a score and magnetic environment count is given to indicate the quality of the calibration.

After proper operation of the unit is established in the 'non magnetic hut ' environment then the unit can be attached to the frame of the BRIDGET vehicle. If a hoist is available then the whole vehicle can be rotated and readings taken to check the compass. When checks are complete digital data output can be disabled as this tends to put noise onto the analogue output line which is being digitised by the data gathering system. This can be done from the PARAMETERS menu.

Further details of compass and software operation are given in the C100 COMPASS ENGINE TECHNICAL MANUAL (KVH part no. 54-0044 May 24, 1993) and appendices.



NOTE
CONNECTOR 1 IS A 4 PIN FEMALE (BRANTNER)
CONNECTOR 2 IS A 4 PIN MALE (MARSH & MARINE)

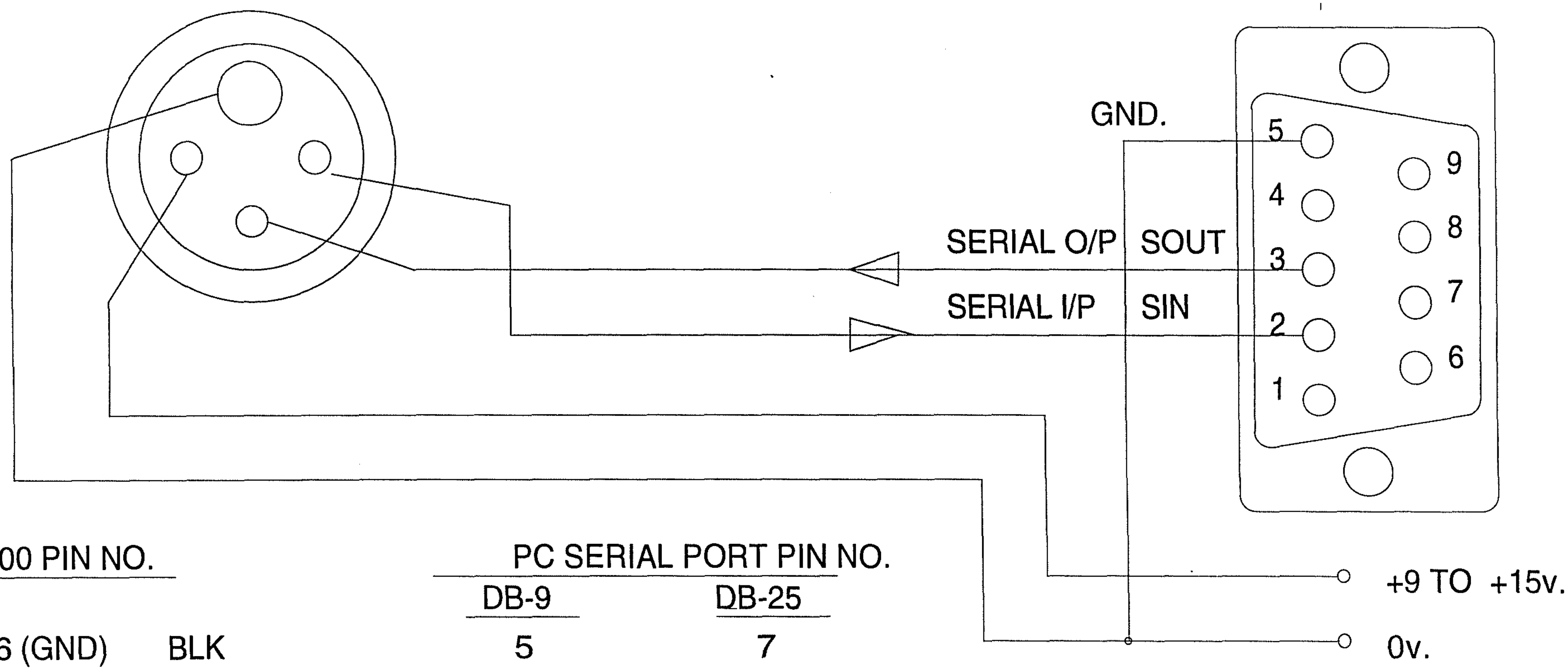
Figure 4 Attitude Sensor Wiring.

Institute Of Oceanographic Sciences Deacon Laboratory Brook Rd. Wormley Surrey England GU8 5UB	Title ATTITUDE SENSOR WIRING	Drawn R.E.Kirk
	Filename ATTWIR.SKD	Date 20/5/94

ATTITUDE SENSOR TO PC CONNECTOR LEAD

VIEW OF PINS ON 4-PIN BRANTNER FREE PLUG

SERIAL PORT WIRING



C100 PIN NO.		PC SERIAL PORT PIN NO. DB-9	DB-25
J2-6 (GND)	BLK	5	7
J2-11 (TXD output)	PNK.	2	3
J2-4 (RXD input)	YELLOW.	3	2

Note :- It may be required on some computers to connect the following pins together on the serial port connector.
1) RTS (request to send) to CTS (clear to send) 2) DSR (data set ready) to DTR (data terminal ready)

BRIDGET

Institute Of Oceanographic Sciences Deacon Laboratory Brook Rd. Wormley Surrey England GU8 5UB	Title ATT. SENS. TO PC CONN. WIRE	Drawn R.E.Kirk
	Filename CONNWIRE.SKD	Date 7/6/94

Figure 5 Attitude Sensor To PC Connecting Lead.

3.4 COMPASS OUTPUT

The following table gives the results of a test with the compass unit when swung in a non magnetic environment.

As the unit produces a hysteresis output the figure for 0 degrees and 5 degrees (anti clockwise travel) are duplicated as 360 degrees and 365 degrees (clockwise travel) respectively.

Sensor Orientation Degrees	Voltage Output	Voltage Error	Degrees Error
0	0.108	+ 0.008	+1.6
5	0.13	+0.005	+1.0
20	0.201	+0.001	+0.2
40	0.3	0.0	0.0
60	0.395	-0.005	-1.0
80	0.487	-0.013	-2.6
100	0.585	-0.015	-3.0
120	0.687	-0.013	-2.6
140	0.786	-0.014	-2.8
160	0.889	-0.011	-2.2
180	0.989	-0.011	-2.2
200	1.089	-0.011	-2.2
220	1.193	-0.007	-1.4
240	1.293	-0.007	-1.4
260	1.391	-0.009	-1.8
280	1.494	-0.006	-1.2
300	1.596	-0.004	-0.8
320	1.699	-0.001	-0.2
340	1.801	+0.001	+0.2
360	1.904	+0.004	+0.8
365	1.925	0.0	0.0

Calibration figures above can be applied to acquired data.

3.5 Compass Calibration At Sea.

Calibrations could be carried out whilst the ship was stable in port if necessary due to additions to the framework for example. Again the whole vehicle should be suspended and rotated for an eight point calibration to be carried out.

It is probably prudent not to rely on being able to carry this out at the work area where calibration may not be possible due to ship's motion.

4. OPERATIONAL USE AT SEA.

The BRIDGET deep-tow was prepared for it's first deployments during RRS Charles Darwin Cruise 90 in September 1994. This was a BRIDGE funded trials cruise for the instrument.

The attitude sensor was secured to a PVC mounting plate by two pairs of PVC half-clamp brackets. The mounting plate was designed to be fixed to the BRIDGET framework near the front of the vehicle. This position would reduce the length of cable for the analogue signals to pass through and also put this sensor near the centre of motion of BRIDGET. Power for the unit (12 v.dc) was derived from the main BRIDGET power supply which was supplied from the ship via the tow cable. Analogue signals, from the attitude sensor, were passed to the BRIDGET electronics tube for digitisation and transmission to the ship.

During the cruise the system was deployed several times. The attitude sensor performed well and reliably. Some examples of pitch, roll and heading data are given in the graphs (30 seconds long) on the following pages.

FIGURE 6. ATTITUDE SENSOR OUTPUT DURING HAUL.

FIGURE 7. ATTITUDE SENSOR OUTPUT DURING VEER.

Depth data, from the FSI micro CTD, is included to indicate whether the deep tow was being raised or lowered through the water. It will be noticed that the depth data rate is approximately 4 Hz. and pitch, roll and heading outputs are digitised at 1 Hz.

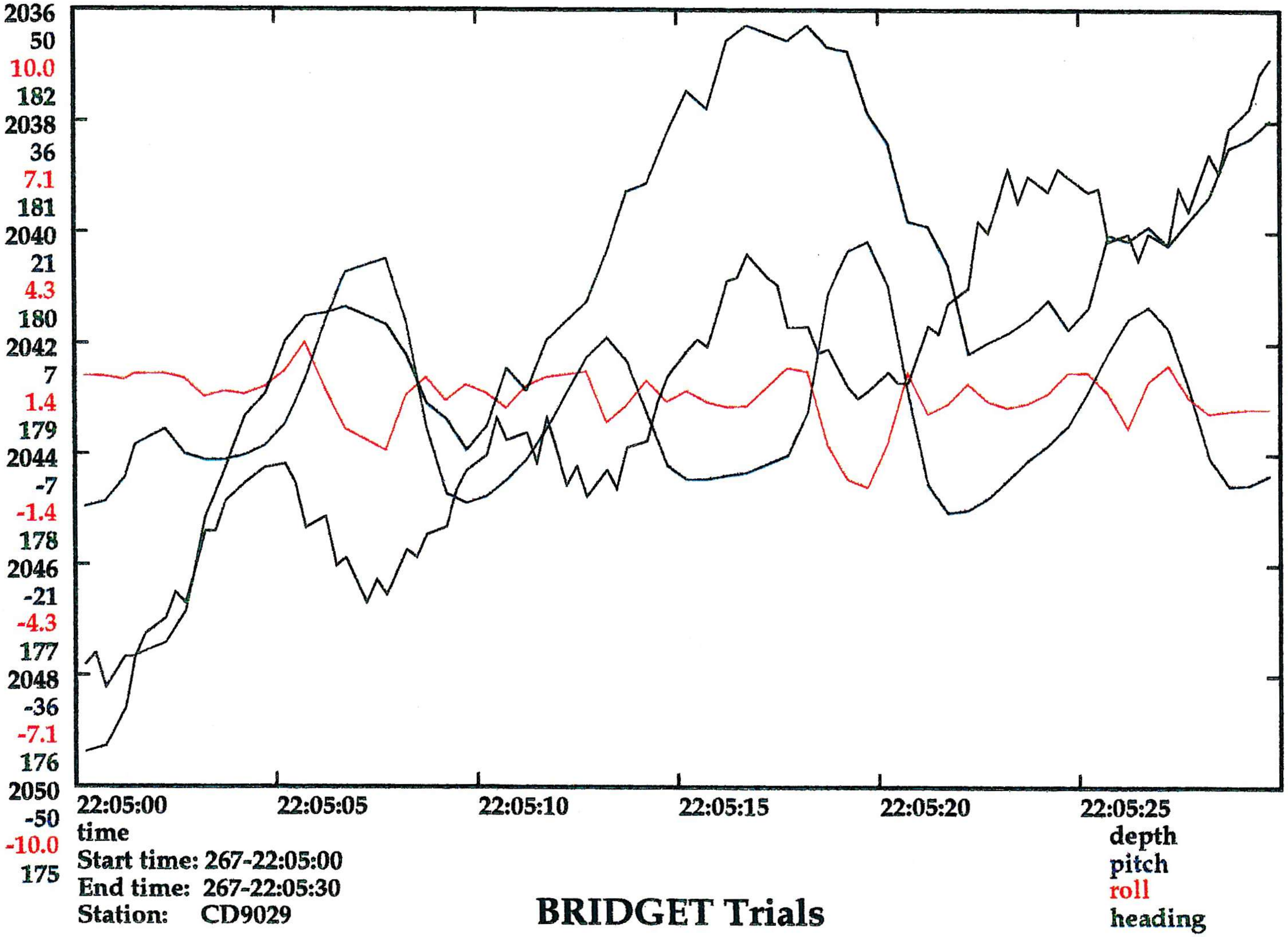


FIGURE 6. ATTITUDE SENSOR OUTPUT DURING HAUL.

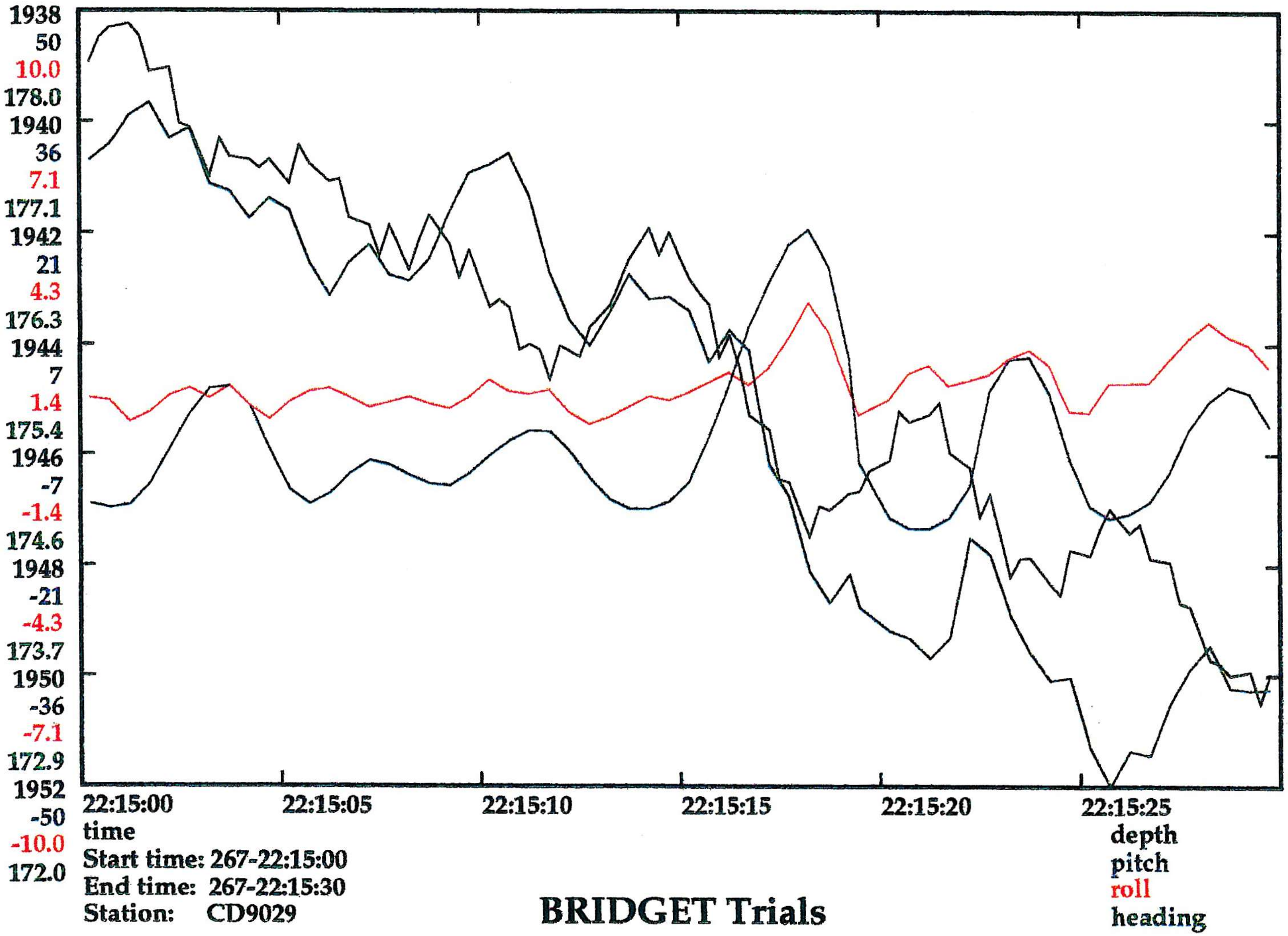


FIGURE 7. ATTITUDE SENSOR OUTPUT DURING VEER.

4.1 Conclusions

The graphs indicate that even during haul and veer the heading and roll readings are reasonably stable. However there does seem to be excessive pitching of the deep tow indicated. This was not totally unexpected in a vehicle attached directly to the end of the tow cable which would be transmitting the heave of the ship along its length.

All of this information will assist us in making necessary modifications to BRIDGET and monitoring performance during future deployments.