TRIAXYS™ OEM
Directional Wave Sensor

USER'S MANUAL

Manufactured by:

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May 2005

Revision History

Rev	Date	Change	By
03	Oct. 9, 2001	Added file selection command <F>ile Added Ability to change data output mode (Hex or Bin) Added MeanDir and HNE capability	RP
04	May 10, 2005	Added new NMEA sentence specifications for rev 3.40 EPROM	

Model Identification by Serial Numbers

The TRIAXYS™ OEM Wave Sensor is identified by a unique Serial Number. Software version numbers are identified for the three EPROMs (1- Gpuc, 2- PC104) in the Wave Sensor. Always provide the TRIAXYS™ Serial Numbers in any correspondence with Axys Technologies Inc.

This manual is supplied for use with the TRIAXYS™ OEM Wave Sensor,

Item	Location	Serial Number/Version
TRIAXYS™ OEM Wave Sensor	On the back lip of the lid of the Module.	
Gpuc EPROM in TRIAXYS™ OEM Wave Sensor	Shown in the title of the Main Menu (Section 2.1)	
PC104 EPROMs in TRIAXYS™ OEM Wave Sensor	In the Housekeeping files (Section 3.3.2).	

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1.0 INTRODUCTION

1.1 System Description, Features and Specifications

Options

The TRIAXYS™ OEM Wave Sensor samples and processes the wave data and provides the output through the serial port with internal data storage.

Table 1

TRIAXYS™ OEM Wave Sensor System Specifications

Item		Specification	
Physical Description			
Height/Length/Depth		35cm x 35cm x 20cm (13” x 13” x 6”)	
Weight		6 Kg (14 lb)	
Material		Stainless Steel/Aluminium	
Sensors/Processor			
Accelerometers		Flexure suspension servo (Range ±2g)	
Rate		Piezoelectric vibrating gyroscope (Maximum angular velocity ±80°/s)	
Compass		Microprocessor controlled fluxgate (Accuracy ± 0.5°)	
A/D and sampling frequency		8 channel 14 bit at 4 Hz	
Microprocessor		PC104 and 80C552	
Power Requirements		11.5 to 13.5 VDC, ~0.15 amps (1 amp peak load)	
Communications		RS 232 (3 wire), 9600, 8, N, 1	
Resolution/Accuracy			
	Range	Resolution	Accuracy
Heave	±20 m	0.01 m	Better than 2%
Period	1.50 to 33.0 seconds	0.05Hz	Better than 2%
Direction	0 to 360°	1°	±1°

1.2 Power Budget

The following table indicates approximate power usage. Assuming an hourly 20-minute sample period, the total power usage in 24 hours would be 24 x 0.090 = 2.16 amps. (based on 12 volts)

Sample Duration min/hr	Power Usage Amp hr/hr
5	0.037
10	0.055
15	0.072
20	0.090
25	0.107

1.3 TRIAXYS™ OEM Wave Sensor

The TRIAXYS™ OEM Wave Sensor contains the Wave Sensors (accelerometers, rate sensors and compass) and the processing unit. The processing unit samples and analyses the data and controls all the systems in the TRIAXYS™ OEM sensor The processing unit is set up through a series of computer commands. For details of these menus and their operation see Section 2.0. For details of data sampling and analysis software and how the data are handled see Section 4.0.

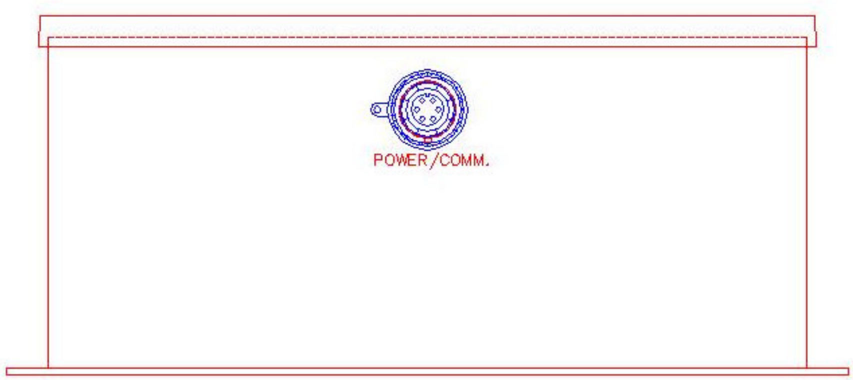

Figure 1. Side Elevation of TRIAXYS™ OEM Wave Sensor

The connection to the Wave Sensor is shown in the drawing above. The sensor requires one cable and connector, BULGIN PX0738/S (five conductors, ground, +12V, and 3 for the RS232), as shown in Table 2. The communication with the Wave Sensor is as detailed in Section 2.

Table 2
TRIAXYS™ OEM Wave Sensor Connector Description

Connector	Description
6 pin male Bulgin	Power and Communications Pin 1: not used Pin 2: Pin 2: Power Control (enable High) Can be used with a PC's DTR RS232 output Pin 3: RS232 Data/Comms in to Sensor Pin 4: RS232 Data/Comms out from Sensor Pin 5: Power Ground Pin 6: +12V (11-14V, 1 amp peak load)

1.4 Internal Data Logging (Optional)

The TRIAXYS™ OEM Sensor comes with an internal data logging capability. The processed wave data files are logged onto a PCMCIA Flash RAM card per section 4.3 of this manual.

The following table indicates the approximate storage required on the buoy for some typical sampling regimes.

Sampling Regime	Standard Files
AC INT = 60 AC DUR = 25	32 MB/year
AC INT = 30 AC DUR = 20	65 MB/year

2.0 COMMAND INTERPRETER

A command interpreter is used to set the operational parameters and initiate the Run sequence of the TRIAXYS™ OEM Wave Sensor. The terse, single line commands are ideal for computer-to-computer communications, as in a typical case where the Wave Sensor activation may come from a host computer.

A typical operational scenario for the TRIAXYS™ OEM Wave Sensor would involve the application of the +12 Volt supply (or enabling the control line (pin 2) high) followed by commanding the Run Mode. After sampling and processing, the Wave Sensor makes the results available in various message formats. The host computer then polls the Wave Sensor to recover the processed wave data. The power to the Wave Sensor would normally be shut off (or the control line is set to 0 (pin 2)) until the next desired sampling period.

The commands fall into one of two groups, "!" character for Set and "?" character for request (Query). The Set group handles modifying parameters and initiating the Run mode, and the Query group handles requesting parameter values and requesting results. All Set and Query commands require a carriage return character at the end of the message (ASCII character 13 decimal) indicated here by <cr>. If more than one parameter is required to complete a command, commas are used to separate the fields.

2.1 Set (!) Commands

2.1.1. Set Time

!TYY-MM-DD<sp>HH:MM:SS<cr> is sent to the Wave Sensor to set the date and time. YY represents a two-character year code (00 for 2000), MM for month (01 to 12 for January to December), DD is the day of month. Note that a space is required between the date and time fields indicated here by the <sp>. HH are the hours, MM are minutes, and SS for seconds. As with all Set and Query commands a carriage return character (ASCII character 13 decimal) indicated here by <cr> is required at the end of the message.

2.1.2 Set Center of Mass Translation Offsets

!Ox,y,z<cr> is sent to the Wave Sensor to set the Center of Mass translation offsets. x, y, and z are offset values in metres for the orthogonal components of the translation displacements. The Wave Sensor is always at the centre of its reference system and has x ,y, and z co-ordinates of 0,0,0. Thus the signs of the offset values are entered to indicate a vector from the Wave Sensor back to the Center of Mass of the body.

2.1.3 Set File Enable

!Fa,b,c,d,e,f,g<cr> is sent to the Wave Sensor to enable/disable the files that are required in the MFH or MFB outputs. The value 1 enables the files and the value 0 disables the file. The files are listed below:

a = 1 Buoy Stat
b = 1 Wave Stat
c = 1 Nondirspec
d = 1 Dirspec
e = 1 MnDir
f = 1 HNE
g = 1 Aux

2.1.4 Set Run Mode

!Rx<cr> is sent to the Wave Sensor to initiate the Run Mode. The required number of minutes of sampling is represented by the range of the parameter x in units of minutes. The acceptable ranges for x are 5 to 35 minutes. If no value of x is entered, the default value of 26 minutes is used.

2.1.5 Automatic Run Mode

After power-up the Wave Sensor issues "…" (ASCII period) characters indicating it is ready to accept a command. After 20 seconds of inactivity from the host computer it will automatically initiate a Run command using the default value of 26 minutes for the sampling duration (or whatever was set with the previous Run command).

A typical Run sequence would be as follows (Note <cr> = ASCII 13):

1) Power up system (either externally switched 12 volts on Pin 6 or setting Pin 2 High (DTR) with power supplied to pin 6)
2) At the "…..", issue the !F1,1,1,1,0,0,0<cr> if you wish to change the files available
3) Next, Issue the !R20<cr> to initiate the Run sequence for 20 minutes
4) After approx. 22 minutes (20 + Processing), "*****" will appear. At this point, enter the Query (?) commands for the desired messages.
5) Once data is transferred, either remove power from Pin 6 or set Pin 2 low.

See below for an example:

Description	Output/Input to Sensor
At start up, user will see **......** !T sets the time !F sets the files required (only required first time sensor is used) !R20 starts the sensor for a 20 minute sample At the end of sample, **** appears, at which point a file can be requested! (such as ?MWA), then followed by *** again waiting for other Queries. When the Querying is complete, sensor can be turned off.	...!T01-10-31 16:57:00 ....!F1,1,1,1,0,0,0 **...!R20** ********?MWA** $WA,21,0.00,28.6,0.00,157,51,13 ******

Note: in the simplest form, only the commands in **BOLD** are required.

2.2 Query (?) Commands

2.2.1 Query Time

?T<cr> displays the time issued by the Wave Sensor. The time string consists of the characters YY-MM-DD<sp>HH:MM:SS<cr><lf> where YY represents a two-character year code (00 for 2000), MM for month, DD is the day of month. Note that a space is issued between the date and time fields indicated by the <sp>. HH is the hours, MM minutes, and SS for seconds. The response message ends with both ASCII carriage return <cr> and line feed <lf> characters (13 decimal and 10 decimal respectively).

2.2.2 Query Offsets

?O<cr> causes the Wave Sensor to issue the current offset values used in the data processing sequences. For the case where there are no offsets (i.e. the Wave Sensor is at the centre of Mass of the body) the response to the ?O query would look like the following:

Xoff=0.0, Yoff=0.0, Zoff=0.0<cr><lf>

2.2.3 Query Processed Wave Data – prior to version 3.40 EPROM

After sampling and processing the wave data, the Wave Sensor indicates that a new set of wave results are available by issuing "*" characters at a 1 second interval. The host computer should wait for this response and then issue the appropriate Query Message command to retrieve the processed data.

2.2.3.1 Short Wave Message (WA)

?MWA<cr> is entered to get the WA message. A typical response to this query may look like the following:

$WA,26,2.00,2.83,10.0,270,5,1641<cr><lf>

where: **$** is the character that precedes all formatted message types
WA indicates the type of message (WA is a short wave message)
26 is the message size (i.e. the number of characters in the message not including the message type, size or checksum characters)
2.00 is the value for the significant wave height (Hs) in metres
10.0 is the peak period (Tp) in seconds
2.83 is the value for the maximum wave height (Hmax) in metres
270 is the Mean Direction in degrees
5 is the Direction Spread in degrees
1641 is the arithmetic Checksum of the message not including the last comma and the checksum characters

2.2.3.2 Housekeeping Message (WB)

?MWB<cr> is entered to get the WB message. A typical response to this query may look like the following:

$WB,57,000125,0210,13.5,1200,TAS000000,3.14T,1.12R,0,0,0.0,0.0,0.0,
3259<cr><lf>

where: **$** is the character that precedes all formatted message types
WB indicates the message type (WB is the housekeeping message)
57 is the message size (i.e. the number of characters in the message not including the message type, size or checksum characters)
000125 is the date in YYMMDD format
0210 is the time in HHMM format
13.5 is the voltage (V)
1200 is the number of samples (gathered at 4 Hz – in this case the sample duration was five minutes – 5*60*4=1200)
000000 is the serial number of the TRIAXYS™ OEM Wave Sensor
3.14 is the version of the Gpuc EPROM
1.12 is the version of the PC104 EPROM
0 is the number of boot times
0 is the status code
0.0 is the x offset
0.0 is the y offset
0.0 is the z offset
3259 is the is the arithmetic checksum of the message not including the last comma and the checksum characters

2.2.3.3 Combined Message (WC)

?MWC<cr> is entered to get the WC message which is a combination of the WA and WB messages.

2.2.3.4 Full Processed Wave Data for WaveView™

<u>Command</u>: ?MFH<cr> **or** ?MFB<cr>

This is the complete wave and status message that is normally processed by the WaveView™ Base Station software. This message can be in either hexadecimal (H) or Binary (B) format. The data sent in the MF message is dependant on the (File a..g) arguments used with the <F>ile command. By default, the MF message contains:

1 – Buoy Stat
2 – Wave Statistics
3 – Nondirspec
4 – Dirspec
5 – MeanDir (optional)
6 – HNE (optional)
7 – Auxiliary (optional)

This message is normally processed by the WaveView™ Base Station software. See Section 3.2.4 for details of the parameters.

2.2.4 Query Processed Wave Data – version 3.40 EPROM and later

After sampling and processing the wave data, the Wave Sensor indicates that a new set of wave results are available by issuing "*" characters at a 1 second interval. The host computer should wait for this response and then issue the appropriate Query Message command to retrieve the processed data.

The OEM sensor is configured by default to output the following NMEA messages:

1) Buoy Status = $TSPSA

2) Wave Statistics = $TSPWA

3) Non Dirspec = $TSPNA

4) Mean Dir = $TSPMA

They are queried collectively by the ?MFB command, or individually, thus:

1) $TSPSA with a ?MNS

2) $TSPWA with a ?MNW

3) $TSPNA with a ?MNN

4) $TSPMA with a ?MNM

The NMEA message format for each is as follows:

Buoy Status

$TSPSA, Date, Time, Serial, BuoyID, Latitude, Longitude, Sea Surface Temperature, Battery Voltage, Sample Rate, Samples, Acquisition Interval, Transmission Interval, Radio Transmissions, Serial No., GPuC Firmware Version, PC104 Firmware Version, Boot Times, Status, Solar Current, Magnetic Variation, Acquisition Duration, *cs<cr><lf>

Wave Statistics

$TSPWA, Date, Time, Serial, BuoyID, Latitude, Longitude, Number of Zero Crossings, Havg (Average Wave Height), Tz (Mean Spectral Period), Hmax (Maximum Wave Height), Hsig (Significant Wave Height), Tsig (Significant Period), H10 (average height of highest tenth of waves), T10 (average period of H10 waves), Tavg (Mean Wave Period), TP (Peak Period), TP5, HMO, Mean Direction, Mean Spread, *cs<cr><lf>

Non Dirspec

$TSPNA, Date, Time, Serial, BuoyID, Latitude, Longitude, Number of Bands, Initial Frequency, Frequency Spacing, Energy 1, Energy 2, Energy 3, Energy N, *cs<cr><lf>

Mean Dir

$TSPMA, Date, Time, Serial, BuoyID, Latitude, Longitude, Number of Bands, Initial Frequency, Frequency Spacing, Mean Average Direction, Spread Direction, Energy 1, Mean Direction 1, Direction Spread1, Energy N, Mean Direction N, Direction Spread N, *cs<cr><lf>

3.0 SOFTWARE AND DATA FORMATS

3.1 Software

All data processing is performed in the TRIAXYS™ OEM Wave Sensor. A unique proprietary iterative algorithm developed by the Canadian Hydraulics Centre (CHC) of the National Research Council of Canada (NRC) is used to solve the full non-linear equations of motion that define the buoy motions relative to a fixed reference frame in terms of the raw data from the six motion sensors and the compass. See Section 10, References for relevant published papers on these algorithms. Any updates can be downloaded from the Axys Technologies Inc. web site: www.axystechnologies.com.

Motion analysis is performed in the frequency domain using specialised Fast Fourier Transform (FFT) integration techniques. This complete motion analysis procedure, including all six degrees of freedom, allows the vertical displacement and the north and east velocities of the buoy to be measured with very high accuracy because no simplifying approximations have to be made regarding earth gravity terms, cross-coupling terms or other spurious effects.

A practice commonly used in spectral analysis is to taper the data record over the first and last 5% or 10% of its length to avoid producing any spurious Gibbs oscillations due to cyclic discontinuities. In the processing unit a cyclic merging process is carried out. The brief details of this process are described below.

3.1.1 Cyclic Merging

The first 5% of the record is defined as the merging zone. The original record is multiplied by a ramp function that goes linearly from 0 to 1 over the merging zone. The last 5% of the original record is removed and multiplied by another linear ramp function that goes from 1 to 0 over its length. This segment is then added to the original record in the merging zone. Since one ramp is going up while the other is going down, the average energy in the merging zone is preserved. The resulting cyclic-merged record is 95% as long as the original record and is cyclic over its own length because the beginning of it has the same amplitude and slope as the end of it. The data in the merging zone is artificial because it is a linear combination of the first and last 5% sections of the original record. After all FFT operations have been completed, the software removes the data in the merging zone and only outputs motion time series for the remainder of the cyclic merged records. This ensures that the computed motions apply only to the time interval where the input signals were not modified by the cyclic merging process.

CHC has found from simulations that cyclic merging produces more accurate motions than tapering because it preserves the average energy of each signal in the merging zone. It is because of the cyclic merging process that the data record is 10% shorter than the Acquisition Duration (AC DUR) (see Section 9, Glossary).

3.1.2 Data Sampling and Re-sampling

The data from the accelerometers, the angular rate sensors and the compass are sampled at 4 Hz. To enable the Acquisition Duration (AC DUR) length to be variable between 5 and 35 minutes, the software re-samples the record length to get 2^n points where n is the smallest integer such that the new number of points is greater than or equal to the cyclic merged record length (AC DUR minus 5%).

Example

- Original Record Length (AC DUR) L_1 = 25 minutes = 1500 seconds.
- Original Number of Data Points N_1 = 6000 with dT_1 = 0.25.
- The cyclic merging zone corresponds to the first 300 data points (5%).
- Cyclic-merged Record Length L_{1C} = (N_{1C} * dT_1) = 1425 seconds.
  where the cyclic-merged number of data points N_{1C} = 5700 corresponds in time to the first 5700 points of the original record.
- Re-sampling occurs after the removal of the last 5% of the original record in the cyclic merging process.
- Cyclic-merged record is resampled to 2^n points such that 2^n is greater than or equal to 5700. With n = 13, N_{2C} = 8192, and the new sampling frequency $dT_{2C} = dT_1 * N_{1C}/N_{2C}$ = 0.1736 seconds.

3.1.3 Motion Analysis

Motion analysis is performed using the re-sampled, cyclic merged records. Because the first 5% of the record is artificial due to the cyclic merging, after all the FFT operations have been completed, the first 5% of the computed motions are also removed. Thus the record length of the final computed motions is 10% shorter than the original record length (AC DUR) for the measured raw sensor signals.

The wave analysis includes:

- a zero crossing analysis of the wave elevation record to produce time domain wave statistics;
- a spectral analysis that computes the non-directional wave energy spectrum, S(f), which defines the distribution of wave energy as a function of frequency;
- a directional spectral analysis, using the wave elevation and the north and east buoy velocity components, that computes the directional wave spectrum, S (f, theta), which defines the distribution of wave energy as a function of frequency and direction of propagation;
- calculation of the mean wave direction and the directional spreading width as functions of frequency.

3.1.4 Frequency Bands

The frequency bands range from 0.64 Hz (1.56 seconds) to 0.03 Hz (33.33 seconds). 0.005 Hz separates the bands. Thus the number of frequency bands is 123 with the first band centred at 0.03 Hz and the last band centred at 0.64 Hz. These are the frequency bands in the output file.

3.1.5 Low Frequency Energy

The Root Mean Square (RMS) noise value for the accelerometers in the TRIAXYS™ sensor is about 0.0005g. This noise is uniformly distributed over the nominal measurement bandwidth of 1 Hz so the vertical acceleration spectra have a fairly constant amplitude of approximately 0.00001 $(m^2/s^4)/Hz$ at all frequencies. However the wave elevation displacement spectrum $S_D(f)$ is related to the vertical acceleration spectrum $S_A(f)$ as follows:

$$S_D(f) = S_A(f)/\omega^4$$

Where $\omega = 2\pi f$. Since $S_A(f)$ is constant for a given RMS noise level, the relative effects of the noise on the wave elevation spectrum become much larger at low frequencies because $S_D(f)$ is inversely proportional to f^4. This leads to the presence of low frequency energy peaks in the power spectrum.

Although these peaks represent only a very small amount of spurious wave energy in absolute terms, the following method is used to reduce the effects of accelerometer noise when the buoy is stationary or when the wave amplitude is small.

The wave elevation displacement spectrum corresponding to an RMS accelerometer noise level of 0.001g* is given by ($S_N(f)$). If, at a given frequency, the measured spectral density of the wave elevation displacement spectrum, $S_D(f)$, lies below the spectral density for $S_N(f)$, then it can be assumed that $S_D(f)$ is mostly due to noise rather than real wave energy. In this case the corresponding Fourier transform coefficients at the frequency f are multiplied by 0.1 to reduce the spurious wave amplitude by a factor of 10 and the spurious spectral density by a factor of 100. If the measured spectral density of $S_D(f)$ is above the spectral density for $S_N(f)$, then it is assumed to be mostly due to real wave energy and the amplitude is not reduced.

*Note: The value of 0.001g is chosen as a compromise between adding a safety margin above the stationary accelerometer noise levels and not restricting the ability of the buoy to measure small amplitude waves.

3.1.6 Directional Wave Analysis

The directional wave analysis is based on the cross spectra between the vertical and horizontal motions of the buoy. Consequently, the directional wave analysis results will not be meaningful when the buoy is stationary because there are no real vertical or horizontal motions but only random accelerometer noise. Reliable directional wave measurements can only be made when there is a reasonable amount of vertical and horizontal buoy motion. Based on test and simulation results carried out at the Canadian Hydraulics Centre of the National Research Council, the following approximate guidelines can be used:

1. If Tp is less than 10 seconds, then Hmo must be at least 0.1m for reliable directional wave analysis

2. If Tp is greater than 10 seconds, then Hmo must be at least ($0.001*Tp^2$)m for reliable directional wave analysis. For example if Tp = 20 seconds then Hmo must be at least 0.4m for reliable directional wave analysis.

The significant wave height required for reliable directional wave analysis increases at the lower frequencies because the accelerometer noise effects are relatively larger at lower frequencies.

3.2 Output Files

The TRIAXYS™ OEM Wave Sensor can create four types of messages, depending on how the sensor is set up. See Section 2.2

The four types are:

- Basic Wave Statistics (WA message type)
- Housekeeping details (WB message type)
- Basic Wave Statistics and Housekeeping details (WC message type)
- Complete Processed wave data (MFH or MFB message type)

3.2.1 <u>Basic Wave Statistics</u>

The five basic wave statistics that are created are:

- Significant Wave height (Hs)
- Maximum Wave Height (Hmax)
- Peak Period (Tp)
- Mean Direction (MnDir)
- Mean Spread (MnSprd)

Definitions of these terms are included in the Glossary

<u>3.2.2 Housekeeping Details</u>

The housekeeping details are:

- Date

- Time
- Volts
- Number of samples
- Serial number of sensor
- EPROM version on the GPuC card
- EPROM version on the ESPIC card
- Number of Boot times
- Status Code
- x, y, z, offsets (See Glossary for details)

3.2.3 Combined Wave and Housekeeping

A combination of the information in Sections 3.2.1 and 3.2.2

3.2.4 Complete Processed Wave Data

The complete processed wave data are in a format designed for display and archiving with the TRIAXYS™ WaveView™ software. They are presented in a hexadecimal or Binary file that includes all the statistics calculated from both the time domain and the frequency domain analyses, the power (2D) spectra and the directional (3D) spectra, and a full suite of housekeeping information. The uploaded file must be sent through the WaveView™ software to produce the files detailed in Appendix D.

3.3 Logged Data Only

Wave data and housekeeping files can be logged in the TRIAXYS™ OEM Wave Sensor. The Flash Ram card is accessed from inside the Wave Sensor. When the Wave Sensor lid is opened, the slot for the Flash Ram card is on the right hand side. The card can easily be removed by pressing the release. A new card can then be installed.

3.3.1 Format of Processed Wave Data

The wave data on the Flash Ram card is logged to files with the filename representing the encoded date of the start time of the wave sampling. The files are named XXDDMMHH.WYY where:

XX = 2-letter month code (JA, FE, MR, AP, MY, JN, JL, AU, SE, OC, NO, DE)
DD = 2-digit day of the month (01-31)
MM = 2-digit hour code (00-23)
HH = 2-digit minute code (00-59)
YY = 2-digit year code

e.g., AP120930.W00 = 09:30 a.m. 12-Apr-2000

The data types for the parameters and the order in which they are stored in the binary file are as follows:

Data Type	Parameter
CHARACTER*8	DATE (ddmmyyyy)
CHARACTER*6	TIME (hhmmss)
CHARACTER*8	Program_Name
CHARACTER*8	Version_Number
REAL*4	MTN_F1 (System Parameter)
REAL*4	MAGNETIC_VAR (Magnetic Variation. Not used – set to zero)
REAL*4	FREQ-SPACING (Frequency Interval, Hz)
REAL*4	LOW_FREQ_CUT (Low Frequency Cut-off, Hz)
REAL*4	HI_FREQ_CUT (High Frequency Cut-off, Hz)
REAL*4	WVN_STR (System Parameter)
INTEGER*4	N1 (Re-sampling parameters – See Section 3.1.2)
REAL*4	T1 (Re-sampling parameters – See Section 3.1.2)
REAL*4	DT1 (Re-sampling parameters – See Section 3.1.2)
INTEGER*4	M33_STATUS (System Parameter)
INTEGER*4	N_ZERO_CROSS (Number of Zero Crossings)
REAL*4	AVE_HEIGHT (Average Wave Height, m)
REAL*4	AVE_PERIOD (Average Wave Period, s)
REAL*4	MAX_HEIGHT (Maximum Wave Height, m)
REAL*4	SIG_HEIGHT (Significant Wave Height - Hs, m)
REAL*4	SIG_PERIOD (Significant Wave Period, s)
REAL*4	F1 (System Parameter)
REAL*4	F2 (System Parameter)
REAL*4	PEAK_PERIOD (Peak Period, s)
REAL*4	TP5 (Tp5, s)
REAL*4	4*(M0^0.5) (Significant Wave Height - Hmo, s)
INTEGER*4	N_FRQ_NONDIR (Number of frequencies in non-directional spectrum, N).
REAL*4	INIT_FREQ (First frequency in non-directional spectrum, n)
REAL*4	FREQ_SPACING (Frequency interval in non-directional spectrum)
REAL*4	S(n), n = 1..N (Non-directional Spectrum)
REAL*4	MEAN_DIR (Mean Wave Direction)
REAL*4	MEAN_SPREAD (Mean Spread)
INTEGER*4	N_FOURIER (Number of frequencies in directional spectrum. May be less than the number of frequencies in the non-directional spectrum because Fourier coefficients are not created when there is no energy)
REAL*4	INIT_FOURIER (First frequency in directional spectrum)
REAL*4	FREQ_SPACING (Frequency interval in directional spectrum)
REAL*4	A1, B1, A2, B2 (Fourier SIN and COS components for frequencies n = 1..N)
	STATUS (status message in the following format - yymmddhhmm, Owner ID, , , Battery voltage, sampling rate Hz, number of samples per channel, , , ,OEM Sensor Serial Number, Gpuc EPROM Version, PC104 EPROM Version, boot times, status code, , , Acquisition Duration

An example of this format is given in Appendix C.

Note: The TRIAXYS™ OEM Wave Sensor always returns the Magnetic Direction. Any corrections for Variation or local Deviation need to be made outside the Wave Sensor.

3.3.2 Housekeeping Files

The logged data files also include the ASCII comma-delimited housekeeping files. These files include the following data. Note in the format (Section 3.3.1) some of the fields are separated by a series of commas. These represent fields that are used when the Wave Sensor is installed in a TRIAXYS™ Directional Wave Buoy. For the Wave Sensor alone these fields are left blank.

Message Date and Time (UTC)
Owner ID
Battery Voltage
Sample Rate (4 Hz)
Samples per channel
OEM Sensor serial number
Gpuc EPROM Version
PC104 EPROM Version
Boot Times
Status Code
Acquisition Duration

4.0 RETRIEVING STORED DATA FROM THE WAVE SENSOR

The TRIAXYS™ OEM Wave Sensor can be opened to remove the data storage RAM disk if this option is included.

- ✓ Loosen the two captive screws on the front of the top of the lid of the Wave Sensor.
- ✓ Lift up the lid of the Wave Sensor. It is hinged at the back.
- ✓ Press the release button and remove the Flash Ram card.

NOTE: A Cover Plate protects the inside of the Wave Sensor. Removal of this Cover Plate or tampering with the Cover Plate fastening bolts will automatically void the warranty. The data storage RAM disk can be accessed without removing the Cover Plate.

- ✓ Place a new formatted Flash Ram storage disk in the slot, being careful to align the card and ensure that it is seated properly.
- ✓ Carefully lower the Wave Sensor lid and fasten the screws.

5.0 INSTALLATION PROCEDURES

The TRIAXYS™ OEM Wave Sensor is very easy to install. Please note the following for optimum results.

- ✓ The TRIAXYS™ OEM Wave Sensor is oriented North when the front side (with electrical connector) points North. The compass inside the Wave Sensor sets this orientation.
- ✓ The TRIAXYS™ OEM Wave Sensor should be attached via the four feet. It is recommended that M6 flat washers and M6 Nylock nuts (SS 316) be used to attach the Wave Sensor. It is also recommended that some rubber pads be used underneath the feet to provide a degree of protection against severe shock. The bolts should be tightened until the rubber pads are slightly compressed.

Table 3
Acceptable Ranges for Sensors at Rest in a Still, Level, and Upright Position

Sensor	Range	Check Procedure
Compass Heading	0 to 359	Check against hand held compass
Accelerometer X	Near 0 ± 0.06 g's	
Accelerometer Y	Near 0 ± 0.06 g's	
Accelerometer Z	Near -1 ± 0.06 g's	
System Current	30 to 40 milliamps	PC104, Motion Sensors
	550 to 750 milliamps	PC-104 only powered
	120 to 180 milliamps	Motion Sensors only powered
Rate Gyro X	Near 0 ± 6 °/sec	
Rate Gyro Y	Near 0 ± 6 °/sec	
Rate Gyro Z	Near 0 ± 6 °/sec	

6.0 GLOSSARY

Acquisition Duration (AC DUR)	The duration of a data acquisition event (minutes). This duration is limited to between 5 and 35 minutes. Since the maximum time possible for the processing unit is 34.13 minutes (see Section 2.1.1), a time entered of 35 minutes will default to 34.13 minutes).
Acquisition Interval (AC INT)	The interval between successive data acquisition events (minutes). The allowable intervals are: 5, 6, 8, 9, 10, 12, 15, 16, 18, 20, 24, 30, 32, 36, 40, 45, 48, 60, 72, 80, 90, 96, 120, 144, 160,180, 240, 288, 360, 480, 720, 1440.
Average Wave Height (Hav)	Average zero down-crossing wave height (m).
Average Wave Period (Tav)	Average zero down-crossing wave period (s).
Cyclic Merging	See Section 3.1.1.
Zero Crossing	Number of waves detected by zero-crossing analysis of the wave elevation record.
Maximum Wave Height (Hmax)	Maximum zero down-crossing wave height (trough to peak) (m)
Mean Wave Direction	Overall mean wave direction in degrees obtained by averaging the mean wave angle θ over all frequencies with weighting function S(f). θ is calculated by the KVH method.
Mean Spectral Period (Tz)	Estimated period from spectral moments m0 and m2, where Tz = SQRT(m0/m2).
Mean Spread	Overall directional spreading width in degrees obtained by averaging the spreading width sigma theta, σ_θ, over all frequencies with weighting function S(f). σ_θ is calculated by the KVH method.
Peak Period (Tp)	Peak wave period Tp in seconds. Tp = 1.0/fp where fp is the frequency at which the wave spectrum S(f) has its maximum value.
Significant Wave Period (Ts)	Average period of the significant zero down-crossing waves (s).
Significant Wave height (Hmo)	Significant wave height in metres as estimated from spectral moment mo. Hmo = 4.0 * SQRT(m0) where m0 is the integral of S(f)*df from f = F1 to F2 Hz .

Significant Wave Height (Hs)	Zero down-crossing significant wave height, Hs, where Hs is the average height of the highest third of the waves (m).
Tp5	Peak wave period in seconds as computed by the Read method. Tp5 has less statistical variability than Tp because it is based on spectral moments.
X, Y, Z Offsets	Allows for the fact that the sensor may not be at the Centre of Mass of the floating body. By inserting the offsets from the Wave Sensor to the centre of mass, the conditions at the centre of mass (or any other point on the body) are calculated and output by the sensor. Note that the Wave Sensor is always at the centre of its frame of reference i.e. the offsets are always measured away from the Wave Sensor, which has the co-ordinates of 0, 0, 0. The variables X, Y and Z are measured in m and have the following sign convention: With point A as the geometric centre of the Wave Sensor and point B representing the point about which the motions are to be resolved then: X is positive if point B is forward of point A, along North arrow on OEM sensor. Y is positive if point B is to starboard of point A Z is positive if point B is below point A

7.0 REFERENCES

References to the software used in the TRIAXYS™ OEM Wave Sensor include:

Benoit, M., P. Frigaard and H.A. Schaffer (1997) "Analysing Multidirectional Wave Spectra: A Tentative Classification of Available Methods". IAHR Seminar on Multidirectional Waves, 27th IAHR Congress, San Francisco, pp. 131-158.

Darras, M. (1987) "IAHR List of Sea State Parameters: A Presentation". IAHR Seminar on Wave Analysis and Generation in Laboratory Basins, Lausanne, pp. 11-73.

Hawkes, P.J., J.A. Ewing, C.M. Harford, G. Klopman, C.T. Stansberg, M. Benoit, M.J. Briggs, P. Frigaard, T. Hiraishi, M. Miles, J. Santas, H.A. Schaffer (1997) "Comparative Analysis of Multidirectional Wave Basin Data". IAHR Seminar on Multidirectional Waves, 27th IAHR Congress, San Francisco, pp. 25-88.

Miles, M.D. (1986) "Measurement of Six Degrees of Freedom Model Motions using Strapdown Accelerometers". 21st American Towing Tank Conference, Washington, D.C., pp. 369-375.

Miles, M.D. and E.R. Funke (1989) "The GEDAP Software Package for Hydraulics Laboratory Data Analysis". IAHR Workshop on Instrumentation for Hydraulics Laboratories, Burlington, Canada, pp. 325-339.

Miles, M.D., M. Benoit, P. Frigaard, P.J. Hawkes, H.A. Schaffer, C.T. Stansberg (1997) "A Comparison Study of Multidirectional Waves Generated in Laboratory Basins". IAHR Seminar on Multidirectional Waves, 27th IAHR Congress, San Francisco, pp. 89-129.

Nwogu, Okey (1989) "Maximum Entropy Estimation of Directional Wave Spectra from an Array of Wave Probes". Applied Ocean Research, 1989, Vol. 11, No. 4, pp. 176-182.

Nwogu, O.U., E.P.D. Mansard, M.D. Miles, M. Isaacson (1987) "Estimation of Directional Wave Spectra by the Maximum Entropy Method". IAHR Seminar on Wave Analysis and Generation in Laboratory Basins, Lausanne, pp. 363-376.

Appendix A

Warranty and Service

WARRANTY

LIMITED WARRANTY

AXYS TECHNOLOGIES INC ("AXYS") warrants that the Equipment shall conform to Specifications and shall remain free from defects in materials and workmanship for a period of twelve (12) months from the date of shipment (the "Warranty Period"); provided, however, that the Equipment is applied, installed, operated and used substantially in accordance with the Specifications. This Warranty shall not apply to Products that have been damaged through negligence, accident, misuse, or acts of nature such as floods, fires, earthquakes, lightning strikes, etc.

AXYS shall replace or repair (at its discretion) any Equipment within such warranty period, provided:

- AXYS receives written notice of any non-conformance or defect within the Warranty Period.
- After AXYS' authorization, the Equipment is returned to AXYS' factory of origin or to an Authorized AXYS Distributor with all freight charges prepaid.
- AXYS determines the Equipment to have a non-conformance or defect covered under this warranty.
- AXYS will pay for the return transportation for valid warranty claims. All return shipments shall be by best-way surface freight.
- Any products repaired or replaced under this warranty will be warranted for the balance of the warranty period or for a period of 90 days from the repair shipment date, whichever is greater.

LIMITATION OF LIABILITY

AXYS does not grant any further representations or warranties on the Equipment than as expressly set forth above and expressly disclaims all other warranties, express or implied, including any warranties that the Equipment shall be merchantable, suitable or fit for any purpose other than expressly stated. Notwithstanding any other term of this Agreement, in no event shall AXYS be liable to the Customer, its officers, employees, agents or contractors for any lost or anticipated profits, for any incidental, consequential, exemplary or special damages whether or not AXYS was advised of such claim, or for damages and loss due to personal injury. Under no circumstances will AXYS cover or reimburse the claimant for costs incurred in the removing and/or reinstalling the equipment. In any event, AXYS' liability shall not exceed the purchase price of the Equipment.

NON-AXYS MANUFACTURED EQUIPMENT

The above Warranty applies only to Products manufactured by AXYS. Equipment provided, but not manufactured by AXYS, is warranted and will be repaired to the extent of and according to the current terms and conditions of the respective equipment manufacturer.

WARRANTY SERVICE

To obtain service under the warranty during the warranty period:

- Write, fax, e-mail or call AXYS Technologies Inc to describe precisely and completely the nature of the problem;
  PO Box 2219, 2045 Mills Rd West,
  Sidney, BC, Canada V8L 3S8
  Ph 250 655 5874
  Fx 250 655 5856
  Email info@AXYS.com
- Carry out any minor adjustments or service as instructed by AXYS technical personnel;
- If proper operation is still not achieved**,** obtain an RMA (Return Material Authorization) number from AXYS and return the instrument, freight prepaid, to the factory or to an authorized Service Centre. The instrument will not be accepted by AXYS without an RMA. The instrument will be repaired and returned free of charge in accordance with the terms of the warranty.
- All systems returning to AXYS are put through an incoming inspection to determine the validity of the warranty claim. If a valid warranty claim is established, an inspection fee is waived; otherwise the owner will be invoiced the minimum inspection fee of $250.

NON-WARRANTY SERVICE

Proceed as for Warranty Service described above. If AXYS personnel can provide assistance by phone, letter, fax, or e-mail they will be pleased to do so at no charge.

As with Warranty Service, if the return of the instrument is necessary, an RMA number must be obtained from AXYS prior to shipping. The instrument must be returned to the Company freight prepaid. Once the instrument is received at the factory, a firm estimate of the repair cost will be provided.

AXYS WARRANTY

Return Material Authorization (RMA) Form

PLEASE FILL FORM OUT COMPLETELY
FAX COMPLETED FORM TO +1 (250) 655-5856
PLEASE ALLOW 24 HOURS BEFORE CONTACTING SHIPPING/RECEIVING +1 (250) 655-5871

DATE: ___ *RMA#:*______________ *ISSUED BY:* ____ _________

CUSTOMER / RETURN SHIPPING INFORMATION

CONTACT NAME	
COMPANY NAME / DIVISION / BRANCH / ASSOCIATION	
STREET ADDRESS	
CITY / PROVINCE / COUNTRY	POSTAL CODE
TELEPHONE	BETWEEN THE HOURS OF
E-MAIL	FAX

PRODUCT DESCRIPTION	PART NO.	SERIAL #	QTY#	INVOICE#

(Continue list in Notes section if needed)

NOTES

SHIPPING INSTRUCTIONS

Address each carton to: *Axys Technologies Inc.*
2045 Mills Road, Sidney, BC, Canada, V8L 3S8

- ❑ Clearly mark each carton with: **"CANADIAN MADE GOODS BEING RETURNED FOR REPAIR"** ***"RMA No.________________ Carton #________ of _______."***
- ❑ RMA shipments must be prepaid by customer
- ❑ Enclose a copy of this RMA Form in each carton

APPENDIX B

TRIAXYS™ FAQ

1. **Can the data be logged in the TRIAXYS™ OEM Wave Sensor?**
   A: Yes. The operator can log the processed data onto Flash Ram in the Wave Sensor. Refer to sections 1.4 for capacity.

2. **What are the benefits over a Hippy Wave Sensor?**
   - ✓ Robust state-of-the-art solid state Wave Sensor;
   - ✓ Proven high precision measurement with 6 degrees of freedom used and validated by the National Research Council of Canada;
   - ✓ Complete motion measurement;
   - ✓ Sensor can calculate motion at any location on the body regardless of the sensor location
   - ✓ Sensor is not subject to damage if rolled or spun. This facilitates use in the field;
   - ✓ Sensor is not subject to damage by freezing;
   - ✓ Sensor is rugged and compact and is easy to transport and install;
   - ✓ Easy access to all modularized system components for servicing;
   - ✓ Excellent plug and play TRIAXYS ™ OEM Wave Sensor Software;
   - ✓ Full range of wave statistics are calculated in near real time.

APPENDIX C

Logged Data Format

```
DATE         : 27-10-1999
TIME         : 00:00:00
WAVAN4  2.0
MTN_F1       :    0.030
MAGNETIC_VAR :    0.000
FREQ_SPACING :    0.005
LOW_FREQ_CUT :    0.030
HI_FREQ_CUT  :    0.640
WVN_STR      :    0.010
N1           :     7761
T1           :   59.978
DT1          :    0.139
M33_STATUS   :        0
N_ZERO_CROSS :      281
AVE_HEIGHT   :    0.136
AVE_PERIOD   :    3.828
MAX_HEIGHT   :    0.346
SIG_HEIGHT   :    0.209
SIG_PERIOD   :    6.235
F1           :    0.030
F2           :    0.640
PEAK_PERIOD  :   28.571
TP5          :   28.854
4*(M0^0.5))  :    0.265
N_FRQ_NONDIR :      123
INIT_FREQ    :    0.030
FREQ_SPACING :    0.005
             1    0.030 1.34452641010284E-0001
             2    0.035 2.21106648445129E-0001
             3    0.040 8.43078494071960E-0002
             4    0.045 3.14780473709106E-0002
           119    0.620 1.69821281451732E-0003
           120    0.625 2.26324098184705E-0003
           121    0.630 2.32355110347271E-0003
           122    0.635 2.30335025116801E-0003
           123    0.640 1.72895647119731E-0003
MEAN_DIR     :  222.353
MEAN_SPREAD  :   63.297
N_FOURIER    :      118
INIT_FOURIER :    0.030
FREQ_SPACING :    0.005
             1    0.030 -7.83297792077064514E-0002 -7.21813365817070007E-
0002 -5.53748726844787598E-0001  1.23462758958339691E-0001
             2    0.035 -6.40451833605766296E-0002 -8.91567021608352661E-
0002 -5.42389452457427978E-0001  1.05476781725883484E-0001
             3    0.040 -3.87482307851314545E-0002 -1.40509992837905884E-
0001 -5.27283012866973877E-0001  7.43258669972419739E-0002
             4    0.045  1.09544638544321060E-0002 -1.96370631456375122E-
                  0001 -5.74521005153656006E-0001 -1.04809254407882690E-
                  0002
             .
             .
             .
             .
           117    0.610 -2.52318441867828369E-0001 -5.43326199054718018E-
0001 -4.98808830976486206E-0001  2.25346058607101440E-0001
           118    0.615 -2.55536735057830811E-0001 -5.32469749450683594E-
0001 -4.92384165525436401E-0001  2.60102629661560059E-0001
STATUS
:9910270000,OWNERID,+022.9,3022.614N08638.913W,13.18,4.0,4800,30,30,3,TAS
00080,2.07,1.05,6,0,0.005,+00.0
```

APPENDIX D

Wave Processing Formats

The TRIAXYS™ OEM Wave Sensor prepares four standard data files. The standard comma delimited files are designed for use with the TRIAXYS™ WaveView™ software which automatically displays and archives the data in daily directories, which are in turn archived in monthly and yearly directories. The four standard files are:

19980903.WAVE
19980903.STAT
19980903.FOURIER
19980903.NONDIRSPEC

The TRIAXYS™ OEM Wave Sensor can also be configured to produce two optional files:

20010818.HNE
20010818.Meandir

The YYYYMMDD format is used as the file name, and the extension describes the type of file.

File 19980903.WAVE

The .WAVE data files are comma delimited and include the wave statistics as calculated on the TRIAXYS™ OEM Wave Sensor. The statistics are calculated from both the zero crossing analysis as well as the FFT spectral analysis. The format of the data (transmitted in rows) is:

Date/time
Zero Crossing
Average Wave Height (Hav)
Average Wave Period (Tav)
Maximum Wave Height (Hmax)
Significant Wave Height (Hs)
Significant Period (Ts)
H10
T10
Mean Spectral Period (Tz)
Peak Period (Tp)
Tp5
Hmo
Mean Direction
Mean Spread

File 19980903.STAT

The .STAT files are comma delimited housekeeping files. Also in this file are the sea surface temperature and battery voltage data.

Message Time (UTC)
TRIAXYS™ OEM Wave Sensor ID

System Voltage
Sample Rate (4 Hz)
Samples per channel
Gpuc EPROM Version
PC104 EPROM Version
Boot Times
Status Code
Acquisition Duration

File 19980903.FOURIER

The .FOURIER file contains the first four Fourier coefficients of the directional spectra for each of the frequency bands. The first row of data includes:

Date/time
Number of frequency bands (n)
Centre of the initial frequency band
Frequency separation

The fifth and subsequent rows of data (tab delimited) include:

Date/time Band 1 of n Coefficient a_1 Coefficient b_1 Coefficient a_2 Coefficient b_2
Band 2 of n Coefficient a_1 Coefficient b_1 Coefficient a_2 …..

File 19980903.NONDIRSPEC

The .NONDIRSPEC file contains the power spectra for each of the frequency bands. The first four lines of data include:

Date/time
Number of frequency bands (n)
Centre of the initial frequency band
Frequency separation

The fifth and subsequent lines of data include the m^2/Hz values for each frequency band, for example:

Value for band 1 of n
Value for band 2 of n
Value for band 3 of n
…….

File 20010818.HNE (Optional)

The .HNE file (optional) contains the latest time series data. Its format is provided in the following sample file:

```
TRIAXYS BUOY DATA REPORT
VERSION    =  5D
TYPE       = HNE
DATE       = 2001 Aug 18 10:00(UTC)
NUMBER OF POINTS              =  1382
TIME OF FIRST POINT       (s)     =  60.1645
SAMPLE INTERVAL           (s)     =  0.7813571
COLUMN 1 = TIME           (sec)
COLUMN 2 = HEAVE          (m)
COLUMN 3 = DISP. NORTH    (m)
COLUMN 4 = DISP. EAST     (m)
60.16  -0.6 -0.53  0
60.95  -0.72  -0.4 -0.01
61.73  -0.82  -0.26  -0.02
62.51  -0.89  -0.11  -0.04
63.29  -0.93  0.05 -0.05
64.07  -0.94  0.22 -0.06
64.85  -0.91  0.38 -0.07
65.63  -0.85  0.53 -0.08
66.42  -0.76  0.67 -0.08
.
.
.
```

File 20010818.Meandir (Optional)

The Meandir file (optional) contains the latest mean direction and spreading width as a function of frequency. Its format is provided in the following sample file:

```
TRIAXYS BUOY DATA REPORT
VERSION    =  5D
TYPE       = MEAN DIRECTION
DATE       = 2001 Aug 18 10:00(UTC)
NUMBER OF POINTS                   = 5
INITAL FREQUENCY            (Hz)    = 0.03
FREQUENCY SPACING           (Hz)    = 0.005
RESOLVABLE FREQUENCY RANGE (Hz)    = 0.03 TO 0.055
S(f) WEIGHTED MEAN WAVE DIRECTION  = 355.72
S(f) WEIGHTED MEAN SPREADING WIDTH = 2.68
COLUMN 1 = FREQUENCY          (Hz)
COLUMN 2 = SPECTRAL DENSITY   (M^2/Hz)
COLUMN 3 = MEAN WAVE DIRECTION(DEG)
COLUMN 4 = SPREADING WIDTH    (DEG)
0.030  1.4119420E-01  355.69  5.09
0.035  1.4136670E+01  355.70  3.17
0.040  5.3730660E+01  355.71  2.62
0.045  3.0706180E+01  355.74  2.56
0.050  1.6008640E-01  355.76  2.79
```