STRAPDOWN HEADING REFERENCE

OWNER'S MANUAL

PART NUMBER: SHR-E360

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Watson Industries prides itself on solving customer problems and serving their needs in a timely fashion. This manual is intended to facilitate this goal and to provide written information about your product. We ask that you carefully read this manual. Becoming familiar with the manual will help you understand the product's capabilities and limitations, as well as provide you with a basic understanding of its operation. If, after reading the manual, you require further assistance, do not hesitate to call Watson Industries with your questions and comments.

CAUTION!

Watson Sensors are rugged devices that have been used successfully in a number of harsh environments. The components have been qualified to withstand a mechanical shock of 200g 's or greater, and most enclosures provide an added level of protection. However, dropping a sensor from waist height onto a hard floor can cause a shock level of 600g's. At this level, damage is likely to occur.

Introduction

The Strapdown Heading Reference provides a slaved compass function. It uses a 3-axis fluxgate magnetometer, a solid-state rate gyro, and a microprocessor. The unit measures the Earth's Magnetic Field with a precision 3-axis fluxgate magnetometer and uses tilt information (bank and elevation) from three accelerometers for coordinate transformations. The heading information is susceptible to disturbance by acceleration since the angle sensors are sensitive to dynamic accelerations. The gyro stabilization reduces this sensitivity and still maintains a high accuracy by slaving to the heading output.

Product Description

Watson Industries SHR-E360 uses solid-state fluxgate magnetometer, gyro and silicon accelerometers. Interface to the microprocessor is done through a 16-bit A/D converter. The solid state vibrating structure angular rate gyro used in this system provides extremely high reliability, low power consumption, shock resistance and exceptional stability. There are no physical adjustments required by the user. All of the primary transducers are locked into position during manufacture. Adjustments are made with the aid of PC-based maintenance software, which communicates with the SHR-E360 via the RS-232 serial connection. Calibration is achieved by using the maintenance software to store data in non-volatile memory within the SHR-E360.

Installation

Orientation:

The base plate of the unit is to be mounted on top of a horizontal surface with the connector toward the forward direction of the vehicle. The SHR drawing, with wire call outs, is located in Figure 2. The SHR is a rugged device and will withstand harsh environments. However, due attention needs to be paid to the nature of the sensor and its prime function, which is to measure attitude and motion. The SHR responds to the motion under investigation.

Mounting:

A mounting plate is provided for a flat surface mount. The unit may be adhesively mounted at any of its surfaces. If high shock loads are expected (greater than 20G or repeated shocks greater than 10G), the appropriate shock mounting should be used to prevent damage. Vibration isolation should be used for use in 4G or greater vibration environments.

Environment:

Avoid mounting sites that are subject to significant temperature variation over the duration of the test. Temperature variation will induce significant rate sensor bias drift, which will reflect in poor attitude accuracy.

This is a magnetic device. Use non-magnetic hardware. Watson Industries provides brass connectors with the device. Ideally, the unit should be installed at least 4" away from all magnetic masses. If the unit is being installed in a vehicle, ship, etc., some calibration will still be required. Calibration software is available on our website at http://www.watson-gyro.com

For shipboard applications, install the sensor near the center of gravity. For all applications, it is preferable to install the device where linear dynamic effects are minimized.

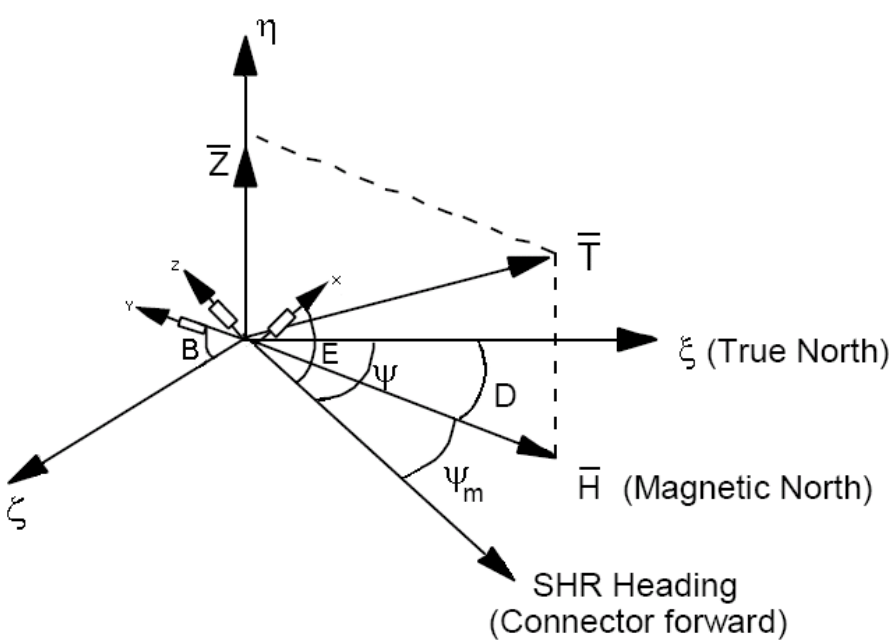
This is a magnetic sensitive device. Use non-magnetic hardware.

Power:

This unit has an internal regulator to allow operation over a wide voltage input range. Best operation is obtained at either 12 or 24 VDC level, although operation is fully satisfactory down to 10 VDC and up to 30 VDC. Power consumption of the unit is less than 4 Watts. The SHR power system is isolated from the SHR signal system. Internal capacitors are provided to remove a reasonable level of power line noise, however, capacitors should be added for long power line wiring or if noise is induced from other loads on the circuit.

Theory of Operation

The Earth's Magnetic Field can be described as a Vector T located in the horizontal geographic coordinate system $O_{\zeta\xi\eta}$ (See Figure 1)



Where:

- H - Vector of Horizontal Component of Earth's Magnetic Field
- Z - Vector of Vertical Component of Earth's Magnetic Field
- J - Magnetic Dip Angle
- D - Magnetic Declination
- Ψ_m - Magnetic Heading
- Ψ - True Heading
- X,Y,Z - Sense Axes for Fluxgate Magnetometer
- E - Elevation - With Respect to Level.
- B - Bank - With Respect to Level.

The microprocessor transforms the x, y, and z measurements to a horizontal geographical coordinate system and calculates the magnetic heading Ψ_m as :

$$\Psi_m = \text{Atan}(-Y_T/X_T)$$

Where X_T, and Y_T are coordinate transformed to the horizontal system for Fluxgate Magnetometer measurement. To calculate D, the SHR must be turned to true North or its true direction needs to be known.

$$D = \Psi - \Psi_m$$

If you are only interested in the variation of declination, you do not need to know True Heading. However, when the measurements are taken, the SHR has to be oriented in the same Azimuth position. For more details about declination measurement, please contact Watson Industries. Watson Industries provides software for heading calibration in your installation package because each unit will likely have significant magnetic deviations. Your location on the globe will also cause error in the magnetic heading (Ψ_m) by Magnetic Dip Angle (J) and Leveling Error (ΔL). The following is a general relationship:

$$\Delta\Psi_m = tgJ * \Delta L$$

Table 1 lists a general relationship between Magnetic Dip Angle and latitudes on the Earth's surface.

Latitude	30	45	56	70	80
Dip Angle	45	60	68	80	85

Table 1. Magnetic Dip Angle versus Latitude

Specifications

Attitude			
	Range: Bank	±180°	
	Range: Elevation	±90°	
	Resolution:	0.02°	Binary mode (14 bit)
	Analog Scale Factor:	18°/V	±10V Bank ±5V Elevation
	Accuracy: Static	±0.3°	
Magnetic Heading			
	Range:	0° - 360°	
	Resolution:	0.02°	Binary mode (14 bit)
	Analog Scale Factor:	18°/V	±10V Output
†	Accuracy: Static	±1.5°	
*	Accuracy: Dynamic	0.5%	
Angular Rate			
	Range: Yaw	±100°/sec	
	Resolution:	0.025°/sec	Binary mode (14 bit)
	Scale Factor Accuracy:	0.5%	
	Bias: Yaw	< 0.2°/sec (Analog)	±0.02°/sec Binary mode (14 bit)
	Non-Linearity:	< 0.1%	Full scale range
	Bandwidth:	20 Hz	
	Noise:	< 0.03°/sec rms	
Acceleration			
	Range: X, Y, Z	±10g	
	Resolution:	4mg	
	Scale Factor Accuracy:	1%	
	Bias: X, Y, Z	< 10mg	
	Non-Linearity:	0.1%	Full scale range
	Bandwidth:	3 Hz	
Magnetic			
	Range: X, Y, Z	±1000 mGauss	
	Resolution:	0.1 mGauss	Binary mode (14 bit)
	Scale Factor Accuracy:	1%	
	Bias: X, Y, Z	< 5 mGauss	
	Non-Linearity:	< 0.01%	Full scale range
	Bandwidth:	10 Hz	
Environmental			
	Temperature: Operating	-40°C to +85°C	
	Temperature: Storage	-55°C to +85°C	
	Vibration: Operating	5g rms	20 Hz to 2 KHz
	Vibration: Survival	10g rms	20 Hz to 2 KHz
	Shock: Survival	500g	10mS ½ sine wave
Electrical			
	Frame Rate:	284.44 Hz	Maximum
	Startup Time: Data	5 sec	
	Startup Time: Fully operational	10 sec	
	Input Power:	10 to 35VDC	< 4W
	Input Current:	260mA @ 12VDC	150mA @ 24VDC
	Digital Output:	RS-232	
	Analog Output:	±10VDC	
	Analog Output Impedance:	300 Ohm	Per line
Physical			
	Axis Alignment:	< 0.25°	
	Size: Including Mounting Flanges	3.24"W x 5.78"L x 2.67"H	8.2 x 14.7 x 6.8 (cm)
	Weight:	27 oz (1.7lb)	765 grams (0.8Kg)
	Connection: RS-232	9 pin female "D" subminiature	
	Connection: Power / Analog Outputs	9 pin male "D" subminiature	

* Actual accuracy can be calculated as the listed percentage multiplied by the change in value over the entire dynamic maneuver.

† Static heading accuracy is dependent on the magnetic environment.
This sensor will meet or exceed this spec within the 48 contiguous United States.

- Specifications are subject to change without notice.
- This product may be subject to export restrictions. Export Classification ECCN 7A994.

RS-232 Output Format

The nominal RS-232 output consists of a string of decimal ASCII characters sent asynchronously at regular intervals at about 11.85 strings per second. The string is sent at 9600 baud with eight data bits, one stop bit and no parity. The contents of a typical string are formed as follows:
(See Appendix A for information on how to change the data string.)

1. A single letter and a space used to indicate the start of the data string. The letter “I” indicates the start of an inertial data string. The letter “R” indicates the start of a Reference data string. If the letter is in lower case (“i” or “r”), an error over-range condition is indicated (see below).

2. A seven character string representing the bank angle starting with a “+” or a “-“, followed by three digits, a decimal point, one digit and a space for up to ±180.0 degrees.

3. A six character string representing the elevation angle starting with a “+” or a “-“, followed by two digits, a decimal point, one digit and a space for up to ±90.0 degrees.

4. A six character string representing the relative heading angle by three digits, a decimal point, one digit and a space for zero to 359.9 degrees.

5. A six character string representing the Z axis angular rate starting with a “+” or a “-“, followed by two digits, a decimal point, one digit and a space for up to ±99.9 degrees/second.

6. The string is terminated by a carriage return. There will then be a short interval with no data transmission before the next string begins.

Example:

```
   I   +002.5     -05.0    273.4   -00.4     <CR>
  ___________________________________________________
     ^              ^        ^        ^
     | bank angle   |  elev. | Head.  |  Z  axis
     |              |  angle | angle  |   rate
 (1) |     (2)      |   (3)  |  (4)   |   (5)        (6)
   space          space    space    space
```

This may be reduced to attitude and heading information to improve the update rate to almost twice the previous rate by using special commands to modify the EEPROM of the unit. More channels are available for output – see Appendix A.

The system is protected from inadvertent write-over of the EEPROM by requiring two spacebar commands during the initialization interval to access the EEPROM or related functions.

The baud rate may be changed from the nominal value of 9600 baud by modifying the default value in the EEPROM of the unit to 38.4K, 19.2K, or 4800 baud.

A text header that is sent by the SHR during initializations identifies the unit by part number and by serial number and gives the date of last calibration. Additionally, a line of text characters that identifies the data channel columns is sent if the serial output is set to ASCII decimal. This whole message can be temporarily or permanently suppressed or restored by a "*" command from the interfacing computer.

Data transmission sent by the SHR can also be suppressed or restored by a "+" command from the interfacing computer.

The error over range condition is indicated by the use of a lower case "i" or "r" when the calculated attitude or heading error exceeds the ranges listed above. Internal functions that require these error values are disabled while the condition exists. The system will continue to operate in an extended time constant mode with a low level of error accumulation until the condition is cleared. Occasional blips of this condition are expected with no detectable affect on the resulting data.

The other output format available is a binary format. The binary format provides generally the same information as the decimal ASCII format, but in a compact binary file format. In this format, there are nominally 13 words sent that represent 6 fourteen bit output channels followed by a carriage return. Again, this may be reduced to attitude and heading information to improve the update rate (in this case the rate would be 71.11 Hz) by using special commands to modify the EEPROM of the unit. This format is for highly experienced users only. Consult the factory for further details.

RS-232 Input Commands

The RS-232 input commands are provided for the purpose of unit test and installation set-up. Use the same parameters that are used for the RS-232 output (9600 baud ASCII nominal, or as reset in the units EEPROM).
Note: Many commands require command or "Double spacebar mode" in order to access them. Fore more information on how to activate Command Mode, see the instructions in the second part of Appendix A.
These commands are available to the user (others are used at the factory for alignment and calibration).

1. An "R" or "r" will set the outputs (analog and serial) to their Reference Command modes. This will also disable the logic input Reference Command, Coast Mode Command and Invalid Velocity Command until the next time the unit is powered up. This mode is used in installation to physically align the unit. Double spacebar at initialization is required for access to this command.

2. An "I" or "i" will clear the Reference Command mode if it had been set by the serial input. This is the default mode at power up and is the normal operating mode. This will also disable the logic input Reference Command, Coast Mode Command and Invalid Velocity Command until the next time the unit is powered up. Double spacebar at initialization is required for access to this command.

3. An "F" will disconnect the references from the attitude system and is the Coast Mode Command. This coast mode is used to make the system ignore the references during high maneuvers and brief disturbances. This mode is not intended for use except in brief intervals, since errors will grow geometrically. This will also disable the logic input

Reference Command, Coast Mode Command and Invalid Velocity Command until the next time the unit is powered up.

4. A “K” will clear the Coast Mode Command.

5. An “!” will reinitialize the unit. Further, the access to initialization is inhibited such that a spacebar command must be sent within 2.5 seconds of the “!” command for initialization to be engaged.

There are two output format serial commands: “_” for decimal output and “^” for binary. See second part of Appendix A for more information on change output formats. There are several interface commands as well: “:” will toggle the output to send a frame of data upon receiving any non-command character and “+” will toggle the output for no output data. These and other changes are made non-volatile in the unit on EEPROM by keying in the quote (“) character. Double spacebar at initialization is required for access to these commands.

The “&” command calls a menu which allows any of several parameters to be set. These are system time constants, selection of data channels for serial output and baud rate. Double spacebar at initialization is required for access to this command.

The commands “~”, “@”, “#”, “$”, ‘(“, “)”, “{“, “}”, “|”, “<”, “>” and “?” are used by the Watson factory to calibrate the unit and should be used only with the assistance of the factory. If an undesired function is called, a “Q”, and sometimes Escape or a Delete will interrupt the command and return to operation with the least disturbance to the system. All other unspecified characters such as carriage return, line feed and space are ignored by the system.

If there are problems with the system “hanging up” during the binary output mode, check for crosstalk between the serial transmit and receive line in your installation. In addition, check to see that the communications program used is not sending an echo. This will not happen in the decimal or hexadecimal modes because command characters recognized by the system are not produced in those modes.

Analog Outputs

Analog signals are output from a 14 bit digital to analog converter through an operational amplifier. Each analog output has a 300 ohm resistor in series to eliminate oscillations from high capacitance loads. The output range for all of the analog output channels is ±10 Volts with respect to the common signal ground. The outputs include:

Signal	Pin	Range	Output Range	0 VDC	Scale Factor
Bank	6	±180°	±10V	0°	18°/s/V
Elevation	7	±90°	±5V	0°	18°/s/V
Heading	8	0-360°	±10V	0° (South)	18°/s/V

Note that the analog switches are disabled after certain serial commands are sent to the unit. This prevents software/hardware switch conflicts.

Connections

9 –Pin Male Power/ Analog Output Connector

Pin	Description
1	Power Ground
2	+ 12 or + 24 VDC
3 - 5	No Connection
6	Bank Analog Output
7	Elevation Analog Output
8	Heading Analog Output
9	Signal Ground

9 –Pin Female RS-232 Connector

Pin	Description
1	No Connection
2	TXD**
3	RXD
4	Shorted to pin 6
5	Signal Ground
6	Shorted to pin 4
7	Shorted to pin 8
8	Shorted to pin 7
9	No Connection

**User Receives data on this line

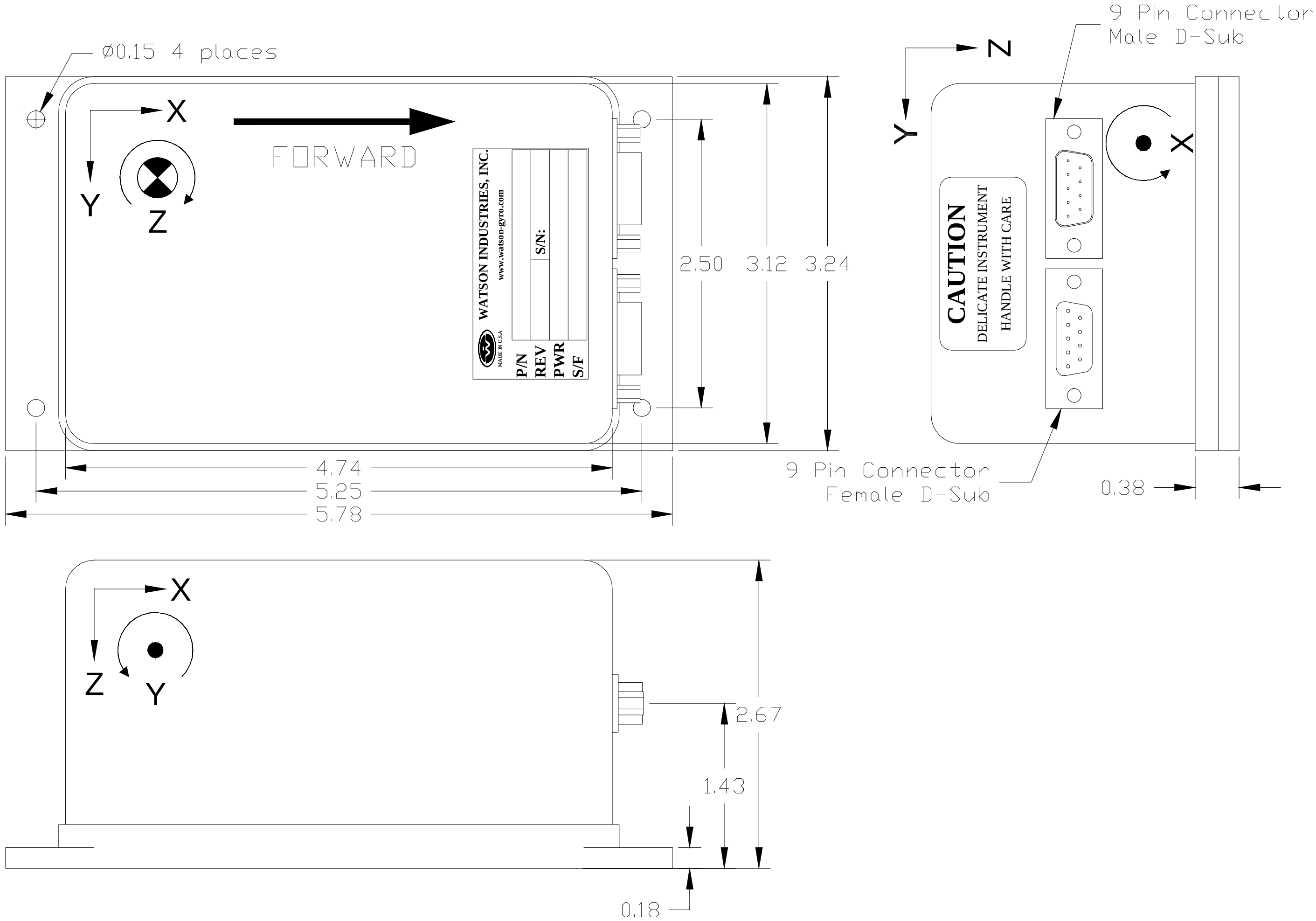


Figure 2 SHR-E360

WARNING

Rough handling or dropping of this unit is likely to cause damage. Over-voltage and/or miswiring of this unit will cause damage. This unit should be protected against prolonged exposure to high humidity and/or salt air environments.

DISCLAIMER

The information contained in this manual is believed to be accurate and reliable; however, it is the user's responsibility to test and to determine whether a Watson Industries' product is suitable for a particular use.

Suggestion of uses should not be taken as inducements to infringe upon any patents.

WARRANTY

Watson Industries, Inc. warrants, to the original purchaser, this product to be free from defective material or workmanship for a period of two full years from the date of purchase. Watson Industries' liability under this warranty is limited to repairing or replacing, at Watson Industries' sole discretion, the defective product when returned to the factory, shipping charges prepaid, within two full years from the date of purchase. The warranty described in this paragraph shall be in lieu of any other warranty, express or implied, including but not limited to any implied warranty of merchantability or fitness for a particular purpose.

Excluded from any warranty given by Watson Industries are products that have been subject to abuse, misuse, damage or accident; that have been connected, installed or adjusted contrary to the instructions furnished by seller; or that have been repaired by persons not authorized by Watson Industries.

Watson Industries reserves the right to discontinue models, to change specifications, price or design of this product at any time without notice and without incurring any obligation whatsoever.

The purchaser agrees to assume all liabilities for any damages and/or bodily injury that may result from the use, or misuse, of this product by the purchaser, his employees or agents. The purchaser further agrees that seller shall not be liable in any way for consequential damages resulting from the use of this product.

No agent or representative of Watson Industries is authorized to assume, and Watson Industries will not be bound by any other obligation or representation made in connection with the sale and/or purchase of this product.

PRODUCT LIFE

The maximum expected life of this product is 20 years from the date of purchase. Watson Industries, Inc. recommends the replacement of any product that has exceeded the product life expectation.

Customer Service

All repairs, calibrations and upgrades are performed at the factory. Before returning any product, please contact Watson Industries to obtain a Returned Material Authorization number (RMA).

Return Address & Contact Information

Watson Industries, Inc.
3035 Melby Street
Eau Claire, WI 54703
ATTN: Service Department
Telephone: (715) 839-0628 Fax: (715) 839-8248 email: support@watson-gyro.com

Returning the Product

Product shall be packaged making sure there is adequate packing around all sides. Correspondence shall include:

- Customer's Name and Address
- Contact Information
- Equipment Model Number
- Equipment Serial Number
- Description of Fault

It is the customer's responsibility to pay all shipping charges from customer to Watson Industries, including import and transportation charges.

Appendix A

The following outputs are available via the RS-232 serial link. Their full-scale ranges are listed for both decimal and binary format.

Inertial Output	Label	Full Scale Decimal	Full Scale Binary
Bank	BK	±75.0º	±180º
Elevation	EL	±75.0º	±180º
Relative Heading	HG	359.9º	±180º
X Acceleration	FA	±9.99 g	±10 g
Y Acceleration	LA	±9.99 g	±10 g
Z Acceleration	VA	±9.99 g	±10 g
Z Angular Rate	ZR	±99.9 º/s	±200 º/s
Heading Rate	HR	±99.9 º/s	±200 º/s
X Magnetometer	XM	±999.9 mGauss	±1000 mGauss
Y Magnetometer	YM	±999.9 mGauss	±1000 mGauss
Z Magnetometer	ZM	±999.9 mGauss	±1000 mGauss
Bank Pendulum (simulated)	XI	±89.9º	±180º
Elevation Pendulum (simulated)	YI	±89.9º	±180º
Temperature	TP	-40º to 88ºC	-40º to 88ºC (7 bit)
Status Bits	ST	1 byte	1 byte
Flag Bits	FL	1 byte	1 byte

The Flag Bits contains the following information:

a) Bits 0-2 show the current system time constant, using the following equations:

$$TC=2^{(\text{Flag Value} + 1)}$$

b) Bit 3 - If set, reference command selected.
c) Bit 4 - If set, Steady Turn Mode Selected
d) Bit 5 - If set, Coast mode is selected.
e) Bit 6 - If set, the analog switches are disabled.

Activating Command mode or Double Spacebar Access to commands

Hook the unit up to your computers serial port.
Use HyperTerminal program to interface with unit.

Turn on unit. Wait for the startup message to appear on display.
Hit the space bar twice within the first 5 seconds of turn on.
Sometimes it takes a few tries to get the hang of this.
Wait for the data string to start transmitting.

Now the unit will take in the keyboard commands.

Determining and Setting Output Channels

Activate Command Mode (See above). To determine which channel present, first type '&'.
This will bring up the menu:

```
TYPE IN THE NUMBER OF YOUR SELECTION (OR 'Q' TO QUIT):
   1 = ADJUST TIME CONSTANTS
   2 = SET OUTPUT CHANNELS
   3 = LIST CURRENT OUTPUT CHANNEL SELECTION
   4 = SET NEW BAUD RATE
```

typing in '3' will show which channels are currently active.

To change which channels are output type '&'(this will bring up the menu again)

Now type '2' to set up channels
The following message will appear:

```
TO SET FOR OUTPUT FOR ANY OF THE FOLLOWING DATA ITEMS, PRESS Y
TO AVOID ANY OF THE FOLLOWING DATA ITEMS, PRESS N
TO QUIT AND DISREGARD ANY OTHER DATA, PRESS Q

***  DO YOU WANT TO PROCEED?  (Y/N/Q)
```

To proceed type 'Y'
Now each channel will come up one at a time
For example:

```
DO YOU WANT OUTPUT OF BANK ANGLE?
```

Type 'Y' to output channel , type 'N' to remove channel
When you get to bottom of list, this message will appear:

```
Y = GOBACK, N = INSTALL DATA & QUIT, Q = QUIT
   DO YOU WANT TO TRY TO SET DATA AGAIN?
```

To accept channels type 'N', then hit space bar output data to resume.
To make this channel selection the default the next time you power the unit on type in'"' (double quote)

Setting Output Format

There are two output formats.
Decimal output - "_" Command.
Binary output – "^" Command.

To change the output format:
Hook the unit up to your computers serial port.
Use HyperTerminal program to interface with unit.

Turn on unit. Wait for the startup message to appear on display.
Hit the space bar twice within the first 5 seconds of turn on.
Sometimes it takes a few tries to get the hang of this.
Wait for the data string to start transmitting.

Now the unit will take in the keyboard commands. Press the key Command corresponding to the format you want to switch into. (for example type "_" to change into Decimal Format.)
To make this format selection the default the next time you power the unit on type in'"' (double quote.)

Appendix B

Sensor Test Instructions

B <u>Sensor Test Instructions</u> Tests within this section have been designed to provide assurance of the correct operation of the sensor without the use of elaborate test equipment other than a means of accurately observing the outputs. The "HyperTerminal" program provides a suitable means of observing the outputs.

B.1 Parameter Exercise Test

After successful initialization, move the sensor in all three axes using both linear and angular motion, making certain each of the measurement parameters responds to the motion.

B.2 Angular Displacement Scale Factor Tests

After successful initialization, place the sensor on a level surface and observe the pitch and roll displacement signals. Place the sensor on a pivot and incline the sensor by a small angle of 6 to 10 degrees in the pitch. A suitable pivot is a 10mm square bar attached to the sensor base plate with adhesive tape. Give the "Reference" command. The signals from the simulated pendulums will be outputted instead of the normal angular displacement signals. Careful note should be taken of the angles indicated in the reference mode. The sensor should then be tipped on the pivot into the other stable position and the angle again noted.

The procedure of tipping the sensor should be repeated with the "Reference" command removed. The angles obtained should agree with those noted with the reference.

The procedure should be repeated in the Roll axis. The same pivot may be used, but some care will be needed to avoid exceeding the 100 degree/second limit. A more appropriate size of bar would be 5mm square.

B.3 Accelerometer Scale Test

After successful initialization, place the sensor on a level surface and monitor the acceleration outputs. Observe the X and Y outputs will read near zero while the Z axis will read minus 1G within the accuracy of the sensor.

Set the sensor at a 45 degree angle to the horizontal in Pitch only. The value of X and Z acceleration should read 0.71G , within the accuracy of the sensor , while the Y acceleration should remain at the level value. The values of Forward, Lateral and Vertical Acceleration should remain at the values when level.

Repeat the test for the roll axis of the sensor. Under this test, Y and Z acceleration will read 0.71G and the X acceleration will retain its value at level.

B.4 Earth Axes Test

After successful initialization, place the sensor on a level surface, and observe the pitch and roll displacement signals as well as acceleration outputs.

The Forward, Later and Vertical outputs should correspond to the X, Y and Z outputs to within the accuracy of the sensor.

Set the sensor at a 45 degree angle to the horizontal in pitch only, taking care not to move the sensor at an angular rate of more than 100 deg/sec.
The Forward, Lateral and Vertical output should not change from the values, when level, by more than the accuracy of the sensor.

Move the sensor through a further 45 degrees in pitch such that the base plate is now vertical, again taking care not to exceed the 100 deg/sec limit. The sensor should then be rotated about the vertical and the Yaw output will respond accordingly.

The test should then be repeated for the Roll axis.

Appendix C

Binary Data Format

One word per output parameter.

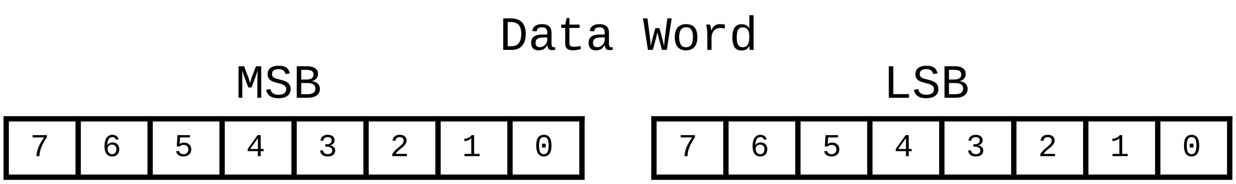
Example 1: The Unit is seeing these conditions:

Bank	Elevation	Heading	X Mag	Y Mag	Z Mag
15.0˚	-5.0˚	315.0˚	-002 mGauss	+314 mGauss	+567 mGauss

2) Binary output Format:

Word1	Word2	Word3	Word4	Word5	Word6	<CR> byte
0x85AA	0xFE9C	0xF080	0xFFF2	0x998F	0xA4A4	0x0D

Word 1 is the 2 byte Bank Angle
Word 2 is the 2 byte Elevation Angle
Word 3 is the 2 byte Magnetic Heading Angle
Word 4 is the 2 byte X Magnetometer
Word 5 is the 2 byte Y Magnetometer
Word 6 is the 2 byte Z Magnetometer



Bit 7 of the MSB is set to 1. Bits 6 to 0 of the MSB are the upper 7 bits of the data. (sign plus 6 bits of data)
Bit 7 of the LSB is set to 1. Bits 6 to 0 of the LSB are the lower 7 bits of the data.

As the data words are received, the LSB is shifted left to shift out the 7th bit (always set to 1). The MSB is then connected to the LSB as a 16 bit word. This word is then shifted left to shift out the 7th bit (always set to 1). What remains is a signed fractional word with a resolution of 13 bits plus a sign bit.

To convert binary data:

Bank	Elevation	Heading	X Mag	Y Mag	Z Mag
0x85AA	0xFE9C	0xF080	0xFFF2	0x998F	0xA4A4

Need split each word into two bytes:

Bank	Elevation	Heading	X Mag	Y Mag	Z Mag
0x85 0xAA	0xFE 0x9C	0xF0 0x80	0xFF 0xF2	0x99 0x8F	0xA4 0xA4

Remove the most significant bit from each byte:

Bank	Elevation	Heading	X Mag	Y Mag	Z Mag
0x05 0x2A	0x7E 0x1C	0x70 0x00	0x7F 0x72	0x14 0x0F	0x24 0x24

Shift lower byte left once (to remove 1 bit space between bytes):

Bank	Elevation	Heading	X Mag	Y Mag	Z Mag
0x05 0x54	0x7E 0x38	0x70 0x00	0x7F 0xE4	0x14 0x1E	0x24 0x48

Shift lower & upper bytes left once (to remove 1 bit space a top of high byte):

Bank	Elevation	Heading	X Mag	Y Mag	Z Mag
0x0A 0xA8	0xFC 0x70	0xE0 0x00	0xFF 0xC8	0x28 0x3C	0x48 0x90

Bank	Elevation	Heading	X Mag	Y Mag	Z Mag
0x0AA8	0xFC70	0xE000	0xFFC8	0x283C	0x4890

Convert from hexadecimal to decimal counts:

Bank	Elevation	Heading	X Mag	Y Mag	Z Mag
2728	64624	57344	65480	10300	18576

Correct bank, elevation, and magnetometer for the sign
If >32767 then subtract 65536 (2^{16}) from the data

Bank	Elevation	Heading	X Mag	Y Mag	Z Mag
2728	-912	57344	-56	10300	18576

Convert to units: counts x scale factor
For bank & elevation: Scale factor is: 180 ˚ / 32768 counts
For Heading: Scale factor is: 360 ˚ / 65536 counts
For Accelerations: Scale factor is 1.000g / 32768 counts
For Magnetometer: Scale factor is 1000mg / 32768 counts

Multiply the data (in counts) by the scale factor
Convert to units: counts * scale factor
For Bank Scale factor is 180˚/ (2^{15}) or 32768 counts = 2728 counts * (180˚/2^{15} counts) = 14.985 ˚
For Elevation Scale factor is 180˚/ (2^{15}) or 32768 counts = -912 counts * (180˚/2^{15} counts) = -5.010 ˚
For Heading Scale factor is 360˚/ (2^{16}) or 65536 counts = 57344 counts * (360˚/2^{16} counts) = 315.000 ˚
˚For X Mag: Scale factor is 1000 mG/ (2^{15}) or 32768 counts = -56 counts * (1000 mG /2^{15} counts) = -1.71 mG
For Y Mag: Scale factor is 1000 mG/ (2^{15}) or 32768 counts = 10300 counts * (1000 mG /2^{15} counts) = 314.33 mG
For Z Mag: Scale factor is 1000 mG/ (2^{15}) or 32768 counts = 18576 counts * (1000 mG /2^{15} counts) = 566.89 mG

Bank	Elevation	Heading	X Mag	Y Mag	Z Mag
14.985 ˚	-5.010 ˚	315.000 ˚	-1.71 mGauss	314.33 mGauss	566.89 mGauss