VRS-S132-1AD

Single Axis Vertical Reference
Owner's Manual

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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 Watson Industries Vertical Reference represents a significant advancement in inertial sensor technology. It is a highly accurate and rugged device with many advantages over other types of angular rate and incline-sensing devices. This manual describes operation of the Watson Industries Vertical Reference and also provides useful application information to the system designer.

Product Description

The Watson Industries Vertical Reference System (VRS) is an entirely solid-state sensor that provides exceptional rejection from the adverse effects of inertia and short-term lateral accelerations. It does this through the use of both an accelerometer based vertical reference and an angular rate sensor which is integrated to provide additional information on angular position. It can be a functional replacement for mechanical gyros which are often more expensive and which cannot provide the reliability of a solid-state sensor. Theory of operation is described with more detail on page 4. Size and pinouts are described on pages 8-9. Specifications are shown on page 5.

The Watson Vertical References provide for two types of analog output voltages. One is proportional to angular rate and the other is proportional to angular displacement. Full-scale analog outputs produce an output of ±10 volts dependent upon the direction of angular position or rotation. During rotation, positive voltage output occurs in the direction of the rotational arrow on the case. At horizontal and zero angular rotation rate, both outputs for displacement and rotation rate are near zero. A power supply, providing +10 to +30 Volts DC, is required to operate the unit.

Special options in power supply, output voltage, scale calibration, and special packaging are available as custom units. Pricing and delivery information on custom units is available by contacting the factory.

Cross Axes Concerns:

Turning while banked will cause errors in the pitch angle.

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 VRS drawing, with wire call outs, is located on page 8. The VRS 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.

Mounting:

The unit has four 0.15” diameter mounting holes for using 6-32 screws. 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.

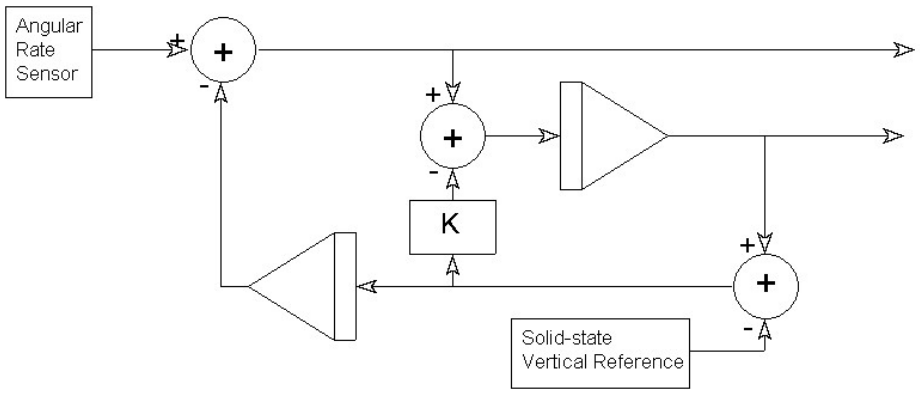
For shipboard applications, install the sensor near the center of gravity. For all applications, it is preferable to install the device where linear dynamic effects are minimized.

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. The power ground is isolated from the signal ground. Power consumption of the unit is 2.2W. The VRS power system is isolated from the VRS 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

In order to obtain an accurate signal in both the short-term and in the long-term, the Vertical Reference relies upon a Watson Industries angular rate sensor (ARS) combined with a solid-state accelerometer. The position output is derived by integrating the angular rate output. This signal is compared with the output from the accelerometer and the resultant error signal is passed through a long time constant filter and fed back as a bias to the rate sensor. The system is damped by sending a portion of the error directly to the position integrator. By using a long time constant, the effect of the short-term errors in the accelerometer is minimized. Thus, the adverse effects of inertia, damping and short-term lateral accelerations on the pendulum essentially do not show up on the vertical reference output. See Figure 1 for system overview.



The solid-state angular rate sensor used here works on the basic principle of detecting coriolis forces. These forces are generated when a moving particle is rotated. To use the coriolis effect to detect angular rotation, a solid structure is forced to vibrate normally at its resonant frequency. The vibration provides the structure with a linear velocity component. When the structure is rotated, the coriolis forces cause the vibration motion of the structure to be coupled to another vibration mode or plane of the structure. The magnitude of this secondary vibration is proportional to the angular rate of turn.

Specifications

Attitude			
	Range: Elevation	±90° (±50°)	Digital (Analog)
	Resolution:	0.02°	Binary mode (14 bit)
	Analog Scale Factor:	5°/V	±10V Output
	Accuracy: Static	±0.5°	(up to 75°)
*	Accuracy: Dynamic	2%	
Angular Rate			
	Range: Pitch	±100°/sec	
	Resolution:	0.025°/sec	Binary mode (14 bit)
	Analog Scale Factor:	10°/sec/V	±10V Output
	Scale Factor Accuracy:	2%	
	Bias: Pitch	< 0.3°/sec	
	Non-Linearity:	< 0.05%	Full scale range
	Bandwidth:	20 Hz	
Acceleration			
	Range: X, Z	±10g	
	Resolution:	4mg	
	Scale Factor Accuracy:	1%	
	Bias:	< 10mg	
	Non-Linearity:	0.1%	Full scale range
	Bandwidth:	3 Hz	
Environmental			
	Temperature: Operating	-40°C to +85°C	
	Temperature: Storage	-55°C to +85°C	
	Vibration: Operating	2.5g 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	1.7W
	Input Current:	125mA @ 12VDC	70mA @ 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 2.38"H	8.2 x 14.7 x 6.0 (cm)
	Weight:	19.4oz (1.2lb)	550 grams (0.6Kg)
	Connection: RS-232 / Analog Outputs	9 pin female "D" subminiature	
	Connection: Power	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.

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

Analog Output

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 analog outputs can be found on the 9-pin female D-Sub connector. The outputs include:

Signal	Pin	Range	Output Range	0 VDC	Scale Factor
Elevation	7	±50°	±10V	0°	5°/V
Pitch Rate (Y Axis)	9	±100°/s	±10V	0°/s	10°/s/V

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

RS-232 Digital Output

The Digital RS-232 outputs can be found on the 9-pin female D-Sub. The Digital output pin map can be found on page 8. The RS-232 signals are reference to the Signal Ground. The digital connections are:

1. RXD is the data receive line – pin 2. The commands are sent to unit on this line.
2. TXD is the data transmit line – pin 3. User Receives data on this line.
3. Signal Ground for RS-232 signals is on pin 5.

RS-232 Output Format

The nominal RS-232 output on the 9-pin female connector consists of a string of decimal ASCII characters sent asynchronously at regular intervals at about 35.5 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.)

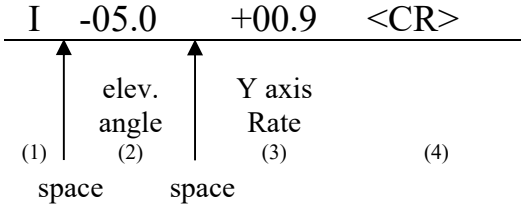
1. A single letter and a space used to indicate the start of the data string. The letter "I" indicates the start of an inertial data string. The letter "R" indicates the start of a Reference data string. If the letter is in lower case ("i" or "r"), an error over-range condition is indicated (see below).

2. A 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 ±75.0 degrees.

3. A six character string representing the Y 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.

4. 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:



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 38400, 19200, or 4800 baud.

A text header that is sent by the VRS 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 VRS 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 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 9 Bytes sent that represent 4 fourteen bit output channels followed by a carriage return. Again, this may be reduced to attitude 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. For 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 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. 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. .

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 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.

Connections

9 –Pin Male Power Connector

Pin	Description
1	Power Ground
2	+ 10 to + 30 VDC
3 - 9	No Connection

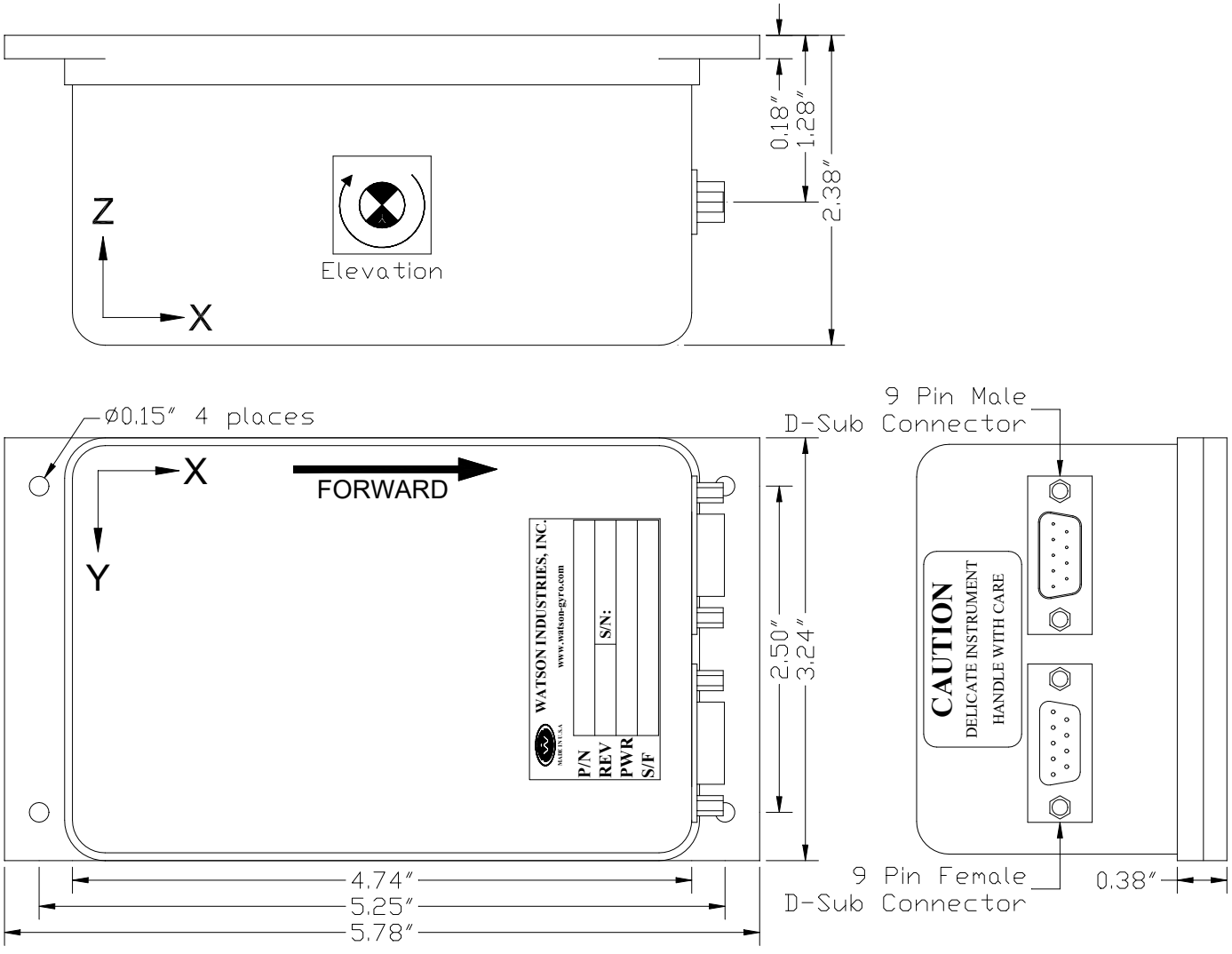
9 –Pin Female RS-232/Analog Output Connector

Pin	Description
1	No Connection
2	TXD**
3	RXD
4	No Connection
5	Signal Ground
6	No Connection
7	Elevation (Y) Angle Analog Output
8	No Connection
9	Y Angular Rate Analog Output

**User Receives data on this line

The RS-232 serial and analog output connections are referenced to Signal Ground on pin 5.

Dimensions



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 one full year 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
Time Since Reset	TM	65535 seconds	16383 seconds
Elevation	EL	±89.9º	±180º
X Acceleration	XA	±9.99 g	±10 g
Z Acceleration	ZA	±9.99 g	±10 g
Y Angular Rate	YR	±99.9 º/s	±200 º/s
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 TIME SINCE RESET?

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

Binary Data Format

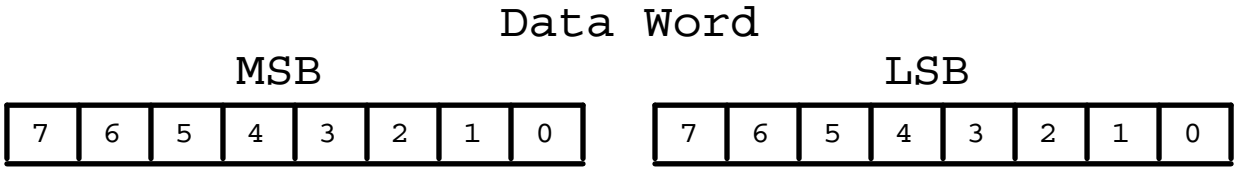
Example: Unit is sending out Elevation & Y Angular Rate
The Unit is seeing these conditions:

Elevation	Y Rate
2.3˚	-3.1˚/s

2) Binary output Format:

Word1	Word2	<CR> byte
0x80E9	0xFF81	0x0D

The Carriage return byte is the only byte that is less than 128 (0x80). This is the Synchronizing Byte.



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:

Elevation	Y Rate
0x80E9	0xFF81

Need split each word into two bytes:

Elevation	Y Rate
0x80 0xE9	0xFF 0x81

Remove the most significant bit from each byte:

Elevation	Y Rate
0x00 0x69	0x7F 0x01

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

Elevation	Y Rate
0x00 0xD2	0x7F 0x02

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

Elevation	Y Rate
0x01 0xA4	0xFE 0x04

Convert from hexadecimal to decimal counts:

Elevation	Y Rate
420	65028

Correct elevation and angular rate for the sign
If >32767 then subtract 65536 from the data

Elevation	Y Rate
420	-508

Convert to units: counts x scale factor
For Elevation: Scale factor is: 180 ˚ / 32768 counts
For Angular Rate: Scale factor is: 200 ˚/s / 32768 counts

Elevation	Y Rate
+2.307 ˚	-3.100 ˚/s

All of the data words have a high sign bit, but the delimiter byte is an ASCII carriage return character that has a low sign bit. The nominal interface settings are:

```
9600 Baud
8 Bit Data
1 Start Bit
1 Stop Bit
No Parity
```