

# **ATTITUDE AND HEADING REFERENCE SYSTEM**

## **OWNER'S MANUAL**

**PART NUMBER: AHRS-S305**



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## INTRODUCTION

This manual is intended to help in understanding the installation and operation requirements of the Watson Attitude and Heading Reference System.

## PRODUCT DESCRIPTION

Attitude and heading gyros need frequent correction to compensate for the 15° per hour of earth rotation. Watson Industries has produced a solid state gyro system, which models these functions for an attitude gyro and a slaved heading gyro. This system uses a microprocessor to integrate angular rate sensor data and provides a closed loop system of error correction to adjust biases from earth rotation and from instrument offsets. Interface to the microprocessor is done through a 16-bit A/D and a 12-bit D/A converter. The solid state vibrating structure angular rate gyros used in this system provide extremely high reliability, low power consumption, shock resistance and low cost.

## OPERATION

The angular rate sensor signals are coordinate transformed and then integrated to produce attitude and heading outputs that reflect normal attitude coordinates. These attitude and heading signals are compared against three accelerometers and a triaxial fluxgate magnetometer to derive short-term absolute errors. These errors are filtered over a long time constant and are used to adjust biases in the system so that the long-term convergence of the system is to the vertical references and the magnetic heading. Compensations for centrifugal forces and velocity changes on the accelerometers are used to improve overall stability and accuracy.

## INSTALLATION

### ***Orientation:***

This device utilizes an earth's magnetic field orientation sensor, so orientation is important. The base plate of the AHRS is intended to be mounted on top of a horizontal surface with the connector toward the forward direction of the vehicle.

### ***Mounting:***

A mounting plate is provided for a flat surface mount. Use non-magnetic hardware. Ideally, the unit should be installed at least 4 feet away from all significant magnetic materials. Some highly magnetic materials require even greater separation from the AHRS unit. The unit may be adhesively mounted at any of its surfaces. If high shock loads are expected (greater than 10G or repeated shocks greater than 5G), the appropriate shock mounting should be used to prevent damage. Vibration isolation should be used for use in 2.5G or greater vibration environments. Symmetry is very important in such mount designs (consult Watson Industries for application notes on this if needed).

### ***Environment:***

High level AC magnetic fields, such as from large transformers, motors, or soldering guns, are to be avoided as being potentially damaging to the circuitry, even if the system is not powered. Exposure to high DC magnetic fields are to be avoided since this can produce a lingering self-magnetization of the sensor, which can cause distortion of the heading reference.

**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 draw of the unit is about 3 Watts. The AHRS power system is isolated from the AHRS 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.

**ERROR CORRECTION**

The correction systems, which all attitude systems use, unfortunately also allow errors from the forces from vehicle maneuvers to enter the system. To control these effects, a balance of time constant and error limits are used:

Limiting Factor Causing Error Reduction:

Axis of Error Limit	Bank Angle Error	Elevation Angle Error	Heading Angle Error	Centrifugal Force Offset	Acceleration Force Offset
Bank	±10°	None	None	±5 g	None
Elevation	None	±10°	None	None	±5 g
Heading	None	None	±20°	None	None

It would not be a problem to cross over into these limits since the rate of deterioration from the original reference should be about 0.03 degrees per second. However, prolonged strong maneuvers should be avoided if accuracy is to be minimized. In normal attitudes, error is corrected with a 30-second time constant.

While this AHRS is "all attitude", the accuracy deteriorates rapidly within about 5 degrees of straight up or straight down.

**Centrifugal Force Compensation:**

The compensation for centrifugal force is based on calculating the horizontal turn rate and multiplying it by the forward velocity. The result is subtracted from the vertical reference accelerometers for the roll axis. This system directly depends on the quality of the velocity signal.

**Delta Velocity Compensation:**

The compensation for forward acceleration is based on calculating the changes in average forward velocity. The result is subtracted from the vertical reference accelerometers for the pitch axis. This is limited in unusual attitudes and the error correction system is locked out when the attitude and conditions are outside of a reasonable range. This system also directly depends on the quality of the velocity signal.

# SPECIFICATIONS

## Attitude

Range: Bank	±180°	
Range: Elevation	±90°	
Resolution:	0.02°	Binary mode (14 bit)
Analog Scale Factor:	18°/V	±10V Output
Accuracy: Static	±0.5°	
* Accuracy: Dynamic	±2%	

## Heading

Range:	0° - 360°	
Resolution:	0.02°	Binary mode (14 bit)
Analog Scale Factor:	18°/V	±10V Output
† Accuracy: Static	±1°	
* Accuracy: Dynamic	±2%	

## Angular Rate

Range: Roll, Pitch, Yaw	±100°/sec	
Resolution:	0.01°/sec	Binary mode (14 bit)
Analog Scale Factor:	10°/sec/V	±10V Output
Scale Factor Accuracy:	1%	
Bias: Roll, Pitch, Yaw	< ±0.2°/sec	
Non-Linearity	< 0.05%	Full scale range
Bandwidth	20 Hz	

## Acceleration

Range: X, Y, Z	±10g	
Resolution:	4mg	
Analog Scale Factor:	1g/V	±10V Output
Scale Factor Accuracy:	1%	
Bias: X, Y, Z	< ±5mg	
Non-Linearity:	< 1%	Full scale range
Bandwidth:	20 Hz	

## Magnetic

Range: X, Y, Z	±1000 mGauss	
Resolution:	0.1 mGauss	Binary mode (14 bit)
Scale Factor Accuracy:	1%	
Bias: X, Y, Z	< ±5mGauss	
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	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	71.1 Hz	Maximum
Startup Time: Data	5 sec	
Startup Time: Fully operational	10 sec	
Input Power:	10 to 30VDC	2.8W
Input Current:	215mA @ 12VDC	115mA @ 24VDC
Input Velocity: (Optional)	±10VDC	Full scale (±800kph)
Digital Output	RS-232	
Analog Output	±10VDC	

## 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 (cm)
Weight:	22oz (1.4lb)	620g (0.6Kg)
Connection:	25 pin male "D" subminiature	

\* Assumes accurate velocity data.

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.

## 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 the string are formed as follows:

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 overrange 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  $\pm 179.9$  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  $\pm 89.9$  degrees.
4. A six character string representing the 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 X axis accelerometer starting with a space, then a “+” or a “-“, followed by one digit, a decimal point and two digits for up to  $\pm 9.99$  g.
6. A six character string representing the Y axis accelerometer starting with a space, then a “+” or a “-“, followed by one digit, a decimal point and two digits for up to  $\pm 9.99$  g.
7. A six character string representing the Z axis accelerometer starting with a space, then a “+” or a “-“, followed by one digit, a decimal point and two digits for up to  $\pm 9.99$  g.
8. A six character string representing the X axis angular rate starting with a “+” or a “-“, followed by two digits, a decimal point, one digit and a space for up to  $\pm 99.9$  degrees/second.
9. 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  $\pm 99.9$  degrees/second.
10. 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  $\pm 99.9$  degrees/second.
11. A six character string representing the velocity starting with a “+” or a “-“, followed by three digits, a decimal point and one digit for up to  $\pm 799.9$  Km/hr.
12. 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:

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	I	+002.5	-05.0	273.4	+1.02	+0.15	-1.57	-00.4	+01.2	+10.4	+001.4	<CR>
	^	^	^	^	^	^	^	^	^	^	^	
(1)	bank angle	elev. angle	Head. angle	X axis accel	Y axis accel	Z axis accel	X axis rate	Y axis rate	Z axis rate	Velocity	(11)	(12)
	space	space	space	space	space	space	space	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.

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 4800, 2400, or 1200 baud.

A text header is sent by the AHRS during initializations that 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 AHRS can also be suppressed or restored by a "+" command from the interfacing computer.

The error overrange 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 which 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.

## ANALOG OUTPUTS

The analog outputs are operational amplifier driven so they are limited in drive capacity. Each analog output has a 300 ohm resistor in series internal to the AHRS to eliminate oscillations from high capacitance loads. The analog output voltage range is  $\pm 10\text{VDC}$ .

## RS-232 INPUT COMMANDS

The RS-232 input commands are provided for the purpose of unit test and installation set-up. The same parameters are used as for the output (9600 baud ASCII nominal, or as reset in the units EEPROM). There are eight commands intended for use by 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 “T” or “t” will clear the Reference Command mode if it had been set by the serial input. 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. Double spacebar at initialization is required for access to this command.
4. A “K” will clear the Coast Mode Command. Double spacebar at initialization is required for access to this command.
5. A “V” will disconnect the velocity input from the attitude system and is the Invalid Velocity Command. This mode is used to protect the system from accumulating errors when the velocity reference is not functioning. Double spacebar at initialization is required for access to this command.
6. A “C” will clear the Invalid Velocity Command. Double spacebar at initialization is required for access to this command.
7. 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.
8. An “L” in the decimal mode will return a line of characters which will identify the data columns. Double spacebar at initialization is required for access to this command.

There are two output format serial commands: “\_” for decimal output and “^” for binary. 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.

To provide a calibration means, a command may be used to offset the heading output from any given angle to North. To use this, simply aim the vehicle platform to the North reference required, set an “R” command on the keyboard and then send an upper case “N”. This is a nonvolatile correction, can be used with any North reference, will correct most local magnetic distortions. Double spacebar at initialization required for access to this command.

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.

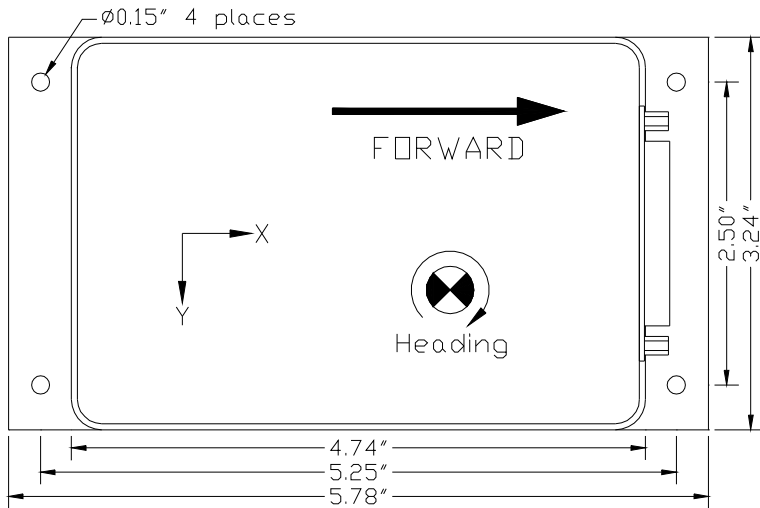
The commands “~”, “@”, “#”, “\$”, “(”, “)”, “{”, “}”, “|”, “<”, “>”, “S”, “M”, “X”, “T”, “D”, and “?” are used by the Watson factory to calibrate the unit and should be used only with the assistance of the factory. If an undesired function is called, a “Q”, and sometimes Escape or a Delete will interrupt 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 mode because command characters recognized by the system are not produced in this mode.

## **ANALOG INPUTS**

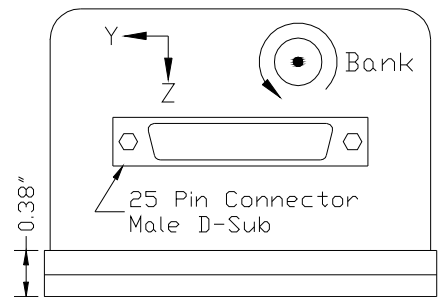
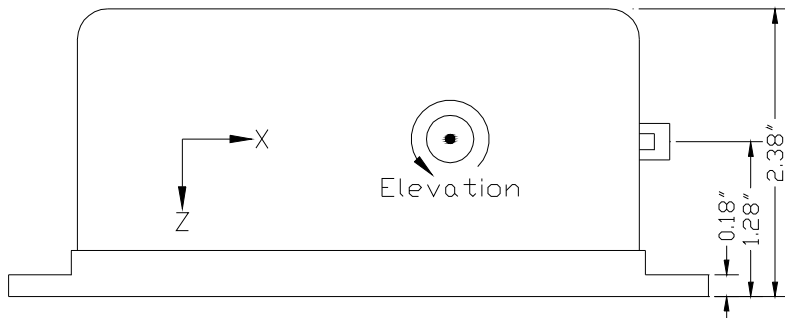
In an effort to make this system more versatile, this system allows the user to input analog data that can then be added to the serial data output. This allows the system to act as a data acquisition unit for other vehicle information such as engine RPM, engine temperature, fuel remaining, altitude/depth or any other important data. The four analog user inputs as well as the velocity input have one megohm input impedance, 16 bit A/D conversion resolution,  $\pm 10$  volt input range and have a bandwidth of DC to 25 Hertz.

# CONNECTIONS / DIMENSIONS



25 Pin Male "D" Subminiature Connector

Pin	Description
1	Power Ground
2	+10 to +30 VDC
3	RS-232 Input (RXD)
4	RS-232 Output (TXD)
5	Signal Ground
6	Analog Output 1 – Bank
7	Analog Output 2 – Elevation
8	Analog Output 3 – Heading North
9	Analog Output 4 – Heading South
10	Analog Output 5 – Heading Rate
11	Analog Output 6 – Roll Rate
12	Analog Output 7 – Pitch Rate
13	Analog Output 8 – Yaw Rate
14 - 17	No User Connection
18	Analog Input – User Channel 1
19	Analog Input – User Channel 2
20	Analog Input – User Channel 3
21	Analog Input – User Channel 4
22	Analog Input – Forward Velocity ( $\pm 10$ VDC)
23 - 24	No User Connection
25	Signal Ground



**AHRS-S305**

## **WARNING**

1. Rough handling or dropping of this unit is likely to cause damage.
2. Over-voltage and/or miswiring of this unit will cause damage.
3. The non-magnetic connectors supplied with the unit must be used to preserve heading accuracy. The user must use non-magnetic hardware to install the unit.
4. 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 one full year 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 which 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.

## SERVICE

Watson Industries, Inc. has no service outlets. All service is performed at the factory. In order to insure prompt service, prior to returning a unit for repair please call, write or fax:

Watson Industries, Inc.  
3041 Melby Road  
Eau Claire, WI 54703  
ATTN: Service Department  
Telephone: (715) 839-0628  
Fax: (715) 839-8248

All sensors returned under warranty will be repaired (or replaced at the sole option of Watson Industries) at no cost to the customer other than shipping charge from customer to Watson Industries (plus any export and transportation charges outside the United States).

In the case of units not under warranty, a flat repair fee will be charged. This fee can be determined by contacting Watson Industries. Modified units or those subjected to extreme abuse may be returned to the customer unrepaired.

## 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.

<u>Inertial Output</u>	<u>Label</u>	<u>Full Scale Decimal</u>	<u>Full Scale Binary</u>
Time Since Reset		65535 seconds	16383 seconds
Bank	BK	±179.9°	±180°
Elevation	EL	±89.9°	±180°
Heading	HG	359.9°	±180°
X Accelerometer	XA	±9.99 g	±10 g
Y Accelerometer	YA	±9.99 g	±10 g
Z Accelerometer	ZA	±9.99 g	±10 g
X Angular Rate	XR	±99.9 °/s	±200 °/s
Y Angular Rate	YR	±99.9 °/s	±200 °/s
Z Angular Rate	ZR	±99.9 °/s	±200 °/s
Heading Rate	HR	±99.9 °/s	±200 °/s
X Magnetometer	XM	±999 mGauss	±1000 mGauss
Y Magnetometer	YM	±999 mGauss	±1000 mGauss
Z Magnetometer	ZM	±999 mGauss	±1000 mGauss
X inclinometer (simulated)	XI	±179.9°	±180°
Y Inclinometer (simulated)	YI	±89.9°	±180°
User Channel 1	U1	±9.99 VDC	±10 VDC
User Channel 2	U2	±9.99 VDC	±10 VDC
User Channel 3	U3	±9.99 VDC	±10 VDC
User Channel 4	U3	±9.99 VDC	±10 VDC
Forward Velocity	VS	±799.9 Km/hr	±800 Km/hr
Temperature	TP	-40° to 88°C	-40° to 88°C (7 bit)
Status Bits	ST	1 byte	1 byte
Flag Bits	FL	1 byte	1 byte

The Flag Bits contains the following information:

Bit	Description
0 to 2	Show the current system time constant, using the following equation: $TC=2(\text{Flag Value} + 1)$
3	If set, Reference Command selected
4	If set, Velocity disabled
5	If set, Free Mode selected
6	If set, Analog Switches disabled

The Status Bits contain the following information:

Bit	Description (If Set)
0	Bank Error Flag
1	Elevation Error Flag
2	Heading Error Flag
3	System Error Flag
4	Velocity Error Flag
5	South Heading Flag
6	Checksum Error Flag

## Appendix B

### **DETERMINING & SETTING OUTPUT CHANNELS**

To determine which channels are present.  
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.  
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?  
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)

## ADJUST TIME CONSTANTS

Consult Factory

## 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.

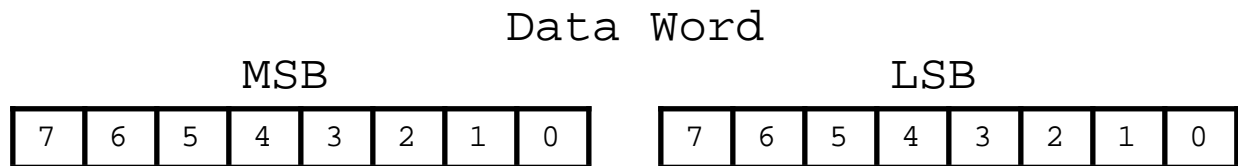
Sometimes it takes a few tries to get the hang of this.

Wait for the data string to start transmitting.

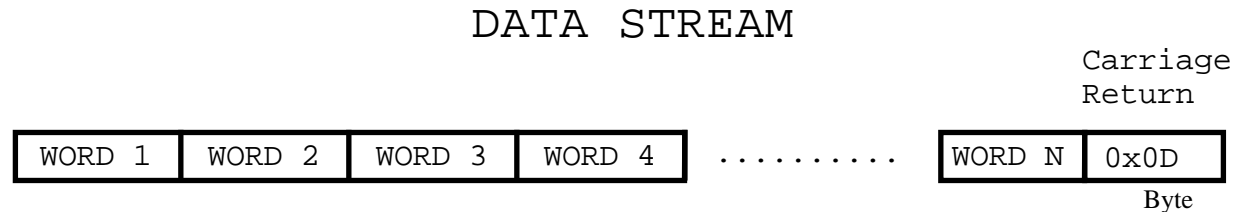
Now the unit will take in the keyboard commands. Press the key Command corresponding to the format you want to switch into. (for example type “\_” to change into Decimal Format.)

To make this format selection the default the next time you power the unit on type in"" (double quote.)

## Appendix C



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



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

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