

Model WOS-120  
Miniature Angular Orientation Sensor  
**MSP430 CPU Version**

User's Manual and Technical Reference

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## I. Introduction

This manual describes the Model WOS-120 orientation sensor. This system is designed to enable high accuracy measurement of the inclination, roll (or tool face) and azimuth orientation angles of the system to which it is mounted. A common application of the WOS-120 is to measure the orientation of borehole logging and directional drilling systems.

The Model WOS-120 orientation sensor contains both a 3 axis fluxgate magnetometer and a 3 axis accelerometer. The combination of these two sensor systems enables the inclination, roll and azimuth angles of the WOS-120 reference frame to be determined. Inclination and roll angles are determined from the accelerometer subsystem, which measures the pull of gravity. After inclination and roll are known, the magnetometer subsystem is used to determine system azimuth angle. Knowledge of the inclination and roll angles enable determination of the horizontal components of the earth's local magnetic field; this information defines the azimuth angle.

The WOS-120 System contains a microprocessor and 8 channels of 16-bit analog to digital conversion. Six channels are assigned to the magnetometer and accelerometer outputs. One channel provides temperature data from an internal thermometer and one channel is configured to measure the system input voltage.

The WOS-120 System communicates with the outside world over one of two serial bi-directional interfaces that can be selected for either TTL or RS-232 voltage levels. An ASCII character command language has been created to facilitate communication with the WOS-120. For instance, if the ASCII string "0SD"<CR> is sent to the unit, the WOS-120 interprets this as a "send data" command and responds by sending over the serial interface an ASCII string representing the value of all magnetometer, accelerometer and temperature outputs. The leading zero in this sequence denotes the system serial number. The WOS-120 can also be configured to send angle data (roll, pitch and azimuth) instead of the accelerometer and magnetometer sensor data.

An autosend data mode is included in the WOS-120 firmware. When this mode is active, data is repeatedly sent after power is applied to the system.

The WOS-120 accelerometers are calibrated by placing the system in a precision rotation fixture and systematically changing the system orientation in the earth's gravitational field. The WOS-120 system magnetometers are calibrated by placing the system in a precision 3-axis Helmholtz coil system, which enables the application of known magnetic fields to the system. Both the rotation fixture and Helmholtz coil mounting fixture have alignment pins and reference surfaces, which mate to the WOS-120 reference surface.

When the system is calibrated over a temperature range, data is read from the system at temperature intervals between the minimum and maximum temperature specification. For instance, for calibration over the interval of 0°C – 75°C, data is read at 25°C temperature intervals between 0° and 75°C. The data taken at each temperature includes scale, offset and sensor alignment data. The recorded data is then used to create a look up table for scale offset and alignment corrections. This table is then downloaded into the WOS-120 internal EEROM memory, where it can be accessed by the system internal microprocessor. Corrections to the read sensor data can then be made by the internal microprocessor system before data is transmitted.

## II. System Specifications

Specification	Value	Notes
Angular Accuracy		
Azimuth	$\pm 1.2^\circ$	Inclination=90 deg
Inclination	$\pm 0.4^\circ$	
Roll	$\pm 0.4^\circ$	
<b>Power</b>		
Voltage	+4.9 to +12 VDC	
Current	55 mA	
Operating Temperature	0 °C – 70 °C	Optional range of 0° to 125°C available
Vibration	10 g RMS, random 20–250Hz	
Shock	750 g 1ms half-sine	
Size	0.75" x 0.80" x 4.6"	
Mass	50 grams	
Digital Outputs		
Logic Level	TTL or RS-232	User selectable
Baud rate	300 – 9600 baud	User selectable
Protocol	ASCII text or Binary	User selectable
Leads	6" flying leads	Color coded
Data output speed in autosend mode		Data rates listed are for a filter setting of 30 Hz
ASCII angle mode	6 Samples/sec	
ASCII sensor mode	9 Samples/sec	
Binary sensor mode	18 Samples/sec	

Table 1. WOS-120 System Specifications

## III. Mechanical Features of the WOS-120

An outline drawing of the WOS-120 System is shown in Fig. 1. (All figures are at the end of this manual.) The system dimensions are 0.75" x 0.80" x 4.60" (1.90 cm x 2.03 cm x 11.68 cm). The system is normally mounted by using four 2-56 x 0.250 long screws to secure the WOS-120 reference surface to a flat mating surface. Two 0.062" dia. x 0.125" long pins protruding from the external mating surface can be used to orient the WOS-120 on the external mounting surface. The orientation of the X-, Y- and Z- axes and the approximate location of the magnetometer and accelerometer sensors are also shown in Figure 1. The output polarity sense of the axes is such that a field pointing in the direction of the arrows shown in Fig. 1 will produce a positive output voltage. For example, if the X magnetometer is oriented so the X-axis arrow points north, then the X-axis magnetometer output will record a positive value. If the X-axis accelerometer arrow is pointed down, the X-axis accelerometer output will be positive. The orientation of the axes is silk-screened onto the WOS-120 case.

Fig. 2 shows the definition of the angles output by the WOS-120.

#### IV. Electrical Interface of the WOS-120

The WOS-120 electrical interface is shown in Table 2 below. The serial communications interface to the WOS-120 is provided by the serial in and serial out lines shown in the table. Two serial interfaces are provided. The RS-232 interface can be connected directly to an external computer COM port. The TTL serial interface is used for communication between the WOS-120 and other system electronics. The serial interfaces are normally set to operate at 9600 baud using 8 bits with one stop bit and no parity. The user, however, can change the baud rate by setting bits in the system EEROM. (See Section VIII.)

Wire Color	Function
Red	+4.9 to +12 VDC Unregulated
Black	Ground
Orange	RS-232 Serial In
Yellow	RS-232 Serial Out
White/Orange	TTL Serial In
White/Yellow	TTL Serial Out

**Table 2. WOS-120 Electrical Interface**

#### V. Initial Setup of the System

In order to operate the WOS-120, power must be applied to it and an interface with an external computer must be set up. Input power should be applied to the red (+4.95 to +12 VDC) and the Black (Ground) wires of the system. In order to set up a computer interface with the system, select the output protocol of the WOS-120. This can be either TTL or RS-232. The TTL protocol is usually used in microprocessor-to-microprocessor communications. Since PC serial COM ports use RS-232 protocol, they can be directly connected to a WOS-120 employing this protocol. PC's use either a 25-pin or a 9-pin D connector on their serial ports. This connector is always a bulkhead male connector on the PC chassis. The serial in, serial out and ground connections for these connectors are shown in Table 4. The WOS-120 serial output line is connected to the computer serial in line and the WOS-120 serial input line is connected to the computer serial out line.

Function	WOS-120 Wire	25-Pin D	9-Pin D
WOS-120 Serial In	Orange	2	3
WOS-120 Serial Out	Yellow	3	2
Ground	Black	5	5

**Table 3. RS-232 Interface Connections**

An easy way of communicating with the WOS-120 using the ASCII protocol is to run a terminal program on the PC. The Windows HyperTerminal program is one choice for this. Other suitable terminal programs are ProComm and ASCII Pro. These programs turn the computer into a dumb terminal. In this mode, whatever you type on the keyboard goes out the selected serial port (e.g. COM 1) and whatever comes in the serial port is displayed on the computer video display.

If the program HyperTerminal is used, the proper Com port (e.g. COM 1, COM 2, etc.) must be selected. In addition, a baud rate of 9600 with one stop bit and no parity must be selected.

Set the port up for direct connect and select "none " for handshaking.

After setting up communications with an external computer the WOS-120 will respond with the following startup message when power is turned on:

```
APS: S/Nxxxxxxxxx
Ver: 3.67 Bow Dip
```

In the above messages, the x's represent the unit serial number.

A Second method of communicating with the WOS-120 is to use the Windows program Sensor.exe described in section VIII of this manual.

## VI Computer Interface of the WOS-120

### 6.1 WOS-120 Internal Binary and Float Constants

The operating characteristics of the WOS-120 are controlled by the value of internal binary constants. The most important constants are:

Binary constant	Function
00	enables echoing when non zero
01	enables autosend upon power up when = 5A
02	enables sensor A/D count output when zero, calibrated sensor output (in Gauss and Gees) when =2 and angle output (roll, pitch, azimuth) when =3 (Alternate labels Roll: Pitch: Az: ) when =4
05	Controls sending of power up sign on message (default=0, message enabled)
08	Sets power on mode (e.g., 10 enables ASCII autosend upon power up)
09	Baud rate lock (must be =5A if any baud rate other than 9600 is used)
10	Sets baud rate
23	Sets up averaging of the output
35	Sets delay between transmissions in autosend mode

In order to change the internal system binary constants, a write enable command must first be issued. This is:

```
0l <CR>
```

Where 0 is zero, l is the letter L (lower case or capital) and <CR> is a carriage return.

When this command is sent to the WOS-120, it will respond with the reply

```
enabled!
```

To write byte constant 02=03, the command

```
0WC0203b03 <CR>
```

is issued. After receiving this and acting upon it, the WOS-120 will respond with the reply

done

The reading of internal constants can be accomplished by issuing the command

OSC02b <CR>

(0 Send Constant 02 binary). When this command is sent, the WOS-120 will respond by sending the value of constant 02. Wildcards are also recognized. The command OSC\*b will cause the WOS-120 to send the value of all internal binary constants.

In addition to internal byte constants, the WOS-120 also has a number of float constants. These are used to store the calibration data in the WOS-120 EEROM. These constants can be read by using the commands

OSC\*f <CR> for all constants

OSC06F <CR> for constant 06

The most important float constants are:

Float Constant	Description
04	X Magnetometer Offset
05	Y Magnetometer Offset
06	Z Magnetometer Offset
07	X Accelerometer Offset
08	Y Accelerometer Offset
09	Z Accelerometer Offset
10	X Magnetometer scale
11	Y Magnetometer scale
12	Z Magnetometer scale
13	X Accelerometer scale
14	Y Accelerometer scale
15	Z Accelerometer scale

Float constants 16 to 34 contain the system alignment coefficients. For example, float constant 17 contains data on the magnetometer X sensor alignment in the Y direction.

The WOS-120 sensor is temperature compensated to insure that the accuracy of the sensor is maintained over its intended temperature range. The temperature calibration data is stored in the system EEROM memory. This data can be accessed by using the following commands:

0st*b <CR>	Send temperature calibration table in binary format
0st*i <CR>	Send temperature calibration table in integer format
0st*f <CR>	Send temperature calibration table in floating format

## 6.2 ASCII Communication Mode

Communication is initiated when the external computer issues a command such as ASCII characters OSD. The characters OSD stand for O Send Data. When this command is issued, the WOS-120 will respond with a formatted output similar to the following:

```
MX:+0.20346 AX:-0.07852
MY:+0.23165 AY:+0.72136
MZ:+0.29525 AZ:+0.70226
T: +28.148
```

When internal binary constant 02=02, the WOS-120 is in sensor output mode and the above numbers represent the magnetometer X, Y and Z sensor outputs in Gauss and the accelerometer outputs in Gees. When binary byte 02=03, the WOS-120 is in angle mode and

The WOS-120 responses to a send data command with the following format,

```
MX: +35.17825      AX: +198.24032
MY: +90.14559     AY: +0.43326
MZ: +26.76792    AZ: +1.00101
T: +28.026        DA: 55.893
```

When binary byte 02=04, the WOS-120 is in angle mode and The WOS-120 responses to a send data command with the following format,

```
ROLL: +35.17825    MAGROLL: +198.24032
PITCH: +90.14559  MAG: +0.43326
HEAD: +26.76792   GRAV: +1.00101
TEMP: +28.026     DA: 55.893
```

where ROLL is gravity roll (or toolface), PITCH is inclination, HEAD is Azimuth, MAGROLL is magnetic roll, MAG is the total magnetic field, GRAV is the total gravity field , and DA is the magnetic field dip angle

### 6.3 Changing Data Output Mode

The WOS-120 can be configured to output in raw ADC counts, sensor values or angles. Data output format is determined by the value of binary constant 02 as follows:

Binary 02 value	Output data format
0x00	Raw A/D Counts (Uncalibrated)
0x02	Calibrated Sensor Outputs (Accelerometer and Magnetometers)
0x03	Angular Outputs (Roll, Inc, Azimuth)
0x04	Angular Outputs with Alternate labels

**Table 4. WOS-120 Operating Modes**

### 6.4 Changing the Baud Rate

The communications baud rate can be changed by using the following sequence:

1. Set binary constant 10 according to Table 1.
2. Set binary constant 09 to 0x5a.
3. Cycle power off and on.



The following commands illustrate setting the baud rate to 2400.

```
0l<CR>
0wc10b32<CR>
0l<CR>
0wc09b5a<CR>
```

When byte constant 09 is set to any value other than 0x5a, the system baud rate is 9600.

Baud Rate	Byte 10 Value
300	0x35
1200	0x33
2400	0x32
4800	0x31
9600	0x30
19,200	0x38
38,400	0x05

**Table 5. Baud Rate Settings**

**6.5 Enable the Echoing of Incoming Commands**

It is usually desirable to enable the WOS-120 to echo the command characters sent to it. To do this, the value of the binary constant 00 must be set to a non-zero value by issuing the following sequence of commands:

```
0l<CR>
0wc00b01<CR>
```

**6.6 Enter a serial number into the WOS-120 power up sign on message**

Up to 10 digits of serial number can be embedded into the unit sign on message by issuing the following commands:

```
0l<CR>
0tv=xxxxxxxxxx<CR>
```

**6.7 Turn off the WOS-120 power up sign on message**

The WOS-120 power on message can be turned off by setting binary constant 5 to a nonzero value. Resetting binary constant 5 to 0 will enable the turn on message.

**6.8 Configuring for Autosend**

To configure the WOS-120 for autosend, binary constant 01 must to be set to 0x5a and binary constant 08 needs to be set in accordance with table 2.

<b>AUTOSEND MODE</b>	<b>Binary Byte 08 Value</b>
Send ASCII data continuously on power up	0x10
Send Binary Data Continuously on power up	0x11

**Table 6. Autosend Modes**

## 6.9 Averaging and filtering of WOS-120 Output Data

Averaging of the acquired data can be enabled by setting binary constant 23 according to the table shown below. The response times shown are for a full scale change in a sensor output e.g. a change from 0 gee to 1.0gee for an accelerometer or a change from 0 Gauss to 0.5 Gauss for a magnetometer.

Binary constant 23 value	Number of averages n	Time to reach 90% of final value (seconds)	Time to reach to within 0.001 gee or 0.001 Gauss of final value (seconds)
2	2	.94	1.87
4	4	1.87	3.75
8	8	3.25	7.5
10	16	7.5	15
20	32	15	30
40	64	30	60

The above averaging times assume that the A to D low pass filter frequency (see discussion of the feature in the next paragraph) is set to 30 Hz. The averaging times are proportional to this frequency so for instance if the low pass filter frequency is set to 60 Hz and the number of averages is set to 8 then the time to reach 90% of the final output is 1.62 seconds. Each data output of the WOS-120 is a running average of the previous n data acquisitions. When a new data point is acquired, a new average is computed by dropping the oldest data point from the average and adding the new data point.

The maximum average is 64 samples. This average feature is useful for high vibration environments when the user knows the attitude is changing slowly, but vibration produces a large amount of noise in the WOS-120 output.

## 6.10 Single Packet Binary Communication Modes

In addition to an ASCII communication mode, the WOS-120 also has several binary communications modes:

Single data packet binary communications are initiated by an external computer by the issuance of a single byte command, e.g., ASCII 128. On some computers, these commands can be sent from a terminal emulator program by holding the control key down and typing the command number on the number pad on the right side of the keyboard.

### **Command**

### **Command Definition**

ASCII 128

send sensor data in binary format



### 6.11 Autosend Binary Communication Modes

Autosend binary protocol results in the transmission of data packets with the same structure as that described above for the response to binary command 128. However, when in autosend mode, data packets are automatically and continuously sent out after power is applied. Standard autosend binary mode is selected by setting up the system binary constants as follows:

- binary constant 08=11 selects autosend continuously
- binary constant 01=5a autosend enable
- binary constant 35=10 inserts a small delay between data packets (optional)

### 6.12 Comparison of ASCII and standard binary data structures

Consider the following data transmissions from a WOS-120, one in ASCII mode and one in Binary mode:

**ASCII:**  
 MX: +0.3598 AX: +0.2740  
 MY: -0.2490 AY: -0.3510  
 MZ: +0.0145 AZ: +0.4711  
 TEMP: 21.74

**BINARY:**  
 SOT MX AX MY AY MZ AZ TEMP ANA1 ST CS EOT  
 10 0E0E 0AB4 F646 F24A 0091 1267 087E 0320 80 05 7FFF

The two data transmissions transmit the same data content, but the ASCII data transmission uses about 8 times more bytes than the binary transmission. The binary data packet is a much more efficient method of sending data. In addition, binary data is often much easier to parse than ASCII data.

WOS-120 binary data packets will always start with a header byte 0x10 and end with two bytes 0x7FFF. The data is always sent most significant byte (MSB) first, then least significant byte (LSB). Angle, sensor and temperature data is sent as 16-bit signed integers.

The following table shows the definition of the binary data packet for sensor mode and angle mode.

Byte	Sensor mode	Angle Mode
01	SOT = 0x10	SOT = 0x10
02	MX MSB	Roll MSB
03	MX LSB	Roll LSB
04	AX MSB	Mag Roll MSB
05	AX LSB	Mag Roll LSB
06	MY MSB	Inclination MSB
07	MY LSB	Inclination LSB
08	AY MSB	Mag Total MSB
09	AY LSB	Mag Total LSB
10	MZ MSB	Azimuth MSB
11	MZ LSB	Azimuth LSB
12	AZ MSB	Total Accel MSB
13	AZ LSB	Total Accel LSB
14	Temperature MSB	Temperature MSB

15	Temperature LSB	Temperature LSB
16	Analog MSB	Analog MSB
17	Analog LSB	Analog LSB
18	ST	ST
19	Checksum	Checksum
20	EOT MSB = 0x7F	EOT MSB = 0x7F
21	EOT LSB = 0xFF	EOT LSB = 0xFF

**Table 7. Binary Data Packets**

Magnetometer and accelerometer sensor values can be decoded by first converting to decimal and then dividing by 10,000. For instance, in the above transmission:

$$\begin{aligned} MX &= 0E0E = 3598/10,000 = 0.3598 \text{ Gauss} \\ MY &= F646 = -2490/10,000 = -0.2490 \text{ Gauss} \\ AX &= 0AB4 = 2740/10,000 = 0.2740 \text{ Gee} \end{aligned}$$

Angles are decoded by converting to a decimal value and then dividing by 100. If the above data packet was data sent in angle mode, you would have:

$$\begin{aligned} MX &= 0E0E = 3598/100 = 35.98 \text{ }^\circ \text{ Roll} \\ AX &= 0AB4 = 2740/100 = 27.40 \text{ }^\circ \text{ Magnetic Roll} \end{aligned}$$

Total magnetic field and total acceleration are decoded using the same conversion as the normal sensor values (divide by 10,000.)

Temperature is decoded by converting to decimal and dividing by 100

$$TEMP = 087E = 2174/100 = 21.74^\circ\text{C}$$

The ANALOG MSB and ANALOG LSB transmission represents the WOS-120 voltage. This voltage can be decoded by dividing by 100:

$$ANA1 = 320=800/100 = 8.0 \text{ (VDC)}$$

The ST byte is a status byte that is unused in the WOS-120. The value of this byte will have no meaning.

The CS byte is a checksum. The checksum is calculated by summing all of the bytes in the transmission before the CS byte excluding the SOT and status (ST) characters. For the above transmission the checksum is calculated as follows:

$$CS = 0E+0E+0A+B4+F6+46+F2+4A+00+91+12+67+08+7E+03+20 = 0505$$

The checksum is the lower byte of the sum, or 05.

**6.13 Changing the WOS-120 Coordinate System (Optional Feature not present in all WOS-120s)**

The directions of the X, Y and Z axes of the WOS-120 can be changed by selecting the values of binary constants 47-52 in accordance with the following list:

Binary constant	Description
47	Controls Magnetometer X
48	Controls Magnetometer Y
49	Controls Magnetometer Z
51	Controls Accelerometer X
50	Controls Accelerometer Y
52	Controls Accelerometer Z

The axes can be selected by setting the appropriate binary constant as follows:

Magnetometer X=0x00  
 Magnetometer Y=0x01  
 Magnetometer Z=0x02  
 -(Magnetometer X)=0x80  
 -(Magnetometer X)=0x81  
 -(Magnetometer X)=0x82

Accelerometer X=0x10  
 Accelerometer X=0x11  
 Accelerometer X=0x12  
 -(Accelerometer X)=0x90  
 -(Accelerometer X)=0x90  
 -(Accelerometer X)=0x90

The default value of the constants 47-52 selects the standard APS coordinate system shown in Fig. 2. The default values of the axis selection constants are:

Binary constant	Description
47	0x00
48	0x01
49	0x02
50	0x10
51	0x11
52	0x12

A coordinate system in which the X and Z axes have been interchanged can be selected by using the following constants:

Binary constant	Description
47	0x02
48	0x01
49	0x00
50	0x12
51	0x11

51  
52

0x10

For this coordinate system, the system Z axis is oriented parallel to the long axis of the WOS-120. To reverse the direction of the magnetometer Z axis in the above coordinate system change the value of binary constant 49 from 0x00 to 0x80

## VII Definition and Method of Calculation of the Orientation Sensor Angles

This section provides a definition of the system orientation angles and describes how to calculate them from accelerometer and magnetometer sensor outputs.

### 7.1 Sensor Based Coordinate System

The coordinate system of the WOS-120 System is defined in Fig. 2. The accelerometer and magnetometer coordinate systems are both aligned with the physical package coordinate system. For the magnetometer sensors, a positive output voltage will result if the sensor is pointed north. For the accelerometers, a positive voltage will result if the sensors are pointed down.

### 7.2 Definition of Orientation Angles

Azimuth is defined as the angle measured from magnetic north (clockwise from above) to the projection of the X axis on the horizontal plane.

Inclination is the angle that the X axis makes with the down direction and is 0° when the X axis is down and 90° when the X axis is horizontal.

Roll or gravity tool face is defined as the angle of counterclockwise rotation about the X axis (looking in the positive X axis direction) required to zero the Y axis accelerometer output and position the Z axis accelerometer so that its output polarity is positive.

Magnetic roll or magnetic toolface is defined as the angle of counterclockwise rotation about the X axis (looking in the positive X axis direction) required to zero the Y axis magnetometer output and position the Z axis magnetometer so that its output polarity is negative.

Magnetic roll is useful in defining the WOS-120's orientation when inclination is near vertical, generally less than 5°. In this situation,  $g_y$  and  $g_z$  are near zero and roll and azimuth calculations become less accurate.

### 7.3 Definitions

The following sections describe equations for determining the WOS-120 orientation angles. These equations make use of the following definitions:

$g_x$  accelerometer x axis output  
 $g_y$  accelerometer y axis output  
 $g_z$  accelerometer z axis output  
 $H_x$  magnetometer x axis output

$H_y$  magnetometer y axis output  
 $H_z$  magnetometer z axis output

#### 7.4 Calculation of Roll and Magnetic Roll

The roll angle,  $\theta$ , is determined by using the following equations ( $0 \leq \theta \leq 2\pi$ )

$$\cos \theta = \frac{g_z}{(g_y^2 + g_z^2)^{1/2}}$$

$$\sin \theta = \frac{g_y}{(g_y^2 + g_z^2)^{1/2}}$$

$$\tan \theta = \frac{g_y}{g_z}$$

Roll is  $0^\circ$  when  $g_y = 0$  and  $g_z > 0$ . Roll is  $2\pi$  radians when  $g_y = 0$  and  $g_z < 0$ . When the x axis is near vertical (pitch  $< 5^\circ$ ), the quantities  $g_y$  and  $g_z$  become very small and the above expressions yield a less accurate value of  $\theta$ . In this situation, magnetic roll is often used to determine the angular orientation of the WOS-120 about the longitudinal (X) axis. Magnetic roll,  $\theta_m$ , is given by the following ( $0 \leq \theta \leq 2\pi$ )

$$\sin \theta_m = \frac{-H_y}{(H_y^2 + H_z^2)^{1/2}}$$

$$\cos \theta_m = \frac{-H_z}{(H_y^2 + H_z^2)^{1/2}}$$

$$\tan \theta_m = \frac{H_y}{H_z}$$

#### 7.5 Calculation of inclination

Inclination,  $\varepsilon$ , is determined from the following equations ( $0 \leq \varepsilon \leq 2\pi$ )

$$\cos \varepsilon = \frac{g_x}{g}$$

$$\sin \varepsilon = \frac{(g_y^2 + g_z^2)^{1/2}}{g}$$

$$\tan \varepsilon = \frac{(g_y^2 + g_z^2)^{1/2}}{g_x}$$



$$g_x$$

$$\text{where } g = (g_x^2 + g_y^2 + g_z^2)^{1/2}$$

Inclination is 0 when the WOS-120 X axis is pointed down and 90° when horizontal.

## 7.6 Magnetic Heading (Azimuth)

We first give expressions for the magnetic field in a horizontal reference defined by X1, Y1 and Z1, where X1 is aligned with the projection of the WOS-120 X axis in the horizontal plane and Z1 is down.

$$H_{x1} = \frac{H_x(g_y^2 + g_z^2) - H_y g_y g_x - H_z g_x g_z}{g(g_y^2 + g_z^2)^{1/2}}$$

$$H_{y1} = \frac{H_y g_z - H_z g_y}{(g_y^2 + g_z^2)^{1/2}}$$

$$H_{z1} = \frac{H_x g_x + H_y g_y + H_z g_z}{g}$$

Magnetic heading,  $\vartheta$ , is then given by ( $0 \leq \vartheta \leq 2\pi$ )

$$\cos \vartheta = \frac{H_{x1}}{(H_{x1}^2 + H_{y1}^2)^{1/2}}$$

$$\sin \vartheta = \frac{-H_{y1}}{(H_{x1}^2 + H_{y1}^2)^{1/2}}$$

$$\tan \vartheta = \frac{-H_{y1}}{H_{x1}} = \frac{(H_z g_y - H_y g_z) g}{H_x(g_y^2 + g_z^2) - H_y g_x g_y - H_z g_x g_z}$$

Magnetic heading is 0 when the WOS-120 X axis points North and  $\pi/2$  radians when it points East.

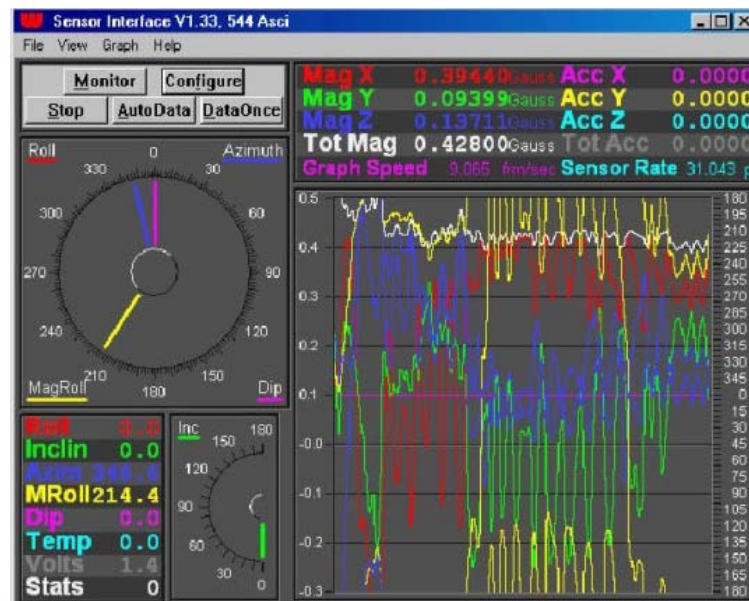
## VIII. Windows Software for the Model WOS-120 Orientation Sensor

The purpose of the Sensor interface program is to provide a graphics interface for the WOS-120 system and allow the user to configure the system.

The software enables the WOS-120 to be programmed to for ASCII or BINARY transfer mode and for corrected or non-corrected data. Log files of sensor data can be created. A scrolling graph of the digital data and graphical indicators of the angular data are displayed to the operator.

Install the Sensor software by using the following procedure:

1. Insert the CD-ROM containing the Sensor software into the CD-ROM drive.
2. Click on "My Computer" and then click on the disk drive the software disk was inserted into.
3. Left click and hold on the Sensor icon and drag it to the desktop. Release mouse button. The software icon should now be on your desktop and the software ready to use.



## MODEL WOS-120 MAIN DISPLAY USING SENSOR

### SOFTWARE

The figure above shows the main display of the Sensor Interface Program. The upper left corner of the main window contains the command buttons. The Monitor button brings up the monitor window and the Configure button brings up the configuration window. The Stop button issues the command to the sensor to stop sending data. The Auto button issues the command to the sensor to send data repeatedly. The Once button issues the command to send the data one time.

In the View menu, each check mark before Magnetometer Min/Max or AC/DC Magnetic enables or disables the feature from appearing on the screen. In the example display, the Magnetometer Min/Max is enabled.

In the Graph menu, each check mark before Magnetic X, Y, Z, T, Mag Roll and Azimuth labels enables or disables the item to be scrolled on the graph. The color of the item on the graph matches the color of the text in the numeric display windows.

The minimum and maximum values are tracked and displayed in the upper right corner window. The values can be reset back to zero by pressing the Reset button.

The number of packets per second the sensor is receiving is displayed as Sensor Rate. This value is continually being updated and sampled.

When the Configure button is pressed, the following window is displayed:

## Configure

The screenshot shows the 'Configure' dialog box with the following settings:

- Sensor Settings:** Graph Speed (frm/sec) is 10, Scale Refresh Time is 30, and Long Term Avr. AC/DC is 100.
- Serial Port:** Com 1 and 9600.
- Sensor:** 1540, Ascii, and Corrected.
- Log File:** C:\Projects\APS\Sensor\Debug\SensorLog.T; Write Log File and Write Time Stamp are unchecked.
- Special Settings:** Binary Format is 16 Bit Fixed Point.

Buttons at the bottom: Cancel and Save.

### SENSOR CONFIGURATION WINDOW

The Graph Speed represents the maximum scrolling speed of the graph on the main window in frames per second. The PC operating system limits the maximum scrolling speed. The Scale Refresh Time sets the time at which the auto-scaling routine can decrease the scale factors on the main scrolling window. When the scrolling window scale maximum output is exceeded, it is automatically increased. To decrease the scale, Scale Refresh Timer is used. The Check Sum box allows the sensor to send a check sum with each data packet from the sensor. The Long-Term Avg. AC/DC value is the number of samples of AC and DC values that are collected in order to create the AC and DC values display on the main window.

The computer serial port to be used with the WOS-120 may be set from Com 1 to Com 8. The default baud rate is 9600 baud. Other baud rates may be selected using this panel.

To use the WOS-120, the operator selects the WOS-120 in the top Sensor window. In the next window, below, the option for ASCII or Binary transfer may be entered. ASCII transfers may easily be viewed from the monitor window. Binary transfers are always faster. Raw data is expressed in A/D counts. Corrected data is in Gauss and has been corrected for physical misalignments, scale factors and offsets.

To save data output from the WOS-120, the operator may enter a logging file name. This file will capture all data sent to the program from the sensor. The type of data logged is set in the menu in the Monitor Window and can be either ASCII for Logging or Hex for Logging.

The monitor sensor window allows the operator to view the data being sent from the sensor and allows the operator to send commands to the sensor.

File	Mode	Mag Z	Mag T	Acc X	Acc Y	Acc Z	Acc T	Roll	Mag Roll	Incline	Azimuth	Dip
0.0	Ascii	0.30456,	0.45032,	-0.05963,	0.02551,	-0.15551,	0.32992,	170.684,	227.286,	0.301,	98.346,	-32.723
0.0	Hex	0.30456,	0.45032,	-0.05981,	0.32989,	-0.15545,	0.16848,	170.724,	0.305,	110.793,	98.406,	0.450
0.0	Ascii for Logging	0.30456,	0.45034,	-0.05957,	0.03472,	-0.15545,	0.16841,	170.702,	227.289,	110.715,	98.346,	-32.739
0.0	Hex for Logging	0.30459,	0.45039,	-0.05963,	0.02539,	-0.15545,	0.16842,	170.724,	227.289,	110.736,	0.305,	-32.756
0.0	Hex and Ascii	0.30456,	0.04503,	-0.05969,	0.02539,	-0.15545,	0.16844,	0.330,	227.289,	110.755,	98.377,	-32.754
0.0	Decoded	0.30456,	0.45051,	0.03046,	0.02545,	-0.15545,	0.16851,	0.450,	227.307,	110.811,	-98.378,	-32.715
0.03506,	0.33020,	0.03500,	0.45058,	-0.05987,	0.02551,	-0.15545,	0.33013,	170.681,	227.313,	110.810,	98.341,	-32.698
0.03503,	0.33026,	0.03505,	0.45060,	-0.05993,	0.02557,	-0.15539,	0.33020,	170.656,	227.321,	110.835,	98.346,	-32.662

**MONITOR SENSOR DISPLAY MODES**

The monitor window (see figure above) has a number of display modes. They are ASCII, Hex, ASCII for Logging, Hex for Logging, Hex and ASCII, and Decoded. In ASCII mode (see figure below), the monitor window acts like a simple ASCII terminal. In Hex mode (see figure below), each ASCII character received is converted to the hexadecimal value that it represents, followed by a space. For example, the ASCII character 'A' would be printed as '41', which is its hexadecimal value. ASCII for Logging and Hex for Logging are designed to be used with file logging mode. They are formatted with a <CR><LF> at the end of each line so that then can be written into a Logging file. Hex and ASCII is a mixed display with hexadecimal data on the left and the same ASCII data on the right. Decoded is a mode where only the processed data values are displayed.

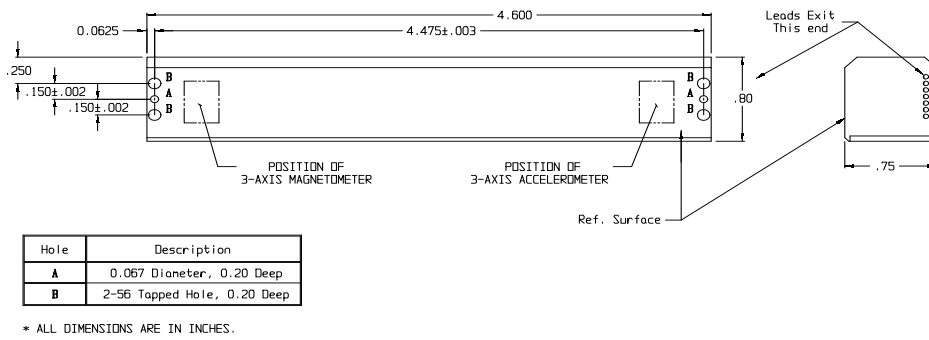
**MONITOR SENSOR WINDOW FOR CORRECTED ASCII MODE**

Note that sensor commands may be directly entered from the monitor window.

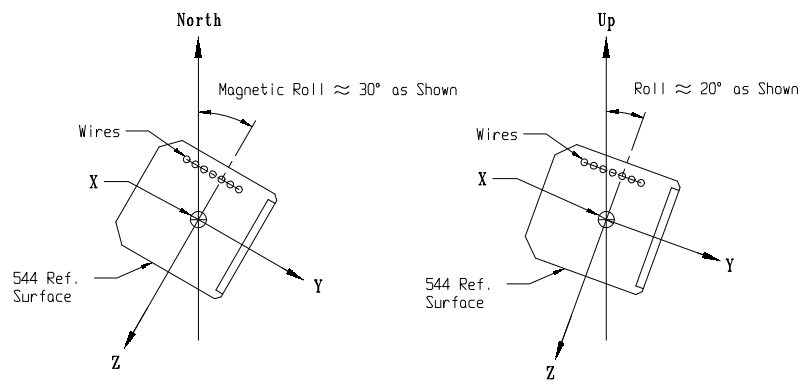
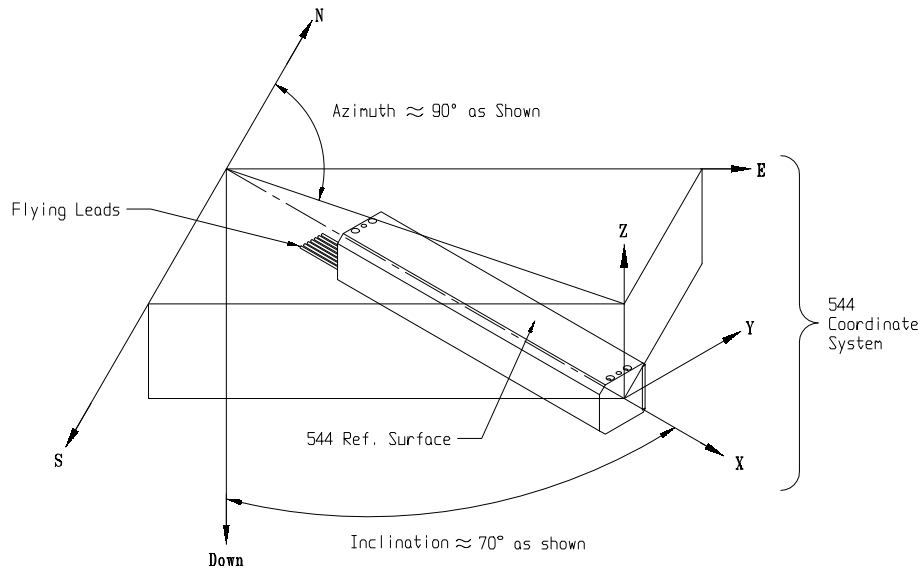
The monitor window (see Fig. 3) has a number of display modes. They are ASCII, Hex, ASCII for Logging, Hex for Logging, Hex and ASCII, and Decoded. In ASCII mode (see Fig. 6), the monitor window acts like a simple ASCII terminal. In Hex mode (see Fig. 4), each ASCII character received is converted to the hexadecimal value that it represents, followed by a space. For example, the ASCII character 'A' would be printed as '41', which is its hexadecimal value. ASCII for Logging and Hex for Logging are designed to be used with file logging mode. They are formatted with a <CR><LF> at the end of each line so that then can be written into a Logging file. Hex and ASCII is a mixed display with hexadecimal data on the left and the same ASCII data on the right. Decoded is a mode where only the processed data values are displayed.

**MONITOR SENSOR WINDOW FOR CORRECTED HEX MODE**

**Fig. 1. WOS-120 Mechanical Diagram**



**Fig. 2. WOS-120 Coordinate System and Orientation Angles.**



**Appendix A. Azimuth Accuracy Estimates**

### **A.1 Orientation Sensor Azimuth Accuracy as a Function of the Earth's Magnetic Field Dip Angle**

Orientation sensors measure the horizontal component of the Earth's magnetic field, using accelerometers, to determine vertical. At high magnetic field dip angles the vertical component of the magnetic field becomes much larger than the horizontal component. This has the consequence that small uncertainties in the direction of down, or small misalignments of the sensors, can result in large errors in azimuth. At a dip angle of 90 degrees, there is no horizontal component, and an orientation sensor based upon the measurement of acceleration and magnetic field will no longer be able to determine azimuth. The following table gives expected errors in azimuth due to sensor errors of 1mg for accelerometers and 0.5mG for the magnetometers. These errors could arise from measurement inaccuracy or sensor misalignment. It is assumed that the pitch is in the middle range  $-20$  to  $20$  degrees. The errors were nearly independent of azimuth and roll. Accuracy may be less than shown for small dip angles, due to imperfect calibration, and other systematic errors, but will be less than 0.3 degrees. Azimuth accuracy also degrades as the inclination approaches 90 degrees, but this is a coordinate system singularity and does not reflect any underlying error in orientation.

Dip angle (degrees)	Azimuth Error (degrees)rms
89	5
87.5	2
85	1
80	0.5
70	0.26
67	0.23
60	0.175
0	0.072

### **A.2 Orientation Sensor Azimuth Accuracy as a function of the Inclination**

Azimuth accuracy becomes poor as one approaches inclination of 0 degrees (vertical). (Refer to figure 2 for a definition of the WOS-120 coordinate definition.) This is not the result of a real degradation of sensor performance, but is an artifact of the coordinate system, which is singular at an inclination of 0 degrees. The following graph shows the uncertainties in azimuth, as a function of inclination. At small inclination angles, the error is approximately  $1/\text{Inclination}$ , while at larger angles, error will be dominated more by systematic errors, such as imperfect calibration. It is assumed for this calculation that the accelerometers are accurate to 0.001g and the magnetometers are accurate to 0.0005 Gauss. The dip angle is assumed to be 60 degrees. When the system is to be used at small inclination angles, the user can use the magnetic roll calculations shown in 11.4 as an alternative to the azimuth output.

