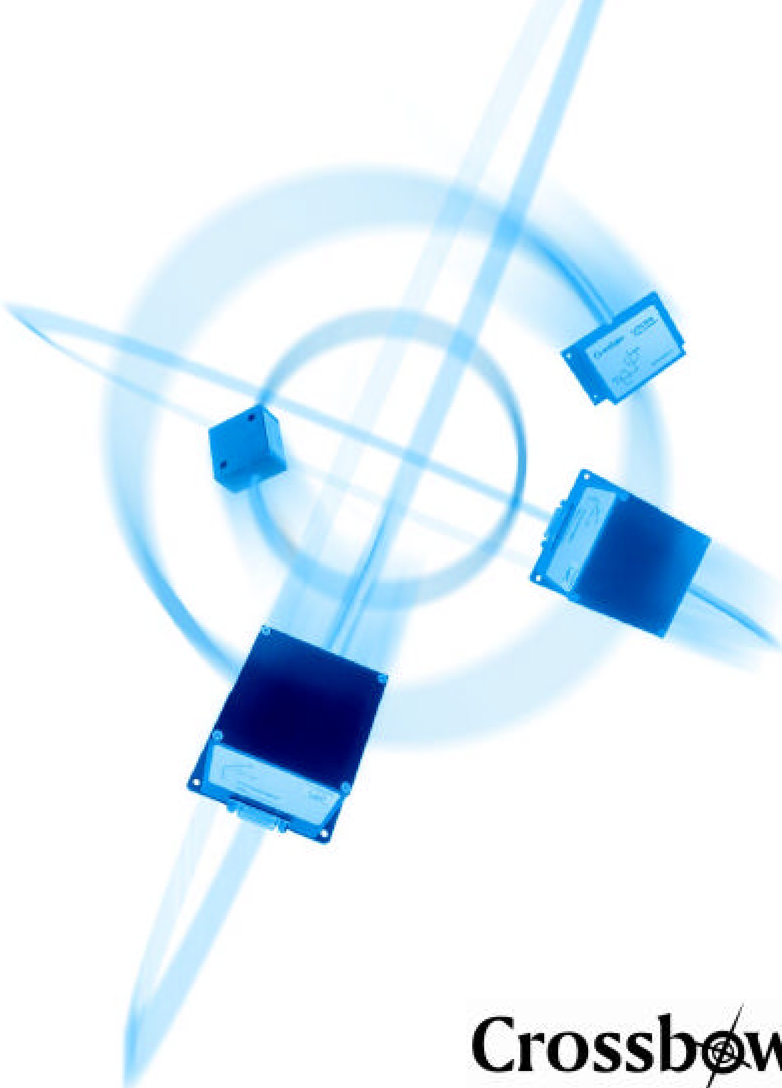
CXM543 User's Manual

High Speed Orientation Sensor

Revision 1.2, October 2001

PN 6001-0015



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About this Manual

The following annotations have been used to provide additional information.

🔈 NOTE

Note provides additional information about the topic.

☑ EXAMPLE

Examples are given throughout the manual to help the reader understand the terminology.

🏳 IMPORTANT

This symbol defines items that have significant meaning to the user

💣 WARNING

The user should pay particular attention to this symbol. It means there is a chance that physical harm could happen to either the person or the equipment.

The following paragraph heading formatting is used in this manual:

1 Heading 1

1.1 Heading 2

1.1.1 Heading 3

Normal

1 Description Of The System

The model CXM543 is a high-speed digital output orientation measuring system. It can transmit the orientation angles (roll, pitch and azimuth) of a body to which it is mounted at a rate of 25 samples/second. The basic accuracy of the CXM543 is ±0.5°. Data transmissions are made over a bi-directional serial port using either RS-232 or TTL levels. The baud rate and sampling rate are user programmable.

The CXM543 measures orientation by employing a 3-axes accelerometer to measure roll and pitch and a three-axis magnetometer to determine azimuth. The CXM543 can be configured to run in two modes viz. Vector and Angle. In vector mode, the unit transmits the accelerometer and magnetometer sensor outputs and transmission speeds up to 250 samples/sec are possible. In angle mode, the CXM543 transmits the system roll, pitch and azimuth angles.

The CXM543 can be used in either a command mode or autosend mode. In the command mode, the CXM543 responds to commands to transmit data issued by an external computer. In autosend mode, the CXM543 commences sending data as soon as power is applied to the unit.

The CXM543 can be supplied with an optional connector box, which allows easy powering and connection to an external computer.

2 System Specifications

Accuracy	roll, pitch	±1°
	azimuth	±1.5°
Range	roll	0 to 360°
	pitch (inclination)	0 to 180°
	azimuth	0 to 360°
Data levels		RS232 and TTL
Data output rate (Angle mode)		100 Hz
Power		100 mA @ +6 to +15 VDC
A to D		16 bit Sigma Delta
Baud rate (user selectable)		300, 1200, 2400, 4800, 9600, 19200, 38400, 72800
Temperature range		0 to 50°C
Size		2.75"W x 4.08"L x 1.13"H 7 cm x 10.4 cm x 2.9 cm
Connector		9 pin nonmagnetic "D" (female)
Sensor axis alignment to case		±0.5°
Linearity		±0.1% full scale

3 Electrical and Mechanical Interface

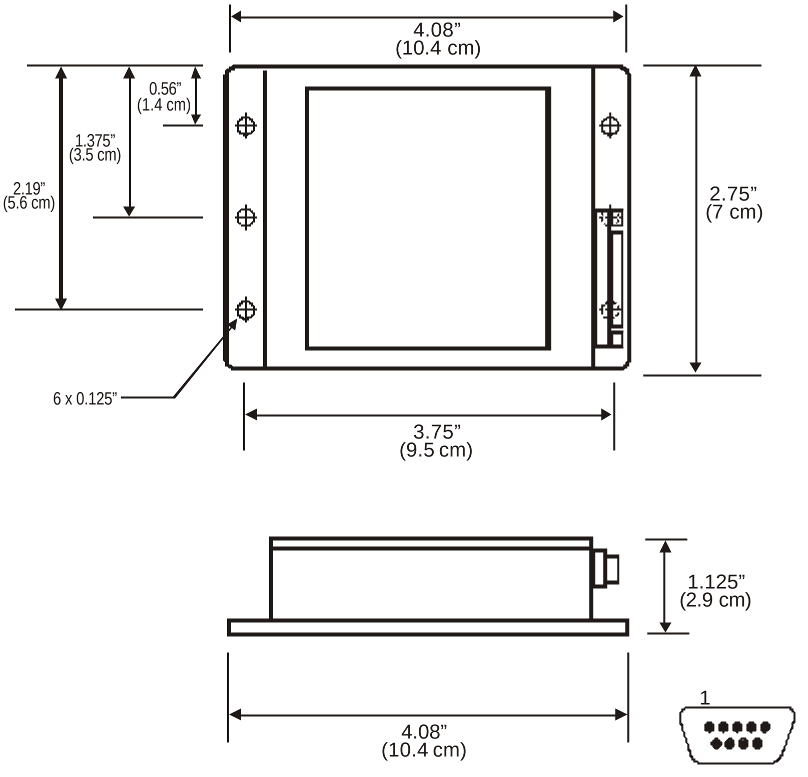
The CXM543 is powered from a single input voltage that can range between +6 V and +15 V. Current consumption is 100 mA. Two serial interfaces are present; one that uses RS-232 levels and one that uses TTL levels. The baud rate is user programmable and can be set at the following values: 300, 1200, 2400, 4800, 9600, 19200, 38400, and 72800. The data words employ 8 bits with one stop bit and no parity.

A female 9 pin D connector is used to provide an electrical interface to the CXM543 system. The Pin out of this connector is as follows:

Pin	Function
1	not used
2	RS 232 out
3	RS 232 in
4	not used
5	ground
6	TTL serial out
7	TTL serial in
8	configure
9	+ V in (+7.5 V to +15 V)

A drawing showing the dimensions and mounting hole design of the CXM543 is shown below in Fig. 1.

Fig. 1 CXM543 High Speed Orientation Sensor



4 System Startup and Checkout

4.1 Startup Using a Terminal Emulator Program

Connect the CXM543 to the connection box using the supplied ribbon cable (use 9-pin male on connection box). Connect a cable from a serial port on a PC to the connection box (use 9-pin female on connection box). Select the AUTO option on the connection box switch. This connects pin 1 (CD) of the 9 pin serial interface connector to the configure port on the CXM543. Note that on the 9-pin computer connector, pins 1, 4 and 6 are shorted and pins 7 and 8 are shorted). Connect a power supply (+6 V to +15 V) to the red (positive) and black banana plug on the connection box.

Alternatively, according to the I/O pin functions described in Chapter 3, use the RS-232 interface when connecting to a PC COM port.

Start up a terminal emulator program on the PC, e.g. Windows HyperTerminal, PC Plus, etc. Configure the terminal emulator program for direct connect to an available COM port and select the baud rate 9600 with one stop bit and no parity. On the electrical interface to the system, ground pin 8; this will put the system in configure mode and assure that the baud rate is 9600 baud. If a connection box is used, select the "config" option on the connector box switch.

Apply power to the system and check to see that the unit transmits a start up message:

APS 543 V1.12 Config. Mode

The system can now be configured for operation in various modes as described in Appendix A by issuing commands over the serial interface.

After configuring the CXM543 system, ungrounded pin 8. If a connector box is used, select the "Run" option in the connector box switch. In run mode, the CXM543 sign on message sent at power on is

APS 543 V1.12.

In run mode, most of the CXM543 parameters, e.g. baud rate, sample rate, etc. can be set by the user. The main differences between the system operation in run and configure mode are as follows:

1. The CXM543 can only be calibrated in config mode (by issuing the l command). The unit is always factory calibrated and recalibration by the user is not normally required.
2. The unit always starts in the (known) baud rate of 9600 baud.
3. The unit always starts in command mode (as opposed to autosend mode).
4. The data output format is selected to be A to D count mode.

The main functions of the config mode are to assure that the CXM543 communicates using a known baud rate (9600) and to enable calibration of the system.

WARNING

Always operate the CXM543 run mode (when using a terminal program) unless the baud rate setting of the unit is unknown or calibration of the unit is required. The output of the CXM543 in the calibrated mode (M=C) is only valid in the run and auto modes.

4.2 System Checkout

After the CXM543 is operational and communicating with a computer, its proper operation can be checked out by placing it on a flat, level, non-magnetic surface. The non-magnetic nature of the surface is necessary to prevent magnetic field errors, which will reduce the accuracy of the azimuth reading. The roll and pitch readings are not affected by the magnetic field present so a flat level surface, even if it is magnetic, can be used to check roll and pitch.

Place the CXM543 on a level surface with the mounting flange down. Rotate the system so that the connector is pointed North (use a compass to accomplish this). Issue the following commands to the CXM543:

M = T <CR>

M = A <CR>

where, <CR> is a carriage return.

These commands put the CXM543 in text (as opposed to binary) mode and angle (as opposed to vector) mode. Set the transmission speed to a slow value (about once per sec.) by issuing the command:

F1 <CR>

Next, put the CXM543 in autosend data mode by issuing the command:

A <CR>

The CXM543 will commence to send data in the format

<Roll> <Pitch> <Azimuth> <Total gravity field> <Total magnetic field>

Verify that the roll angle is near 0°, pitch is near 90° and azimuth is near 0°. Verify that the total gravity field is near 1.00 and the total magnetic field is between 0.4 and .6. The magnetic field amplitude (in Gauss) varies around the world between these values. Next, orient the CXM543 in various different known orientations and check the accuracy of the measured data.

Stop the data transmission and change to sensor (vector) output mode by issuing the commands

S <CR>

M = V

A <CR>

The sensor data is transmitted with the format:

<AX> <AY> <AZ> <MX> <MY> <MX>

where, AX is the X accelerometer output, MX is the X magnetometer output, etc. All accelerometer outputs should range between +1 (down) and –1 (up). The magnetometer outputs should range from about –0.45 Gauss to +0.45 Gauss.

Transmission speed can be changed from among 9 different values by issuing commands of the format

f#

where, # can be set between 1 (slowest speed) and 9 (highest speed). Different filter values corresponding to the f# command are as listed in the table below. Different filter values and corresponding data rates, resolution and frequency are provided in Appendix B.

Command	Filter Value
f1	8000
f2	4000
f3	2000
f4	1000
f5	2002
f6	1002
f7	802
f8	402
f9	282

5 CXM543 Configuration Options and Data Output Formats

The user can configure the CXM543 system in the following ways:

1. Mode
2. Autosend or command
3. Baud rate
4. Pacing

The mode settings are used to change the format of the data output. The user can select the data output to be raw A/D counts (M=R) calibrated sensor (vector) output (M=V) or angles (M=A). The serial output format can be selected to be text (M=T) or binary (M=B). The user can also choose whether to append a checksum to the transmission (M=E) or omit this (M=N).

Some examples of different data output formats and the commands used to create them follow:

Commands to set up	**Data Formats**
M=T	Raw data in a text hex format without a checksum:
M=R	AX AY AZ MX MY MZ
M=N	1234 5678 9ABC 1234 5678 9ABC<CR><LF>
	The data values are encoded as four digit hex values separated from each other with a single space. The last digit of the Z data is followed by a carriage and a line feed.
M=T	Raw data in a text hex format with a checksum (cs):
M=R	AX AY AZ MX MY MZ cs
M=E	1234 5678 9ABC 1234 5678 9ABC 4E <CR><LF>
	This just like the last example except for an addition of a space and a two Hex digit checksum in between the last digit of Z and the carriage return. The checksum is

	composed of the sum of all of the digits in all the data values.
M=T	Corrected data in a text decimal format without a checksum:
M=V	AX AY AZ MX MY MZ
M=N	0.23456 0.78900 0.23997 0.98765 0.53210 0.12345 <CR><LF>
	The X,Y,& Z values are encoded as decimal values in Gauss. Each is separated from the next with a single space. The last digit of the Z data is followed by a carriage return and a line feed.
M=T	Corrected angle data in a decimal format without a checksum
M=A	Roll Pitch Azimuth Tot. Acc Tot. Mag
M=N	100.00 190.00 180.00 1.00000 0.49543 <CR> <LF>
	The angle data is in degrees. Each value is displayed as a 3 digits point 2 digits value (XXX.XX) separated by a space from the next value. The total . field is displayed in "G"s and the total magnetic field is displayed in Gauss.
M=T	Corrected angle data in a decimal format with a checksum
M=A	Roll Pitch Azimuth Tot.Acc Tot. Mag CS
M=E	100.70 190.05 1.12 1.00000 0.49543 35<CR> <LF>
	The angle data is in degrees. Each value is displayed as a 3 digits point 2 digits value (XXX.XX) separated by a space from the next value. The total . field is displayed in Gs and the total Mag field is displayed in Gauss. This is followed by a two hex digit check sum.
M=B	Raw Data in a binary format without a checksum:
M=R	AX AY AZ MX MY MZ CS
M=N	12 34 56 78 9A 98 76 54 32 21 FE BC 5A <CR> <LF>
	The data values are each encoded as a two-byte value. The Z magnetometer data is followed by a Check Sum and that is followed by a constant synchronization byte (SB) of 5A.
M=B	Raw data in a binary format with a checksum:
M=R	AX AY AZ MX MY MZ CS
M=N	12 34 56 78 9A 98 76 54 32 21 FE BC FF 5A
	<CR> <LF>

The data values are encoded as two byte values followed by a checksum consisting of the lower eight bits of the sum of the bytes comprising all the data. This is followed by a synchronization byte of 5A.

IMPORTANT

When in Binary mode, the X, Y & Z values for acceleration and magnetometer data are encoded as a signed integer, 2's complement, with a conversion factor of

$$A_x \ or \ A_y \ or \ A_z = \frac{(MSB * 256 + LSB)}{2^{14}} \text{ in G and}$$

$$M_x \ or \ M_y \ or \ M_z = \frac{(MSB * 256 + LSB)}{2^{15}} \text{ in Gauss}$$

The pitch, roll and heading are calculated as follows:

$$Pitch = \tan^{-1} \frac{\sqrt{A_y^2 + A_z^2}}{A_x}$$

$$Roll = \tan^{-1} \frac{A_y}{A_z}$$

$$Heading = \tan^{-1} \left[\frac{\sqrt{A_x^2 + A_y^2 + A_z^2}\,(M_z A_y - M_y A_z)}{M_x (A_y^2 + A_z^2) - M_y A_y A_x - M_z A_z A_x} \right]$$

This is followed by a checksum consisting of the lower eight bits of the sum of the bytes comprising the X, Y & Z Data for accelerometers and magnetometers and calculated as,

$$Checksum = \left| \frac{sum \ of \ all \ bytes \ except \ checksum \ and \ 5A}{256} \right|$$

This is followed by a synchronization byte of 5 A, which represents the end of the data packet.

To determine the mode of a CXM543, issue the command M?

The autosend command (A) enables data to be sent continuously upon power on. The output rate of the sent data is set by issuing the command of the form:

f#

where, # is a single digit integer between 0 (slow) and 9 (fast). Different filter values and corresponding data rates, resolution and frequency are provided in Appendix B. When the CXM543 is set to the slowest rate (f0), data is transmitted at a rate of about 1 sample/sec when the pacing value is 0000. If slower rates are desired, the user can set the pacing value. This ranges from 0000 (fast) to FFFF (slow). The pacing value is set by issuing a command:

P = ####

The user can set the baud rate of the CXM543 to the standard values from 300 to 76800 baud. The baud rate command is of the form:

B = XXXX <CR><LF>

A complete list of the CXM543 commands can be found in Appendix A.

6 Description of the CXM543 Orientation Angles

The roll angle of the CXM543 is zero when the Y-axis sensors are oriented horizontally. A drawing showing the CXM543 in a roll orientation of 90° (Y sensors down) is shown in Fig. 2.

The inclination angle of the CXM543 is defined as 0° when the X-axis sensors are pointed down and 180° when the X-axis sensors are pointed up. The X sensors are aligned with the CXM543 package and point along the package edge shown in Fig. 2. Fig. 3 illustrates the CXM543 positioned at an inclination angle of 127°.

The azimuth angle of the CXM543 is referenced to magnetic North and is zero when the projection of the CXM543 X-axis in a horizontal plane is oriented North. A diagram showing the CXM543 system oriented at an azimuth of 45° is shown in Fig. 4.

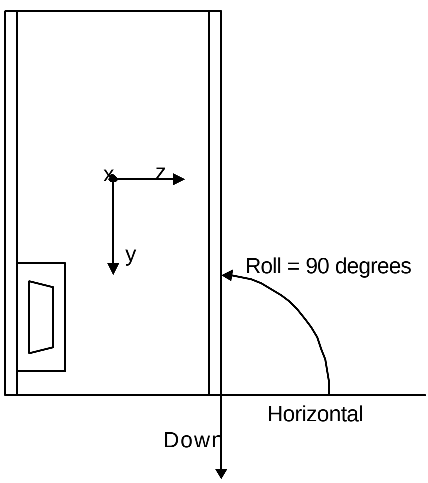


Fig. 2 CXM543 Roll Definition

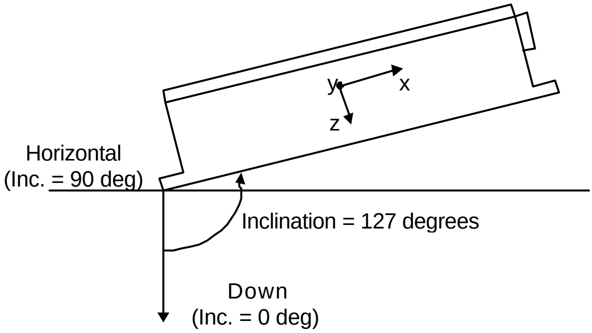


Fig. 3 CXM543 Pitch Definition

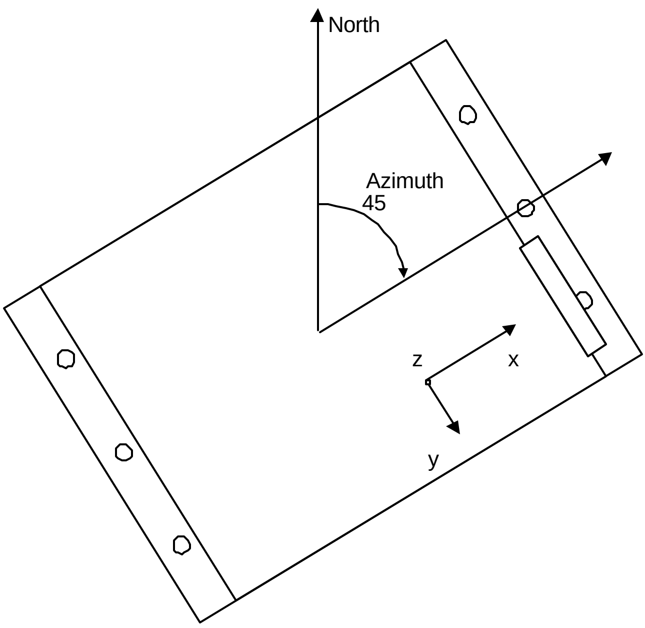


Fig. 4 CXM543 Azimuth Definition

7 Appendix A. CXM543 Command and Data Format Specifications

7.1 CXM543 command specification

All Commands must be followed by a return.
All changes to the mode value are saved as the power-up mode.

M?	Send the current mode value
M=R	All data is sent as raw A/D Counts in ASCII four digit hex values or binary values depending on the current mode.
M=C	All data is sent as Gammas, formatted as Base Ten fixed point text or binary values depending on the current mode.
M=B	Set data is formatted as binary numbers
M=T	Set data is formatted as text numbers
M=E	Send a checksum with all data
M=N	Don't send a checksum
M=A	Send corrected data as angles rather than vectors.
M=V	Send data as vectors rather than angles.
A	Start Auto Send Data
S	Stop Auto Send
D	Send the current calibrated data value in a floating-point format.
DR	Send the current raw data value in a hex format.
L	Unlock calibration mode
O	Calibration zero all the sensors
XM	Calibration +1/2 Gauss X field applied
YM	Calibration +1/2 Gauss Y field applied
ZM	Calibration +1/2 Gauss Z field applied
QM	Calibration -1/2 Gauss applied field delta
XA	Calibrate +1G applied gravitation field
YA	Calibrate +1G applied gravitation field
ZA	Calibrate +1G applied gravitation field
QA	Calibrate -1G applied gravitation field delta
F=####	Set the filter value for the A/Ds.
F?	Display the filter value for the A/Ds

F#	Quick set filter value # can be 1-9 with 1 giving the slowest and most accurate data and 9 giving the fastest and least accurate data.
B?	Send the run mode baud rate
B=#####	Set run mode baud rate 300 - 76800 baud is accepted.
	In Config Mode the baud rate is always 9600.
P?	Display the current pacing value.
P=####	Set a pacing value to slow the data rate
E?	Send all EEROM data
E####	Send EEROM data followed by 4 hex digits address and optional 2 digits representing the number of bytes to send
W###XX	Write EEROM data followed by a 4 hex digit address and 2 hex digits of data
C	Reset and calibrate A/D(s)
I	Send ID and many internal values
*	Reset and restart sensor
?	Display help

7.2 Discussion of the CXM543 Data Transmission Modes

At the top level the CXM543 can be put in either raw (M = r) or corrected (M = c) mode. Raw mode is seldom used after a CXM543 system has been factory calibrated. This mode is used mainly to enable direct access to the system analog to digital (A to D) converters for troubleshooting.

When the CXM543 mode is selected to be corrected, the magnetometer and accelerometer outputs are corrected for scale, offset and alignment factors.

When the CXM543 mode is selected to be corrected, the transmitted data mode must be further specified as follows:

M = v vector mode

M = a angle mode

When M = v, the magnetometer sensor outputs (in Gauss) and the accelerometer sensor outputs (in Gs) are transmitted. When M = a, the CXM543 orientation (roll, pitch and azimuth) angles are transmitted. For both vector and angle mode the format of the data can be selected as follows:

M = b binary mode

M = d   decimal (ASCII) mode

For decimal mode, ASCII characters representing the data are transmitted. For binary mode the data is encoded in binary format. Decimal mode is ideal for use when the CXM543 is communicating with a PC because the ASCII characters display in intelligible form on a PC running a terminal emulation program (e.g., PROCOM or HyperTerminal). Binary mode uses a considerably smaller number of bytes to encode the data, and is hence, much faster than decimal mode. Binary mode characters however do not display in an intelligible way on a PC and must be decoded using a separate program. Binary mode is used principally for systems where an embedded microprocessor communicates with the CXM543.

In calibrated vector decimal mode (M = cvd), the data format is as follows:

AX AY AZ MX MY MZ T K <CR><LF>

AX is the X accelerometer output (etc.) and is of the form:

±X.XXXXX

where, X is an ASCII character. For instance, a typical transmitted value is

-0.28265 G

T is the system temperature (in degrees C) and is of the form:

TT.T

K is a one-byte checksum calculated by summing all of the digits in the transmitted data ignoring signs and decimal points. For instance, if the transmitted data is

AX	AY	AZ	MX	MY	MZ	T	CS<CR><LF>
-0.00128	+0.03076	+0.98512	+0.02282	+0.25378	+0.34216	32.0	70

The checksum is 70 as indicated since
1+2+8+3+7+6+9+8+5+1+2+2+2+8+2+2+5+3+7+8+3+4+2+1+6+3+2+1 = 112 decimal or 70 hex.

Note that the inclusion of the temperature and a checksum in the transmitted data output is optional. To enable the sending of these data issue the commands:

M = TO

M = KO

To disable the sending of these data issue the commands:

M = TN

M = KN

If corrected data in angle and decimal mode is selected (Mode=cad) the data output format is as follows:

Roll Pitch Azimuth Total M Total A CS <CR><LF>

21.73 90.05 180.01 0.45671 1.00000 3D

For corrected data in vector data in binary mode (Mode=cvb) a typical transmission is as follows:

AX AY AZ MX MY MZ T CS EOT

FFEB01F83FOC02EC7CEA2BCC1000895A

This binary transmission is equivalent to the corrected decimal vector previously shown above, namely:

AX	AY	AZ	MX	MY	MZ	T
-0.00128	+0.03076	+0.98512	+0.02282	+0.25378	+0.34216	32.0

The binary checksum is computed as follows:

FF+EB+01+F8+3F+0C+02+EC+7C+EA+2B+CC+10+00 = 689

The checksum is 89, which is the least significant byte of the sum.

When the CXM543 mode is selected to be raw, the transmitted data represents the raw Analog to Digital (A to D) count outputs for the various magnetometer and accelerometer sensors. The A to D’s have 16 bit resolution, and hence, their output ranges (in decimal) from –32,768 to +32,767. In hex the A to D outputs range as follows:

Count	Hex Output
32767	7FFF
0	0000

-1	FFFF
-32768	8000

If the selection M=R is made, then the mode can be further specified by selecting three sub modes

M = h (hex mode)

M = b (binary mode)

M = i (integer mode)

Note that the above commands can be given individually or as a single combination of commands. For instance, to put the CXM543 in raw binary mode,

M = r <CR>

M = b <CR>

(where, <CR> is a carriage return) could be issued, or the command

M = rb <CR>

could be issued.

In hex mode, the CXM543 will transmit ASCII hex numbers in the following format

MX MY MZ AX AY AZ T K <CR><LF>

MX represents the X magnetometer A to D output and is of the form:

HHHH

where each H is an ASCII character represents a hex digit ranging from 0 to F. The magnetometer and accelerometer outputs all have this same form. T represents a hex number of the same form i.e.,

HHHH

and corresponds to the system temperature. To obtain the temperature in °C divide the hex digits by 128. K represents the system checksum and is a hex number of the form

HH

To obtain the checksum, all of the data bytes in the transmission are added. The checksum is the least significant 8 bits (or 2 hex digits) of this summation.

The <CR> and <LF> in the transmission represent ASCII characters for carriage return (0D Hex), and line feed (0A Hex). Note that the ASCII space character (Hex 20) is transmitted after each sensor output is transmitted.

In raw binary mode (M=rb), the data transmissions are much more compact. The transmissions are of the form:

AXAYAZMXMYMZTK

where AX represents the X accelerometer output etc., T represents the temperature and K represents the checksum. AX consists of two bytes. The most significant byte is transmitted first. The most significant bit of this byte is also transmitted first. Decoding of the binary data is in accordance with the following table:

Count	**Binary Output**
32767	0111 1111 1111 1111
0	0000 0000 0000 0000
-1	1111 1111 1111 1111
-32768	1000 0000 0000 0000

T is a byte number representing the system temperature in °C, and K is a one byte checksum obtained by taking the least significant 8 bits resulting from adding all of the data bytes.

In binary mode, there is no terminating transmission of a carriage return or linefeed. Instead, and end of transmission character (5A) is transmitted.

In raw integer mode, the transmission is of the following form:

±MX ±MY ±MZ ±AX ±AY ±AZ ±T K <CR><LF>

±MX is a 5-digit ASCII number representing the X magnetometer count output. This can range from –32768 to +32767. T represents the system temperature and is of the form:

TT.T

Where, the T's are ASCII characters representing the system temperature in °C. The K is a one byte checksum obtained by adding up all of the ASCII data characters in the transmission (excluding signs, spaces and decimal point), and taking the least significant byte of the sum. A space ASCII character is transmitted after each sensor output.

7.3 Explanation of Checksum Calculation

Calculation of the checksum generally involves summation of the digits of the transmitted data disregarding decimal points and signs. The method of summation is different from the binary data and decimal (ASCII) data formats. For decimal data, the individual digits of the transmitted data are summed. For example, consider the following vector data transmission in decimal format (mode = cvd)

☑ EXAMPLE

AX AY AZ MX MY MZ CS <CR><LF>

+.23456 -.12345 +0.27561 +0.47510 -0.51235 +0.12345 68

The checksum is computed as follows:

2+3+4+5+6+1+2+3+4+5+2+7+5+6+1+4+7+5+1+5+1+2+3+5+1+2+3+4+5
= 104 decimal.

The number 104 (decimal) is 68 in hex; this is the transmitted checksum.

Consider a second example consisting of corrected angle data in decimal forms (mode = cad)

Roll Pitch Azimuth Total A Total M CS <CR><LF>

100.71 90.05 1.12 1.00000 0.49543 53

The checksum is calculated as follows:

1+7+1+9+5+1+1+2+1+4+9+5+4+3 = 53 decimal

The number 53 decimal is 35 hex and this is the checksum.

To calculate the checksum for binary transmissions, the data bytes are summed and the checksum is the least significant byte of the sum. For instance, consider a transmission of raw vector data in binary format (mode = rub)

AX AY AZ MX MY MZ CS EOT

123456789A9876543221FEBC1D5A

The checksum is calculated as follows:

12+34+56+78+9A+98+76+54+32+21+FE+BC = 51D

The least significant byte of this summation is ID and this is the transmitted checksum.

For a binary transmission of corrected angular data (mode = cab) as follows:

Roll Pitch Azimuth Tot A Tot M CS EOT

23F165A3521312345678955A

The checksum is calculated as follows:

23+F1+65+A3+52+13+12+34+56+78 = 395

therefore, the checksum is 95.

7.4 EEROM Map

For all EEROM constants the least significant byte is stored in the lowest address and the most the most significant byte is stored in the highest address.

00	Not Used	
01	CPU Clock Speed Divisor	
		1-7 Clock Divisor
		8- 0=Run at full clock speed 1=Enable clock division
		CPU Speed = 4.9152Mhz/(129-ClockDivisor)
		This allows the use of lower UART baud rates and lower power consumption.
		For example 300 baud could be used with the Clock Divisor set to 125 to divide the clock rate by 4 and the baud rate control register set to 255.
02	Operating Mode	
		1- Send corrected data.
		2- Autosend data until stop autosend command received.
		3- Send data only once (on power up or single data by command)
		4- Send data in a text format
		5- Send data in a decimal format (only checked if in text format)
		6- Calibration mode uses this bit
		7- Send check sum with data.
		8- Send angles
03	More Operating Mode	
		1- Send Check Sum with Data
		2- Not used
		3- Not used
		4- Not used
		5- Not used
		6- Not used
		7- Not used
		8- Not used
04	Baud Rate Control	
		BaudRate = 4.9152Mhz / 16*(BaudRateControl+1)
		Values for common baud rates with no clock dividing:
		1200: 255(FFH) 19200: 31 (1FH)
		2400: 127(7FH) 38400: 7 (7H)
		9600: 63(3FH) 76800: 3 (3H)
05	Not used	
06-07	Soft offset X accelerometer	
08-09	Soft offset Y accelerometer	
0A-0B	Soft offset Z accelerometer	
0C-0D	Soft scale X accelerometer	
0E-0F	Soft scale Y accelerometer	

10-11	Soft scale Z accelerometer
12-13	Soft ortho XY accelerometer
14-15	Soft ortho XZ accelerometer
16-17	Soft ortho YX accelerometer
18-19	Soft ortho YZ accelerometer
1A-1B	Soft ortho ZX accelerometer
1C-1D	Soft ortho ZY accelerometer
1E-1F	Soft bow correction X
20-21	Soft bow correction Y
22-23	Soft bow correction Z
24-25	Soft offset X magnetometer
26-27	Soft offset Y magnetometer
28-29	Soft offset Z magnetometer
2A-2B	Soft scale X magnetometer
2C-2D	Soft scale Y magnetometer
2E-2F	Soft scale Z magnetometer
30-31	Soft ortho XY magnetometer
32-33	Soft ortho XZ magnetometer
34-35	Soft ortho YX magnetometer
36-37	Soft ortho YZ magnetometer
38-39	Soft ortho ZX magnetometer
3A-3B	Soft ortho ZY magnetometer
3C-3D	Pacing value

Accelerometer A/D Configuration Settings

3E-40	A/D offset calibration 0 set when the A/D is calibrated
41-43	A/D gain calibration 0 set when the A/D is calibrated
44-46	A/D offset calibration 1 set when the A/D is calibrated
47-49	A/D gain calibration 1 set when the A/D is calibrated
4A-4C	A/D offset calibration 2 set when the A/D is calibrated
4D-4F	A/D gain calibration 2 set when the A/D is calibrated

Magnetometer A/D Configuration Settings

50-52	A/D offset calibration 0 set when the A/D is calibrated
53-55	A/D gain calibration 0 set when the A/D is calibrated
56-58	A/D offset calibration 1 set when the A/D is calibrated
59-5B	A/D gain calibration 1 set when the A/D is calibrated
5C-5E	A/D offset calibration 2 set when the A/D is calibrated
5F-61	A/D gain calibration 2 set when the A/D is calibrated

62-63 Filter Settings (Set for Data Rate vs. Data Noise)

01- FAST mode enabled
02- Skip mode enabled

03- Chop mode enabled
04- Must be 0
05-16- 12 bit sync filter

7.5 Software Data Correction Equations

Xout = ((((Xin + XOffset) * XScale)/32768)+
((((Yin + YOffset) * YScale)/32768) * YOrtho)+
((((Zin + ZOffset) * ZScale)/32768) * ZOrtho))/65536
Yout = ((((Yin + YOffset) * YScale)/32768)+
((((Xin + XOffset) * XScale)/32768) * XOrtho)+
((((Zin + ZOffset) * ZScale)/32768) * ZOrtho))/65536
Zout = ((((Zin + ZOffset) * ZScale)/32768)+
((((Xin + XOffset) * XScale)/32768) * XOrtho)+
((((Yin + YOffset) * YScale)/32768) * YOrtho))/65536

8 Appendix B. Hard Iron Correction for CXM543

A hard iron offset refers to the perturbation of magnetic field experienced by an orientation sensor caused by nearby magnetic materials which are on the same platform as the sensor i.e. a constant offset in the magnetic field in the frame of the sensor. This perturbation could be measured directly by placing the sensor and platform in a magnetically shielded enclosure, but this is often not practical. The CXM543 sensor has the capability to measure the hard iron offset by placing the sensor (and platform) at a set of different orientations and collecting data at each orientation. Once measured, the hard iron offset can be subtracted from the magnetometer readings, thus enabling a more accurate measurement of orientation. The set of orientations used for hard iron corrections do not need to be precise, in fact a set of random orientations will usually work. The accuracy of the correction is better for some sets of orientations than for others, however, so the CXM543 software leads the user through a set of orientations which are known to work well. The ability to use orientations that are not precisely set greatly eases use in the field. Two versions of hard iron measurement are available, one for three-dimensional orientations and another for the case where the platform moves in only two dimensions. The two dimensional case would apply to land vehicles, for example, where only azimuth is varied. On the other hand, if roll, pitch and azimuth are all varied, as is often the case for airborne platforms, the three dimensional corrections would be needed. Slightly different data are accumulated, depending upon whether a 2 or 3 dimension correction will be determined, so best results are obtained if the dimension is specified before the procedure begins. The three dimensional data do allow for the determination of a two dimensional correction, at slightly reduced accuracy, but the two dimensional data are not sufficient to measure the three dimensional correction.

8.1 Setup procedure

The CXM543 is calibrated at the factory and no hard iron offset should exist unless it is rigidly mounted to a movable platform. The movements of the CXM543 to be described require that the entire platform be moved with it. If the platform cannot be turned upside down then only the 2 dimensional hard iron correction will be possible.

The CXM543 must be connected to a terminal emulator program on a PC to perform the correction. The Section 4.1 explains the procedure for setting the CXM543 up with a terminal emulator program. The CXM543 must be in run mode to do the hard iron correction. For this, you will need the CXM543, a PC with a terminal emulator program, a power supply capable of delivering 7.5 to 15 volts and cables.

The CXM543 and the terminal emulator must both be set to the same baud rate (usually 9600). If the CXM543 baud rate is unknown or cannot be used, you may need to temporarily set the CXM543 to Config. mode. In Config. mode, the sensor is always at 9600 baud. The Run mode baud rate can be set only when the sensor is in Config. mode. If a 543 Breakout Box is available, then set up the sensor as described in section 4.1 of the manual. The mode switch on the box should be in "Run" not "Auto" or "Config". If a connection box is not available, then the sensor will have to be connected by means of homemade wiring. Chapter 3 provides the pin out of the sensor. The ground should be connected to the computer ground and the negative side of the power supply. RS 232 out from the CXM543 should be connected to RS 232 in on the PC serial port, while RS 232 in should be connected to RS 232 out on the PC serial port. The power supply positive should be connected to +V (+7.5 to +15 Volts). The TTL serial lines and the configure line can be left unconnected, but not grounded. In particular, do not ground the configure pin (pin 8) during the hard iron correction. Grounding this pin will set the CXM543 to Config. mode.

When the PC is connected and running a terminal emulator program, the string "APS 543 V1.162" should be displayed. If the CXM543 follows this with a stream of data, then type "s" and a carriage return to take it out of autosend mode. The CXM543 can be checked out using the procedure described in Section 4.2.

8.2 Determining the Hard Iron Offset and Enabling the Hard Iron Correction

Once the CXM543 is connected, communicating and in Run mode, one can determine the hard iron correction. The hard iron offset can only be determined with the CXM543 rigidly mounted to a platform and the entire platform must be moved during the correction procedure, as will be described. The hard iron correction which uses this offset can be turned on or off.

The CXM543 is described in the following text as having x, y, and z axis. These are a set of approximately orthogonal directions described by the label on the top of the sensor. One might think of these as the forward direction, the sideways direction and the up direction for the platform. The "left side" is the left side of an imaginary pilot facing forward and sitting with his head up. Left and right side do not refer to the left and right of the operator.

8.3 Hard Iron Commands

The hard iron correction procedures are described in the following sections. The commands that are used with the 543 to complete the procedure are described as follows:

? Lists all commands recognized by the sensor, both those related to hard iron corrections and those not related to hard iron.

HI The hard iron correction is toggled on or off, if a correction is available.

H2 2-dimensional data is to be collected, with the CXM543 prompting the user with a set of good orientations. These orientations do not need to be precisely met. If some data points have already been gathered then this data is lost and the process starts all over. H2 uses 4 data points.

H3 3-dimensional data is to be collected, with the CXM543 prompting the user as with H2. For H3, 6 data points are used.

HP Records a hard iron data point using the present orientation. If an H2 or H3 is being used to prompt the data, then the correction will be calculated when the proper number of points have been gathered. If neither H2 nor H3 has been used then data will be gathered until the HC command is used, or the gathering of data is aborted by means of the HQ command, or restarted by means of the H2 or H3 commands.

HC Calculates a hard iron correction using the data gathered so far. The hard iron correction continues to be available until HC is used again, even if the sensor has begun to accumulate data for another correction. The command reports the "residuals" both with and without the use of a hard iron correction. Small residuals indicate a good fit to the data. A hard iron correction should be used when the residual with hard iron is much smaller than the residual without. If the residuals are comparable, this indicates that the hard iron correction is too small to be determined with the data gathered (and usually is sufficiently small that use of the correction is not indicated).

HW# Where, # is a number 0-10, hereinafter referred to as the weight. This number sets the way corrections are calculated. The corrections make maximal use of accelerometer data if the weight is 10, and use only magnetometer data if the weight is 0. The degree to which accelerometer data is used increases gradually with the specified weight. In actual use, this command would rarely be used, as the default value of 5 works well for most situations.

H? Gives the hard iron data in use, the number of data points gathered, the dimensionality, etc. as well as additional help.

HQ Quit the present data collection, discarding all data gathered so far. The correction, if any, resulting from the last HC command will continue to be available and can be turned on or off with the HI command.

HT Toggle between 2D and 3D mode. Because the H2 and H3 commands automatically set the dimension, this would only be used if a user wanted to use his own set of orientations, without being prompted. Any data gathered is lost, and data acquisition is restarted.

8.4 Three dimensional Correction

To determine a 3-dimensional offset, begin by typing "H3" followed by a carriage return. The CXM543 will then prescribe a set of 6 orientations. The prescribed orientations and their interpretation in up, down, front, back, left side and right side are as follows (replies from the CXM543 are enclosed in quotation marks ""):

"Place the sensor z axis down to start a 3D correction then type HP
if possible place the x axis toward north"

Any direction will do, but it should remain the same throughout the procedure. This will be called "north" even though it may not be true north.

Type HP followed by a carriage return.

"Rotate 90 degrees about the y axis so the x axis points up then type HP"

Set the platform on its backside, with the sideways direction remaining unchanged and the bottom facing north.

Type HP followed by a carriage return.

"Rotate 90 degrees about the y axis so the z axis points up then type HP"

Place the platform upside down, with the x-axis pointing south.

Type HP followed by a carriage return.

"Rotate 90 degrees about the y axis so the x axis points down then type HP"

The front should face down and the top should face north.

Type HP followed by a carriage return.

"Rotate 90 degrees about the z axis so the y axis points up then type HP"

Rest the platform on the left side, with the top facing north.

Type HP followed by a carriage return.

"Rotate 180 degrees about the z axis so the y axis points down then type HP"

Rest on the right side, with the top facing north.

Type HP followed by a carriage return.

At this time, the CXM543 will automatically calculate the hard iron offsets and display them. Also displayed are a set of parameters indicating the quality of the fit. If the residuals without correction are substantially larger than those with corrections, this indicates that the hard iron correction would improve orientation accuracy. The hard iron correction can be turned on by typing HI followed by a carriage return.

8.5 Two dimensional Correction

To determine a two dimensional correction, begin by typing "H2" followed by a carriage return. The CXM543 will then prescribe a set of 4 orientations. The top of the platform will always point up, so we only need to specify the direction of the front.

The prescribed orientations and their interpretation in up, down, front, back, left side and right side are:

"Place the sensor z-axis down to start a 2D correction then type HP";

Any initial direction will do, but it should remain the same throughout the procedure. This will be called "north" even though it may not be true north.

Type HP followed by a carriage return.

"Rotate 90 degrees clockwise about the z axis then press HP"

The forward direction should now face east.

Type HP followed by a carriage return.

"Rotate 90 degrees clockwise about the z axis then press HP"

The forward direction should now face south.

Type HP followed by a carriage return.

"Rotate 90 degrees clockwise about the z axis then press HP"

The forward direction should now face west.

Type HP followed by a carriage return.

At this time, the CXM543 will automatically calculate the hard iron offsets and display them. Also displayed is a set of parameters indicating the quality of the fit. If the residuals without correction are substantially larger than those with correction, this indicates that the hard iron correction would improve orientation accuracy. The hard iron correction can be turned on by typing "HI" followed by a carriage return.

8.6 Caveats

The hard iron correction will not be accurate unless the magnetic environment is of a uniform field (other than the hard iron field). The data obtained near large magnetic objects not on the platform will not be accurate, for example.

The correction will only be accurate if the sensor has been calibrated for scale and orthogonality, which is normally the case.

In some cases, highly permeable material on the platform can interfere with obtaining an accurate correction. This is often referred to as a "soft iron" perturbation.

9 Appendix C. Filter Values and Data Rates

A table containing some filter values and corresponding data rates, resolution and frequency tested on CXM543 is provided below.

Filter Value	Measured Text Data rate (/sec)	A/D Single Axis Sample Rate (/sec)	A/D All Axis Sample rate (/sec)	A/D Resolution in bits	-3db Frequency (Hz)
8000	2.06	150	2.08	19	3.94
6000	2.77	200	2.77	19	7.8
4000	4.1	300	4.16	19	11.7
3000	5.5	400	5.55		15.6
2000	8.17	600	8.33	18.5	23.4
1800	10.8	800	8.33		31.2
1000	16.0	1200	16.7	17.5	46.8
900	21.5	1600	16.7		62.4
800	31.5	2400	22.2	17	93.6
600	41.1	3200	44.4		124.8
400	51.2	4800	66.7		187.2
300	61.3	6400	88.9		249.6
8002		150	50	16	39.3
6002		200	66.7	15.5	52.4
4002		300	100	15.5	78.6
3002		400	133	15	104.8
2002	57.7	600	200	15	157
1002	73.0	1200	400	14	314
802	88.4	2400	800	12.5	629
402	97.2	4800	1600	10.5	1260
282	104.9	7680	2560	9.5	1676

NOTE

CXM543 is limited by its CPU clock speed rather than either A/Ds or baud rate.

10 Appendix D. Warranty and Support Information

10.1 Customer Service

As a Crossbow Technology customer you have access to product support services, which include:

- Single-point return service
- Web-based support service
- Same day troubleshooting assistance
- Worldwide Crossbow representation
- Onsite and factory training available
- Preventative maintenance and repair programs
- Installation assistance available

10.2 Contact Directory

United States:	Phone:	1-408-965-3300 (7 AM to 7 PM PST)
	Fax:	1-408-324-4840 (24 hours)
	Email:	techsupport@xbow.com
Non-U.S.:	refer to website	www.xbow.com

10.3 Return Procedure

10.3.1 Authorization

Before returning any equipment, please contact Crossbow to obtain a Returned Material Authorization number (RMA).

Be ready to provide the following information when requesting a RMA:

- Name
- Address
- Telephone, Fax, Email
- Equipment Model Number
- Equipment Serial Number
- Installation Date
- Failure Date
- Fault Description

10.3.2 Identification and Protection

If the equipment is to be shipped to Crossbow for service or repair, please attach a tag TO THE EQUIPMENT, as well as the shipping container(s), identifying the owner. Also indicate the service or repair required, the problems encountered, and other information considered valuable to the service facility such as the list of information provided to request the RMA number.

Place the equipment in the original shipping container(s), making sure there is adequate packing around all sides of the equipment. If the original shipping containers were discarded, use heavy boxes with adequate padding and protection.

10.3.3 Sealing the Container

Seal the shipping container(s) with heavy tape or metal bands strong enough to handle the weight of the equipment and the container.

10.3.4 Marking

Please write the words, "***FRAGILE, DELICATE INSTRUMENT***" in several places on the outside of the shipping container(s). In all correspondence, please refer to the equipment by the model number, the serial number, and the RMA number.

10.3.5 Return Shipping Address

Use the following address for all returned products:

Crossbow Technology, Inc.
41 E. Daggett Drive
San Jose, CA 95134
Attn: RMA Number (XXXXXX)

10.4 Warranty

The Crossbow product warranty is one year from date of shipment.

Crossbow

Crossbow Technology, Inc.
41 E. Daggett Drive
San Jose, CA 95134
Phone: 408.965.3300
Fax: 408.324.4840
Email: info@xbow.com
Website: www.xbow.com