BILLINGSLEY

Aerospace & Defense

DFM24PT

DIGITAL FLUXGATE MAGNETOMETER

DFM24PT
Digital Fluxgate Magnetometer

TABLE OF CONTENTS

1.0 Introduction

Model DFM24PT is a digital triaxial fluxgate magnetometer.

2.0 Fluxgate Magnetometers

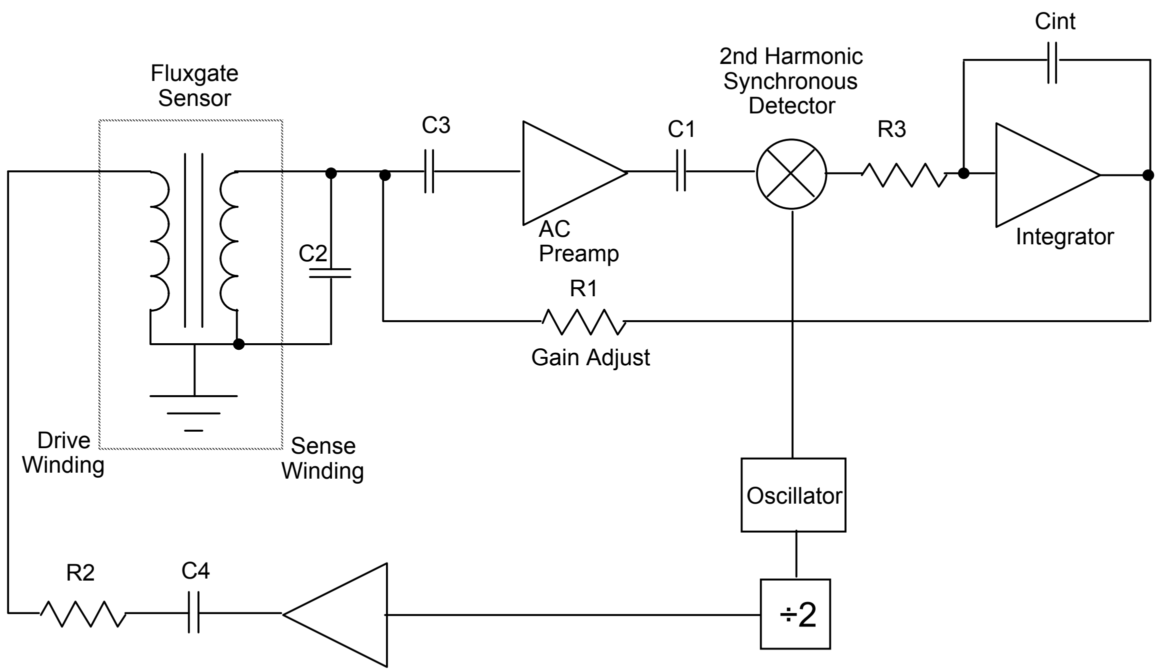
2.1 Theory of operation

The typical fluxgate sensor consists of a “sense” (secondary) coil surrounding an inner “drive” (primary) coil that is wound around permeable core material. Billingsley currently manufactures three types of sensors; ring core, racetrack, and rod. Each type has magnetic core elements that can be viewed as two carefully matched halves. An alternating current is applied to the drive winding, which drives the core into plus and minus saturation. The instantaneous drive current in each core half is driven in opposite polarity with respect to any external magnetic field. In the absence of any external magnetic field, the flux in one core half cancels that in the other. The total flux seen by the sense coil is zero. If an external magnetic field is applied it will, at a given instance in time, aid the flux in one core half and oppose flux in the other. This causes a net flux imbalance between the halves, so that they no longer cancel one another. Current pulses are now induced in the sense winding on every drive current phase reversal (or at the 2nd, and all even harmonics). This results in a signal that is dependent on both the external field magnitude and polarity. There are additional factors that affect the size of the resultant signal. These include the number of turns in the sense winding, magnetic permeability of the core, sensor geometry and the gated flux rate of change with respect to time. Phase synchronous detection is used to convert these harmonic signals to a DC voltage proportional to the external magnetic field.

High quality, low noise fluxgates typically use a feedback loop to keep the core at zero field. The phase synchronous detector (or analog multiplier) is utilized to detect the even harmonics and these signals are integrated in an analog integrator to develop a voltage that represents the ambient field through the core. This signal is then fed back to the core to null it to zero. The level of complexity involved in the drive current circuit and at each step of the sense signal processing is detailed below.

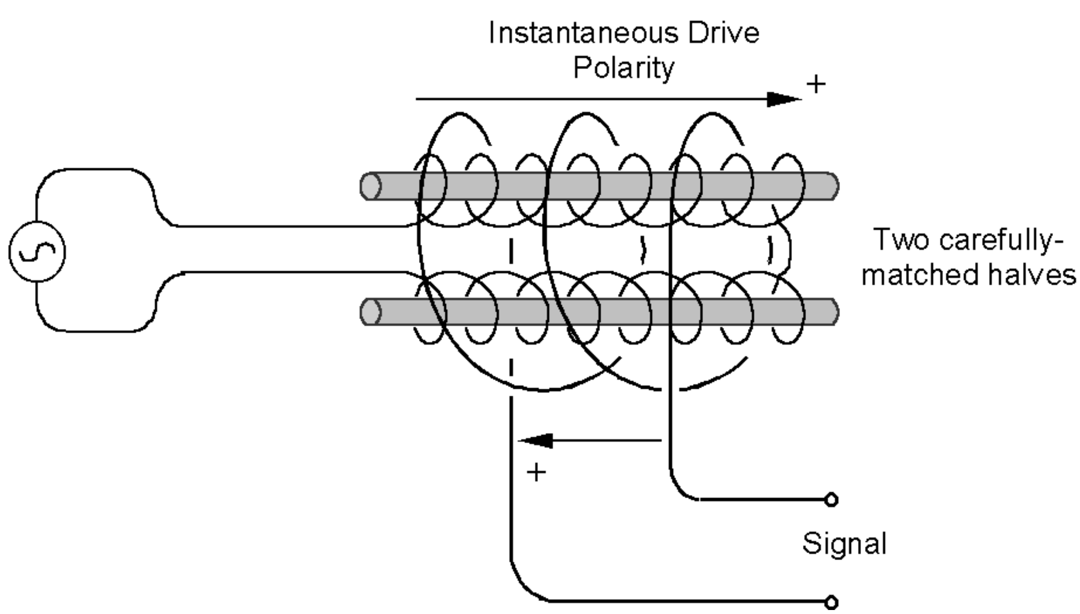
It is necessary to drive the sensor core deep into saturation while minimizing power consumption to produce fluxgates with very low noise and stable zero offsets. The core driver usually employed consists of an oscillator/divider, a low output impedance driver and an R/C network R2 and C4 (see Figure 3-1). The drive waveform, typically in the 10 to 30 kHz range, is applied to R2, C4. As the core goes through the high permeability region of the B-H curve, the impedance of the drive winding connected in series with capacitor C4 is high and the capacitor charges through resistor R2. When the core reaches saturation, the impedance of the drive winding drops to a very low value and the capacitor discharges through the core winding. A large current surge of short duration will occur in the core winding, which will drive the core deeper into saturation. The core will be saturated in the other direction on the other half of the drive waveform.

This topology drives the core into saturation while maintaining a low average power consumption. It also ensures that the timing of the core saturation is very constant and is *reasonably* independent of drive voltage and core temperature effects. This timing of saturation is very important because it affects the phase of the generated second harmonic signal and it must be held constant for ideal operation of the magnetometer's synchronous detector. Any shift of the second harmonic signal phase changes the signal level, and therefore increases sensor noise and zero offset.



SIMPLIFIED BLOCK DIAGRAM OF A FLUXGATE SENSOR

2.2 Basic Fluxgate Principle



2.3 Sense / Feedback Winding

The magnetometer sense/feedback winding is wound in a solenoidal form around the outside of the sensor core. This winding detects the even harmonics of the drive frequency that are proportional to the magnetic field through the sensor. They are also used to feed back a current to null the core. Dual use of the coil is possible since the harmonics are AC signals and the feedback is near DC. Used as a sense coil, it is AC coupled via C3 to the sensor circuit's preamplifier. Capacitor C2, in parallel with the sense winding, tunes the winding whose inductance is being modulated at the core frequency by the second, and higher even harmonics of the drive frequency.

Since this coil is also used with feedback to null the ambient field, its mechanical, electrical, and thermal characteristics are critical. The magnetometer output circuit provides feedback current to this coil. This creates a field in the opposite direction to the measured field, canceling the measured field at the sensor core. If the feedback current and the current to field relationship of this coil is known, then the field being measured is known. This coil's dimensions must not change with temperature, or must change in a predictable way, since the field it creates is a function of its dimensions and its input current.

2.4 AC Preamplifier

The operational amplifier selected for the AC preamplifier has very low noise at the frequency of operation of the magnetometer circuit. Its wide bandwidth is necessary for preventing phase shift of the harmonic signals, which can cause an unstable sensor zero offset. The AC coupled gain of this stage is typically > 30 dB and reduces the DC errors of the following integrator stage by this amount.

2.5 Synchronous Detector

A synchronous detector is used to convert the harmonic signals from the sense coil to a DC voltage that is proportional to the integral of the even harmonic's magnitude. The voltage sign indicates the signal's phase. This switch must have low noise and low feed through of the switch's controlling signal (which is at the 2^{nd} harmonic frequency) to prevent unwanted sensor offsets.

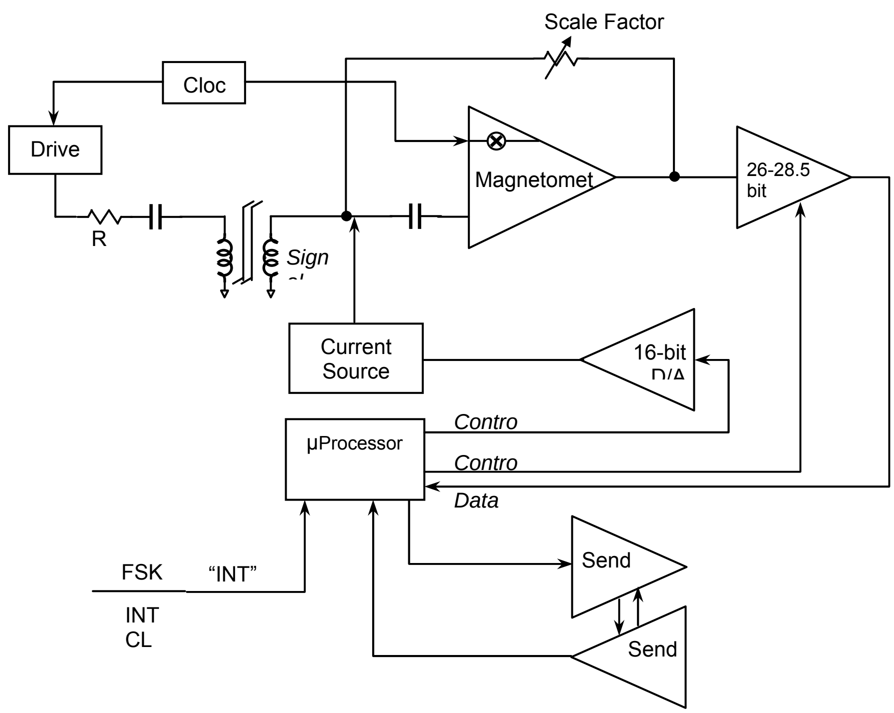
2.6 Integrator

The amplifier used in the magnetometer circuit's integrator must have low 1/f noise as well as low current/voltage offsets and drifts. The integrator output is fed back to the sensors signal winding through a resistor. This feedback nulls the ambient field as seen by the sensor. The sensor's non-linearity is reduced by the "open loop" gain factor (typically > 100 dB) of the integrator amplifier.

2.7 Contributors to Noise

There are multiple contributors to noise and sensor zero offset stability. The primary contributor is the core itself. Careful selection of the material and processes to fabricate the core can have a major impact on zero offset performance. Various electronics factors also affect *low frequency* noise, including thermal drifts that induce a zero drift, feed through of the second harmonic in the phase detector and offset drifts of the integrator circuit.

3. Digital Magnetometer



Simplified Block Diagram of Digital Magnetometer

3.1 ASCII Mode Command Set Description (code version 23-Aug-06)

All command responses in the ASCII mode begin with the Command Letter and then the data.

COMMAND	COMMAND DESCRIPTION	RESPONSE DATA	TEXT RESPONSE EXAMPLE
1	Displays raw X-axis magnetometer value in ASCII	Command letter followed by six digit hex value: 800000= 0 field 800000-FFFFFF= positive 7FFFFF-000000= negative	`1800000`
2	Displays raw Y-axis magnetometer value in ASCII	Command letter followed by six digit hex value: 800000= 0 field	`2800000`
3	Displays raw Z-axis magnetometer value in ASCII	Command letter followed by six digit hex value: 800000= 0 field	`3800000`
4	Displays raw X-axis accelerometer value in ASCII	Command letter followed by six digit hex value: +g = high value -g = low value	`4C0D0A2` `(typical high value)`
5	Displays raw Y-axis accelerometer value in ASCII	Command letter followed by six digit hex value:	`5A659DC` `(typical low value)`
6	Displays raw Z-axis accelerometer value in ASCII	Command letter followed by six digit hex value:	`6C0D0A2`
7	Displays raw pressure sensor value in ASCII	Command letter followed by six digit hex value:	7853692 (typical of 1 atmosphere)
8	Displays raw temperature sensor value in ASCII	Command letter followed by six digit hex value:	888D03B (typical of room temp)

A	Displays processed accelerometer and temperature data in binary.	Binary output format (16 bytes per message)
		Byte 1: Command byte
		(41)
		Byte 2,3,4: X-axis accl data
		(FF B8 90)
		Byte 5,6,7: Y-axis accl data
		(FF CE 75)
		Byte 8,9,10: Z-axis accl data
		(FE 83 82)
		Byte 11,12,13: Raw temperature data (85 37 EC)
		(1ºC/count =215E(H))
		(0ºC = 855029(H))
		Byte 14: Sample count (EE)
		Byte 15: checksum #1 (A3)
		Byte 16: checksum #2 (BF)
			`41 FF B8 90 FF CE 75 FE 83 82 88 C9 97 EE A3 BF`
			
			`Note: +1g = +100,000`
			`0g = 0`
			`-1g = -100,000`
			
			`(1ºof angle= 1111.1111)`

COMMAND	COMMAND DESCRIPTION	RESPONSE DATA	TEXT RESPONSE EXAMPLE
M	Displays processed magnetometer and temperature data in binary.	Binary output format (16 bytes per message) Byte 1: Command byte (4D) Byte 2,3,4: X-axis mag.l data (0 0 30) Byte 5,6,7: Y-axis mag. data (FF FF F0) Byte 8,9,10: Z-axis mag. data (0 0 41) Byte 11,12,13: Raw pressure data (88 C9 97) 1 PSI/count= 2E12 (H) 0 PSI= 854DE0(H) Byte 14: Sample count (F1) Byte 15: checksum #1 (15) Byte 16: checksum #2 (CC)	4D 0 0 30 FF FF F0 0 0 41 85 34 BF F1 15 CC
J	Displays EEPROM contents	Locations start from left to right, top to bottom. Start 00-27. EEPROM locations described in assignment list.	A7F5 C2D9 DDBE A712 C0A2 DA32 A642 BFDD D979 0080 2AAE 29AD 2ADD 1C00 D000 2C00 F280 E880 08A8 FE00 1AA0 FF00 3030 3235 0001 0018 0000 0005 0080 865B 7E07 6FED E020 0014 FFFF FFFF FFFF FFFF FFFF FFFF
P	Programs (writes) data into EEPROM one location at a time	2 hex character address and 4 hex character data.	`P00A7F5` `( this command programs the value A75F into EEPROM location 00)`
T	Tilt sensor calibration	The T command followed by the axis followed by a +/-. (*see calibration procedure)*	`TX+` `Writes the raw accl. data to its correct EEPROM location`
d	Displays processed magnetometer data in nT and tilt data in degrees.	MX,MY and MZ: Mag. Values before tilt correction in nT. TX,TY and TZ: tilt values in degrees with .1 ° resolution. AX,AY and AZ: Tilt adjusted (future development) P: pressure sensor 1 PSI/count= 11794.9982 (D) 0 PSI= 8736224.52407(D) T: temp sensor data in decimal. 1ºC/count = 8542.64698 (D) 0ºC = 8736809.49177 (D)	MX = 0080.883 MY = -057.021 MZ = 0098.365 AX = AY = future development AZ = TX = -17.2 TY = -9.7 TZ = -87.6 P = 8731847 T = 8980774
Z	Displays d command with offsets only	Does not correct for slope.	SAA

3.2 EEPROM Contents

```
//============================================================================
//
//      EEPROM content assignments.
//
//      The following tilt sensor data is written by the "T" command.
//
//      Location     Data Type          Function
//      --------     ---------          ---------------------------------------------
//        00         long               X axis -1g calibration.
//        01         long               X axis  0g calibration.
//        02         long               X axis +1g calibration.
//        03         long               Y axis -1g calibration.
//        04         long               Y axis  0g calibration.
//        05         long               Y axis +1g calibration.
//        06         long               Z axis -1g calibration.
//        07         long               Z axis  0g calibration.
//        08         long               Z axis +1g calibration.
//
//      The following location contains the settle time for D/A changes.
//
//      Location     Data Type          Function
//      --------     ---------          ---------------------------------------------
//        09         long               Reserved.

//      The following locations contain Slope calibration values.
//
//      Location     Data Type          Function
//      --------     ---------          ---------------------------------------------
//        0A         float              "fMVal" for X axis.
//        0B         float              "fMVal" for Y axis.
//        0C         float              "fMVal" for Z axis.
//
//      The following locations contain Y = MX + B formula OFFSET values.
//
//      Location     Data Type          Function
//      --------     ---------          ---------------------------------------
//        0D         long               "lOffset" for X axis.
//        0E         long               "lOffset" for X axis.
//        0F         long               "lOffset" for X axis.
//
//      The following locations contain Angular Error Correction values.
//
//      Location     Data Type          Function
//      --------     ---------          ---------------------------------------------
//        10         float              "fMisalign" for X axis, Y value.
//        11         float              "fMisalign" for X axis, Z value.
//        12         float              "fMisalign" for Y axis, X value.
//        13         float              "fMisalign" for Y axis, Z value.
//        14         float              "fMisalign" for Z axis, X value.
//        15         float              "fMisalign" for Z axis, Y value.
//
//      The following locations contain unit Serial Number, Unit ID address
//      and Heater Enable data.
//
//      Location     Data Type          Function
//      --------     ---------          ---------------------------------------------
//        16         ASCII Hex          4 character serial number string.
//        18
//        19-1A                                   Reserved
/\\       1B         ASCII Hex          Holds the sample control number to select the
                                        number of samples averaged by the A/D converter.
//----------------------------------------------------------------------------
```

3.3 Tilt Calibration:

Tilt data is stored in EEPROM locations as noted above. The functions are defined below:

-1g = -90º
0g = 0º
+1g = +90º

For example, if the axis of rotation is on the X plane, a tilt sensor reading of +1g or +90 will define the magnetic sensor as pointing in the +X direction.

The tilt sensors are calibrated using the following procedures:

1. Choose an axis to calibrate.
2. Find a reference surface and edge that is flat and level.
3. Position the bottle to achieve a + or - 90º angle and enter the T command followed by the axis followed by the direction sign.
   Example: enter(TZ-) with the bottle standing on end with the connector pointing up.
4. Rotate the bottle 180º and enter the opposite angle(TZ+).
5. Check EEPROM locations for the correct raw data.

Note: the (0g) center position is calculated finding the midpoint of the other two points.
Note: +1g = +100,000
0g = 0
-1g = -100,000
(1º of angle = 1111.1111)

3.4 Adjusting the number of samples averaged by the A/D converter.

Location "1B" in the EEPROM holds the sample control number. In table 3 from the A/D datasheet, you can identify the correct number to be placed in EEPROM location "1B" to select a specific number of A/D samples. For example, for 1024 samples (found in the OSR column), look to the left and find the number created by the OSR3, OSR2, OSR1, & OSR0 bits. So for 1024 samples, location "1B" of the EEPROM should be loaded with the hex value 0005. The OSR bits make up the 4th hex digit in EEPROM.

Note: The conversion time increases as more samples are averaged, but the reading gets much more stable.

Table 3. SDI Speed/Resolution Programming

OSR4	OSR3	OSR2	OSR1	OSR0	CONVERSION RATE INTERNAL 9MHz CLOCK	CONVERSION RATE EXTERNAL 10.24MHz CLOCK	RMS NOISE	ENOB	OSR
X	0	0	0	1	3.52kHz	4kHz	23µV	17	64
X	0	0	1	0	1.76kHz	2kHz	3.5µV	20	128
0	0	0	0	0	880Hz	1kHz	2µV	213	256*
X	0	0	1	1	880Hz	1kHz	2µV	21.3	256
X	0	1	0	0	440Hz	500Hz	1.4µV	21.8	512
X	0	1	0	1	220Hz	250Hz	1µV	22.4	1024
X	0	1	1	0	110Hz	125Hz	750nV	22.9	2048
X	0	1	1	1	55Hz	62.5Hz	510nV	23.4	4096
X	1	0	0	0	27.5Hz	31.25Hz	375nV	24	8192
X	1	0	0	1	13.75Hz	15.625Hz	250nV	24.4	16384
X	1	1	1	1	6.875Hz	7.8125Hz	200nV	24.6	32768**

**Address allows tying SDI HIGH *Additional address to allow tying SDI LOW

4. DFM24PT Connector Pin Assignments and Addressing

Seacon Brantner XSEE-12-BCR Underwater Connector (RS232 Configuration)		
Pin	Function	
1	Power +	
2	Power Common/ Signal ground to DB9 (Serial port) pin 5	
3	// RS485 Not Used	
4	RS232 RCV to DB9 (Serial port) pin 3	
5	RS232 XMIT to DB9 (Serial port) pin 2	
6	// RS485 Not Used	
7	X Analog Output	
8	Y Analog Output	
9	Z Analog Output	
10	MCLR	PROGRAMMING FUNCTIONS FACTORY USE ONLY
11	PGC	
12	PGD	

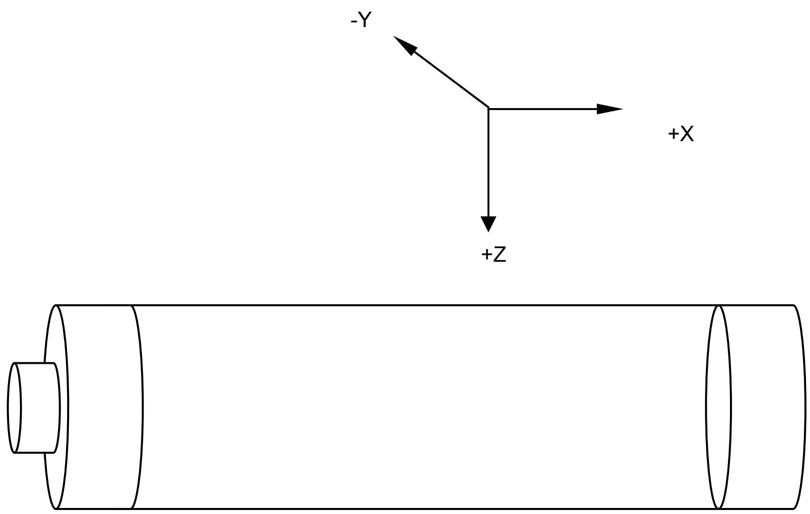
5. Specifications

DFM24PT
Serial Digital Triaxial Fluxgate Magnetometer
Ultra Low Noise / Very High Resolution

Description: Triaxial Fluxgate Magnetometer with 19.2 kB, RS485 serial interface standard. Can drive cable lengths >1000 meter.

Axial Alignment:	Orthogonality better than ± 0.1°
Input Voltage:	16 to 34 VDC @ 850 milliwatts constant power
Field Measurement Range:	± 65 µT standard (other ranges on request)
Accuracy:	± .15 % of Full Scale
Digital Output Resolution:	.2 pT
Scale Factor Temperature Shift:	≤ .01% / ° C
Noise:	≤ 0.008 nT RMS/√Hz @ 1Hz
Zero Shift With Temperature:	≤ 0.5 nT / ° C
Susceptibility To Perming:	< ± 5 nT shift with ± 5 Gauss applied
Digital sample rate:	> 125 Samples/second in binary mode ≈ 55 Samples/second in ASCII mode
Underwater Housing	Rated to > 200 meters
Weight	≈ 1076 grams
Size w/underwater housing:	7.8cm Diameter x 30.5 cm Length
Output Connector:	Seacon Brantner XSEE-12-BCR, XSEE-12-CCP Mating

5.1 Magnetic Coordinate System



Sensors are configured for the geophysical convention of North, East, and Down being positive. When Z is pointing down towards Earth's field, the Z output will be positive.