User Guide

for

MFAM Modules

LCS050G

LCS100S

LCS100X

P/N 770-00103-01

Rev. B4

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GEOMETRICS
Simplify your search

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Congratulations on your purchase!

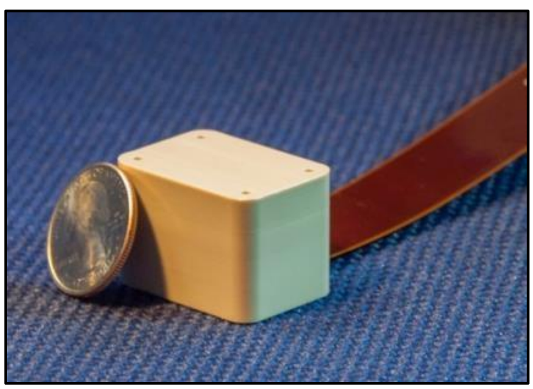
The MFAM

The Micro-Fabricated Atomic Magnetometer (MFAM) is a laser pumped, cesium vapor (Cs133 non-radioactive) total field scalar magnetometer. The miniature magnetometer comprises of two high-performance cesium sensors attached to one sensor driver module. The two sensors can be operated independently or as an intrinsic single sensor (not available for "Regular" module). When operated independently, the MFAM module can be used as a scalar magnetometer as well as a gradiometer at the same time. As a single sensor, the MFAM module can achieve dead-zone-free operation or intrinsic heading-error compensation, depending on the sensor orientations.

Geometrics currently offers three different types of MFAM modules:

- Regular (LCS050G, P/N: 900-00394-01)
- Supermag (LCS100S, P/N: 900-00394-04)
- SX (LCS100X, P/N: 900-00394-05)

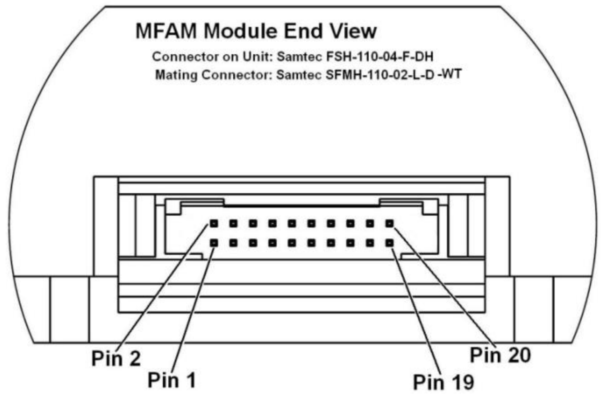
The "Regular" module has two independent sensors operated in the low-noise mode with large heading errors. Individual sensor heading error can be reduced by a factor of ~5 when the sensor is operated in the low-heading-error mode (only available to the "Supermag" module) by sacrificing some of its noise performance. The "Supermag" module has the additional ability of operating two sensors as an intrinsic single sensor by combining the two sensor signals. With the "Supermag" module, customers can automatically achieve significantly better results in both heading error and noise performances, compared with developing their own code to combine the readings from the two independent sensors. The "SX" module has the same option as the "Supermag" module except for its noise performance. The "SX" module can be shipped to most countries without a license from the US Department of Commerce. The flexibility, small size, light weight, low power, and 1000Hz sampling rate make the MFAM a revolutionary sensor in the geophysical market.



One MFAM Sensor

If you are a first-time user, we highly recommend purchasing the MFAM Development Kit together with the MFAM module.

Connector Pin Configuration



Pin	Signal	Description
1	CHASSIS	Chassis ground
2	GND	Power supply ground
3	Vin	Power supply (9.5V to 16V)
4	Vin	Power supply (9.5V to 16V)
5	GND	Power supply ground
6	GND	Power supply ground
7	MSPI_DOUT	Data output (TX), SPI protocol, unit is master
8	DNC	Do not connect, leave pin open.
9	MSPI_DIN	Data input (RX), SPI protocol unit is master
10	DNC	Do not connect, leave pin open.
11	MSPI_SCLK	Clock output, SPI protocol, unit is master
12	DNC	Do not connect, leave pin open.
13	MSPI_CSB	Chip select, active low signal, SPI protocol, unit is master
14	DNC	Do not connect, leave pin open.
15	CTS	Clear To Send handshake signal, INPUT to MFAM unit (not implemented)
16	REF10M	10 MHz reference clock input, OPTIONAL
17	RTS	Ready To Send handshake signal, OUTPUT from MFAM unit (not implemented)
18	1PPS	1 pulse per second input, positive edge triggered
19	GND	Power supply ground
20	GND	Power supply ground

SPI Output

SPI Output Packet Structure

The SPI outputs 28 bytes of data every millisecond. The data packet has the following structure.

Name	Size(bytes)	Description
Frame Id	2	Data Validity, Aux Field Type and Fiducial (See use in Frame Id Table)
Sys Stat	2	System Status bits (See use in SysStat Table)
Mag 0 Data	4	32 bit Mag 0 Data, 50 fT/LSB
Mag 0 Status	2	Mag 0 Diagnostics, Current Status (See use in MagStat Table)
Mag 1 Status	2	Mag 1 Diagnostics, Current Status (See use in MagStat Table)
Mag 1 Data	4	32 bit Mag 1 Data, 50 fT/LSB
Aux Word 0	2	(See use in Aux Fields Table)
Aux Word 1	2	(See use in Aux Fields Table)
Aux Word 2	2	(See use in Aux Fields Table)
Aux Word 3	2	(See use in Aux Fields Table)
Reserved/Junk	4	Currently not used.

Each word in the SPI Packet is transmitted in little-endian format with the Least Significant Byte sent first. Please note that the first bit in every transmitted byte is the Most Significant Bit.

The following C structure can be used as a reference for the SPI packet –

```
typedef struct {
   uint16_t      FrameId;
   uint16_t      SysStat;
   uint32_t      Mag0Data;
   uint16_t      Mag0Stat;
   uint16_t      Mag1Stat;
   uint32_t      Mag1Data;
   int16_t       Aux0;
   int16_t       Aux1;
   int16_t       Aux2;
   int16_t       Aux3;
   uint8_t       Reserved[4];
} mfamSpiTxStruct;
```

Frame ID Table

Bit	Description
15	Mag 1 Data Valid
14	Mag 0 Data Valid
13	Aux Field Identifier (See use in Aux Fields Table)
12	
11	
10	Fiducial - 1-2000 when not in Runtime mode or if PPS not present in Runtime mode of operation; 1-1000 when PPS available and locked
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

System Status Table

Bit	Name	Description
15	PPS Locked	Deviation of Internal 1 KHz from PPS signal is less than ± 500ns for greater than 5 seconds.
14	PPS Available	Signal received at 1 PPS pin
13	10 MHz Available	10 MHz signal sensed at input
12	10 MHz Locked	Internal Oscillator Locked to 10 MHz
8-11	System Fault ID	Error code identifying a system fault *
7	Non-Critical Fault	Set when a fault occurs where the system can continue operation but not optimally, check Fault ID for more info.
6	Reserved	-
5	Reserved	-
4	Running Mode **	Built-In Tests
3		Calibration
2		Magnetometer
1		Startup
0	Critical Fault	Set when a fault occurs where the system cannot continue operation, check Fault ID for more info. Only a power cycle or FPGA reset command can remedy this.

* **Important System Fault IDs:**

3: Compass failed
9: FPGA Temperature > 100°C
System Fault ID >= 7: A critical fault has occurred and the system has shut down its internals. To reset the MFAM, either Power cycle or send an "FPGA Reset" command. Command information can be found in the following “SPI Input” section.

**It is a bit mask denoting the current working status of the MFAM. If no bits are set, the MFAM is in "Hibernate" mode.

Mag Status Table

Bit	Description
15	Startup Diagnostics State, as described in Diagnostics Table
14	
13	
12	Reserved
11	Reserved
10	Reserved
6-9	Sensor Fault ID*
5	Low HE/ Low Noise mode (0/1)
4	Regular/NoDZ mode (0/1)
3	Reserved
2	Reserved
1	Reserved
0	Dead-zone Indicator

Mag Startup Status Diagnostics Table

State	Diagnostic State Identifier
	Mag Status Bits 15-13
Cell Heating	1
Probe Laser Locking	2
Pump Laser Locking	3
Finalize Laser Locking Parameters	4
Startup Complete	5
No Diagnostics	0

* **Important Sensor Fault IDs:**
10: Probe laser unlocked
11: Pump laser unlocked
Sensor Fault ID >= 5: A critical fault has occurred and the system has shut down the sensor. To reset the sensor, either Power cycle, send an "FPGA Reset" command or "Soft Reset, Start from Cell Heating" command. Command information can be found in the following "SPI Input" section.

Auxiliary Fields Table

Bits 11-13 in the Frame Id identifies which auxiliary field reading is included in the 28 bytes output data. Auxiliary field vs identifier information can be found in the “Aux Field Identifier” table. Auxiliary word0-3 repeats output patterns every 10 ms with the output order within the 10 ms given by the “Output Order” table. Since accelerometer and gyro repeat twice every 10 ms, they have a sample rate of 200 Hz, while the compass only has a sample rate of 100 Hz.

Aux Field Identifier	Word 0		Word 1		Word 2		Word 3	
Frame Id Bits 11-13	**Type**	**Value**	**Type**	**Value**	**Type**	**Value**	**Type**	**Value**
"000"	-	-	-	-	-	-	-	-
"001"	Signed	Cmps X	Signed	Cmps Y	Signed	Cmps Z	-	-
"010"	Signed	Gyro X	Signed	Gyro Y	Signed	Gyro Z	Signed	Gyro T
"011"	-	-	-	-	-	-	-	-
"100"	Signed	Accel X	Signed	Accel Y	Signed	Accel Z	Signed	Accel T
"101"	-	-	-	-	-	-	-	-
"110"	Unsigned	FPGA Temp	Unsigned	Board/Osc Temp	Unsigned	Supply Voltage	Unsigned	Total Run Time
"111"	MFAM Module Serial Number							

Output Order:	Identifier	Desc
0	100	Accel
1	010	Gyro
2	001	Cmps
3	111	SN
4	000	-
5	100	Accl
6	010	Gyro
7	011	-
8	101	-
9	110	Aux Data

More information about Compass, Gyro and Accelerometer can be found on Page 16 and 17.

FPGA Temperature conversion to Celsius: (raw value * 503.975 / 4096 – 273.15)

Board/Osc Temperature conversion to Celsius: [(4096 - raw value - 1720) / 8.2 - 35]

Supply Voltage conversion to Volt: (raw value * 34.1325 / 4096)

Total Run Time conversion to Hour: 1 hour / LSB

SPI Input

This section describes how to send a “command” to the MFAM through the SPI input. The available commands that can be sent are also listed.

SPI Input Packet Structure

Each SPI input packet should have 28 bytes with the following structure:

Name	Size(bytes)	Description
Identifier	4	0xF5A0C396 if command is to be sent, else X
Command	4	Defined in the Command Table
Param0	4	Optional, dependent on command
Param1	4	Optional, dependent on command
Reserved	12	Not Used

If a command is to be sent, the first 4 bytes must be 0xF5A0C396! Otherwise, all inputs are ignored. All commands and parameters not listed in the Command Table will also be ignored. Please note that the MFAM is looking for LSByte first in every word and MSBit first in every byte. For example, the Identifier 0xF5A0C396 should be sent as 96-C3-A0-F5 in the MSPI_DIN line (pin 9).

Command Table

Command (Hex)	Param 0	Param 1	Description	Extra Description
0	0/6		Change Serial Number Output in Aux Field "111" to Module SN (0) or Firmware Revision (6)	
1			Continuously cycle through all available S/Ns	
2	0	Reg value	Check page 16 of HMC 5983 datasheet for 3 bit Reg value. This is for legacy MFAM modules only.	Compass Config Range
3	0		Hibernate	Restore
	1			Initiate
4	0		Soft Reset	Start from Cell Heating
	1			Start from Laser Locking
	2			Reset Larmor Locking
5			FPGA Reset	
6			Factory Reset	
9*	2	0/1	Low Heading Error mode (0) / Low Noise mode (1)	
A*	0/1		Individual sensors (0) / Combined sensor (1)	

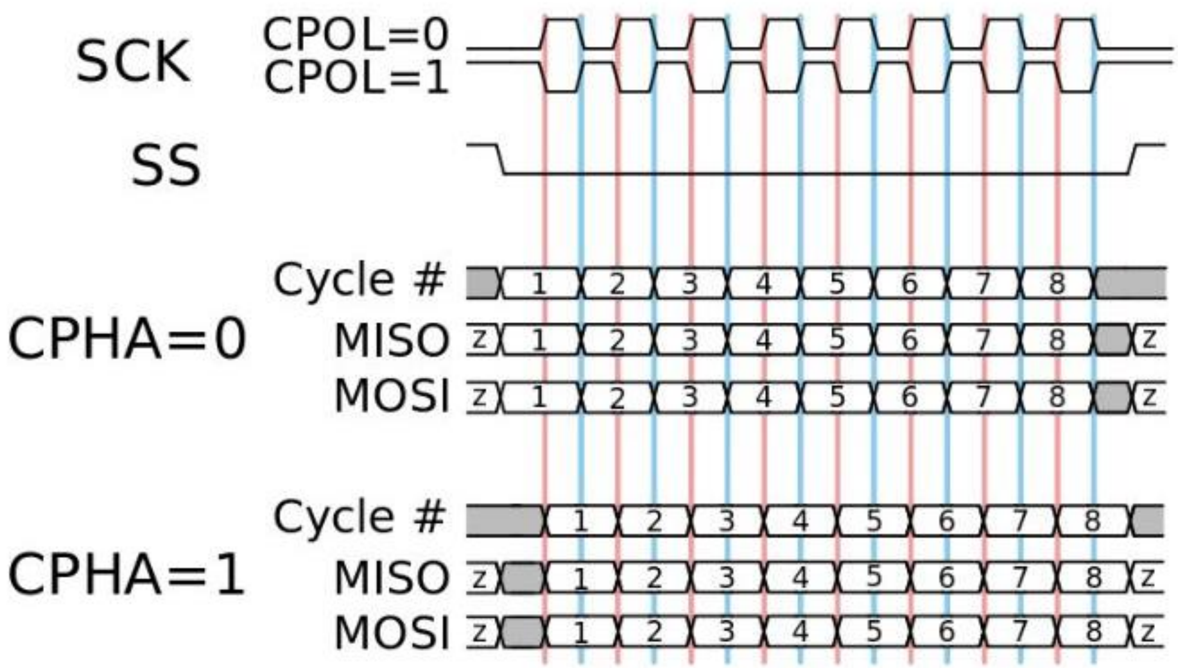
B*	0		Make configuration sticky if commands 2, 9 or A were used.	

*Not available for “Regular” MFAM modules (900-00394-01). “Regular” MFAM modules always operate in the low-noise mode. Command “0x9” + Param0 “2” + Param1 “0/1” can be used by “SuperMag” modules (900-00394-04) to switch between low-heading-error mode and low-noise mode. Command “0xA” + Param0 “0/1” can be used by “SuperMag” (900-00394-04) and “SX” (900-00394-05) modules to switch between two independent sensors and one combined sensor. With proper sensor orientations (please refer to individual Module Test Report), it is possible to achieve a dead-zone-free single magnetometer output. Note that command “0x9” and “0xA” ONLY change the runtime configuration. To set the current configuration as the default startup configuration, command “0xB” needs to be sent.

SPI Bus Hardware Description:

The MFAM is configured as a SPI bus Master using Mode 0 (Clock Polarity = 0, Clock Phase = 0). See timing diagram below:

Clock polarity and phase



A timing diagram showing clock polarity and phase. Red lines denote clock leading edges, and blue lines, trailing edges.

The previous image shows a single byte being transferred bracketed by the Chip Select (SS) signal. In the MFAM there are 28 bytes sent bracketed by a single Chip Select assertion. When the Chip Select line goes low the outgoing data line is asserted. The positive clock edge clocks the data in, the negative edges shift the data out. The first bit in every transmitted byte is the Most Significant Bit (MSB). The first byte in every transmitted word is the Least Significant Byte. Unlike the picture above, the Chip Select line goes high concurrent with the last negative clock edge.

The clock frequency is 1.25 MHz. To transmit a 28 byte packet takes just under 200 uS.

The logic levels for the MFAM SPI bus are 3.3 volt, but all inputs are 5 volt compliant. The inputs of the MFAM are protected against transients, and the outputs are short circuit protected.

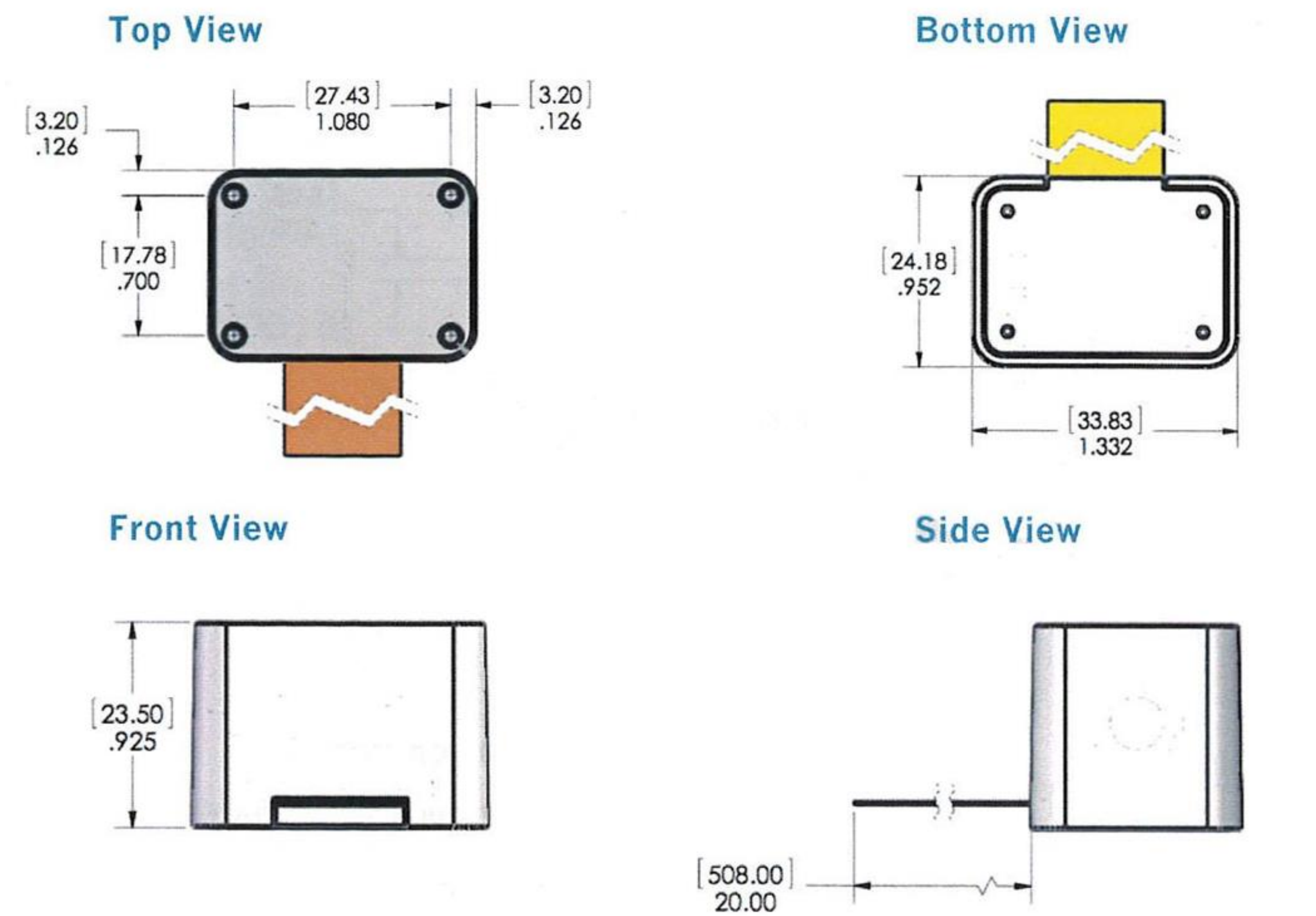
1PPS input:

This line is usually driven with a 3.3-volt pulse (it is also 5-volt compliant) at 1 Hz from a GPS. When present, the MFAM 1000 Hertz cycle-time timer will phase lock to the 1PPS positive edge such that there are exactly 1000 samples between each PPS positive edge. In addition, the center of the 1 mS sample period will also be coincident with the 1PPS edge. Thus two MFAMs running independently from each other, each receiving their own 1PPS pulse, will be in lock step with one another. Any sample skew is thus eliminated. The range of phase lock is very narrow at 1 hertz +/- 0.1%. Since this is usually from a GPS it will be exactly 1 hertz so the phase lock range need not be wide. Minimum pulse width is 50 nS.

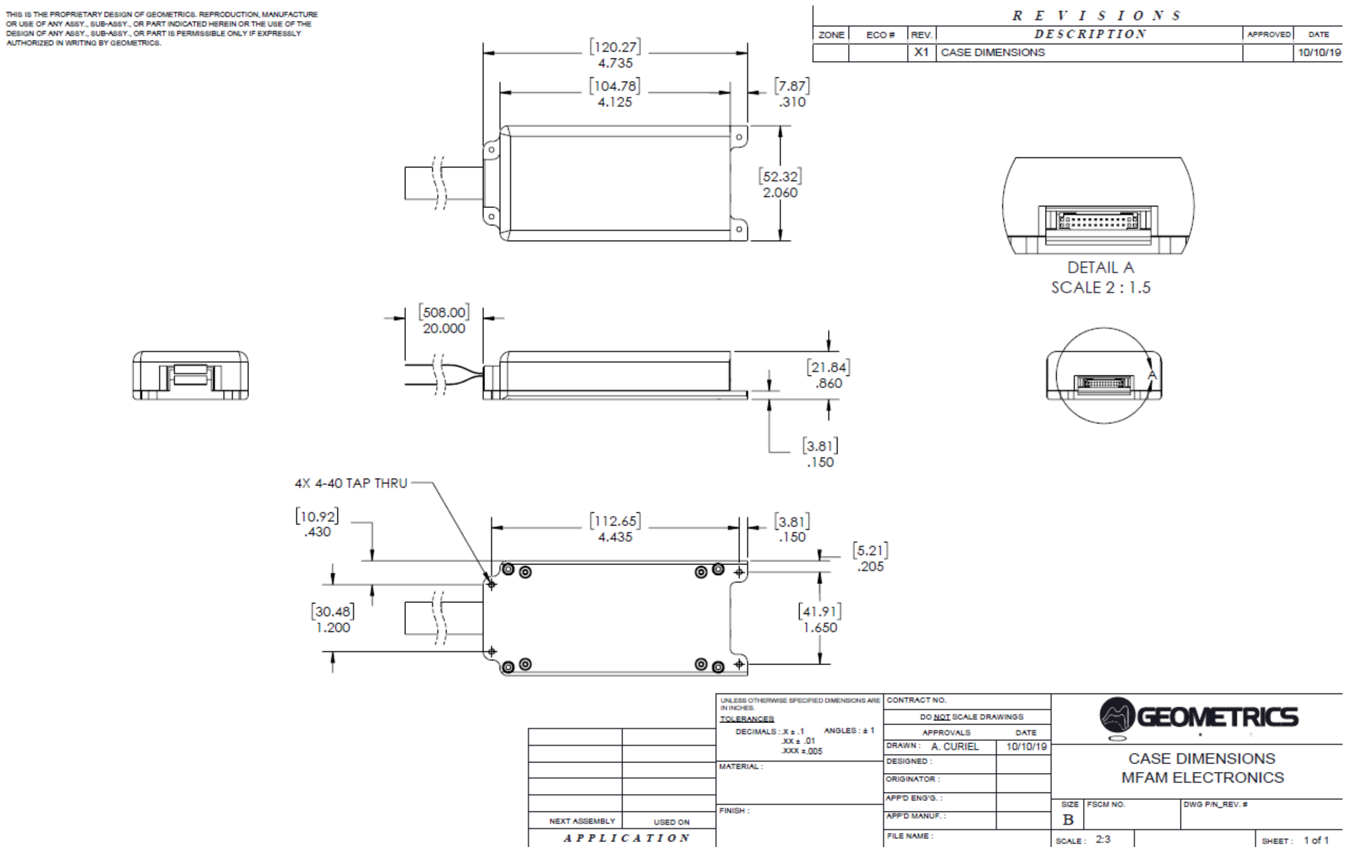
10 MHz Input:

When used, this optional input is driven with a 10 MHz square wave at 3.3 volts (it is also 5V compliant). It will cause the internal 40MHz master oscillator to phase lock to the incoming 10 MHz reference. The master oscillator is used as the timing reference to calculate the Larmor frequency and therefore the magnetic field value. This feature is used when it is desired to measure very low frequency changes on a stationary sensor in the earth’s magnetic field. By phase locking the master oscillator to an external frequency standard any thermal drifts in the internal master oscillator are eliminated. Without this it would be very difficult to separate small low frequency changes in the Earth’s field from thermal drift in the internal master oscillator frequency. The reference used for the 10MHz input is usually a GPS disciplined reference oscillator such as one made by Jackson Labs. The output of this external reference oscillator is a 100 mV 10 MHz sine wave which must be squared up before applying it to the MFAM module. This squaring up circuit is in the Development Kit (schematics for the Development Kit are available on request). The lock range on this Phase Locked Loop is very narrow at +/- 10 PPM.

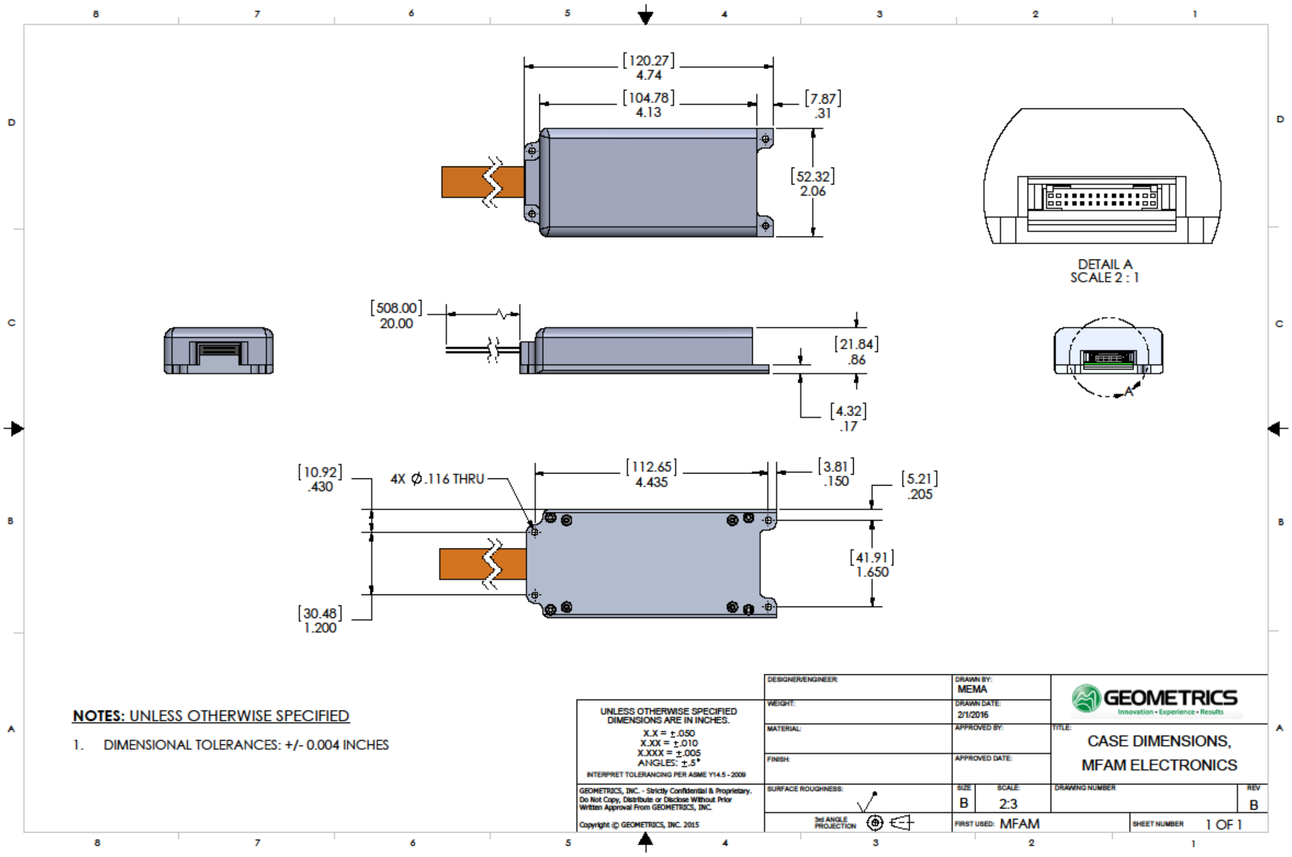
Sensor Dimensions



Module Dimensions

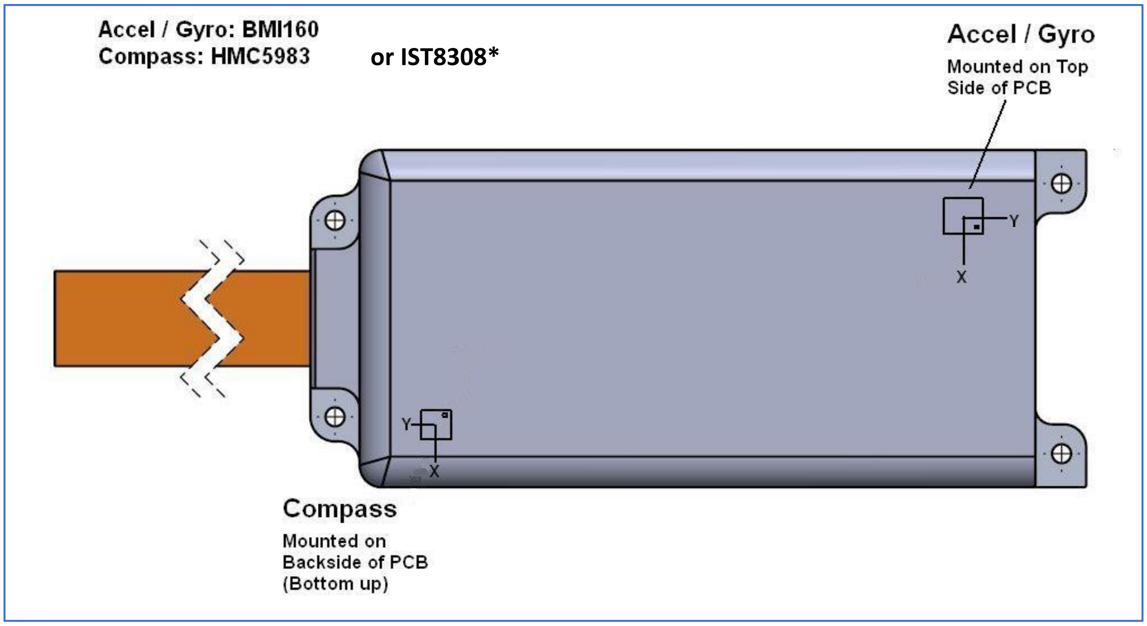


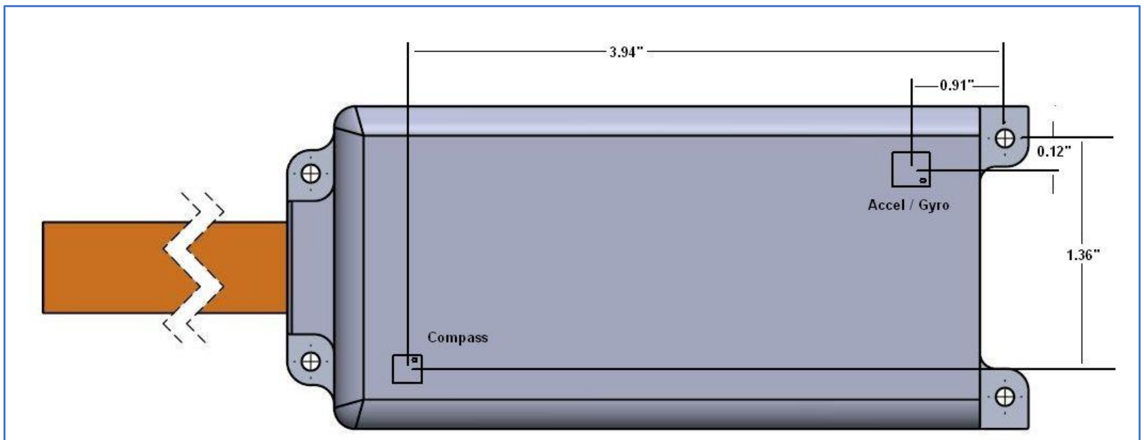
Or the following dimensions for earlier revisions.



Auxiliary Sensor Orientation and Axis Definition

The MFAM module contains an embedded Compass and a Gyro/Accelerometer in the electronics housing. The Figures below show the position and axis orientation of these sensors. Note that the Compass is mounted on the back side of an internal PCB, so when looking down from the top the part is bottom side up. This will need to be taken into consideration when trying to match X/Y axis when comparing with the data sheet (which shows the part right side up).





Auxiliary Sensor Locations

The Gyroscope is set up for +/- 2000 degrees/second, with a bandwidth of 74.6 Hz. Divide the 16-bit signed number by 16.384 to convert the raw value into degrees/second.

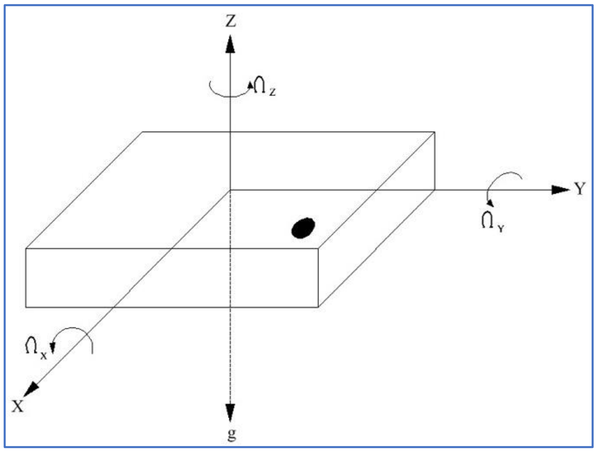
The Accelerometer is set to +/- 2G, with a bandwidth of 80 Hz. Divide the 16-bit signed number by 16384 to convert the raw value into G's.

The Gyro/Accelerometer temperature is also recorded. Divide the raw value by 512 and then add 23 to convert the raw temp data into degrees C.

The compass IST8308 has a total range of +/- 200 uT. The resolution is 75 nT per LSB. *

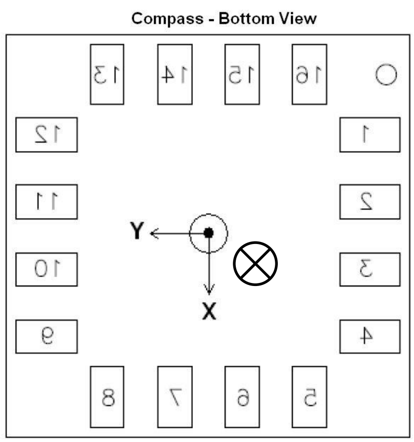
*Note that obsolete MFAM modules (Rev. B0 or earlier. Rev information can be found in SN xxxx**B0**xxxxxxxx) have a different compass HMC5983, which has a total range of +/- 88 uT with a resolution of 73 nT per LSB.

Here are the X/Y/Z axis definitions relative to pin 1 for the Gyro/Accelerometer. Note that pin 1 is marked on both the part below and on the chassis above.



If the sensor is accelerated or rotated in the indicated directions (along the arrow paths), the corresponding channels in the output data will indicate a positive acceleration and/or yaw rate. If the sensor is at rest without any rotation, and the force of gravity is acting counter to the indicated arrows, the output of the corresponding acceleration channel will indicate a positive value.

The compass' X/Y axes are defined as shown in the figure below. Note that the compass is shown bottom side up, as it is mounted in the MFAM module when looking down through the top. The Z Axis is pointing down, through the bottom of the MFAM module.



When an applied magnetic field is in the direction of the X, Y, or Z arrows a positive field value will be reported.

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