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MFAM Ethernet Adapter

User Guide

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1.0 INTRODUCTION:

What Magnetometers Do

A Magnetometer measures the Earth's magnetic field, which occurs naturally and varies in the presence of ferrous materials. Magnetometers are used in a variety of applications and can be fitted to airborne, marine, and land-based surveys.

Geometrics is a leader in magnetometer development and is known worldwide for our total field magnetometers. Our magnetic sensors measure the total magnetic field, or total field, without directional information. In other words, they take the scalar measurement of the magnetic field, and produce a value that is the magnetic field intensity, regardless of the direction in which the field propagates. More information is provided in section 3.0 SENSOR INSTALLATION AND OPERATION.

Magnetometers can be used to map and locate man-made objects and naturally occurring iron or other ferrous metals. For example, the earth's crust contains iron in the form of the mineral magnetite. Magnetometer surveys are frequently used to map concentrations of ferrous minerals in the earth's crust. Magnetite is a mineral often associated with kimberlites (diamonds), native gold, copper and other economic deposits.

Man-made ferrous objects, such as those associated with archaeology, civil engineering, unexploded ordinance, etc., alter the earth's magnetic field in a way that is detectable with a magnetometer. The strength of the altered field depends on many factors, including the object's size, iron content, orientation and depth.

WHAT IS THE MFAM?

MFAM is an acronym for Micro-Fabricated Atomic Magnetometer. Geometrics' highly anticipated MFAM is a miniaturized scalar atomic magnetometer (sensing module) built for the purpose of measuring changes in the earth's magnetic field associated with both natural and man-made phenomena. The MFAM Sensing Module includes two laser pumped cesium sensors connected to the sensor driver electronics via flex cables. These flex cables are circuits and an integral part of the system and cannot be removed or replaced.

The MFAM is a miniature scalar atomic magnetometer that makes the performance of much larger commercially used geophysical magnetometers accessible for UAS platform integration. This is made possible by its small size (1 cubic inch for the sensor), light weight (0.5 lb.) and low power consumption (2.5W per sensor). With a typical sensitivity of 1pT/√Hz, the MFAM brings the detection capability typically associated with ground-based surveys to the air. A high sampling rate of 1 kHz (1000 Hz) not only allows for fast sampling at a high spatial resolution and at high speeds, but also enables direct measurement of high frequency magnetic noise caused by rotary aircraft, thus avoiding aliasing artifacts in the data. This fast-sampling rate also allows for direct measurement of 60Hz fields. The MFAM sensing module is designed to be easily integrated as a component in versatile multi-sensor systems which are commonly found in UAS. Each module has two sensors, providing flexibility for configuring redundancy or for canceling run-time measurement systematics. See the MFAM Specifications listed in Appendix D: MFAM SENSING MODULE LCS050G SPECIFICATIONS*.

THE MFAM Ethernet Adapter

The Geometrics MFAM Ethernet Adapter is a versatile, easy-to-use and compact interface board that allows system developers to quickly design custom applications using the MFAM magnetometer sensor. The board converts data input and output from the MFAM driver into Ethernet protocol. With a standard RJ45 connector, the adapter allows easy integration of the MFAM with other systems. Using the adapter and appropriate housing allows the MFAM magnetometer system to be used for land, airborne or even marine survey applications.

2.0 ETHERNET ADAPTER BOARD OVERVIEW

The MFAM Ethernet Adapter is powered by a Texas Instruments TIVA TMC1294NCPDT microcontroller. **Please handle the adapter board in an electrostatic discharge (ESD) safe environment because the microcontroller chip is extremely ESD-sensitive.** A photo of the adapter with a MFAM is shown in Figure 1. Please note that the adapter board fits ONLY Rev.B MFAM aluminum cases (4 tapped 4-40 holes with 0.15” baseplate thickness). Rev.A cases have through holes with 0.17” baseplate thickness. Due to the extra thickness, the rear mounting part of Rev.A baseplate interferes with the Ethernet adapter board.

Figure 1: Ethernet Adapter Board with MFAM Sensor Module

Input and Output Connections

The adapter board has the standard RJ45 connector as the output port.

The input connectors are from Molex. The input connection information is listed in the table below.

Table 1 Input Connection Information

Label	Function	Input Connections	Mating Connectors
J101	Power Input	Pin1 (square pad) is Positive voltage; Pin2 is Ground 9.5 to 15 V DC power	Connector Molex P/N: 0022013027 Pin Molex P/N: 0008650805
J102	1PPS Input	Pin1 (square pad) is Positive voltage; Pin2 is Ground	Connector Molex P/N: 0022013027 Pin Molex P/N: 0008650805
J304	Analog Input	Pin1 (square pad) and Pin2 (middle pin) are Analog inputs; Pin3 is ground; -2.5 V to +2.5 V full range	Connector Molex P/N: 0022013037 Pin Molex P/N: 0008650805

Micro-SD Card

The micro-SD card is mainly used to update the TIVA code and change the IP parameters.

To update the TIVA code, remove the SD card and plug it into a PC. Copy the btb.bin file (rename it to btb.bin) provided by Geometrics to the SD card root directory. Eject it from the PC and plug it back into the Ethernet adapter board. After powering up the board, the btb.bin file will be automatically updated (and deleted afterwards if the update is successful).

The default parameters are **IP = 192.168.0.2; Mask = 255.255.0.0; Port = 1000**. If a set of different parameters are preferred, for example IP = 192.168.2.23; Mask = 255.255.255.0; Port = 2100, open the geometrics.cfg file inside the micro-SD (in case the file is missing, create a txt file and rename it to “geometrics.cfg”. Copy it to the micro-SD card) and set its content to:

```
StaticIP=192.168.2.23
IPMask=255.255.255.0
TcpStreamingPort=2100
```

Please note that any line starting with “;” is for comment only and will NOT be read by the TIVA code. Please make sure to change the local network setting accordingly (same subnet) if you change the IP.

Remote Software Update

If it is hard to access the micro-SD card after system integration, the TIVA code can be updated remotely. Connect to http://192.168.2.9/uploadupdateform.htm (replacing 192.168.2.9 with your IP).

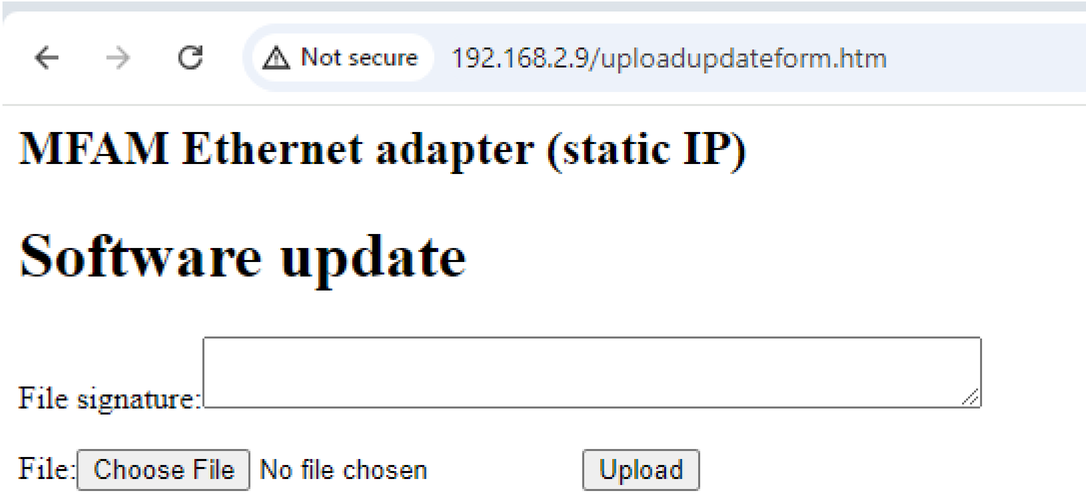


Figure 2: Remote Software Update

- Click “Choose File” and select the .bin file. You don't need to rename to btb.bin.
- Copy the text in the SHA file and paste it (with no trailing spaces or line feeds) into the File Signature on the webpage.
- Click “Upload”. After several seconds, you should see the message "Instrument update loaded. Restart instrument to finish update.". Power cycle to finish the software update.

Data Logging and Displaying Program

Geometrics provides a LabVIEW based program, MagViewMFAM, to gather and display the Ethernet data from the adapter board. More information can be found in section 4 and 5.

Customers can also find example C programs by visiting our Forum online (searching for MFAM packet).

3.0 SENSOR INSTALLATION AND OPERATION

The particular installation requirements must be met in order to obtain the best performance from the system. These installation requirements will depend highly on the geographical location of the magnetic survey.

Although the MFAM measures the total field intensity of the earth’s magnetic field, magnetic fields in general are vector fields. The total field is the sum of the three components as projected onto the earth’s field vector which is roughly vertical at the poles and horizontal at the magnetic equator. At any point, the field is defined by its magnitude and direction. Unless the sensor is very near highly magnetic objects, the local magnetic field will be almost entirely due to the earth’s magnetic field. In order for the MFAM to accurately measure the local magnetic field magnitude, it must be properly oriented relative to the local magnetic field direction.

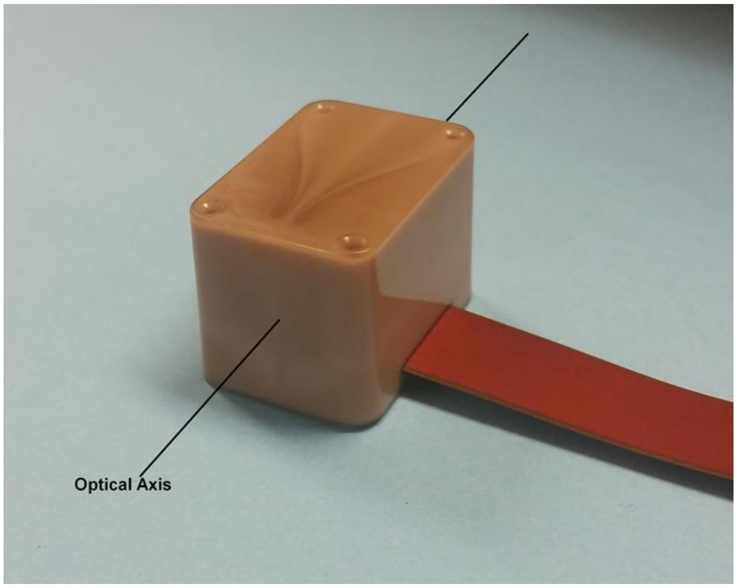


Figure 3 Optical Axis of the MFAM Sensor

The MFAM sensor has one polar dead zone. If the sensor's optical axis is lined up within +/- 35 degrees of the earth's magnetic vector, little or no signal is generated. No signal or low signal indicates that the local magnetic field inclination angle (vector) is intersecting the sensor's polar dead zone. Outside of the polar dead zone, the magnitude of the earth's field will be measured pretty much independent of the orientation. The optical axis of the sensor is shown in Figure 3 above.

Note: Traditional cesium magnetometers have two dead zones – polar and an equatorial dead zone – however, one of the advantages of the MFAM is that it has just the polar dead zone.

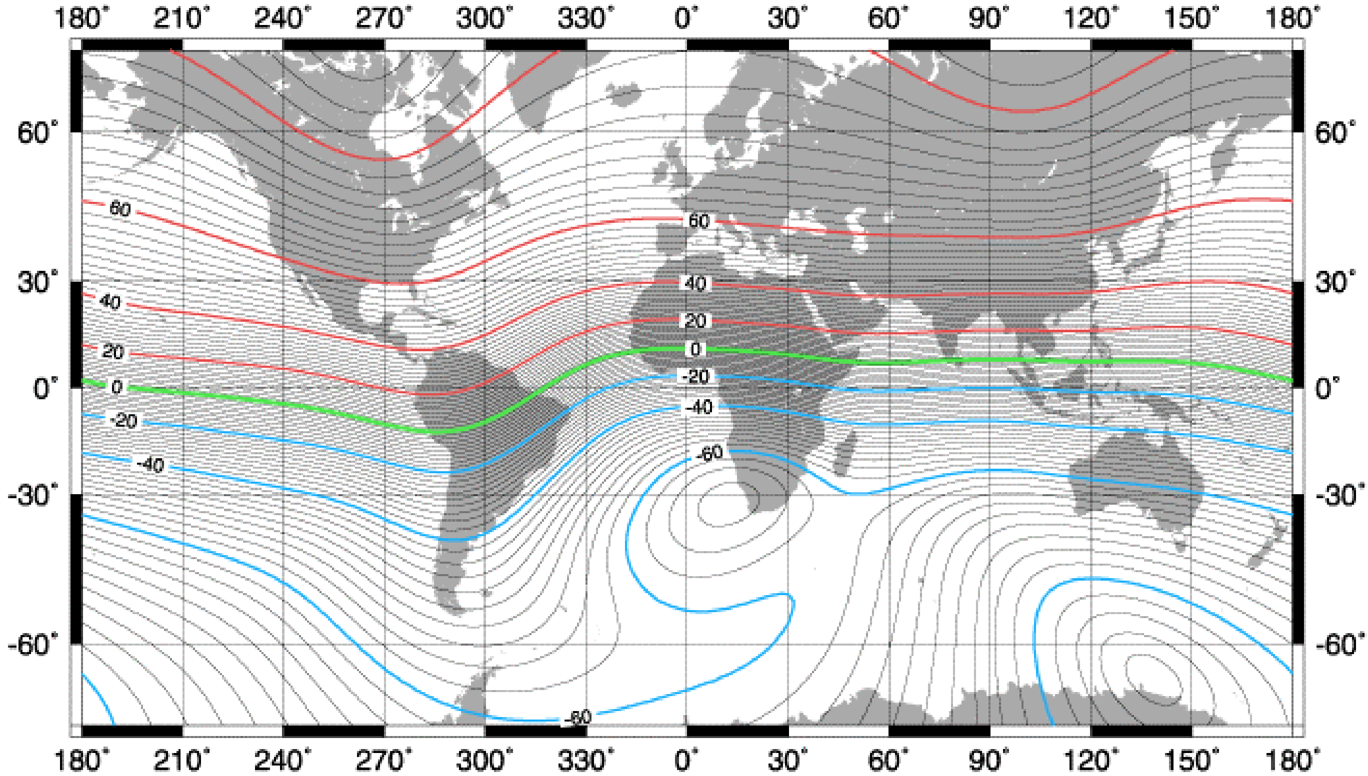


Figure 4 Earth's Magnetic Field Inclination

The earth's vector varies depending on where you are on the planet. See Figure 4, which shows magnetic field vectors (inclination angles) across the globe.

The earth's magnetic field can be modeled using a large bar magnet in the center of the earth. The resulting field at the surface of the earth can be represented like this:

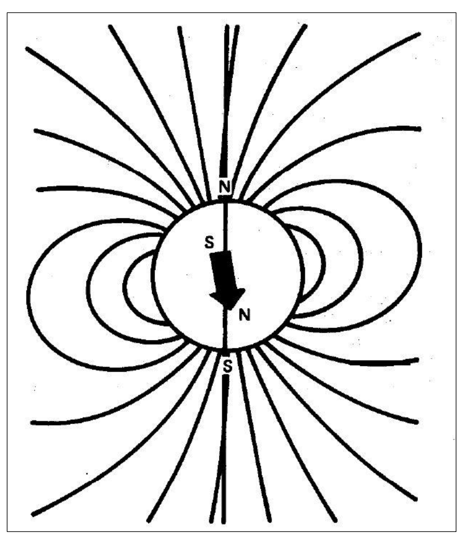


Figure 5 Illustrating Magnetic Field Vector/Inclination Angle at the Earth's Surface

At the magnetic equator, the earth's magnetic vector is horizontal to the earth's surface. At the magnetic poles, the field is vertical. Between these extremes in the northern hemisphere, the earth's magnetic vector is pointing south at an angle somewhere between 0 and 90 degrees from horizontal. In the southern hemisphere, the earth's magnetic vector is pointing north somewhere between 0 and 90 degrees from horizontal.

To get maximum signal, the earth's magnetic vector should be at right angles to the optical axis (shown in Figure 3). Thus, if the sensor and cable is oriented such that the cable is laid flat on a horizontal surface, and the cable is oriented in a north/south direction along the cable length, then the earth's magnetic vector will always intersect the optical axis at right angles regardless of where you are on the planet.

For Optimal Signal, orient the sensor cable lengthwise in a North/South direction, thereby orienting the sensor's Optical Axes at right angles to the local magnetic field vector. *

If you are only interested in only one magnetometer reading from the MFAM the two sensors can be oriented such that the intrinsic heading error of each sensor is similar and opposite to the other. Thus if the two sensors are positioned right next to each other, oriented correctly to get equal and opposite heading errors, and the two sensor values are averaged to produce a single magnetometer reading, then the result will have significantly less heading error than either sensor reading by itself.

Figure 6 shows the proper orientation of the sensors to get heading error cancellation in both Low Noise mode and Low Heading Error mode[1]. Note how the flex cables travel away from the sensors in opposite directions. In Low Heading Error mode, a simpler sensor orientation can also achieve heading error cancellation, as shown in Figure 7

Figure 6 Orienting Sensors for Heading Error Cancellation in both Low Noise Mode and Low Heading Error Mode.

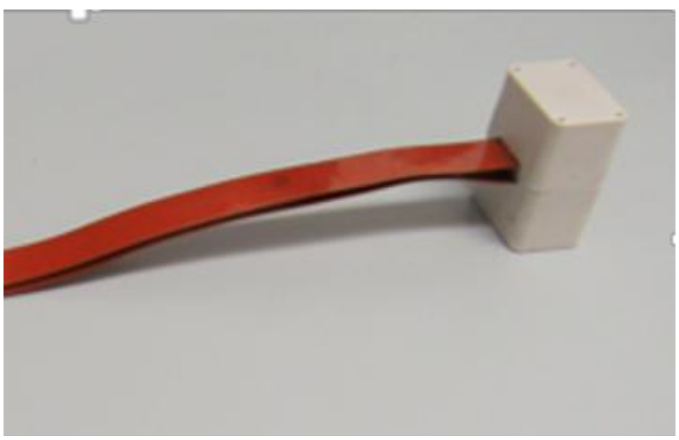


Figure 7 Orienting Sensors for Heading Error Cancellation in Low Heading Error Mode.

[1] Low Heading Error mode is NOT available for Regular MFAMs. More information can be found in MFAM Module User Guide.

4.0 MAGVIEWMFAM EXAMPLE SOFTWARE

MagViewMFAM Version 1.3.2:

This example software allows customers to gather Ethernet data from the MFAM and view the data in real time. The magnetometer and gradient data are plotted graphically as a function of time. Both the time axis and amplitude axis are adjustable via pull down menus. In addition, the FFT plots of the two magnetometers and gradient are plotted as well in a separate graph on Page 2 of the Control Panel.

Several other windows display the values of additional data fields. These include:

1) MFAM S/N
2) MFAM Firmware Version Number
3) Fiducial Count
4) Mag and System Status Words
5) Compass Data (scaled to nT in all three axis', plus device temperature)
6) Accelerometer Data (scaled to G level in three axis', plus device temperature)
7) Gyro Data (scaled in degrees rotation per second for all three axes, plus device temperature)
8) FPGA Temperature (degrees C)
9) Supply Voltage (volts)
10) Cumulative MFAM Run Time (hours)
11) GPS Data (not available)
12) GPS Status (not available)
13) Analog Channels (volts)

Minimum System Requirements:

Windows 7 operating system (or higher)
A display with a resolution of 1920 x 1080 (HDMI) or higher

5.0 INSTALLING AND RUNNING THE EXAMPLE SOFTWARE

Installation:

1) Install the LabVIEW Runtime Engine (setup.exe and all associated files located on the supplied USB stick)
2) Create a folder on your hard drive and name that folder “MagViewMFAM” (Example: “C:\MagViewMFAM\”) and copy the file MagViewMFAM_V1_3_2_Standard.exe into this folder (also located on supplied USB stick)
3) Create a shortcut to this file (right click on file, select “Create Shortcut”)
4) Drag the shortcut to the desktop

Operation:

1) Connect the adapter to the computer using the Ethernet cable. If your computer does not have an Ethernet port (or if you need the existing one for other uses) you can use a USB to Ethernet adapter.
2) Setup the Computer Ethernet port to a fixed IP address as outlined in Appendix A: CONNECTING THE ADAPTER VIA ETHERNET.
3) Power up the MFAM (using the provided AC adaptor is the easiest method)
4) Double click the Shortcut on the computer desktop
5) Make sure the IP and port (1000) match the adapter. Click the Run (little arrow on the top left corner)

The program will run, and the "Connected to MFAM" status LED should light up green. The MFAM may need several minutes to warm up before it will start outputting valid data. If the program stops due to errors (like the Ethernet cable is disconnected for example) then restart the program by clicking on the Arrow icon in the upper left corner of the screen.

To stop the program, click on the “Stop” button next to the “Page 4” tab on the program Control Panel. **Doing this will close the program window**.

Display Traces:

There are four traces that can be plotted on the display on page 1 of the Control Panel:

1) Magnetometer 1
2) Magnetometer 2
3) The difference between Mag 1 and Mag 2 (Gradient)
4) One of the four analog channels (channel 0 through 4)

The time base and the full scale amplitudes for the graphical plots are user selectable via pull down menus on page 1 of the Control Panel. If an analog channel is displayed the full scale value is set to the full range of the analog input (i.e. -2.5V to +2.5V for channels 2 and 3).

The display sample rate is also user selectable via a pull down menu. The data coming out of the MFAM module is fixed at 1 KHz. If a lower sample rate is selected the 1 KHZ data will be averaged over the sample period and then output. For example, if a sample rate of 20 hertz is selected, 50 1 KHz samples from the MFAM will be averaged and sent out every 50 millisecond.

Screen Modes:

There are a few options for displaying the magnetometer data graphically:

1) **Split Screen Mode (default):** In this mode there are two screens (top and bottom) when one screen fills up it clears the other screen then switches to it.
2) **Single Screen Mode:** In this mode there is only one large screen. As the magnetometer data fills the graph to the right edge, the graph scrolls to the left. To enter this mode click on the "Split Screen" toggle switch located on Page 1 of the Control Panel. Click on the toggle switch again to switch back to Split Screen mode.
3) **Full Screen Mode:** Both Split Screen and Single Screen modes can be expanded to take up the whole display (covering up the Control Panel). Toggle between Full Screen and Normal Screen modes by clicking on the Full Screen Switch on the lower left corner of the Magnetometer Display Graph.
4) **FFT Graph:** A FFT (Fast Fourier Transform) graph is displayed for both magnetometers plus the difference (gradient) between them on Page 2 of the Control Panel. It is updated once per second.
5) **Overlap Mode:** As the magnetometer plot goes past the top or bottom of the screen it wraps back around to the other screen edge so that when zooming in on the magnetometer data it is always on screen. If the magnetometer readings fall right on the top or bottom edge of the screen the displayed trace is half on the top edge and half on the bottom edge. To keep this from happening, invoke the “Overlap” mode by clicking on the “Overlap” toggle switch on Page 1 of the Control Panel. The screen divisions are scaled to 120% of full scale, and the top 20% overlaps the bottom 20%. This puts hysteresis in the wrap points.

Commands:

At the bottom of page 1 of the Control panel is a MFAM Command box. This allows a few commands to be sent to the MFAM console:

1) **MFAM Info:** There is an auxiliary data channel in the MFAM output data stream that can have either the MFAM Serial Number or the MFAM Firmware Version Number. This command selects which data value to insert into the auxiliary data field.

2) **Configure Compass:** The magnetic compass built into the MFAM has selectable full-scale values. By default, the full-scale value is 0.88 Gauss (the most sensitive), but this command allows the user to raise it to higher (less sensitive) levels. The following full scales values can be selected: [0.88G, 1.3G, 1.9G, 2.5G, 4.0G, 4.7G 5.6G, 8.1G]. Please note that this only applies to Rev.A MFAMs.
3) **Hibernate:** When the MFAM is put into hibernate mode all servos stop. When coming out of Hibernate mode it will take a couple minutes before the MFAM produces valid magnetometer data.
4) **Soft Reset:** There are two soft reset choices: From Cell Heating, and From Laser Locking. These choose how far back in the startup process to restart from. From Laser Locking is the closest to the end of the startup process.
5) **FPGA Reset:** This starts the startup process from the beginning (like at initial power up).
6) **Factory Reset:** This deletes the current firmware and goes back to the original factory installed firmware. This should only be used as a last resort – such as recovering from a failed firmware update. Because this command can cause major changes in the firmware it is password protected. If this command is ever needed contact the factory for a password to invoke this command. Passwords expire two days after being issued.

Printing Graphs:

To make a printed copy of any of the MagViewMFAM Graphs click the "Print" switch on the bottom edge of the desired graph. This will generate a png format picture file in the "C:\MagViewMFAM\" folder. Then it will call the Microsoft Paint in command line mode and instruct it to print the png file to the computers default printer.

Make sure you have setup a default printer before using this function. Also make sure that you have created a C:\MagViewMFAM folder. If desired you can overwrite the path to the png file (the path is displayed next to the "Print" button) if you want it to be stored elsewhere. You can also change the default file name in the same path window.

In the case of "Split Screen" mode, two picture files will be generated: "Picture(top).png" and "Picture(bot).png". Both will be sent to the default printer.

Writing Data to File:

Page 3 of the Control Panel selects what and how data gets written to disk. There are two methods that can be used to write to disk, and they are quite different in their implementation. There is a binary write box and an ASCII write box. These two write methods operate independently of each other. You can use one or the other, or both at the same time. Just keep in mind the differences in how the data is processed and stored as outlined below:

<u>Binary Format:</u> Binary saves always stores data to disk at the 1 KHz rate straight out of the MFAM module. It is not altered by filter settings, sample rates, or any other setting within the MagViewMFAM program. It is always straight raw 1KHz data from directly from the MFAM module.

To save binary data click on the "Write to Binary File" button on page 3 of the Control Panel. The button will turn green indicating that the data is being stored to disk. The file name is generated automatically based on Date and Time. Alternatively there is another "Write to Binary File" located at the bottom of the magnetometer data graphical display. Either button does the same thing. To stop writing to disk click one of the "Write to Binary File" buttons again and the and it will turn gray, indicating that writing to disk has stopped. The last file name of the data written to disk is remembered and displayed in the "Last File Name" window on page 3 of the Control Panel.

Writing 1 KHz data can quickly make huge files. If it is desired to have the data files broken up into smaller chunks then click on the "Break Binary Files into Chunks". The button will turn green indicating that the files will be broken into smaller blocks. A pull down menu allows the file size / time for each block to be chosen. At the transition from closing one file and opening the next no data will be lost.

<u>ASCII Format:</u> To save ASCII data to disk click on the "Write to ASCII File" button on page 3 of the Control Panel. It will turn green and a file will be opened with a name based on the date and time. Or click the button on the bottom of the

magnetometer data graphical display. Both buttons do the same thing. Clicking either button again will stop saving the data and close the file. The buttons will turn gray to indicate that writing to disk has stopped.

The data stored to disk is all ASCII characters. The fields are all comma delimited.

Unlike the Binary Saved Files, the ASCII files are saved at the selected sample rate. If the sample rate is set to 10 hertz then it will store 10 samples per second to disk. In addition, if any filters are set then the stored data will be filtered data. What gets stored is the same data that is being shown in the magnetometer display.

You may select which fields to save to disk on page 3 of the Control Panel by clicking on the selection buttons in the "File Write Additional Fields" box. These data fields include:

1) The Fiducial Count
2) System Status (written as a 4 digit hexadecimal number – i.e. 'A06F')
3) Mag 1 Status (written as a 4 digit hexadecimal number)
4) Mag 2 Status (written as a 4 digit hexadecimal number)
5) Analog Channel 1 (in volts)
6) Analog Channel 2 (in volts)
7) Analog Channel 3 (in volts)
8) Analog Channel 4 (in volts)
9) Gyro Data (3 channels: X, Y and Z in Degrees per Second, plus a fourth channel that specifies the device temperature in degrees C)
10) Accelerometer data (3 channels: X, Y and Z in G's, plus a fourth channel that specifies the device temperature in degrees C)
11) Compass Data (3 channels: X, Y and Z in nT, plus a fourth channel that specifies the device temperature in degrees C)
12) The Date (MM/DD/YY)
13) The Time (HH:MM:SS [UTC time])
14) The Time Stamp Status - A single hexadecimal character:
    a. Bit 0x8: When set indicates the cycle rate is phase locked to 1PPS
    b. Bit 0x4: When set indicates that the 1PPS pulse is being received
    c. Bit 0x2: When set indicates that the GPS position fix is valid
    d. Bit 0x1: When set indicates that the GPS RMC sentence is being received
15) GPS Data (GPRMC String)

The GPS string (if selected for saving to disk) will always be the last item saved in the comma delimited sample line. This data comes out once per second. For faster sample rates the GPS String will be recorded with sample where it occurred. All other samples where a GPS string did not arrive will not have GPS data saved.

In the "File Write Additional Fields" box there is a button called "Trim Fields". When not clicked (button will be gray) all saved fields will have a constant character length – padded with blanks as required to keep the field length constant. This allows for all the fields to line up in columnar fashion if viewed in a word processor with a fixed font. Thus the fiducial field will always have four characters in every sample, the Compass X, Y, and Z fields will always have 8 characters, etc. The exception to this is the GPS string (always the last field stored in each sample), which by definition has variable length comma delimited fields, and is only recorded to disk when a new GPS output string occurs.

If the "Trim Fields" button is clicked (button will be green) all fields written to disk will have the extra spaces removed to save disk space.

Saved ASCII files can be broken into smaller contiguous files based on time. To do this click on "Break ASCII File Into Chunks" (it will turn green) and Select the length of time for each file from the "ASCII File Time" pull down window.

Configuration Save/Retrieve:

In the C:\MagViewMFAM directory there is a file called “Config.txt”. When the MagViewMFAM program is started this file loads and sets all of the configuration settings in Pages 1 through 4 on the Control Panel to the values that were last saved. If the config.txt is not present, a new config.txt will be generated and set to default values.

Once you have MagViewMFAM configured the way you like click the “Save Configuration” button on page 3 of the Control Panel. Then the next time MagViewMFAM is started up, it will reload all of the configuration settings as they were when the configuration was saved automatically.

If you change the configuration and want to go back to the last saved configuration, click on the “Load Configuration” button.

Filters:

On Page 2 of the Control Panel is a Filter Setup Box. There are three filters that can be set up to filter the magnetometer data:

High Pass Filter:

Select from:

1) Off
2) 0.1 Hertz
3) 0.2 Hertz
4) 0.5 Hertz
5) 1 Hertz
6) 2 Hertz
7) 5 Hertz
8) 10 Hertz
9) 20 Hertz
10) 50 Hertz

Low Pass Filter:

Select from:

1) Off
2) 1 Hertz
3) 2 Hertz
4) 5 Hertz
5) 10 Hertz
6) 20 Hertz
7) 50 Hertz
8) 100 Hertz
9) 200 Hertz
10) 500 Hertz

Notch Filter:

Select between 50 and 60 hertz, and On or Off. This filter is actually three filters in series. For the 60 hertz notch filter, the three filters notch out 60, 120 and 180 hertz. For the 50 hertz notch filter, the three filters notch out 50, 100, and 150 hertz.

Stacked Magnetometer Data (Control Panel Page 4):

The Stacked Magnetometer Data (page 4 of the Control Panel) is a specialized setup which was written to measure and record the magnetic field produced by a human heart (called Magneto Cardiography). This has been done before using squid magnetometers in a shielded room, but we wanted to demonstrate the MFAM magnetometer making this measurement in an ordinary office environment.

The magnetic field from a heartbeat is very small – about 50 picoTeslas peak to peak. This is well below the noise level of a typical office environment, so what we did was to record a couple hundred heartbeats, line the data from each heartbeat up, and add them together (synchronously stacking the heartbeat data). Since the heartbeats are coherent they add up proportional to the number of beats. For example adding together the data from 100 heartbeats would make a heartbeat signal 100 times bigger.

Noise, on the other hand, being random will grow proportional to the square root of the number of heart beats. Thus 100 stacks will grow the noise by 10 times (compared to a 100 times growth in heart beat signal. Therefor with a sufficient number of stacks the heartbeat magnetic signature will grow out of the noise floor and become visible.

Setup: To measure the magnetic signature of the heart two MFAM sensors were mounted 1 inch apart and then placed close to the chest wall of the patient being measured. The two sensors were oriented such that one sensor was very close to the heart while the other sensor was 1 inch further out. The idea is to have the sensor close to the heart get a bigger magnetic signature of the heart than the second sensor, but magnetic noise sources much further away (such as power line currents) will produce the same signature in both sensors. Looking at the difference between the two sensors will enhance the heartbeat signature, and partially cancel far away noise sources.

The patient must remove all magnetic material on their person, and must be positioned on a nonmagnetic platform.

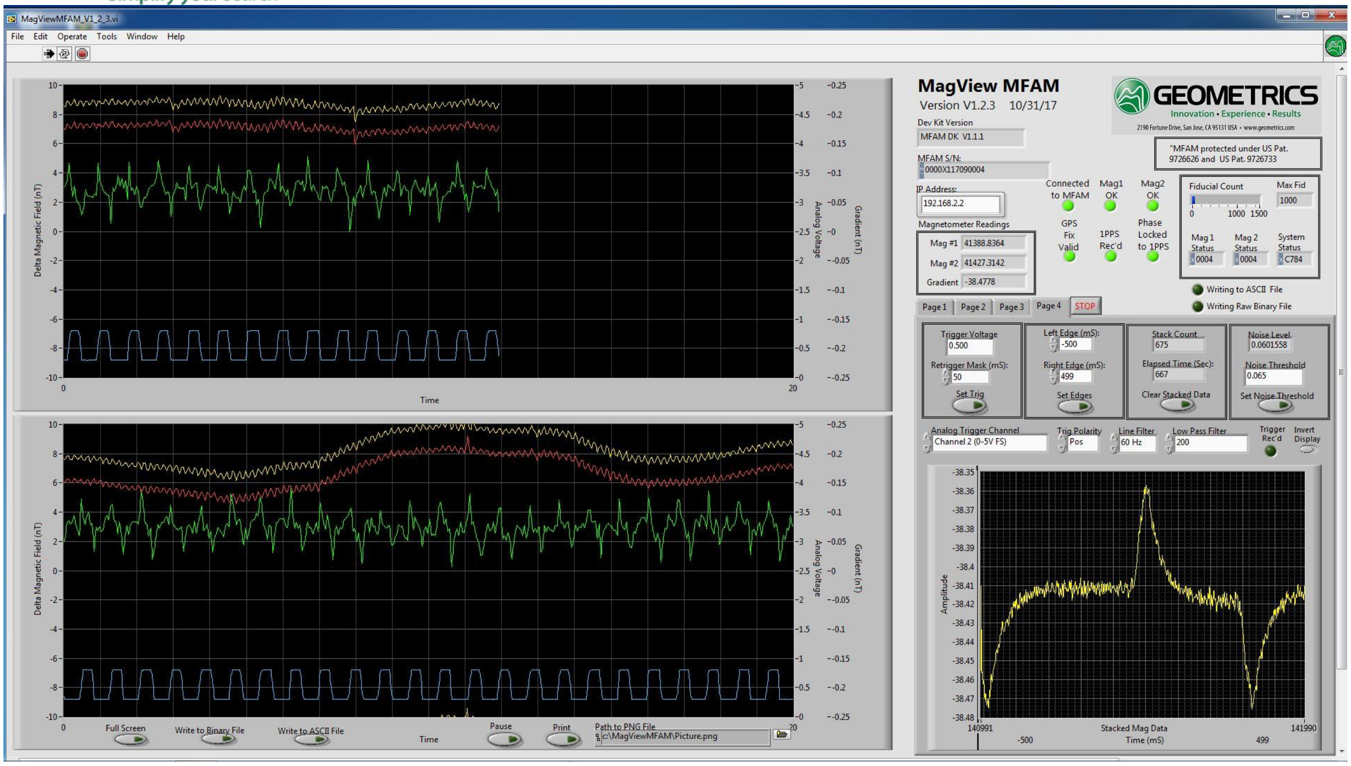
Heartbeat synchronization: To line up all the heartbeats for stacking, an Electro Cardiograph (ECG) machine is hooked up to the patient's left and right shoulder and lower left abdomen. These electrodes pick up electrical voltages from the heart from which the ECG machine makes a trigger signal that identifies the precise timing of the heartbeat.

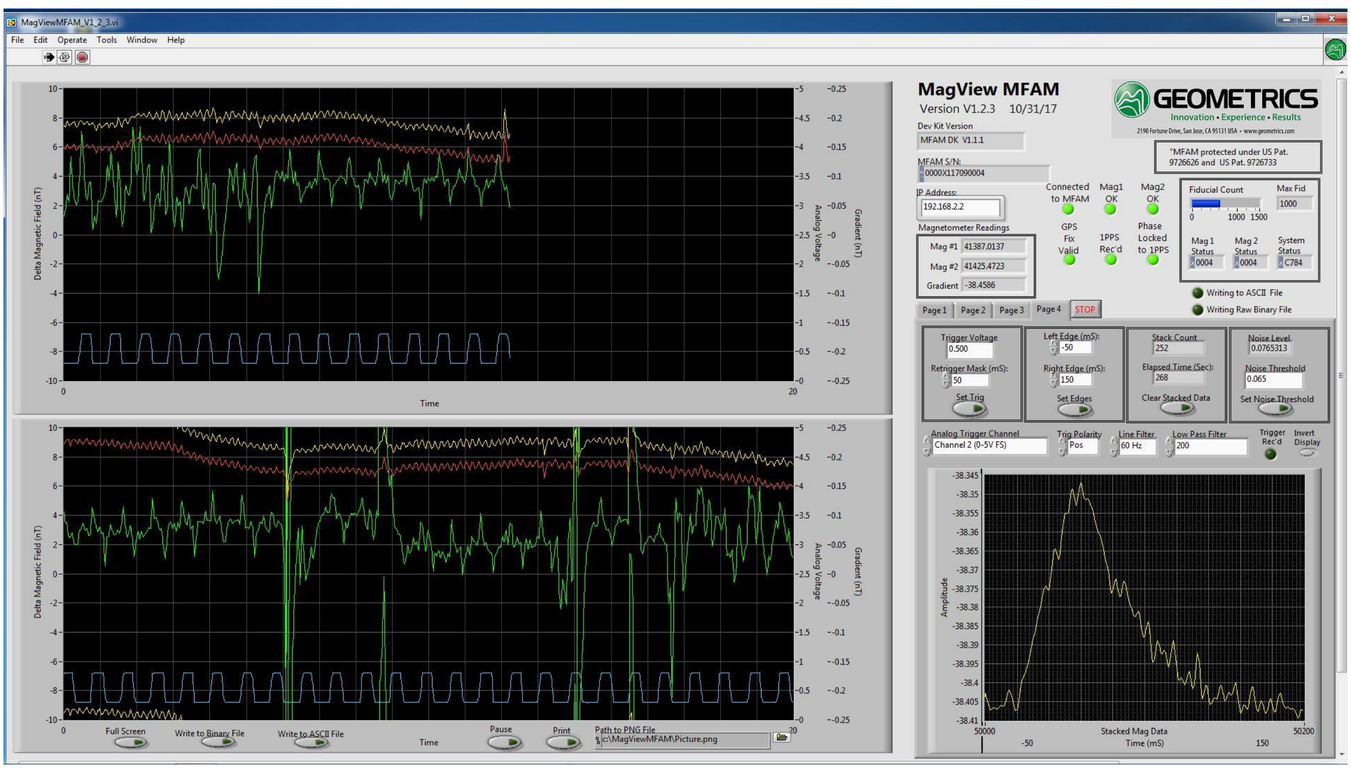
This trigger signal is sent to an analog input in the MFAM Ethernet Adapter where it is digitized at a 1 KHz rate and combined with the 1 KHZ data from the MFAM module and transmitted in the Ethernet data packets.

Page 4 of the Control Panel: Below are two screen shots showing page 4 of the Control Panel. A simulated heartbeat has been made by differentiating the trigger signal and feeding a small current into a small coil. The amplitude of the magnetic field from the coil is similar in amplitude to a heartbeat when place a couple inches from the MFAM sensor pair.

The first thing to do is set up the trigger level and polarity to start the heartbeat stacking process. Then with each trigger (assuming everything else is OK) the heartbeats will stack, and over time the heartbeat signature will grow in the stacked data window.

The first screen shot shows a full 1 second of stacked data (500 mS before the trigger and 500 mS after the trigger, and second one shows the stacked data window zoomed in to one edge of the simulated heartbeat.





The stacked data display is auto scaling, so that it will always take up the full height of the display. Each stack is triggered off of an analog channel which is selected on the left side of page 4 just above the stacked data chart. Usually the analog channel selected as the trigger source will be the same analog channel displayed (on page 1), but they need not be. You can trigger off one and display something different on another channel if you can think of any reason to do this.

There are three trigger parameters to set up:

1) The trigger polarity – you can trigger on a rising edge, or a falling edge of an analog signal. I'm triggering on a rising edge in the screen shots.
2) The trigger voltage – I've set the trigger voltage to 0.500 volts in this case. If you look at the analog display (blue trace) you will see that 0.5 volts is about midway up the trigger signal.
3) The retrigger Mask time – This sets a time in milliseconds that another trigger will not be allowed. This prevents noise from double triggering a stack event. I set it to 50 mS. I chose this value arbitrarily since the trigger wave form is free of noise.

To change the trigger voltage level or retrigger mask, enter the desired values, and press the Set Trig button to load the new values.

Each stack process stacks one second of data – 500 mS before the trigger edge to 499 mS after the trigger edge. This stacking process takes place regardless of what the stack display window is set to. You can zoom into a single heartbeat by setting the left and right edges of the stacked display. In this case the display is zeroed in on one peak of the simulated heartbeat. The left edge is set to -50 mS (50 mS before the trigger pulse), and the right edge is set to +175 mS after the trigger pulse. To change stacked display edges, type in the desired values in the edge variable, then press the Set Edges button. Again, every stack process stacks a full second of data, so you can zoom in and out without affecting the stacked data. You do not need to clear the stacked data and reacquire after zooming.

There is a window that shows the number of stacks taken as well as elapsed time in seconds. To start the process over, press the Clear Stacked Data button. The stack count and elapsed time counters will go to zero and the stacking process will restart.

In the right most window on the top is displayed the standard deviation of all the mag readings in one triggered data window (Noise Value). This updates for every triggered 1 second data window. Underneath that is a Noise Threshold setting. If the triggered data window Noise Value exceeds the Noise Threshold window the data is thrown away and not stacked into the display. In the screen shot that shows a zoomed in stack display the Noise Level shows 0.076. The Noise Threshold is set to 0.065. That triggered data window will not be stacked in the stacked display and will be thrown out.

You can set the Noise Threshold to any level desired by entering a new value and pressing the Set Noise Threshold button.

In the Screen Grab showing the zoomed in stack display you will see some noise spikes in the gradient (green) trace. These noise spikes were caused by a laser printer starting up and printing a couple pages. The laser printer was about 25 feet away. None of the simulated heartbeats during those noise bursts were stacked into the stacked display window.

Notes:

1) The noise threshold and data rejection process is only happening in the stacked display window. If you are recording binary to disk all the data is being recorded. The processing software which handles the save data will have to employ a similar noise measurement and rejection process.
2) When saving data to disk, use the binary save format. That way you will be saving full unfiltered 1 KHz data which can be post processed.

You can also set up filters for the stacked window display. You can put in a power mains notch at 50 or 60 hertz or not. You can put in a variety of low pass filter as well. Remember though, that these filters are only for the data in the stacked display. They do not affect the data displayed in the mag and gradient windows on the left, nor do they affect data saved in a binary file save. Also, the power mains notch filters are a bunch of notches in series. For a notch filter setting of 50 hertz there is actually 5 notches at 50, 100, 150, 200, and 250 hertz to remove 50 hertz and its harmonics. For 60 Hertz the notch frequencies are 60, 120, 180, 240, and 300 hertz.

The magnetometer display plots on the left can be filtered differently than the stacked display. The filters for the magnetometer display window are on page 2 of the Control Panel. These can be set to greatly filter out background noise so that you can easily see the heartbeat signal – even if it distorts the heartbeat signal itself enough that storing this data is not useful. Saving data in the binary format stores raw unfiltered data, so use this method instead of an ASCII format save.

The Trigger Received LED lights briefly every time an analog trigger is detected.

If the heartbeat signature looks upside down, you can flip it around with the Invert Display switch.

Note: When first starting the MagViewMFAM program stacking will not begin for several seconds if a notch filter is selected. This is because the notch filter will have to settle out before the noise level will get down below the Noise threshold setting.

This is still work in process. There are 2 known issues so far:

1) When starting up the program occasionally the stacking process doesn't start – even though the noise levels are below the threshold level and trigger are being received. To fix this press the Set Noise Threshold button.
2) Very rarely when starting up the program the stacking display window shows erratic edge settings. This can be fixed by pressing the Set Edges button.

6.0 ETHERNET DATA FORMAT AND SAVED FILE FORMAT

The Ethernet Adapter board has the same data format as MFAM Development Kit. However, unlike the Development Kit, **it has no GPS input and only 2 analog inputs**. Therefore, in the following Development Kit data format, please ignore the GPS and ADC0/ADC1 parts of data.

Data is sent over the Ethernet in groups containing forty milliseconds of data. Appendix C: ETHERNET DATA TRANSFER FORMAT contains a block diagram of the transmitted data format. Thus, in one second, the TIVA transmits 25 Ethernet packets of 1380 bytes each. Each Ethernet packet contains a header, forty magnetometer samples (taken at a 1 mS sample interval), and an 84 byte place holder for GPS information.

Each data sample is further broken down (referring to Appendix C: ETHERNET DATA TRANSFER FORMAT) into Fiducial Counts, System and Magnetometer Status, Magnetometer Readings, Auxiliary Channels, and ADC channels.

Note that in each Ethernet packet there is a place holder for GPS data. Packets are sent 25 times per second yet the GPS only gets updated once per second. Thus the GPS field is only populated when a new GPS reading arrives. At all other times the field is filled with binary zeroes.

The auxiliary channels contain different data in different samples. The primary purpose of these channels is to multiplex X, Y, Z, and T (temperature) data from the MFAM compass, Gyro, and Accelerometer modules into the data stream. They can also be used to pass internal diagnostic information as well under special conditions. The identity of which data occupies the Auxiliary fields is specified in bits 13-11 in the Fiducial Field (see Ethernet data chart in Appendix C: Ethernet data transfer Format).

Bits 0-10 in the Fiducial Field contain a count that increments by one every sample. It rolls back to count 1 (not zero) every 2000 samples if there is no 1 PPS pulse received. Thus the count would go from 1 to 2000, and then the next fiducial count will be 1. If a 1PPS pulse is received, the count immediately rolls back to one. Thus, when the cycle time is phase locked to the 1PPS pulse, the fiducial counts will count from 1 to 1000, and then start over at count 1.

Bits 15 and 14 in the Fiducial Field (FID in chart) specify whether the magnetometer is outputting valid magnetometer data. When bit 15 is set (M2V), Magnetometer 2 is outputting valid data. When bit 14 is set (M1V), Magnetometer 1 is outputting valid data.

In the System Status Byte, bits 15 and 14 reflect the status of the 1PPS synchronization. If bit 15 is set, the MFAM module is receiving the 1PPS pulse from the external GPS. If bit 14 is set, the internal 1 KHz sample rate is phase locked to the 1PPS input pulse to within +/- 500 nS.

Also in Appendix C: ETHERNET DATA TRANSFER FORMAT, note the byte format of all 16 bit and 32 bit words. The byte transmission format is LSB to MSB for both 16 and 32 bit words.

Each Ethernet packet starts with a 16 byte header containing the Development Kit firmware version number. This is always present in each Ethernet data packet, but if you save the data to disk using the MagViewMFAM program, this header information is stripped out. Thus the saved file format is different than the Ethernet transmission format in this one detail. The rest of the saved file format is the same.

Diagnostic Data (On Start Up)

When the MFAM module is first powered on, the unit sends out a different data set format. In place of the magnetometer and auxiliary channels is internal diagnostic information documenting the start-up process. There are 5 main stages during the startup process. The Diagnostic Stage is documented as Mag Status bits 15-13.

The MagViewMFAM program can be used to save data during startup. In fact, if the start-up process does not complete, providing Geometrics with the saved start-up data can help us diagnose the problem and provide a solution quickly.

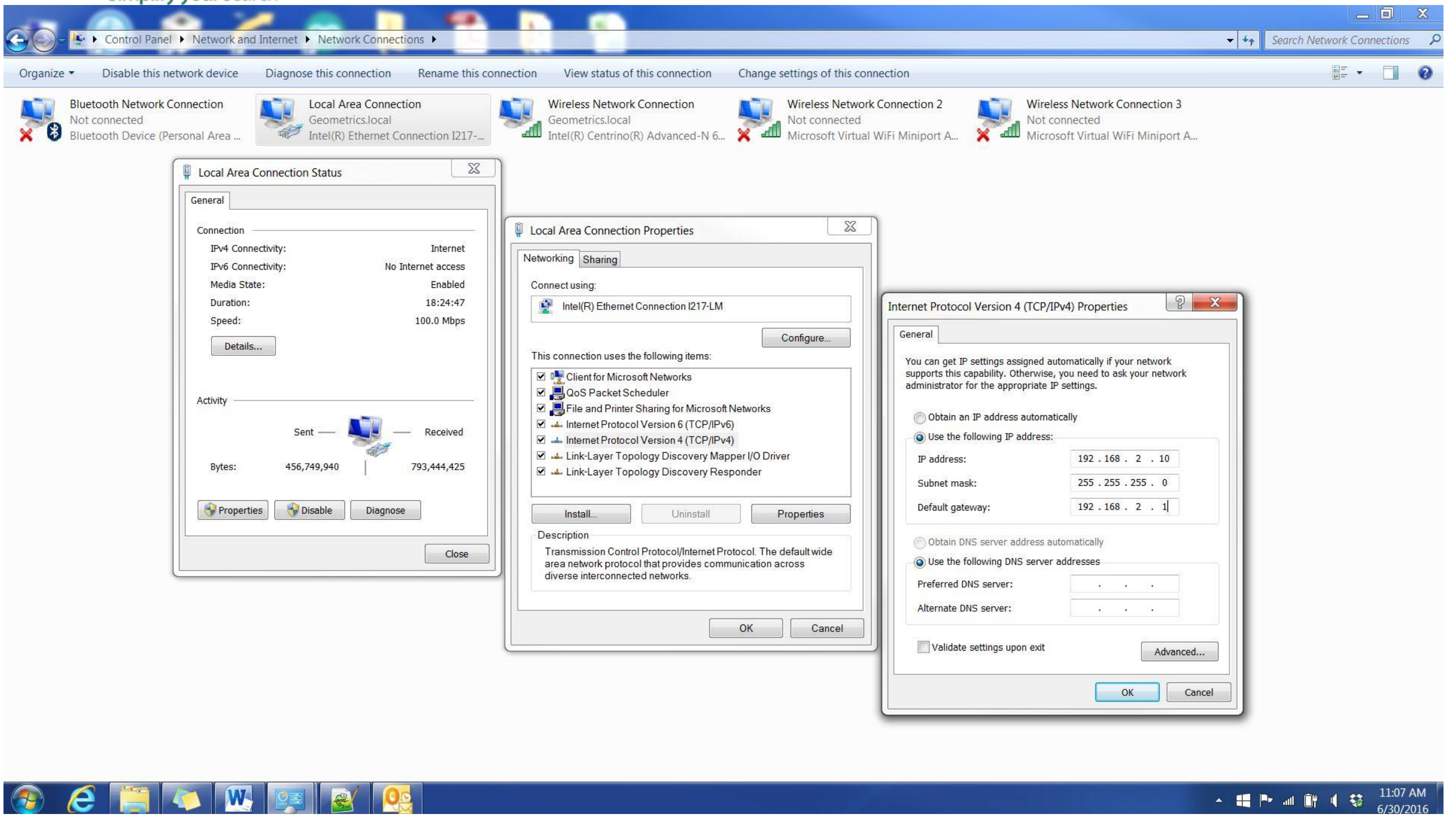
APPENDIX A: CONNECTING THE ADAPTER VIA ETHERNET

To connect to the adapter via Ethernet, you will need to manually set up your network card IP address to:

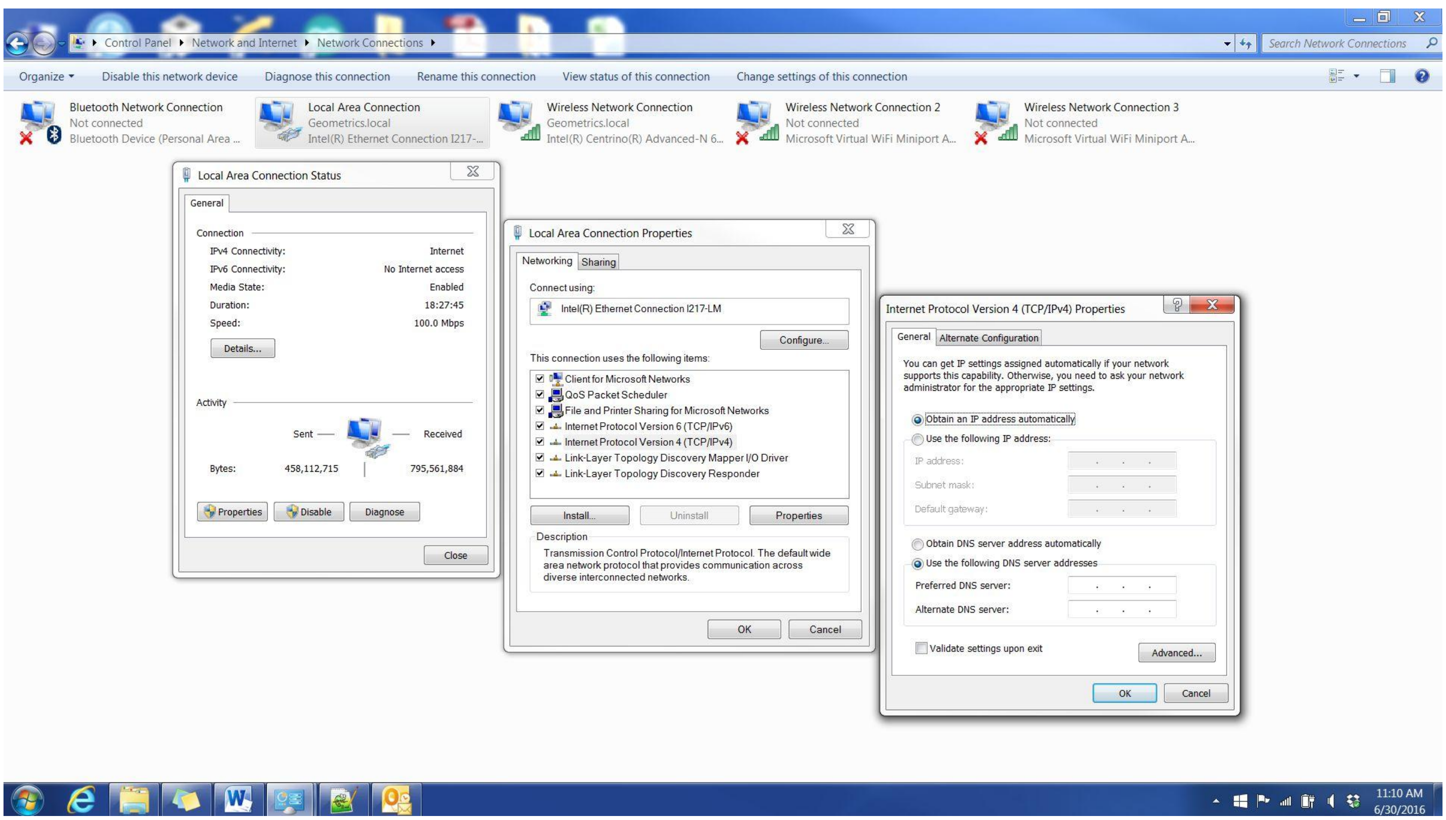
IP Address: 192.168.0.10
Subnet Mask: 255.255.255.0
Default Gateway: 192.168.0.1

This is for the default adapter IP. If you change the IP to 192.168.2.2, then the network card IP needs to be in the same subnet, for example IP = 192.168.2.10 or subnet mask = 255.255.0.0.

To do this in Windows 11:
1) Choose “Network & internet” from “Settings”
2) Click “Advanced network settings”
3) Select the network card the Ethernet cable is connected to and click “Edit”
4) Double Click on the “Internet Protocol Versions 4 (TCP/IPv4)” line
5) Click on “Use the Following IP Address” (and fill out the address info as per the above)



To return to the standard IP address configuration go the same steps to get to the IP address menu as in the above procedure, then click on the “Obtain IP address automatically”.



APPENDIX B: ETHERNET ADAPTER BOARD DIMENSION

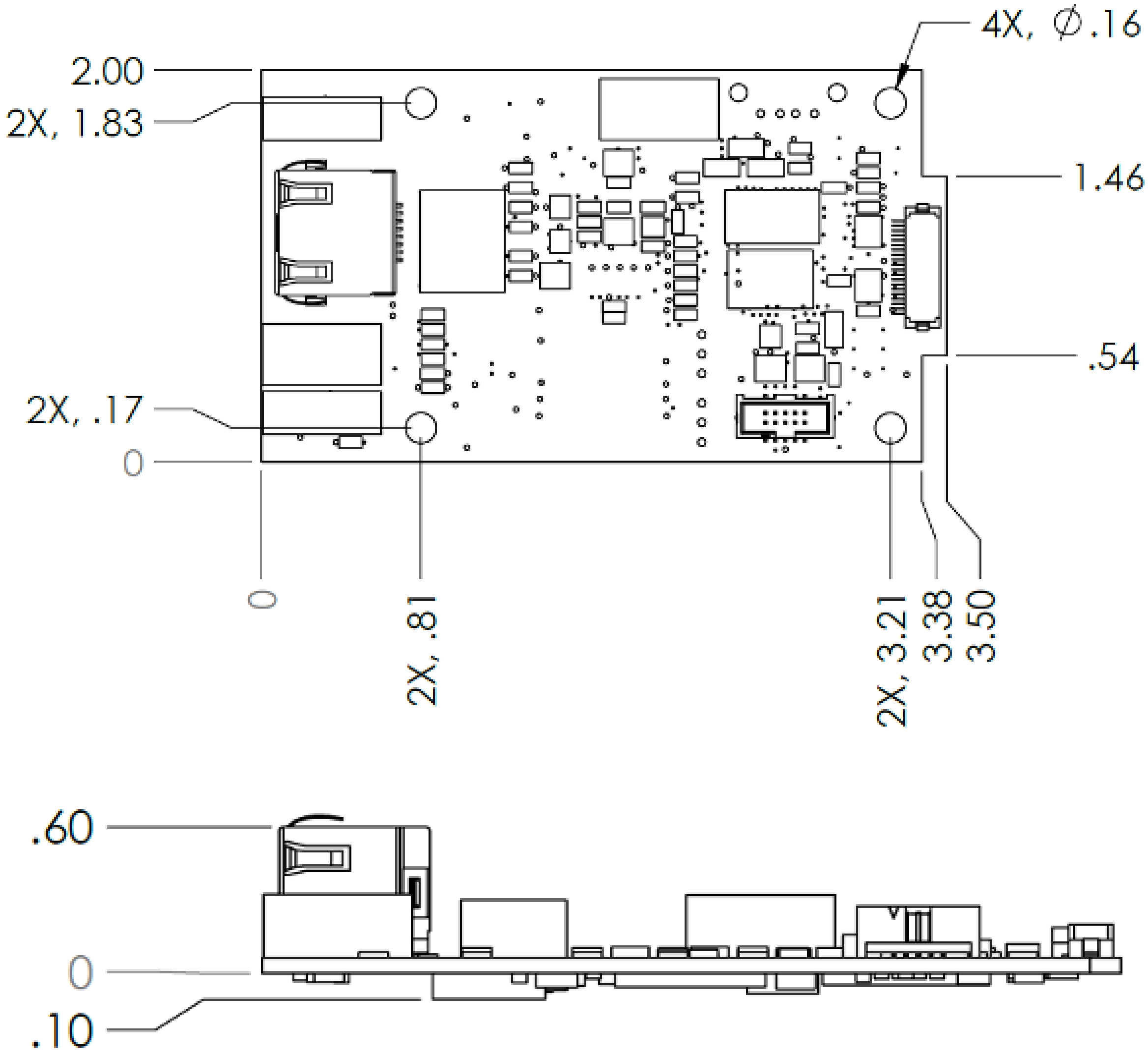
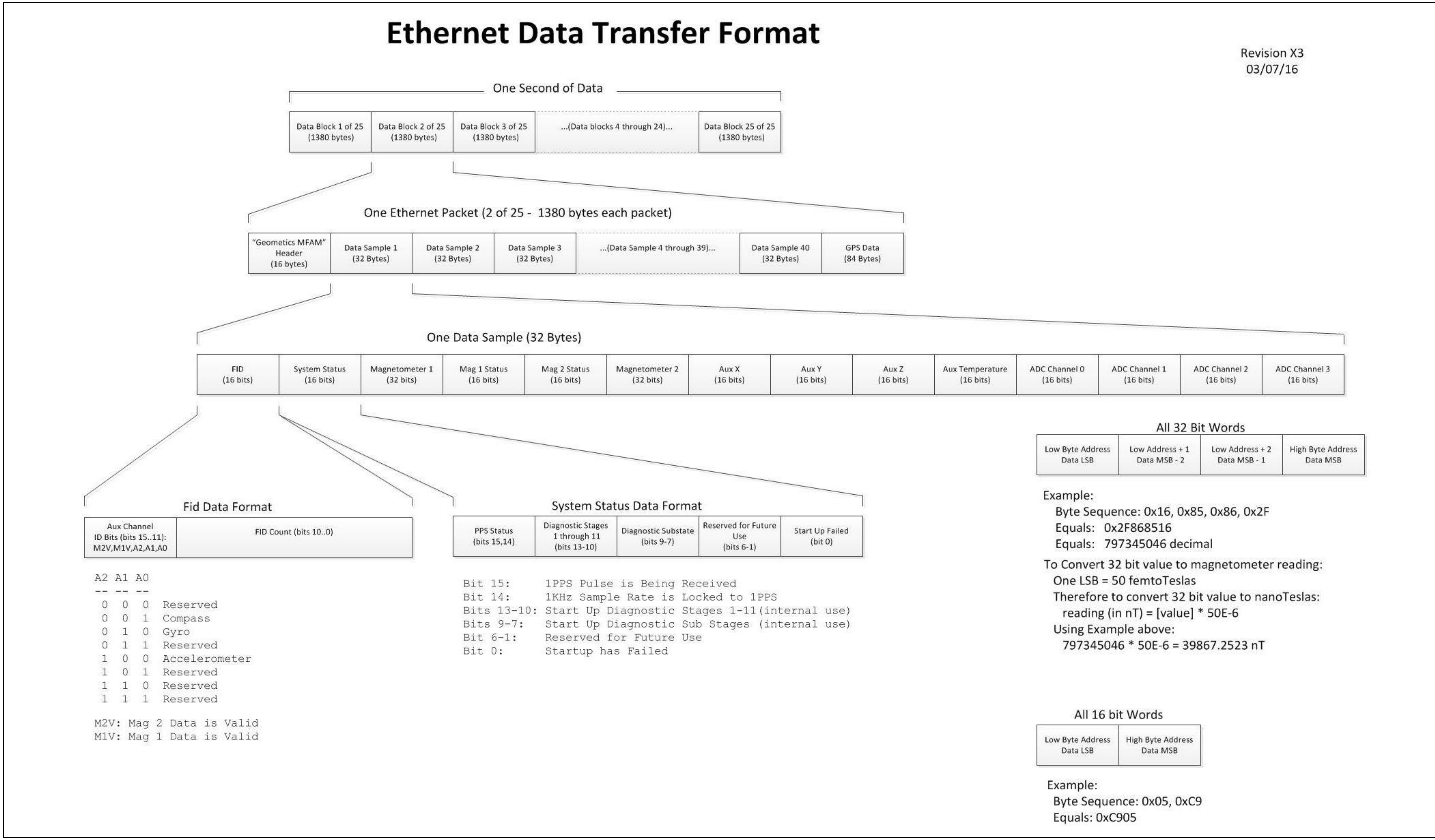


Figure 8 Ethernet Adapter Board dimensions in inch.

APPENDIX C: ETHERNET DATA TRANSFER FORMAT



APPENDIX D: MFAM SENSING MODULE LCS050G SPECIFICATIONS*

Characteristic	Condition	Min	Typ	Max	Units

Power Supply

Characteristic	Condition	Min	Typ	Max	Units
Supply Voltage	Vin referenced to GND	9.5	12	16	Volts
Average Current Draw	Vin = 12V, 25 °C ambient temperature Vin = 12V, -35 °C ambient temperature		0.4 0.65	0.6 0.85	A
Average Power Draw	25 °C ambient temperature -35 °C ambient temperature		5 8	7 10	W

Performance

Characteristic	Condition	Min	Typ	Max	Units
Field Range	Full scale	20		100	µT
Noise Floor	Magnetic field orthogonal to sensor optical axis		2	5	pT/√Hz
Dead Zone	Polar only, included angle		60	70	degree
Heading Effect	Measured at 50µT field strength		+/-25	+/-40	nT
Digital Resolution	32-bit magnetometer output		0.05		pT/LSb
Output Data Rate	Continuous measurement		1000		Hz

Environmental

Characteristic	Condition	Min	Typ	Max	Units
Operating Temperature	Ambient	-35		50	°C
Storage Temperature	Ambient	-40		70	°C
Operating Altitude				10000	Feet
Storage Altitude				45000	Feet

*Preliminary Specifications can change without notice. Specs for other MFAMs can be found on Geometrics website.

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