

# Operation Manual

## MFAM Development Kit

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## 1 – Introduction

A Magnetometer measures the Earth's magnetic, 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 our total field magnetometers are recognized through the world.. Our sensors are designed to measure the total magnetic field (total field), a scalar value without directional information. This value is called the magnetic field intensity and is independent of the direction in which the field propagates. More information is provided in section [3.0 Performance](#).

Magnetometers can be used to map and find manufactured objects and naturally occurring iron or other ferrous metals. The ferrous mineral magnetite occurs naturally in the earth's crust and is often associated with economic minerals such as gold and copper deposits, kimberlite (diamond) pipes, and other mineralized zones. Because of this close association between economic deposits and magnetic gangue minerals, magnetometers are an efficient tool for finding important mineral deposits.

Manufactured ferrous objects, such as those associated with archaeology, civil engineering, unexploded ordinance, etc., can also 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 burial depth.

## 2 – System Components

### 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 fabricated 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 which cannot be removed or replaced.

The MFAM is a miniature scalar atomic magnetometer brings the performance of much larger commercially used geophysical magnetometers to the small, lightweight UAS (Unmanned Aircraft Systems) platform. 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  $1\text{pT}/\sqrt{\text{Hz}}$ , 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, and to avoid introducing aliasing artifacts in the data. This fast sampling rate also allows for direct measurement of 50-60Hz magnetic



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, supplying flexibility for configuring redundancy or for canceling run-time measurement systematics. See the MFAM Specifications listed in [Appendix C: MFAM SENSING MODULE LCS050G SPECIFICATIONS\\*](#).

## THE MFAM DEVELOPMENT KIT

Geometrics' MFAM Development Kit is a versatile, easy to use platform that allows system developers to design custom application interfaces using the MFAM sensing module to meet their specific needs.. By combining the MFAM module with the Development Kit and the right housing, the MFAM magnetometer system can be used for land, airborne or even marine survey applications

The MFAM Development Kit combines the MFAM Sensing Module with an Interface platform (Development Kit) to allow for simple integration and customization into a variety of platforms or larger surveying systems. It is a technology demonstration platform that allows the MFAM output data stream to be read in, processed, converted to a variety of formats, and output via Ethernet, USB, or Wi-Fi. In addition, there is an onboard GPS module, four user-accessible differential analog inputs, two serial ports, and an on-board micro-SD card slot.

### Development Board Overview

The MFAM Development Kit contains the Development board, which is powered by a Texas Instruments TIVA TMC1294NCPDT microcontroller. This is user programmable and has a large library of example programs available that can be copied into your design (using Texas Instruments Code Composer Studio development suite) to quickly get the MFAM system up and running. Your code would be compiled in Code Composer Studio and downloaded via a micro USB cable into the TIVA Microcontroller. The same USB cable is used for debugging. A photo of the Development Board is shown in Figure 1.

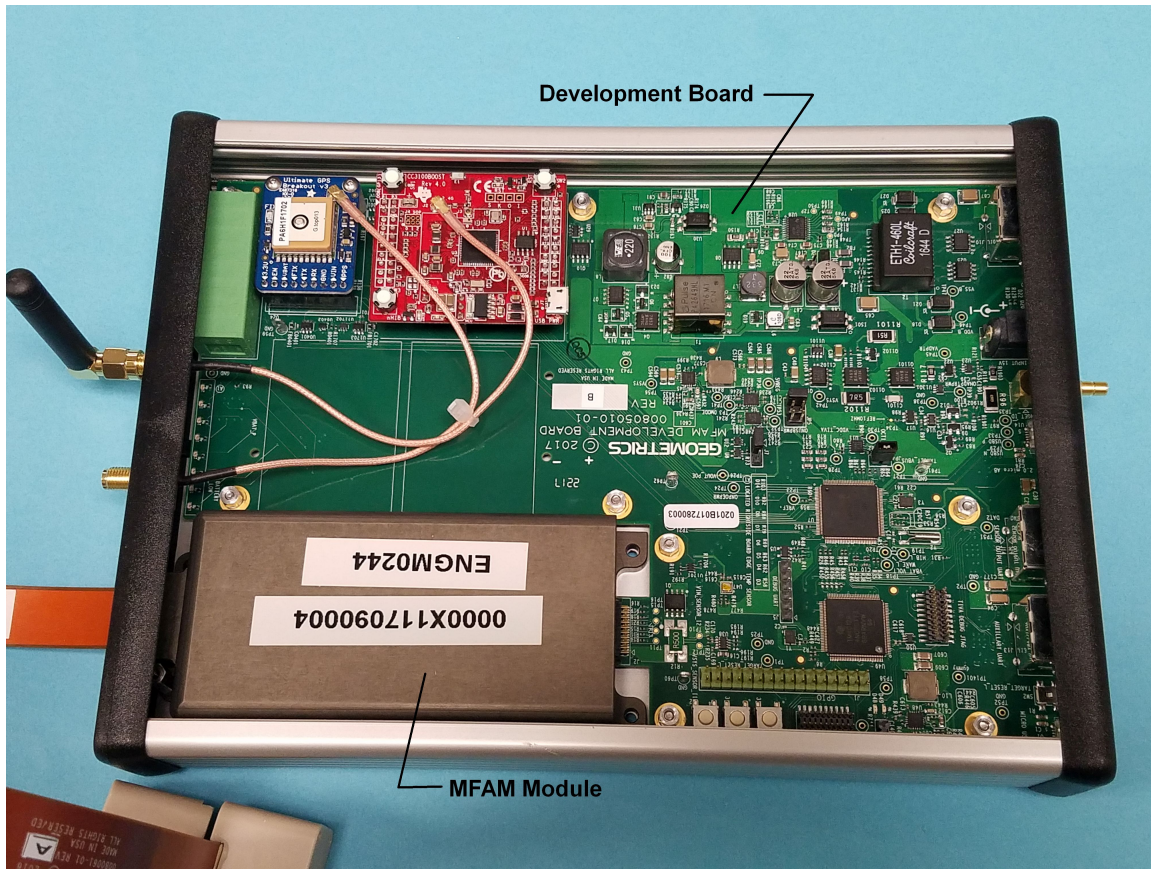


Figure 1 Development Board with MFAM Sensor Module Installed

The Development board / MFAM module can be powered 3 ways:

- Through the Ethernet cable hooked to a Power over Ethernet (PoE) power injector.
- Through an external 15-volt supply (provided).
- Through the external Power Jack using external batteries. See appendix L for recommended non-magnetic batteries.

## Kit Contents

The Development Kit with an MFAM module contains the following items:

- MFAM Sensing Module
- Development Board in an aluminum enclosure
- External power supply for running the Development board and MFAM module
- External GPS Antenna and WiFi Antenna
- PoE Power Injector
- Micro USB programming cable
- Two DB9 to RJ45 Serial Adapter Cables

- Example software MagViewMFAM (Provided on a USB Stick) for displaying the MFAM data on a PC running 64-bit Windows 7 connected via Ethernet.

### Removing the Top Cover

The top cover slides out from either end of the Development Kit enclosure. Remove cables, and then remove the 4 screws as shown below (Figure 2) on the back-panel display. The panel will fall away and the bezel will slide out. The panel is also held by the two upper screws at the front panel end. These will need to be removed as well. The top cover will now slide out.



Figure 2 Showing 4 screws/ Removing Lid Specifications

### Mechanical:

- Enclosure Dimensions: 9 x 6 5/8 x 1 3/16 inches
- Sensor Cable length (Development box to Sensor): 20.5 inches
- Power:
- AC adapter: 13.5 to 16 Volts DC at 1.0A

### Features

**TIVA TM4C1294NCPDT Microcontroller:** This is a 32-bit ARM Cortex-MF4 based microcontroller running at up to 120 . MHz. It has 1024K of flash, with 256K bytes of RAM, and 6 Kbytes of EEPROM.

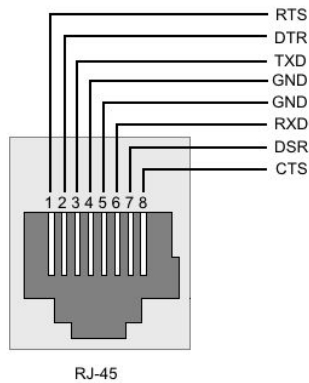
**USB 2.0 Micro Connector:** USB functionality is provided by the TIVA microcontroller and TIVAWare support libraries. This is located on the back panel.

**Four User LEDs:** Four user-controlled LEDs are wired to TIVA microcontroller GPIO pins PK0, PK1, PN0, and PN1. These are visible through a cutout on the front panel.

**Two User Switches:** Two user-read switches are wired to the microcontroller pins PK6 and PJ1.

**One Microcontroller Reset Switch:** This switch is used to reset the microcontroller and is located on the back panel. It is recessed and will have to be activated with a narrow rod.

**Wi-Fi Port for TI CC3100 Wi-Fi Booster Pack:** The Development board layout allows a TI CC3100 Wi-Fi Booster pack to be directly plugged in. Using TIVAWare libraries, software can be developed to allow Wi-Fi communication between the Development board and a computer.



**USB XDS110 Port for Firmware Downloading and Debugging:** This second USB port located on the back panel is used as a debug/firmware download interface between the TI Code Composer Studio development suite and the Development Kit.

**Two RS-232 Serial Ports with RJ-45 Connectors:** Two general purpose serial ports are available to the user on the back panel. The first serial port is wired to TIVA microcontroller UART4, and supports RTS and CTS handshaking. The second serial port is wired to TIVA microcontroller UART5. This port supports only Tx/D and Rx/D. Both ports use +/- 5-volt voltage swings, and support baud rates up to 920 Kbaud. Note that these two ports are wired as Data Terminal Equipment (DTE). Thus, to connect either of these two ports to a computer would require a connection through a null modem.

*Figure 3 Pin Out Diagram*

**On Board GPS Module:** An Adafruit GPS module is included with the Development Kit. It features 66 channels, -165 dBm sensitivity, and 3 Meter accuracy. An external GPS antenna is included so that signals can be received inside the box even with the aluminum cover in place. The port to plug in the GPS antenna is located on the front panel display.

By default, the GPS powers up to 9600 baud with several GPS sentences being output. The firmware that comes with the Development Kit reconfigures the GPS to output only an RMC sentence at 115200 baud. This RMC string is sent with the output TCP data packet as described in the "Ethernet Data Format" Section 6.0 and Appendix B. The GPS is wired to UART7 on the TIVA microcontroller using 0-3.3-volt logic swings.

The 1PPS pulse from this GPS goes to the MFAM Development Module and disciplines the cycle rate to exactly one kilosamples per second.

**Micro SD Card Slot for Storing Data Locally:** A micro SD card slot is available on the back panel for the user to read and write data using a SPI interface. It is connected to SPI port 1 of the TIVA microcontroller. Note that this micro SD card holder is mounted on the underside of the Development Kit PCB, so the micro SD card must be inserted upside down.

**10 MHZ Timing Reference Input Port:** Located on the back panel, this input port takes a 10 MHz reference signal from a GPS disciplined reference oscillator, buffers and squares it up, and sends it to the MFAM module. The purpose of this signal is to lock the MFAM clocking system to this reference signal so that the Larmor frequency can be measured to an absolute standard.

**Ethernet Port with Power over Ethernet Compatibility:** The TIVA microcontroller contains a fully integrated Ethernet MAC and PHY. In addition, the Ethernet port can power the Development Kit via Power over Ethernet (PoE) using an Ethernet power injector. This port is located on the back panel.

**Four Differential Analog Input Channels:** There are four differential analog inputs available for use on the front panel display. Channels 0 and 1 are +/- 2.5 volts full scale, while channels 2 and 3 are 0 to +5 volts full scale. In the firmware supplied with the Development Kit, (which sends MFAM/GPS data to the MagViewMFAM program on the computer) all four channels are sampled synchronously with the MFAM data input to the TIVA and are included in the data stream.

**On board Power/Status LEDs:** Several Status and Power LEDs are arranged along the front edge of the board. They include the four user LEDs, Power status LEDs (which power source is powering the board, and whether the battery is charging or the voltage low). They are listed in the Front and Back Panel Connection and Indicator section below.

## Power Management

### Powering up the Development Kit:

**Via Power over Ethernet (PoE):** If the Ethernet port is connected to an Ethernet Power Injector port, then the Kit will be powered off PoE. In this case, the 'PoE Power' status LED will be lit (the second LED from the left in Figure 4 below).

The Ethernet Power Injector is wired in series between the Local Area Network and the Development board Ethernet port. The injector superimposes the Ethernet data on top of a nominal 48 volts DC which is connected to the Development board. The DC power and AC Ethernet data are then separated on the Development board using a transformer, and then a DC to DC convertor steps the 48 volts DC down to +12 volts to run the MFAM and Development board. On power up, the PoE (Power Over Ethernet) injector goes through a hardware negotiation process with the Development board before applying the 48-volt power. This negotiation first establishes that the Development board is a PoE capable device, and receives back information on how much power it needs to provide. If the PoE can deliver that much power, then (and only then) will it apply the 48-volt power.

**Via an External 13.5 to 16 Volt DC Supply (Provided):** If the AC adapter is plugged in, the Kit will be powered from the AC adapter. If Power over Ethernet is also applied, PoE is not used.

**Note:** Transitioning from PoE power to AC Adapter power (or vice versa) is not smooth. The microcontroller will go errant and must be reset.



## Front and Back Panel Connections and Indicators



Figure 4 Front Panel

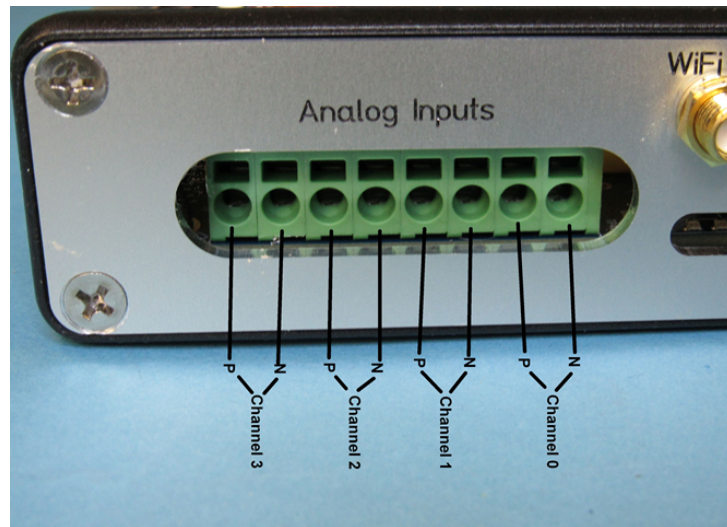
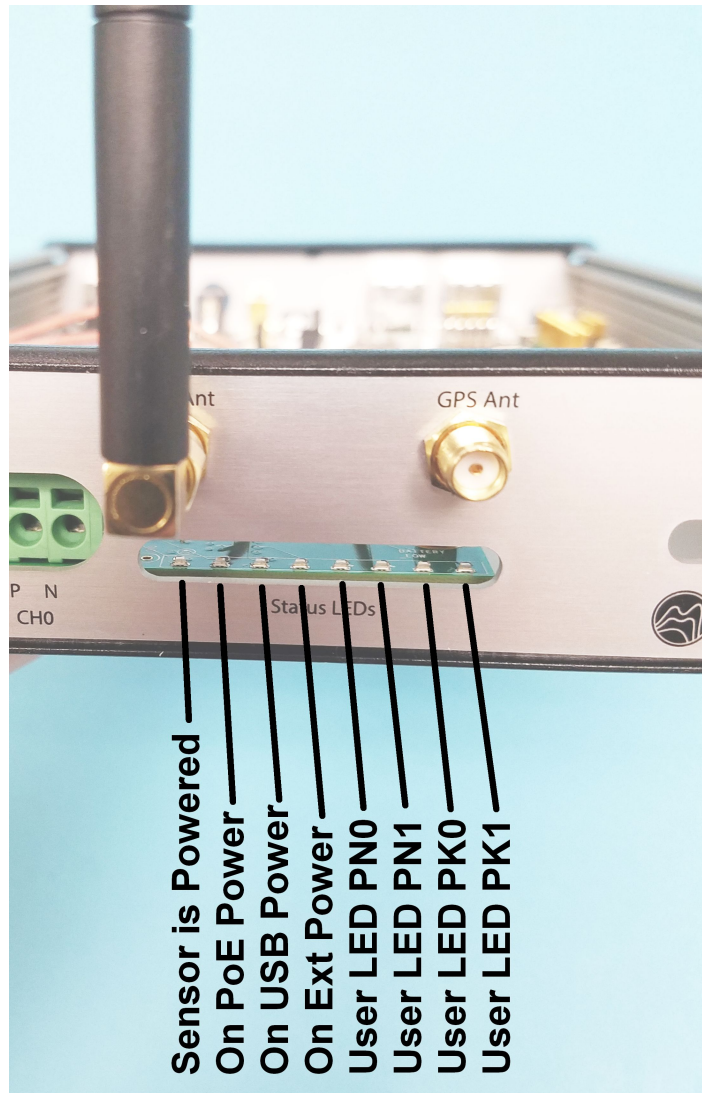


Figure 5 Close-up of the Analogue Input Channels

## Connecting and Disconnecting Analog Inputs

To connect or disconnect wires to the analog inputs, slide a small flat blade screwdriver into the rectangular slot above the round connection hole. This opens a spring-loaded wire grabber. Insert the wire end fully, and then remove the screwdriver. Wire is now connected and firmly attached.

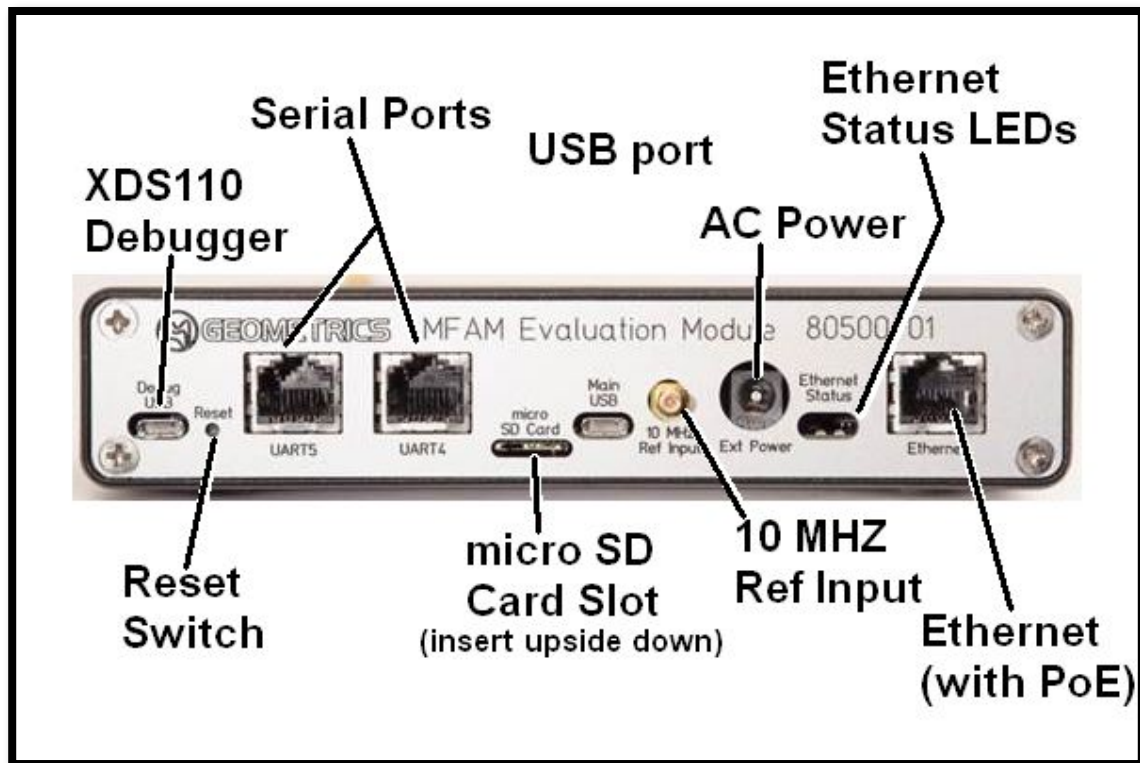
Figure 6 Status LEDs on Front Panel



*Figure 7 All Back-Panel Connections*

### 3.0 Performance

Geometrics' MFAM Development Kit is a magnetometer system, and with the proper housing can be used for land, airborne or even marine survey applications. This versatile, easy to use development platform allows system developers to design custom application interfaces using the MFAM magnetometer sensor. The system's microcontroller supports many different communication protocols for easy conversion of the MFAM magnetometer data into a variety of output protocols. Supported communication channels include:



- 10/100 Ethernet MAC and PHY
- USB 2.0
- Two High Speed RS-232 ports
- Wi-Fi through TI CC3100 Booster Pack

The MFAM outputs data continuously via its SPI port to the Development Kit at 1000 samples per second. Hardware exists in the development kit to then send data via RS-232, Ethernet, or Wi-Fi, or to a Micro SD card. Example firmware for outputting data via the Ethernet port is loaded into the Development kit by default. Another example firmware set takes the MFAM data and stores it to the micro SD card. The control and data interface to the Development Kit is via Wi Fi using any browser such as Google Chrome. Switching between these two example firmware sets is done via the debug USB port. See [Appendix J](#) for instructions on how to do this.

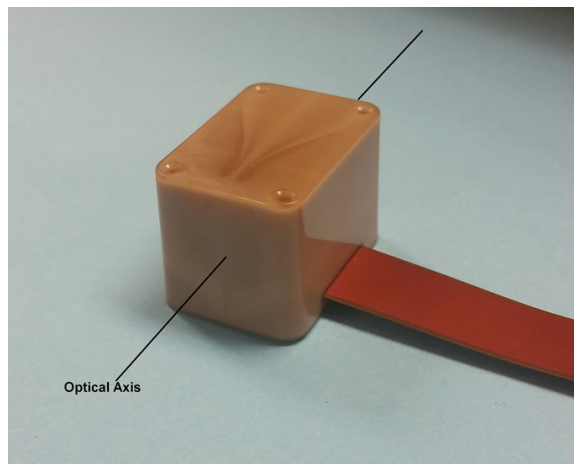
The MFAM operates over the earth's magnetic field range of 17,000 to 100,000nT with a noise floor of  $2\text{pT}/\sqrt{\text{Hz}}$  for the Low Noise version (LCS050G) and  $20\text{pT}/\sqrt{\text{Hz}}$  for the export version (LCS100X). Error due to orientation of the MFAM sensor (heading error) does not exceed  $\pm 25\text{nT}$ , or 60nT peak-to-peak, in spin and tumble throughout the active zones shown in Figure 8. Simple destriping may be used to remove the heading error from survey results. Environmental conditions for proper operation are  $-35$  to  $+50^\circ\text{C}$  ( $-31$  to  $+122^\circ\text{F}$ ), humidity to 99 percent (non-condensing), and an altitude range of 0 to 10,000 feet above ground surface. See full performance specifications in [Appendix C: MFAM SENSING MODULE LCS050G SPECIFICATIONS\\*](#).



Compensation and/or noise reduction techniques normally must be used to minimize the magnetic effect of the platform (aircraft, UAV or AUV) and its motion. Navigational and positional errors, radiated electromagnetic noise, and heading errors from the aircraft's induced and remnant magnetic fields are typically the major contributors to noise affecting the survey results.

## 4.0 Installation and Operation

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



*Figure 8 Optical Axis of the MFAM Sensor*

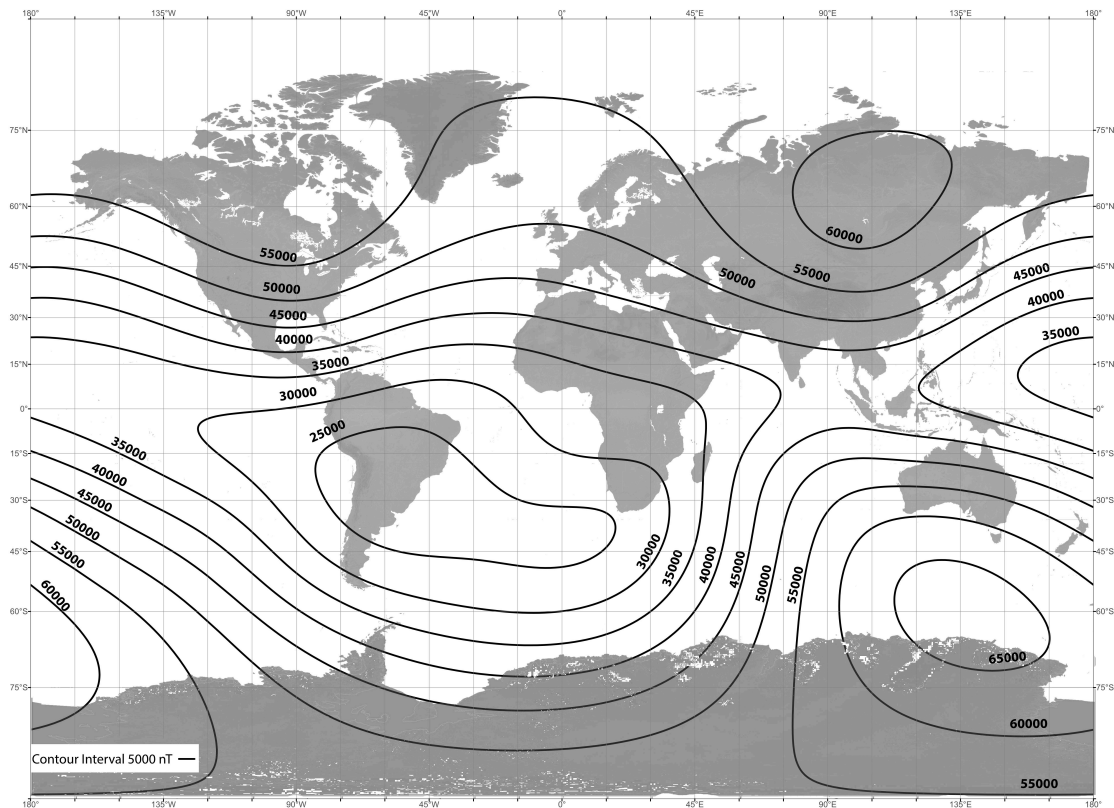
Although the MFAM measures the total field intensity of the earth's magnetic field, magnetic fields in general are vector fields. The total field is the sum of the three components as projected onto the earth's field vector which is roughly vertical at the poles and horizontal at the magnetic equator. 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. For the MFAM to accurately measure the local magnetic field magnitude, it must be properly oriented relative to the local magnetic field direction.

*Figure 9 Variation in the Earth's Magnetic Field*

The MFAM sensor has one polar dead zone. If the sensor's optical axis (Figure 9) is lined up within  $\pm 35$  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 relatively independently of the sensor's orientation.

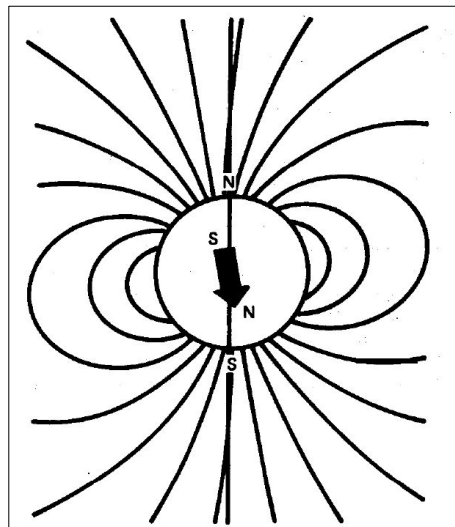
As the MFAM sensor has only one polar dead zone, it is possible to configure your MFAM sensors in such a way as to eliminate the polar dead zone. Thus, the unit may be used anywhere in the world without data dropouts.

US/UK World Magnetic Model - Epoch 2020.0  
Main Field Total Intensity (F)



Map developed by NOAA/NCES and CIRES  
<https://ngdc.noaa.gov/geomag/WMM>  
 Published January 2019

Note: Traditional cesium magnetometers have two dead zones – polar and equatorial. One of the advantages of our MFAM is that it has only one polar dead zone and this can be easily canceled with proper sensor orientation.



*Figure 10 Illustrating Magnetic Field Vector/Inclination Angle at the Earth's Surface*

The earth's vector varies depending on where you are on the planet. See Figure 9, 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:

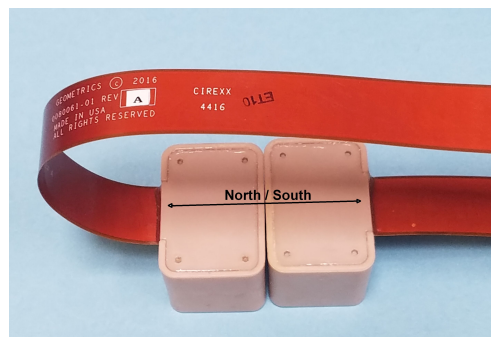
At the magnetic equator, the earth's magnetic vector is horizontal to the earth's surface. . At the magnetic poles, the field is vertical. . Between these extremes in the northern hemisphere, the earth's magnetic vector is pointing south at an angle somewhere between 0 and 90 degrees from horizontal.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

To get the maximum signal, the earth's magnetic vector should be at right angles to the optical axis (shown in Figure 9). 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 a single magnetometer reading from the MFAM, orient the two sensors such that the intrinsic heading error of each sensor is equal 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.

Below is a picture showing the proper orientation of the sensors to get heading error cancellation. Note how the flex cables travel away from the sensors in opposite directions.



*Figure 11 Orienting Sensors for Heading Error Cancellation*

## 5.0 Notes on MagViewMFAM (Version 1.2.4)

### MagViewMFAM Version 1.2.4:

This example software allows customers to gather Ethernet data from the MFAM Development Kit 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 (Fast Fourier Transform) 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:

- Development Kit Firmware Version Number
- MFAM S/N
- MFAM Firmware Version Number
- Fiducial Count
- Mag and System Status Words
- Compass Data (scaled to nT in all three axes, plus device temperature)
- Accelerometer Data (scaled to G level in three axes, plus device temperature)
- Gyro Data (scaled in degrees rotation per second for all three axes, plus device temperature)
- FPGA Temperature (degrees C)
- Supply Voltage (volts)
- Cumulative Board Run Time (hours)
- GPS Data
- GPS Status
- Analog Channels (volts)

#### Minimum System Requirements:

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

## 6.0 Installing and Running the Example Software

### Installation:

Install the LabVIEW Runtime Engine (setup.exe and all associated files located on the supplied USB stick)

Create a folder on your C: hard drive and name that folder "MagViewMFAM" (Example: "C:\MagViewMFAM\") and copy the file MagViewMFAM\_V0\_0\_2.exe into this folder (also located on supplied USB stick)

Create a shortcut to this file (right click on file, select "Create Shortcut")

Drag the shortcut to the desktop

## Operation:

Connect the Development Kit 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.

### **Setup the Computer Ethernet port to a fixed IP address:**

Manually, as outlined in Appendix A: CONNECTING THE DEVELOPMENT KIT VIA ETHERNET. Or run the Batch file "SwitchToStaticIP.bat" on the Memory stick containing the MagViewMFAM program. The batch file must be run in Administrator Mode. Right on the batch file name and select "Run as Administrator". Note: If you have more than one USB port you may need to set up the fixed IP address manually as outlined in Appendix A. There is another batch file which restores the IP address assignment to DHCP. It is called "SwitchToDHCP.bat" and must also be run as Administrator.

### **Power up the MFAM**

(using the provided AC adaptor is the easiest method)  
Double click the Shortcut on the computer desktop

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:

Magnetometer 1  
Magnetometer 2  
The difference between Mag 1 and Mag 2 (Gradient)  
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. 0 to 5V for channels 2 and 3, or -2.5V to +2.5V for channels 0 and 1).

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 milliseconds.

### **Screen Modes:**

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

**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.

**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.

**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.

**FFT Graph:** A Fast Fourier Transform (FFT 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.

**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:**

The MFAM Command Box is located at the bottom of page 1 of the Control panel.. This allows a few commands to be sent to the MFAM console:

**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.

**Compass Configuration:** 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]

**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.

**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.

**FPGA Reset:** This starts the startup process from the beginning (like at initial power up).

**Factory Reset:** This removes the current firmware and the system reverts 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 work 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:

**Binary Format:** 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.

**ASCII Format:** 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 the 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:

### **The Fiducial Count**

System Status (written as a 4-digit hexadecimal number – i.e. ‘A06F’)

Mag 1 Status (written as a 4-digit hexadecimal number)

Mag 2 Status (written as a 4-digit hexadecimal number)

Analog Channel 1 (in volts)

Analog Channel 2 (in volts)

Analog Channel 3 (in volts)

Analog Channel 4 (in volts)



Gyro Data (3 channels: X, Y and Z in Degrees per Second, plus a fourth channel that specifies the device temperature in degrees C)

Accelerometer data (3 channels: X, Y and Z in G's, plus a fourth channel that specifies the device temperature in degrees C)

Compass Data (3 channels: X, Y and Z in nT, plus a fourth channel that specifies the device temperature in degrees C)

The Date (MM/DD/YY)

The Time (HH:MM: SS [UTC time])

The Time Stamp Status - A single hexadecimal character:

Bit 0x8: When set indicates the cycle rate is phase locked to 1PPS

Bit 0x4: When set indicates that the 1PPS pulse is being received

Bit 0x2: When set indicates that the GPS position fix is valid

Bit 0x1: When set indicates that the GPS RMC sentence is being received

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 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 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 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 designed to measure and record the magnetic field produced by a human heart (called Magneto Cardiography). Clinical magnetocardiographic measurements have been made in the past using a SQUID (superconducting quantum interference devices) magnetometer in a shielded room, but the MFAM simplifies the technique by eliminating the need for a shielded room and instead allows the test to be performed in a regular 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). Therefore 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.

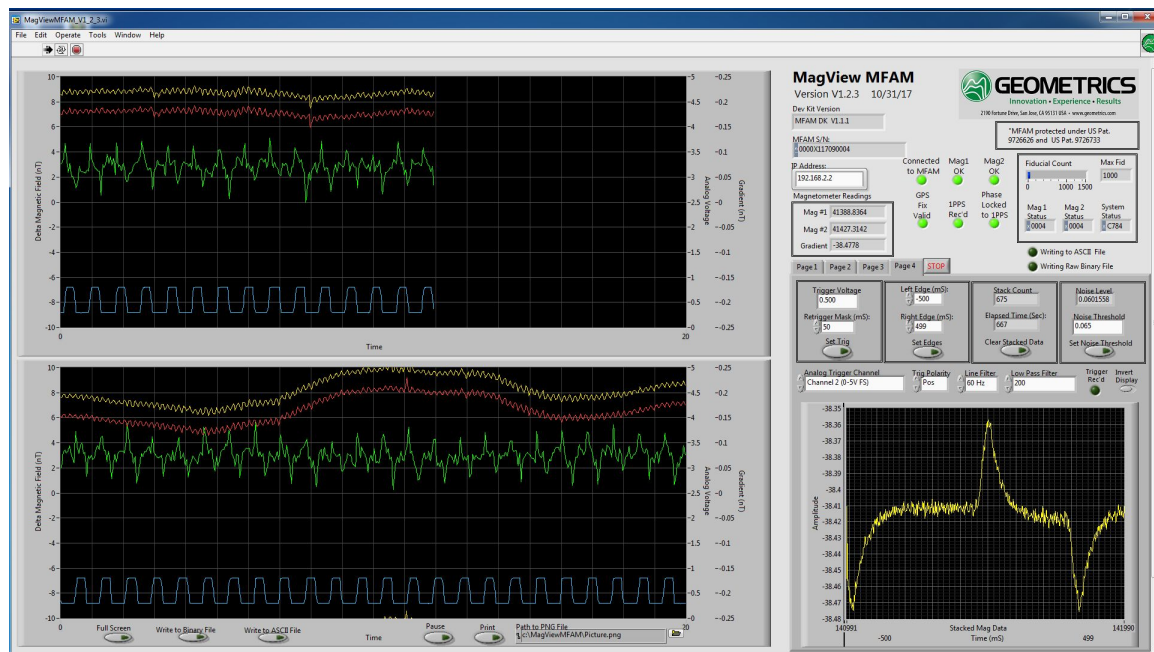
**Heartbeat synchronization:** To line up all the heartbeats for stacking, an Electro Cardiograph (ECG) machine is hooked up to the patient's left and right shoulder and lower left abdomen. These electrodes pick up electrical voltages from the heart, which the ECG machine converts to a trigger signal,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

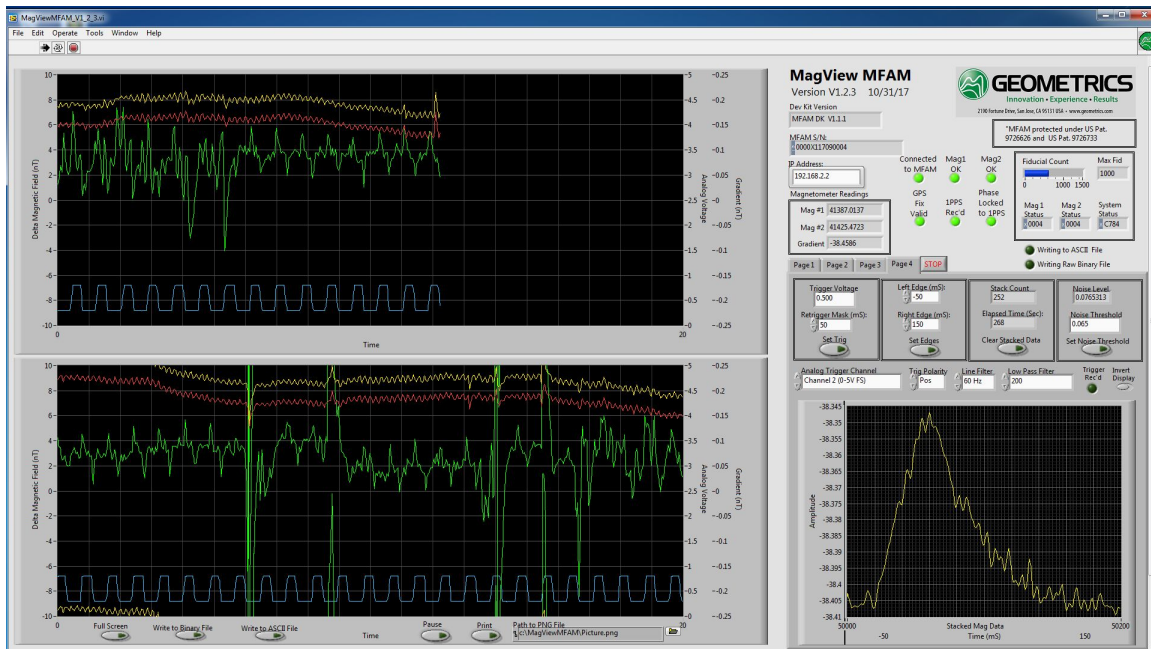
This trigger signal is sent to an analog input in the MFAM development kit where it is digitized at a 1 KHz rate and combined with the 1 KHz data from the MFAM module and transmitted in the Ethernet data packets.

**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 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:

**Trigger polarity** – you can trigger on a rising edge, or a falling edge of an analog signal. The screenshots above are examples of triggering on the rising edge of an analog signal.

**Trigger voltage** – I have 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.

**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 magnetometer 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:

The noise threshold and data rejection process are 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.

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. These filters only effect the stacked window display and do not alter the data saved in the binary file or in the in the mag and gradient windows displayed on the left. Window display filters include the power mains notch at 50 or 60 hertz . and a variety of low pass filters . . Also note that the power mains notch filters are actually a series of notches corresponding to the frequency of interest and its harmonics. . For a notch filter setting of 50 hertz, there are actually 5 notches at 50, 100, 150, 200, and 250 hertz. The same applies for the 60 hertz filter and removes the . 60, 120, 180, 240, and 300 hertz frequencies.

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:

When starting up the program occasionally the stacking process does not 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.

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

## **7.0 Ethernet Data Format and Saved File Format**

The Development board firmware gathers data from the MFAM Module and combines this data with GPS data before sending it out the Ethernet port. The data is received by the MagViewMFAM program and displayed on the computer monitor.

Data is sent over the Ethernet in groups containing forty milliseconds of data. Appendix B: 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 B: 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 B).

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 from the GPS. 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 B: 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 11 main stages during the startup process. The Diagnostic Stage is documented System Status bits 13-10 (stages 1-11). The Diagnostic Stage progression (1-11) are also displayed as text messages in the MagViewMFAM program's lower left window during start up.



After a successful startup, the System Status Diagnostic Stage bits (13-10) are cleared, which indicates that the MFAM is outputting valid magnetometer data. The MagViewMFAM program can be used to save data during startup. In fact, in the unlikely case that the start-up process does not complete, you can provide the saved start-up data to Geometrics, which can help us diagnose the problem and provide a solution more quickly.

## Appendix A: CONNECTING THE DEVELOPMENT KIT VIA ETHERNET

To connect to the Development Kit via Ethernet, you will need to manually set up your IP address to:

IP Address: 192.168.2.10

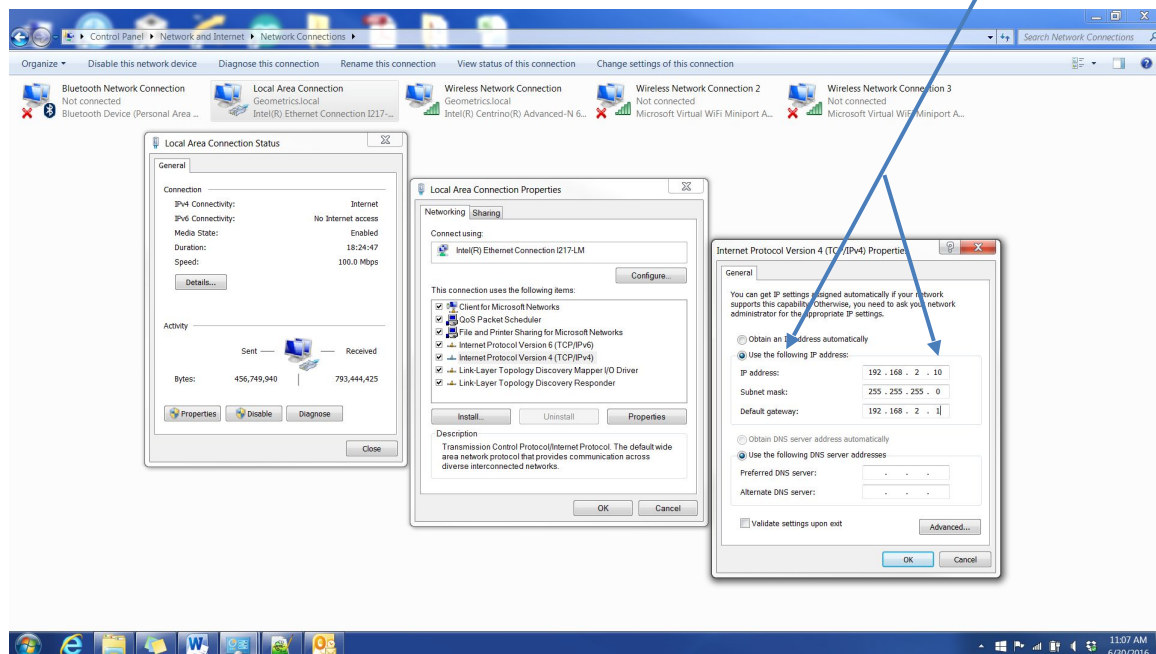
Subnet Mask: 255.255.255.0

Default Gateway: 192.168.2.1

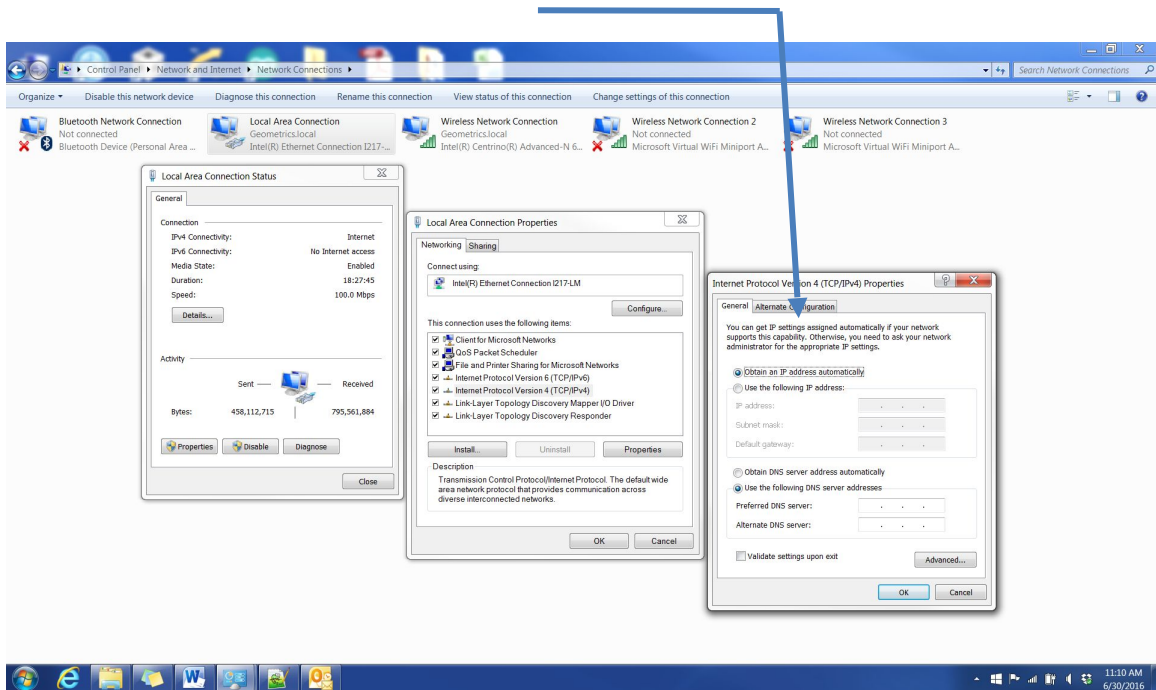
To do this open Windows Explorer, then:

- 1) Double click on "Network" at the bottom of the left pane
- 2) Open "Network and Sharing Center" (on the top title bar)
- 3) Click on Change Adapter Settings (left pane)
- 4) Double Click on "Local Area Connection"
- 5) Click on the "Properties" button
- 6) Double Click on the "Internet Protocol Versions 4 (TCP/IPv4)" line
- 7) Click on "Use the Following IP Address" (and fill out the address info as per the above)

When you open the program use the default IP address.



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”.



# Ethernet Data Transfer Format

Revision X3  
03/07/16

```

graph TD
    A[One Second of Data] --> B[One Ethernet Packet 2 of 25 - 1380 bytes each packet]
    B --> C[One Data Sample 32 Bytes]
    C --> D[All 32 Bit Words]
    C --> E[Fid Data Format]
    C --> F[System Status Data Format]
  
```

## One Second of Data

Data Block 1 of 25 (1380 bytes)	Data Block 2 of 25 (1380 bytes)	Data Block 3 of 25 (1380 bytes)	...Data Blocks 4 through 245...	Data Block 25 of 25 (1380 bytes)
------------------------------------	------------------------------------	------------------------------------	---------------------------------	-------------------------------------

## One Ethernet Packet (2 of 25 - 1380 bytes each packet)

"Stemmerics NIFAM" Preamble (34 bytes)	Data Sample 1 (32 Bytes)	Data Sample 2 (32 Bytes)	Data Sample 3 (32 Bytes)	...Data Sample 4 through 195...	Data Sample 40 (32 Bytes)	GPI Data (38 Bytes)
--	-----------------------------	-----------------------------	-----------------------------	---------------------------------	------------------------------	------------------------

## One Data Sample (32 Bytes)

RD (34 bits)	System Status (32 bits)	Magnetometer 1 (32 bits)	Mag 1 Status (34 bits)	Mag 2 Status (34 bits)	Magnetometer 2 (32 bits)	Aux X (32 bits)	Aux Y (32 bits)	Aux Z (32 bits)	Aux Temperature (34 bits)	ADC Channel 0 (34 bits)	ADC Channel 1 (34 bits)	ADC Channel 2 (34 bits)	ADC Channel 3 (34 bits)
-----------------	----------------------------	-----------------------------	---------------------------	---------------------------	-----------------------------	--------------------	--------------------	--------------------	------------------------------	----------------------------	----------------------------	----------------------------	----------------------------

## All 32 Bit Words

Low Byte Address Data LSB	Low Address + 1 Data MSB = 1	Low Address + 2 Data MSB = 1	High Byte Address Data MSB
------------------------------	---------------------------------	---------------------------------	-------------------------------

## Fid Data Format

Aux Channel (0 Bits [bits 15..31])	RD Count (bits 00..01)
---------------------------------------	------------------------

```

A2 A1 A0
-- -- --
0 0 0 Reserved
0 0 1 Compass
0 0 0 Gyro
0 0 1 Reserved
1 0 0 Accelerometer
1 0 1 Reserved
1 1 0 Reserved
1 1 1 Reserved
  
```

MDV: Mag 2 Data is Valid  
MIV: Mag 1 Data is Valid

## System Status Data Format

PPS Status (bits 15..16)	Diagnostic Stages 1 through 13 (bits 13..05)	Diagnostic Substage (bits 04..07)	Reserved for Future Use (bits 6..5)	Start Up Failed (bit 0)
-----------------------------	--	--------------------------------------	---	----------------------------

```

Bit 15: PPS Pulse is Being Received
Bit 16: 10Hz Sample Rate is Locked to PPS
Bits 13-10: Start Up Diagnostic Stages 1-13 (internal use)
Bits 9-7: Start Up Diagnostic Sub Stages (internal use)
Bit 6-1: Reserved for Future Use
Bit 0: Startup has Failed
  
```

## Example:

Byte Sequence: 0x16, 0x85, 0x86, 0x2F  
 Equals: 0x2F868516  
 Equals: 797345046 decimal

To Convert 32 bit value to magnetometer reading:  
 One LSB = 50 femtoTeslas  
 Therefore to convert 32 bit value to nanoTeslas:  
 reading (in nT) = [value] \* 50E-6  
 Using Example above:  
 797345046 \* 50E-6 = 39867.2523 nT

## All 16 Bit Words

Low Byte Address Data LSB	High Byte Address Data MSB
------------------------------	-------------------------------

## Example:

Byte Sequence: 0x05, 0xC9  
 Equals: 0xC905

## Appendix C: MFAM SENSING MODULE LCS050G SPECIFICATIONS\*

Characteristic	Condition	Min	Type	Max	Units
----------------	-----------	-----	------	-----	-------

### Power Supply

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

### Performance

Field Range	Full scale	20		100	μT
Noise Floor	Magnetic field orthogonal to sensor		1	5	pT/√Hz
	optical axis				
Dead Zone	Polar only, included angle		60	70	degree
Heading Error	Measured at 50μT field strength		25	40	nTp
Digital Resolution	32-bit magnetometer output		0.05		pT/LSb
Output Data Rate	Continuous measurement		1000		Hz

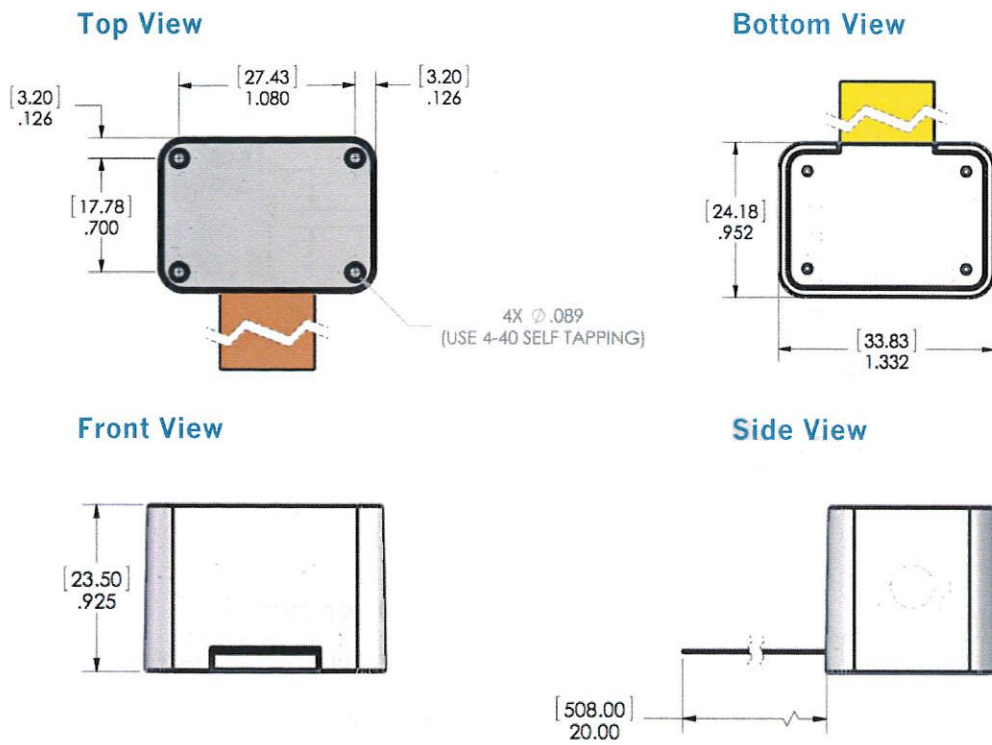
### Environmental

Operating Temperature	Ambient	-35		50	°C
Storage Temperature	Ambient	-40		70	°C
Operating Altitude				10000	Feet (ags)
Storage Altitude				45000	Feet

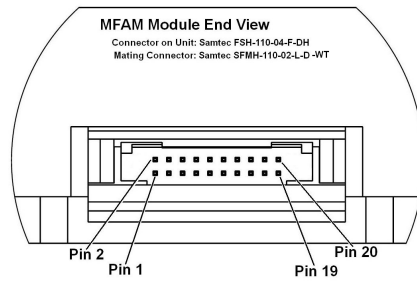
\*Preliminary Specifications can change without notice

## APPENDIX D: Sensor Dimensions

Weight: 30g each, two sensors per magnetometer module.

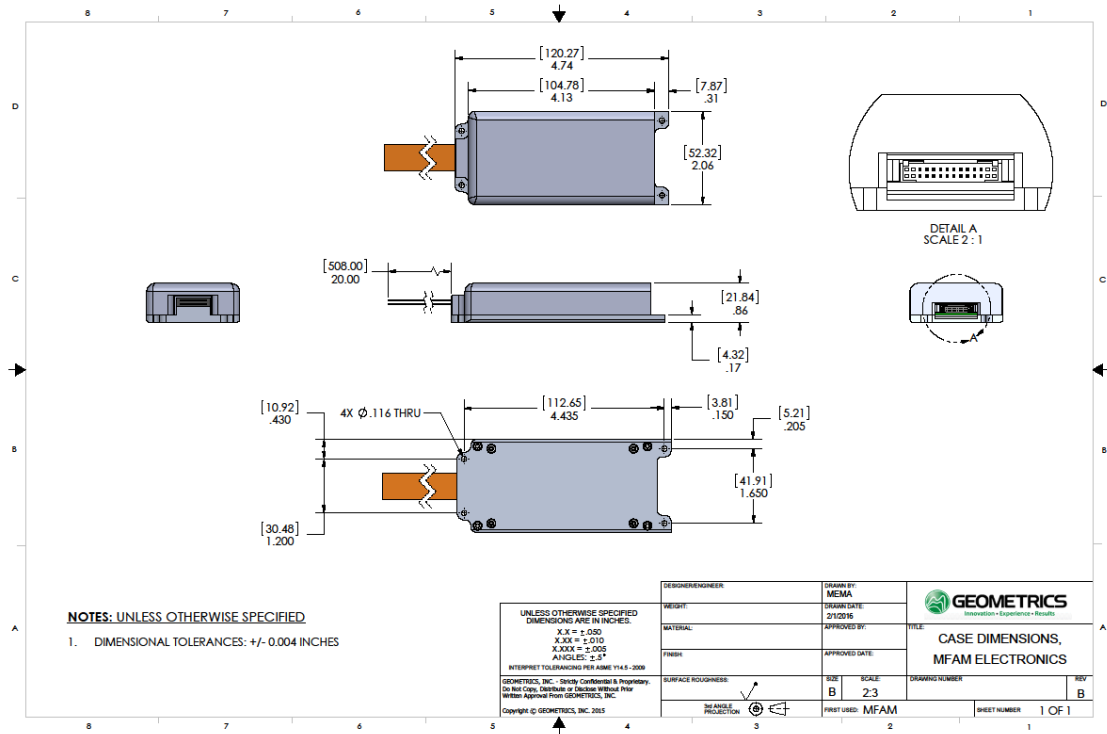


## Appendix E: MFAM Module Pinout



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

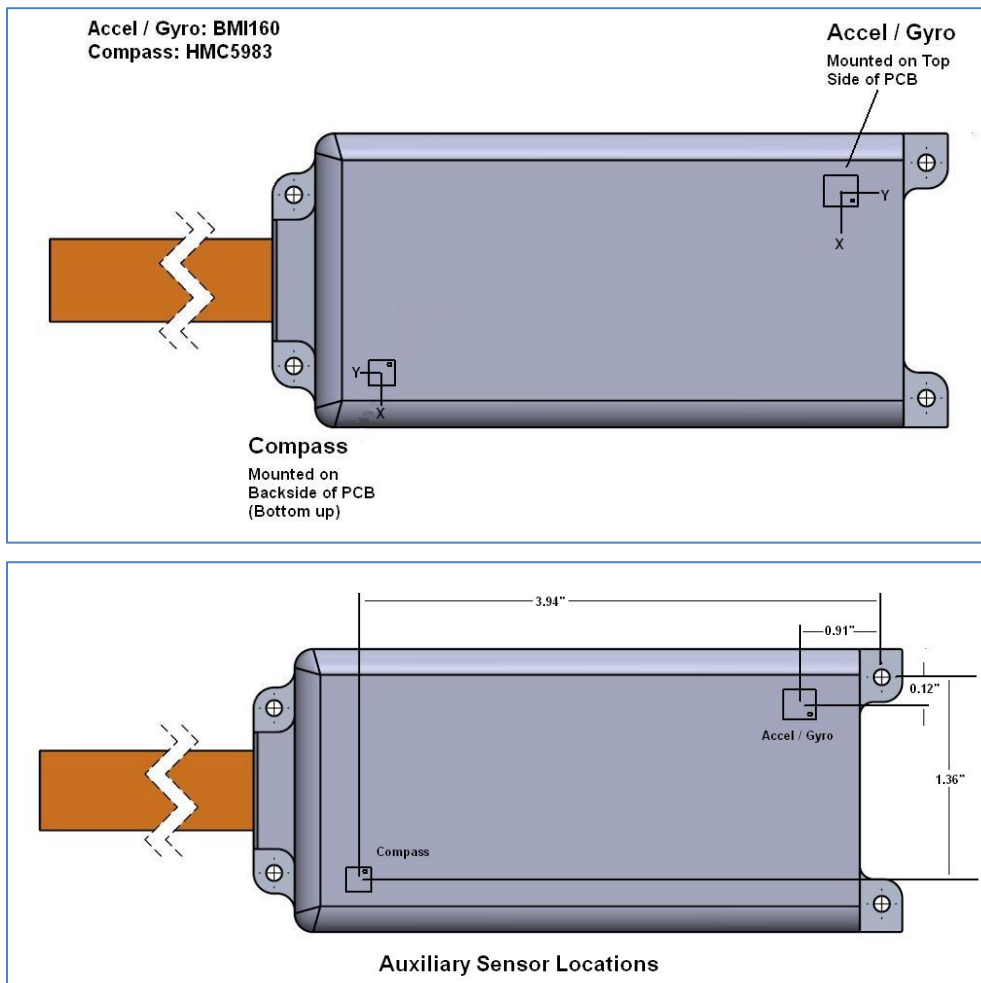
# Appendix F: MFAM Module Dimensions





## Appendix G: Auxiliary Sensor Orientation and Axis Definition:

The MFAM module contains an embedded Compass and Gyro/Accelerometer in the electronics housing. The Figures below define 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).

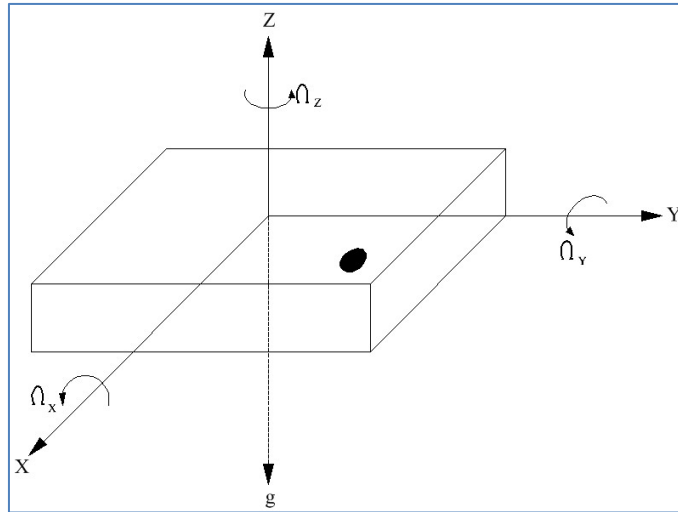


The compass is set up for a total range of  $\pm 0.88$  Gauss. The resolution is 0.73mG per LSB.

The Gyroscope is set up for  $\pm 2000$  degrees/second. Bandwidth is 74.6 Hz.

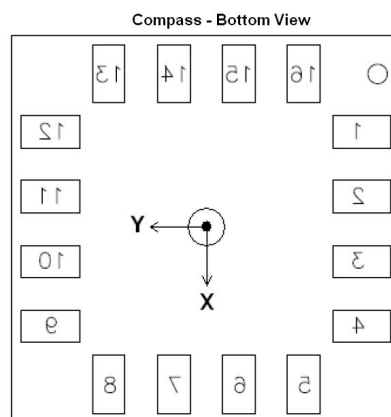
The Accelerometer is set to  $\pm 2G$ , with a bandwidth of 80 Hz.

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



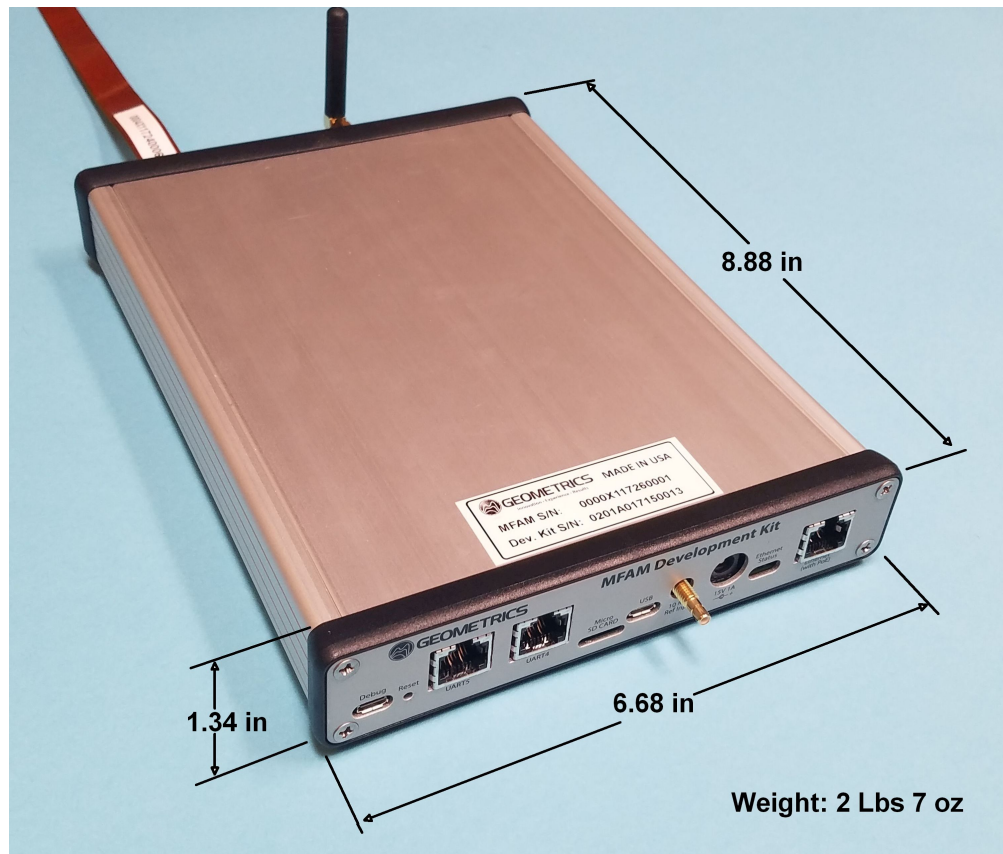
If the sensor is accelerated or rotated in the indicated directions (along the arrow paths), the corresponding channels in the output data will indicate a positive acceleration and/or yaw rate. If the sensor is at rest without any rotation, and the force of gravity is acting counter to the indicated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

## Appendix H: Development Kit Weight and Dimensions



Note: Weight value above includes the MFAM module and sensors.

## **Appendix I: Configuring Code Composer Studio for the On-Board XDS110 Debugger**

Earlier versions of the Development Kit used an on board Stellaris ICDI (In Circuit Debug Interface) debugger. The newer Development Kits now use an on board XDS110 debugger. You will need to tell CCS to use this new debugger:

From inside Code Composer Studio, open a project using the project explorer. In the project folder find the "targetConfigs" sub folder and open it. Double click on the "TIVA TM4C1294NCPDT.ccxml" file to edit it.

In that file under "General Setup" find the "Connection" subheading and change it to "Texas Instruments XDS110 USB Debug Probe". Click the "Save" button under the "Save Configuration" heading.

You can also test the debug connection hooking up the USB cable to the Development Kit debug port and by clicking the "Test Connection" button.

You will need to make this change for all your projects.

## Appendix J: Loading a Precompiled Binary Executable File into the Development Kit Using UniFlash

You will need:

Uniflash Software for TI processors installed on your computer

A binary executable file to load (it will have a file name with a “.out” extension)

A Uniflash configuration file (it will have a “.ccxml” file name extension)

Uniflash for TI microcontrollers is a free software program available from Texas Instruments. Go to [www.ti.com](http://www.ti.com) and type “Uniflash” in the search window. You will have to set up a TI account and agree to terms of use before you can download the installation program.

When choosing the version number use version 3.4.1.

When filling out forms on the TI website keep your answers as generic as possible. You want TI to be able to process and approve your form answers my machine parsing. If your answers are too specialized it will go through a human approval process, which usually results in no response from TI.

Procedure:

Copy the Configuration file (\*.ccxml) and the Binary Executable file (\*.out) to your desktop. If you were given more than one \*.ccxml file, then use the proper one based on the following:

If loading into a development kit use the file “MFAM\_Tiva\_Flash\_XDS110.ccxml”

If loading into a Texas Instruments EK-TM4C1294XL Launchpad use the file “MFAM\_Tiva\_Flash\_ICDI.ccxml”

This instruction tells Uniflash which debugger/loader is being used. The Launchpad has a built in Stellaris ICDI debugger, while the Development kit has a TI XDS110 built in debugger.

Plug a micro USB cable into the “DEBUG USB” port.

On the Development Kit that will be the USB port on the left side bottom of the rear panel. Power up the Development Kit.

On the Launchpad that would be the USB port at the opposite end of the Ethernet connector. Power up the Launchpad, or move the JP1 jumper from OTG to ICDI to power up the board from the USB port.

Find the directory where Uniflash was installed and double click the Uniflash shortcut.

On the Uniflash startup screen click on the “Open Target Configuration” link.

Browse to the \*.ccxml file you just copied to your desktop and select it (and click OK). This file tells the Uniflash program which processor and what debugger version you are using.

On the upper Command bar select the “Program” pulldown menu, select “erase”, and click OK.

Your Development Kit’s built in XDS110 debugger may need to be updated. If it does then let it update, then erase the flash.

On the upper command bar select the “Program” pulldown menu again and select “Load Program”.

Browse to your desktop and select the \*.out file you copied there earlier. Click the “Open” button, then “OK”. The binary executable code will be loaded.

When the executable code has been loaded, unplug the USB cable and press the Reset button on the rear panel (next to the Debug USB connector). If using a Launchpad, and you powered the board from the USB port, put the JP1 jumper back to the OTG position and power it up.

The newly loaded code is now running.

## Appendix K: Updating the MFAM Module Firmware

### You will need:

An MFAM Module and a Development Kit made after October 15, 2016. Units after this date will have the required firmware / software to be able to self-program the internal MFAM flash memory. If your MFAM module and/or Development Kit were made prior to that October 1, 2016 (and has not been upgraded since then) your unit can be reprogrammed at the factory to add the remote firmware upgrade functionality. Note that the MagViewMFAM.exe program must be dated October 13, 2016 or later. After this date the MagViewMFAM program will have the Cntl-Shift-“U” function which will initiate the firmware update).

A file containing the new code to be written into the MFAM flash memory (will have a “\*.yes” Extension).

### Procedure:

Copy the file with the “\*.yes” extension to the same folder that contains the MFAM console.

Right click on the \*.yes file and choose the “copy as” selection. Copy the file to using a new name of “Top\_Update.yes” into the same folder as the MagViewMFAM program.

Run the MagViewMFAM.exe program and connect to the Development Kit (lower left panel will say “Connected to TIVA...”). You may have to press the Reset Button before successfully connecting to the TIVA processor.

Invoke the MFAM Firmware Upload function by pressing the Control – Shift- “U” keys simultaneously. A pop-up dialog box will ask you to confirm that you want to update the firmware. Once you confirm this, the Development Kit firmware will look for the specific file name “Top\_Update.yes” in the MagViewMFAM home directory and then upload it to the MFAM module.

The upload process will take about 10 minutes. During this time, you will see occasional small data changes in the mag display window. Ignore any error messages in the status window such as “MFAM Startup Failed. Please Power Cycle”. At the time this message appears the upload is still going on.

The firmware upload is finished when the magnetometer data window starts displaying all zeros moving to the right. It should take about 4 or 5 seconds to completely traverse the screen from the left edge to the right edge. Only then is the update process complete. There will be not be any other message in the status window to confirm that the upload is complete – only the display of all zeros in the mag data window indicates that the upload is complete. Power cycle the Development Kit and MFAM module to exit the upload mode. The newly loaded firmware will now be running.

## Appendix L: Recommended Batteries and Battery Charger

Below are some links to Lithium Polymer batteries that can be used to power the Development Kit and MFAM via the external power connector. Unlike many LiPo batteries that use nickel straps inside (very magnetic), these batteries have a very low magnetic signature.

[https://hobbyking.com/en\\_us/zippy-flightmax-1800mah-3s1p-20c.html](https://hobbyking.com/en_us/zippy-flightmax-1800mah-3s1p-20c.html)

(Zippy Flightmax 3S1P 1800 mAH)

[https://hobbyking.com/en\\_us/zippy-compact-1500mah-3s-40c-lipo-pack.html](https://hobbyking.com/en_us/zippy-compact-1500mah-3s-40c-lipo-pack.html)

(Zippy Compact 3S1P 1500 mAH)

Here is universal charger that will charge the batteries:

[https://hobbyking.com/en\\_us/accuell-s60-ac-charger-us-plug.html](https://hobbyking.com/en_us/accuell-s60-ac-charger-us-plug.html)

The charger is a balanced charger (charges each of the 3 cells independently). It also has a discharge mode to automatically lower the battery charge state to 30% (required by law before shipment).

1800 mAH is enough battery to run the Development Kit and MFAM for about 2 hours.

**Note:** Lithium batteries can store a lot of energy and can be dangerous if mishandled. In addition, there are several shipping restrictions which need to be followed when sending batteries from one location to another. These restrictions include box labeling requirements, quantity limitations, battery charge state, and many others. It is the responsibility of the end user to comply with all federal and state regulations about the use, charging, storage and transport of Lithium batteries.



## Appendix M: Version Information

Revision	Date	Comments
X0.1	Jan 30, 2016	First Draft (LE)
X0.1b	Jan 31, 2016	Minor updates, corrections and formatting changes (RM)
X1.0	Feb 01, 2016	Released as preliminary documentation
X1.0.2	Feb 11, 2016	Added pinout definition table
X1.0.3	Feb 16, 2016	Added RS-232 Description, pinout and Picture, PoE description, redrew XYZ axis of Accel/Gyro
X1.0.4	Mar 9, 2016	EthConsole renamed to MFAMConsole, document format change that added two more analog inputs, document how to hook up analog wires
X1.0.5	Mar 16, 2016	Added Appendix G: Dead Zone description
X1.0.6	July 1, 2016	Added Appendix H: Weight and Dimensions of Eval Unit Also fixed error in the manual setup of static IP and return to DHCP Added default setting for Gyro, compass and Accelerometer in Appendix F Added description of Fiducial rollover with and without 1PPS being received
X1.0.7	Aug 02, 2016	Changed all references to Eval Kit to Development Kit. Changed all pictures of front and rear panels to match new panels. Changed RS232 connector description. Fixed Analog input and Status LED descriptions to match new Dev Kit Board layout.
X1.0.8	Sept 1, 2016	Added appendices I and J: Configuring CCS for XDS110 and using UniFlash to load binary code into the Development Kit TIVA processor.
X1.0.9	Oct 17, 2016	Added Appendix K: Upgrading the MFAM Module Firmware
X1.0.10	Dec 15, 2016	Fixed error in Samtec mating connector part # in Appendix D
X1.0.11	Mar 19, 2017	Updated formatting and added ITAR footers.
X1.0.12	Aug 24, 2017	Added Table of Contents and Figures (NJ)
	Jan 15, 2018	Added MagViewMFAM and removed MFAM Console information (NJ)
X1.0.13	Feb 06, 2018	Added Control Panel Page 4 Description, removed all references to internal batteries, updated the file writing section, fixed some errors in description
(LE) 8	Sept 10, 2018	Updated Uniflash Instructions appendix J Disclaimer

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