Magnetic precision has a name

Three-axis Magnetometers THM1176 and TFM1186

User's Manual

Version 2.0

(Revision 1.0)

February 2020

REVISION HISTORY

v. 1.0 r. 1.0	May 2008	First release
v. 1.0 r. 1.1	May 2008	Various fixes
v. 1.1 r. 1.0	July 2008	Various fixes
v. 1.2 r. 1.0	December 2009	Updates for version 3.x of software Updates for version 2.x of firmware Updates for THM1176-LF Various fixes
v. 1.2 r. 1.1	February 2010	Add notice concerning WEEE Directive
v. 1.2 r. 1.2	July 2010	Restore formatting of -HF dimensions
v. 1.3 r. 1.0	January 2012	Update for software release 4.0 and firmware release 3.0 Update links for external documentation Add documentation for THM1176-HFC
v. 1.3 r. 1.1	April 2012	Correct installation procedure
v. 1.3 r. 1.2	April 2014	Add documentation for THM1176-MF, TFM1186 Adapt documentation for SoMo™ 655 Remove references to electronic newsletter Update links to USB documentation Update for LabVIEW Mobile Module end-of-life Miscellaneous clean-ups
v. 1.3 r. 1.3	November 2014	Update for different versions of THM1176-MF and THM1176-HFC sensor Correct section numbering in Chapter 5
v. 1.3 r. 1.4	October 2016	Update for different versions of THM1176-MF sensor Update links for USB references
v. 2.0 r. 1.0	February 2020	Rewrite Chapter 2, "Quick Start Guide" Rewrite Chapter 3, "Overview" Delete Chapter 4, "Software User Interface" Rewrite Chapter 5, "Application Programming" Update dimensions of THM1176-HFC

CONTENTS

GETTING STARTED

1-Introduction

Metrolab's Three-axis Magnetometers are used to measure magnetic field strength. Simultaneous measurement of all three components of the magnetic field provides the total field no matter the orientation of the probe, which greatly facilitates many measurement tasks such as field mapping. The extraordinarily compact design, along with the optional ruggedized tablet, makes for a powerful, autonomous and portable magnetometer, excellent for field use.

This manual covers the entire THM1176 family, including the following models:

A. THM1176-MF ("Three-axis Hall Magnetometer – Medium Field"),

B. THM1176-HF ("Three-axis Hall Magnetometer – High Field"),

C. THM1176-HFC ("Three-axis Hall Magnetometer – High Field Compact"),

D. THM1176-LF ("Three-axis Hall Magnetometer – Low Field"), and

E. TFM1186 ("Three-axis Fluxgate Magnetometer").

For an overview of the capabilities of each of these instruments, please see Chapter 3-Overview, Chapter 6-Technical Specifications and Chapter 7-THM1176-MF/HF/HFC Sensor .

The THM1176 family of instruments resembles other standard USB devices; it and its software are easy to install and easy to use. Nonetheless, please take a moment to browse through Chapter 2-Quick Start Guide and Chapter 3-Overview. Pay particular attention to the cautionary notes.

It is easy to develop custom software for the THM1176 family; please see Chapter 4-Options for Computer Control, Chapter 5-USB Interface, and Chapter 8-Error Codes.

Finally, keep your instrument accurate and up to date by having it recalibrated at regular intervals. The recommended calibration interval is 18 months. You can benefit from a discounted price for the calibration if you return your instrument to Metrolab at a time that corresponds to our batch calibrations; please see Section 6-9 for details.

You can also download the latest firmware, software and manual, free of charge. We post all updates on our website. Section 3-7 provides some additional details.

We hope that your Three-axis Magnetometer will help you perform your magnetic field measurements easily and accurately. If you have problems and your reseller cannot help you further, the Metrolab team is ready to help. Even if you don't have problems, we are always interested in knowing more about how our instruments are used. Feel free to contact us at any time at contacts@metrolab.com.

GETTING STARTED
2-Quick Start Guide

2-1 KIT CONTENTS

Your shipment should contain:

- A THM1176 or TFM1186 magnetometer. If you ordered a "Duo Kit", you will receive two probes.
- A calibration certificate.
- A zero-gauss chamber, for measuring and adjusting the probe's zero offset. The TFM1186 does not come with a zero-gauss chamber – see the note in Section 2-6, Precautions.
- A USB thumb drive with the software and documentation.
- A carrying case.
- Optionally, if you ordered the Handheld Kit, a ruggedized Windows tablet. In addition to the tablet itself, you should receive:
  - a Mini-USB to USB-A adapter cable;
  - a pistol grip with an extension battery; and
  - a charger with adapter plugs for Europe/Switzerland, U.K., U.S. and Australia.

2-2 WINDOWS SOFTWARE INSTALLATION AND REMOVAL

2-2-1 Software Installation

The order in which you perform the following steps is not important:

- Run the EZMag3D installer, Metrolab-EZMag3D-InstallerWindows.exe, following the on-screen instructions.
- Run the installer for the libusbK device driver, InstallDriver.exe, following the on-screen instructions.

When the installation is complete, you will find a program link "EZMag3D <version>" on your desktop. You will find the same program link in the folder Metrolab of the Start Menu, alongside a link "EZMag3D <version> Manual" to the online help. As usual, you can also access these items via a search.

2-2-2 Software Removal

- In the Explorer, delete the EZMag3D parameter folder shown in the Settings screen. By default, it is in your AppData folder.
- Open the Apps & Features settings panel.
- Uninstall Metrolab EZMag3D.
- Uninstall UsbK Development Kit.

2-3 MACINTOSH SOFTWARE INSTALLATION AND REMOVAL

2-3-1 Software Installation

- Run the EZMag3D installer, Metrolab-EZMag3D-InstallerMacOs, following the on-screen instructions.

Note that the default installation location is in your personal Applications folder, not the system-wide Applications folder.

When the installation is complete, you will find the program EZMag3D in the folder you specified during installation. In the same folder, you will also find a link "EZMag3D Manual" to the online help. As usual, you can launch EZMag3D by double-clicking its icon; you can also create an alias on the Dock or Desktop, or you can launch it from a Spotlight search.

2-3-2 Software Removal

- In the Finder, delete the EZMag3D parameter folder shown in the Settings screen. By default, this is ~/Library/Application Support/EZMag3D; since your Library folder is usually hidden, you have to select the Finder's Go > Go to Folder... menu item, and then enter ~/Library/Application Support/EZMag3D.
- Open the program folder that you specified during installation (~/Applications/EZMag3D <version> by default) and run the program EZMag3D Uninstaller.

2-4 STARTING TO MEASURE

- Start the EZMag3D software.
  The first time you run EZMag3D, it will open the Connection Screen.
- Plug in the THM1176 or TFM1186.
  The magnetometer will take approximately 10 seconds to boot and should then appear on the Connection Screen, allowing you to connect to the instrument.
- Place the probe in the magnet. On the THM1176-MF and THM1176-HF, you can remove the probe cap to access narrow gaps – see Chapter 3-Overview. See the EZMag3D Manual for details on using the software.
- (**Does not apply to TFM1186 – see Section 2-6!**) Check the offset before each series of measurements by placing the probe in the Zero Gauss Chamber. If the offset is higher than desired, leave the probe in the Zero Gauss Chamber and perform the User Offset Correction procedure.

2-5 USING THE HANDHELD KIT

The ruggedized Windows tablet included in the Handheld Kit is like any other Windows computer; all the procedures in the previous sections apply. Here are some additional hints:

- Use the adapter included to plug the THM1176/TFM1186 into the tablet's Mini-USB connector.
- The Mini-USB connector is also used to recharge the tablet, so the tablet cannot be recharged while measuring. However, a fully charged tablet should provide roughly four hours of operation, making for a compact and lightweight handheld solution.
- The hand strap on the back of the tablet is very practical, but it is unfortunately made for using the tablet in portrait mode, which is not the optimal orientation for EZMag3D.
- The pistol grip, on the other hand, places the tablet in landscape mode, and also dramatically extends the battery life, to more than a day. In fact, by plugging the power supply into the pistol grip rather than the tablet itself, you can recharge while measuring. However, note the precautions below.

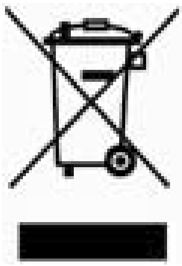
2-6 PRECAUTIONS

CAUTION

⇒ High magnetic field gradients – as found, for example, around an MRI or NMR spectroscopy magnet – will subject the USB connector and the tablet to strong forces. To prevent injury from flying objects or whiplashing cables, be sure to hold these components securely when you are around a strong magnet.

NOTICE

⇒ Do not bend the probe cable sharply. This is a special cable with individually shielded signal wires, in order to minimize induction artifacts. Sharp bends break the shielding.

⇒ 

This product conforms to the WEEE Directive of the European Union (2002/96/EC) and belongs to Category 9 (Monitoring and Control Instruments). For proper environment friendly disposal, you can return the instrument free of charge to us or our local distributor.

SPECIAL NOTICE FOR THE TABLET

⇒ When the tablet's battery level drops below 10%, the THM1176/TFM1186 will no longer function (BIOS > v. 1.11). This is because the tablet's USB port, acting as a USB host, supplies power to the instrument, and must switch back to USB device mode in order to be able to charge the tablet. This should happen before the battery is completely depleted to avoid the USB port being permanently stuck in host mode.

⇒ To use the pistol grip for additional battery power, press the button on the back of the pistol grip for 1 second, to enable its power output. You should see the tablet's power LED turn red, and the Windows "charging battery" icon. Press the button on the pistol grip for 3 seconds to disable its power output.

SPECIAL NOTICE FOR THE THM1176-HF and THM1176-HFC

⇒ Remember that the THM1176-HF is only calibrated to 14.1 T (formerly 3 T), and the THM1176-HFC only to 1.5 T. Consequently, the 20 T range on these instruments is only calibrated up to these limits. You should try to use the lower ranges whenever possible; the best is to leave the instrument in auto-ranging mode (the default).

SPECIAL NOTICE FOR THE THM1176-HFC

⇒ The probe is fragile. Be very careful when handling; even the weight of the instrument cable is sufficient to damage the probe. Damage to either the sensor package or signal cable will destroy the sensor. We strongly suggest storing the probe in its protective case when not in use.

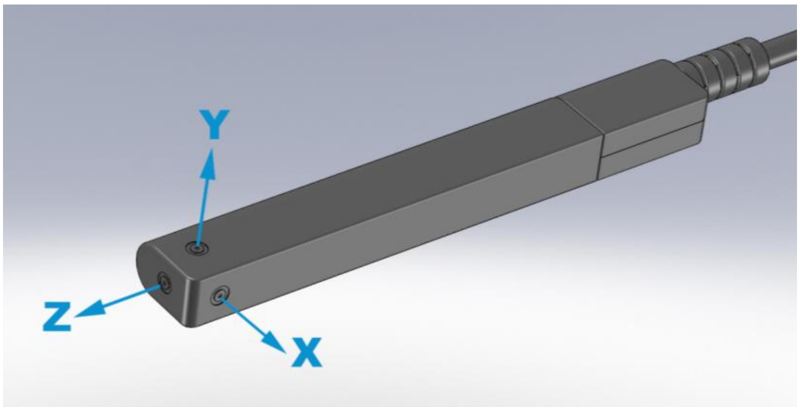
⇒ The sensor is sensitive to Electrostatic Discharge (ESD). Be sure to ground yourself and follow proper procedure when handling the sensor.

SPECIAL NOTICE FOR THE TFM1186

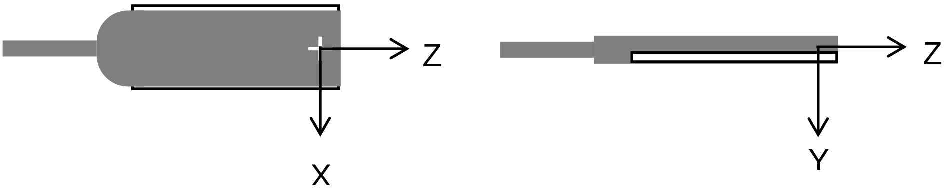
⇒ Do not use the zero-offset correction feature with the TFM1186. In fact, the fluxgate sensor is so sensitive that most zero-gauss chambers are completely inadequate, and the zero-offset procedure will introduce a large offset error. If the zero-offset procedure is nonetheless executed, you can restore the factory offset as described in the EZMag3D manual.

2-7 AXIS ORIENTATIONS

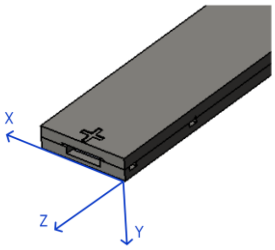
The orientation of the axes relative to a THM1176 probe is as follows:



Relative to the THM1176-MF and -HF sensors:



Similarly for the THM1176-HFC sensor:



For the TFM1186, the axis orientations are printed on the sensor.

USING THE THM1176/TFM1186
3-Overview

This chapter provides a short technical overview of the THM1176 family of instruments and what you can do with them.

3-1 HARDWARE BLOCK DIAGRAM

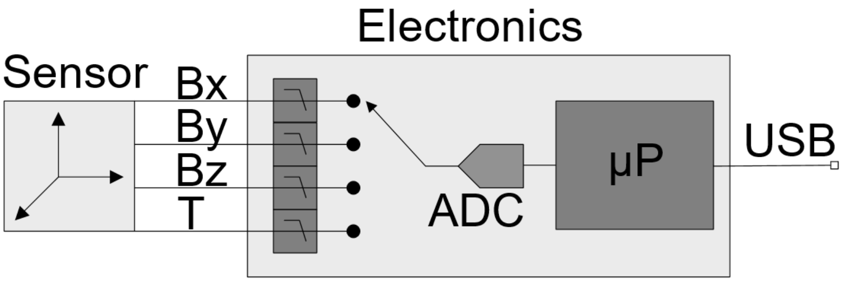


Figure 1. THM1176/TFM1186 functional block diagram

3-2 SENSORS

The sensors used in the different models are as follows:

- THM1176-MF, "Three-axis Hall Magnetometer, Medium Field":
  Single-chip 3-axis Hall sensor with ranges of 0.1, 0.3, 1 and 3 T.
- THM1176-HF, "Three-axis Hall Magnetometer, High Field":
  Single-chip 3-axis Hall sensor with ranges of 0.1, 0.5, 3 and 20 T.
- THM1176-HFC, "Three-axis Hall Magnetometer, High Field Compact":
  Single-chip 3-axis Hall sensor with ranges of 0.1, 0.5, 3 and 20 T, in a compact package.
- THM1176-LF, "Three-axis Hall Magnetometer, Low Field":
  Assembly of 3 single-axis Hall sensors, with on-chip flux concentrators, with a range of 8 mT.
- TFM1186, "Three-axis Fluxgate Magnetometer":
  3-axis fluxgate sensor, with a range of 100 µT (200 µT upon special order). This sensor distinguishes itself from the others in a number of respects: differential output, requiring an input adapter; no integrated temperature sensor; and a connector.

More details on the single-chip 3-axis Hall sensors can be found in Chapter 7-THM1176-MF/HF/HFC Sensor Details.

3-3 MEASUREMENT PROCESS

- The analog sensors measure the three vector components of the magnetic field and the sensor's internal temperature.
- At the input of the electronics, the inputs from the sensor pass through a 1 kHz anti-aliasing filter. This 2nd-order filter is designed to be flat to 1 kHz; the -3 dB point is at several kHz.
- A multiplexer selects each of the inputs in turn and routes the signal to a 16-bit ADC.
- A microprocessor (µP) receives commands from the host computer, controls the measurement process, and returns the data to the host.
- To reduce noise, the µP samples each field component several times, depending on the degree of averaging (oversampling) specified by the user. The sample rate is as fast as possible – in practice just under 10 kHz.
- With this oversampling, the signals are sampled in the following order:
  $$B_x, B_x, B_x, \ldots, B_y, B_y, B_y, \ldots, B_z, B_z, B_z, \ldots, T$$
  where T is temperature.
- The averaged field measurement $[\langle B_x\rangle, \langle B_y\rangle, \langle B_z\rangle]$ is then stored in the acquisition buffer, as one measurement point. T is averaged with the temperature measurements for the other points in the acquisition buffer.
- The µP then waits for a trigger before starting the next acquisition. The trigger can occur immediately, at the expiration of a timer, or at the reception of a USB trigger command, as specified by the user.
- The µP accumulates measurement points in the acquisition buffer, up to the number specified by the user – the so-called "block size". The maximum block size supported by the µP is 4096 measurement points. The acquisition is actually double buffered, to allow the acquisition to continue while data is transferred to the host computer.
- At the end of each block of measurement points, the µP records a 64-bit time stamp, accurate to 167 ns. It is up to the software to reconstruct a full

time stamp for each measurement point, based on the trigger mode and the host computer's date/time information.

- Before sending the data to the host, each measurement point is corrected for the sensor's offset, gain, non-linearity, and temperature drift. The correction factors come from a factory-supplied calibration table stored in the µP's nonvolatile memory. The factory parameters for offset, however, are overridden by an updated value obtained through the zero-offset calibration procedure, performed by the user with the sensor in the zero-gauss chamber. The average temperature for the block is used to compensate for temperature drift. If the user wants the raw measurements, he can disable these corrections.
- The calibration table also contains data concerning the orthogonality of the sensor's axis; however, this correction is applied not by the µP, but by the software.

3-4 CHARACTERISTICS AND BENEFITS

- Three axes:
  Simultaneous measurement of all three axes of the magnetic field provides the total field, no matter the orientation of the probe.
- Field sensitive volume:
  On the THM1176-MF, -HF and -HFC, a microscopic Hall sensor volume provides localization to a fraction of a mm, and a self-consistent measurement of the three axes even in highly inhomogeneous fields. The active field volume of the THM1176-LF and TFM1186 is much larger, on the order of several mm, but this is usually sufficient for weak fields.
- Range, accuracy and resolution:
  Consult these key specifications and choose the probe most appropriate for your application:
  - THM1176-MF: most permanent- and electro-magnet applications, including superconducting magnets up to 3 T;
  - THM1176-HF: high-field superconducting magnets to 14 T;
  - THM1176-HFC: similar, but for sub-millimeter gaps;

  - THM1176-LF: millitesla fringe fields;
  - TFM1186: nanotesla-range perturbations in, for example, the earth's field.

- Bandwidth of DC to 1 kHz:
  The 1 kHz bandwidth allows measuring AC fields generated, for example, by transformers and motors.

- Trigger modes:
  Three trigger modes allow the acquisition procedure to be fine-tuned for the measurement.

  - Immediate trigger mode:
    Immediate trigger mode – the default – starts an acquisition sequence immediately upon receiving the measurement command.
  - Timed trigger mode:
    Timed trigger mode is suitable for measuring rapidly varying fields. The maximum sample rate – writing data into the acquisition buffer – is approximately 5.3 kSa/s, where one sample is a triplet (B_x, B_y, B_z). With a simultaneous readout via USB, the maximum sample rate is approximately 2.3 kSa/s.
  - Bus triggered mode:
    The USB bus trigger command can be used to synchronize the acquisition with external events. The instrument allows up to about 400 bus triggers per second.

- Measurement blocks:
  The THM1176/TFM1186 contains a local memory capable of holding 4096 samples, allowing data to be acquired more quickly than it can be read out by the USB interface.

- Averaging:
  Averaging, or oversampling, can reduce measurement noise. The degree of averaging is controllable, since long integration periods might be beneficial for static fields, but counterproductive for time-varying fields.

- Zero-offset calibration (**not for TFM1186 – see Section 2-6!**):
  To guarantee the specified accuracy, the measurement offset should be checked before each measurement sequence, using the zero-gauss chamber supplied. If needed, the offset correction procedure will measure and correct this offset. The correction value is written to flash memory so that the same correction will be applied the next time the instrument is powered up.

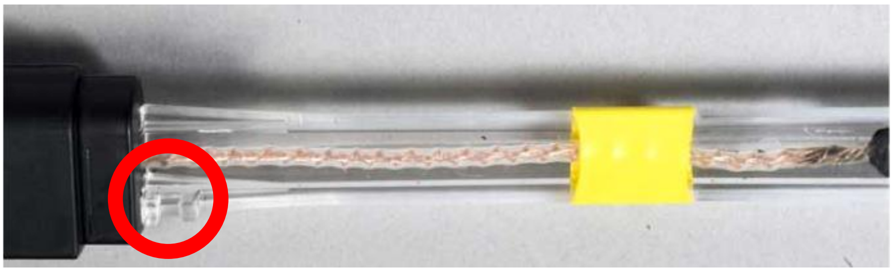
- Readout options:
  The three field components are always acquired, but the readout can be limited to any selected components. The readout can include a single measurement or an entire array of measurements, and can be formatted as an ASCII message or as a binary block. Binary data may be compressed by a factor of two or four, for example to help reduce the traffic on a busy USB hub. Depending on the model, the field values can be returned in Tesla, mTesla, µTesla, nTesla, Gauss, kGauss, mGauss, equivalent proton NMR frequency, or raw ADC values. The timestamp (in ns) and sensor temperature (arbitrary units, not calibrated) can also be read out.

3-5 PROBE MECHANICAL DESIGN

- Protection for the sensor:
  Magnetic sensors are sensitive electronic components. The plastic cover of the THM1176-MF, -HF and -LF protects their Hall sensors from the bumps and scrapes of normal use. For the THM1176-MF and -HF, the sensor packaging provides effective protection even with the cap removed (see below). However, the THM1176-HFC lacks all such protection; please note the special handling precautions in Section 2-6, Precautions. The TFM1186 sensor is relatively large and mechanically very robust.

- Small gaps:
  The THM1176-MF, -HF and -LF probes are 10 mm thick. To measure in a smaller gap, the THM1176-MF or -HF probe cap can be removed, reducing the thickness to 4.1 mm. If needed, the THM1176-MF or -HF sensor – only 2.3 mm thick – can be separated from the probe plastic; note, however, that the sensor wires are delicate and can easily be broken. For even smaller gaps, use a THM1176-HFC, whose probe is only 0.5 mm thick.

- Stationary installation (THM1176-MF and -HF only):
  Removing the cap also reveals a mounting point that allows the probe to be permanently mounted or attached to a scanning arm. The exact position of the field-sensitive point can be determined by optical sighting.



3-6 HOST COMPUTER INTERFACE

- USB interface:
  Compliance with the USB 2.0 mechanical, electrical and protocol standard provides basic connectivity with any USB-capable computer. The instrument supports USB full-speed communication (12 Mbps).
- Standardized USB class driver:
  Compliance with the USB Test & Measurement Class (USBTMC) allows the instrument to be connected without installing a custom USB driver. All that is required is a generic class driver for test and measurement equipment, as provided by suppliers of instrumentation software.
- Standardized IEEE488.2 protocol:
  Compliance with the USB488 protocol specification for USBTMC provides all the capabilities of an IEEE488 instrument on the USB bus. IEEE488, derived from HPIB/GPIB, is the world's most widely used instrumentation protocol. IEEE488 compliance allows any VISA library (Virtual Instrument Software Architecture) to control every aspect of the instrument.
- Standardized instrument command protocol:
  The SCPI standard (Standard Commands for Programmable Instruments) is the standard developed and used by large instrumentation manufacturers such as Tektronix and HP/Agilent/Keysight, and provides a programming interface familiar to many instrumentation system programmers.

3-7 HOST COMPUTER AND SOFTWARE

The THM1176 family of magnetometers requires a host computer for power and control. With the Handheld Kit, this host computer is a ruggedized Windows tablet; otherwise, it is your computer. The probes supplied with the Desktop and Handheld Kits are identical; in other words, you can also plug a probe from a Handheld Kit into your computer.

The THM1176/TFM1186 are supplied with software, called EZMag3D. See the included electronic manual for how to use this software. You can also integrate this software into a larger measurement system, or even write software from scratch; please see Chapter 4-Options for Computer Control for your different options.

3-8 CALIBRATION, MAINTENANCE, REPAIR AND WARRENTY

- Calibration procedure:
  The THM1176 family of instruments can only be calibrated by Metrolab. This is because special magnets, tooling and software are required to calibrate all three axes, at multiple fields and temperatures, and write the results to flash memory.

- Recommended calibration interval:
  You are of course free to fix the interval at which you send your instrument back for calibration, within the context of your quality assurance policy. Metrolab's recommendation is to send the instrument back for calibration at least once every eighteen months.

- Recommended calibration dates:
  To minimize costs, Metrolab establishes a limited number of dates in the year when batches of THM1176 family magnetometers will be calibrated. To avoid substantial extra charges, you should ship the unit back to Metrolab in order to coincide with one of these dates. Please see Section 6-9 for a list of these dates.

- Upgrades:
  Via its website, Metrolab makes available improvements and bug fixes for the THM1176 firmware, software and manual. The Download page of the

Metrolab website (https://www.metrolab.com/downloads/) will always contain the latest versions.

- Firmware upgrades:
  The THM1176 family of instruments is designed such that you can upgrade the firmware yourself. Firmware upgrades are a delicate procedure, as a failure may render the instrument unusable. Metrolab has made every effort to make the process foolproof, but please take your time and follow the instructions provided with the upgrade carefully.
- Repairs:
  Due to the highly integrated construction of the THM1176 family, Metrolab cannot replace individual electronic components. If you send an instrument back for repair, we will send you a replacement unit at a standardized exchange price – please contact Metrolab for a quotation. The replacement unit may contain parts recovered from units previously sent in for repair; however, it will of course be fully tested, calibrated and guaranteed.
- Warranty:
  The standard warranty period is two years from the date of purchase. During this period, Metrolab will replace a failing unit free of charge, unless it is clear that the unit has been abused (crushed probe or electronics, torn cable, etc.). We do not assume responsibility for consequential damage, for example to your PC.

PROGRAMMING THE THM1176/TFM1186
4-Options for Computer Control

The THM1176 family of magnetometers has no built-in display or controls, so computer control of the instrument is indispensable. This chapter outlines the different approaches to computer control that Metrolab supports, and tries to summarize the pros and cons of each.

4-1 EZMAG3D TURN-KEY SOFTWARE

The simplest approach is to use the supplied software, EZMag3D. EZMag3D is the second generation of software for the THM1176 family, and its rich feature set is based on more than ten years of experience in a wide variety of applications.

EZMag3D is supplied as Open Source software, so if you just need that "one additional feature", modifying EZMag3D might be the simplest approach. To get started, please see the chapters in the EZMag3D manual concerning the source code and license conditions.

Even if you plan to develop your own control software from scratch, we strongly recommend you install EZMag3D, to learn the instrument and to serve as a baseline.

4-2 EZMAG3D PLUGINS

You can integrate the THM1176 family of magnetometers into a larger measurement system by writing a plugin to support your trigger source or your mapping system. With this approach, you do not have to worry about the details of the instrument or EZMag3D, but you can take advantage of all of EZMag3D's features. Sample plugins provide manual triggering and mapping. EZMag3D plugins are written in C++ and use the Qt framework; to get started, please see the corresponding chapter in the EZMag3D manual.

4-3 THM1176 INSTRUMENT CONTROL API

EZMag3D communicates with the THM1176/TFM1186 via a C++ Application Programming Interface (API). This second-generation API is completely public and well-documented. Unlike the plugins, the API is "pure" C++11, and does not rely on the Qt framework. To get started, please refer to the chapter in the

EZMag3D manual describing the source code structure. Detailed documentation is supplied in Doxygen format.

Metrolab also plans to supply wrappers for the THM1176 API for other development systems, such as LabVIEW and Python. This is still a work in progress at the time of this writing; please consult the supplied software source code and the Metrolab web site.

Finally, the first-generation THM1176 API, written entirely in LabVIEW, is no longer maintained, but is still functional and available for download as part of the "THM1176 Desktop Kit software".

4-4 THM1176 INSTRUMENT MANAGER

EZMag3D includes a layer on top of the THM1176 Instrument Control API, the THM1176 Instrument Manager, a Qt Object abstraction of the instrument. It uses none of the user-interface components of the Qt framework, only the core thread and synchronization functionality. The benefit of the Instrument Manager is simplicity: whereas the API provides access to every single feature of the instrument, the Instrument Manager reveals just the minimally required functionality, in a simplified form. To get started, again refer to the chapter in the EZMag3D manual describing the source code structure and the detailed Doxygen documentation in the source.

PROGRAMMING THE THM1176/TFM1186
5-USB Interface

5-1 GENERAL

The THM1176 family of instruments communicates with a computer host via a Universal Serial Bus (USB) interface. If you use one of the recommended approaches for computer control, described in the preceding chapter, you generally don't have to understand the details of this interface. For completeness, however, this chapter describes the lowest level of the communication.

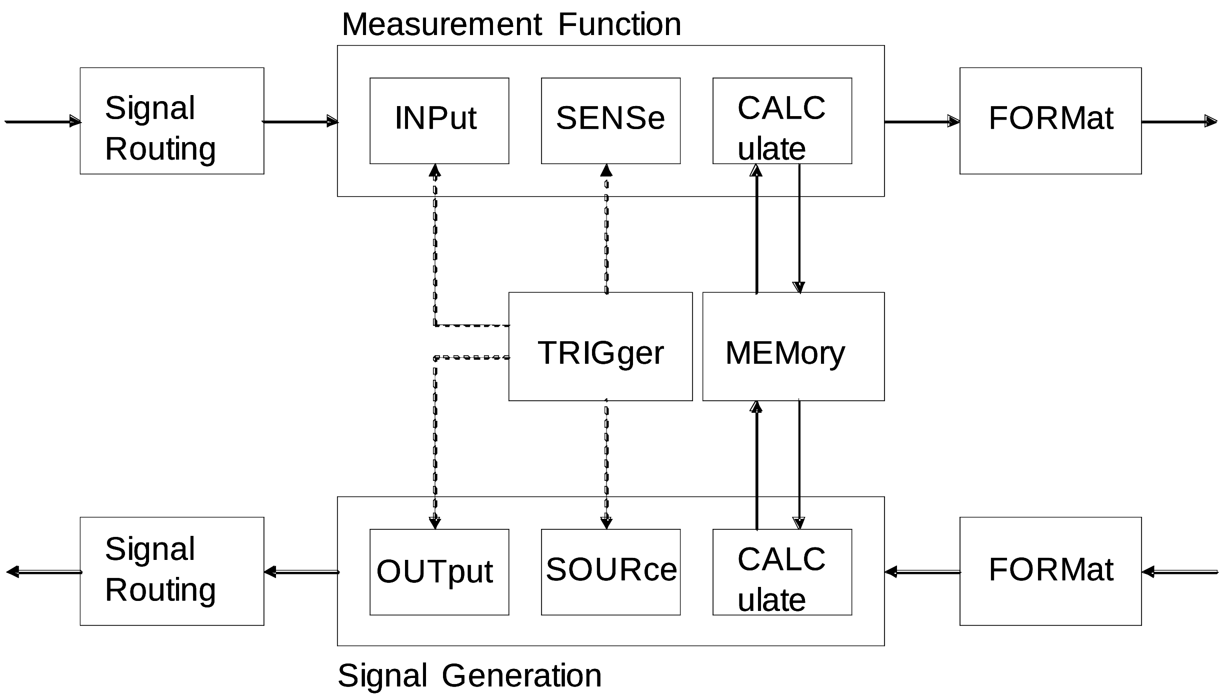
The THM1176 family was originally designed to plug-and-play with a Virtual Instrument Software Architecture (VISA) compliant software library – in particular, the NI-VISA library from National Instruments (see http://www.ni.com/). If you are not using NI-VISA, you will probably need information that is not provided in this chapter:

- USB 2.0
  See "Universal Serial Bus Specification, Revision 2.0, April 27, 2000" available from http://www.usb.org/developers/docs/usb20_docs/.
- USBTMC and USBTMC-USB488
  See "Universal Serial Bus Test and Measurement Class Specification (USBTMC), Revision 1.0, April 14, 2003" and "Universal Serial Bus Test and Measurement Class, Subclass USB488 Specification (USBTMC-USB488), Revision 1.0, April 14, 2003," available from http://www.usb.org/developers/docs/devclass_docs/.
- SCPI
  See "Standard Commands for Programmable Instruments (SCPI), VERSION 1999.0, May, 1999," available from http://www.ivifoundation.org/specifications/default.aspx.
- IEEE 488.2
  See "IEEE Standard Codes, Formats, Protocols, and Common Commands for Use With IEEE Std 488.1-1987, IEEE Standard Digital Interface for Programmable Instrumentation, IEEE Std 488.2-1992," available from https://standards.ieee.org.

- VISA
  See "VPP-4.3: The VISA Library," "VPP-4.3.2: VISA Implementation Specification for Textual Languages," "VPP-4.3.3: VISA Implementation Specification for the G Language," VPP-4.3.4: VISA Implementation Specification for COM," all Revision 2.2 (March 17, 2000) by the VXI plug & play Systems Alliance, available from http://www.ivifoundation.org/specifications/default.aspx.

5-2 SCPI INSTRUMENT MODEL

The THM1176/TFM1186 complies with the Standard Commands for Programmable instruments (SCPI) standard. SCPI uses a standard instrument model to organize the command structure. The diagram below shows the subsystems concerning the signal flow.



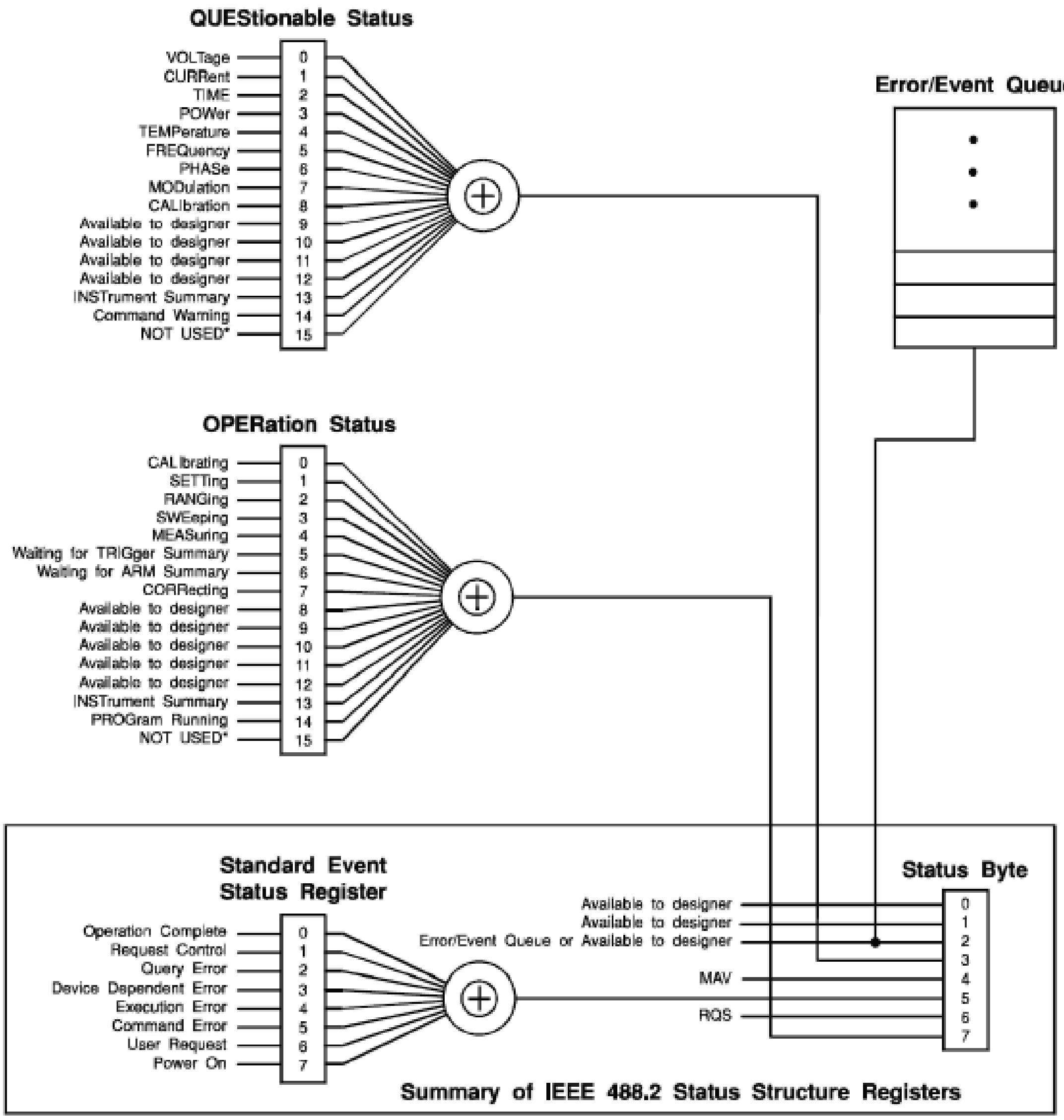
The following table provides a summary of the instrument capabilities, organized according to the SCPI instrument model. The supported commands include IEEE 488.2 "Common Commands" (start with "*") as well as SCPI commands. Many commands have additional options, or query forms to return the currently set value; see later sections for details. In addition to ASCII commands, the THM1176/TFM1186 also supports certain USBTMC-USB488 controls, also noted in this table.

Functional Block	Command(s)	Function
Measurement Function	:MEASure …	Measure with standard settings. Equivalent to *RST;:READ …
	:READ …	Measure with custom settings. Equivalent to :ABORt;:INITiate …;:FETCh …
	:FETCh …	Fetch measurement results previously acquired with MEASure, READ or INITiate
	:CALCulate …	Control averaging
• **Signal Routing**	-	Not used
• **INPut**	-	Not used
• **SENSe**	:SENSe …	Select range and auto-ranging
• **CALCulate**	CALibration …	Compute and apply calibration factors
FORMat	:FORMat …	Set output format
	:UNIT …	Set output units
TRIGger	*TRG USBTMC-USB488	Generate a trigger
	:INITiate …	Enable triggers
	:ABORt	Abort triggers
	:TRIGger …	Select trigger source and characteristics
MEMory	-	Not used
Signal Generation	-	Not used
STATus	*CLS	Clear status

Functional Block	Command(s)	Function
	*STB?, *SRE USBTMC-USB488	Read and enable bits in Status Byte
	USBTMC-USB488	Request service from host
	*ESR?, *ESE	Read and enable bits in Standard Event Status Register
	*OPC, *WAI	Detect and wait for operation complete
	:STATus …	Read and enable bits in OPERation and QUEStionable registers
	:SYSTem:ERRor	Query error queue
SYSTem	USBTMC-USB488	Clear input and output buffers
	USBTMC-USB488	Remote/local control – ineffective since THM1176/TFM1186 has no local controls
	*RST	Perform reset
	*TST?	Perform self-test (not supported)
	*IDN?	Return Instrument ID
	:SYSTem:VERSion	Return SCPI version
	:SYSTem:HELP …	Provide command help
	:SYSTem:SLEEp	Power down analog subsystem
MMEMory	:MMEMory …	Manipulate FLASH memory files
DIAGnostic	:DIAGnostic: …	Initiate firmware upgrade

5-3 IEEE 488.2 / SCPI STATUS REGISTERS

IEEE 488.2 compliant instruments have at least two registers: the Status Byte and the Standard Event Status Register. SCPI adds the Operation Status Register, Questionable Status Register and Error/Event Queue. The diagram below, taken from the SCPI standard, provides a good summary. This section describes how the THM1176/TFM1186 uses these status registers.



* The use of Bit 15 is not allowed since some controllers may have difficulty reading a 16 bit unsigned integer. The value of this bit shall always be 0.

- Status Byte

  Contains a 1-byte status summary. The THM1176/TFM1186 uses the following bits:

Bit	Name	Description
2	EAV	Error AVailable (in Error/Event Queue)
3	QSB	Questionable Summary Bit
4	MAV	Message AVailable: response ready to be read
5	ESB	Event Summary Bit
6	RQS	ReQuest for Service
7	OSB	Operation Summary Bit

- Standard Event Status Register

  Latches certain standardized events. The THM1176/TFM1186 uses the following bits:

Bit	Name	Description
0	Operation Complete	*OPC has flagged operation complete
2	Query Error	Error in preceding query
3	Device Dependent Error	Errors specific to the THM1176 family, including internal errors
4	Execution Error	Error detected during command execution
5	Command Error	Error in preceding command
7	Power On	Instrument has been powered up

- OPERation Status

  Captures conditions which are part of the instrument's normal operation. The THM1176/TFM1186 uses the following bits:

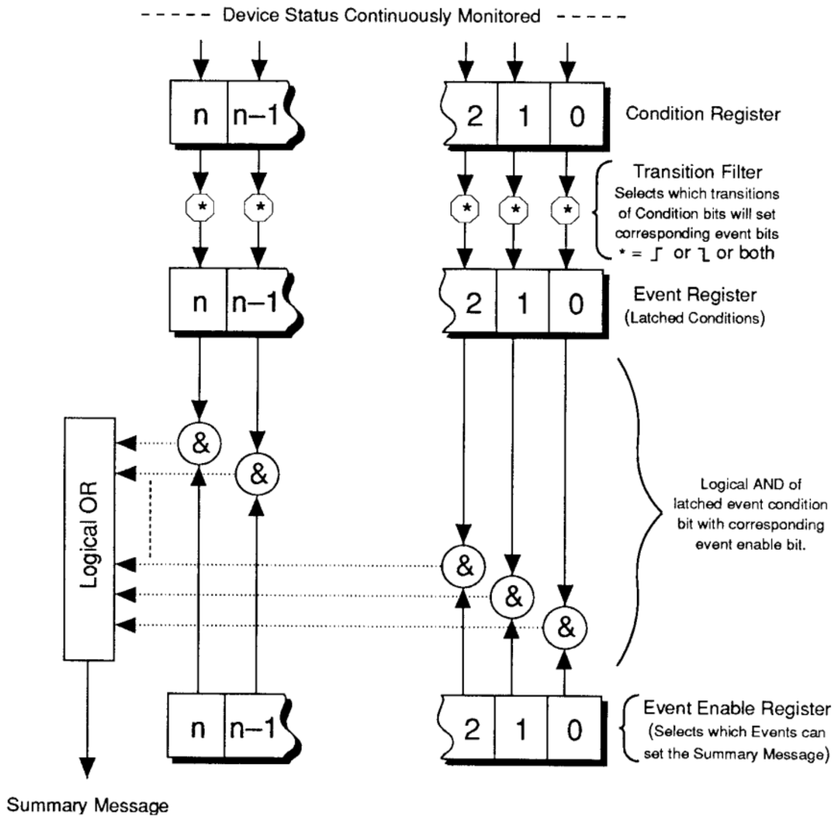
Bit	Name	Description
0	CALibrating	Measuring zero-offset
2	RANGing	Changing range
4	MEASuring	Measuring magnetic field strength
5	Waiting for TRIGger	Waiting for trigger

- QUEStionable Status

  Indicates conditions that may reduce the quality of the measurement. The THM1176/TFM1186 sets the following bits:

Bit	Name	Description
5	FREQuency	The acquisition buffer or the timed trigger has been overrun, which makes the frequency questionable
9	–	The measurement was over-range, which makes the amplitude questionable

As shown in the figure below, taken from the IEEE 488.2 standard, each of the registers above is actually a set of three registers:



- Condition Register
  Read-only register that is constantly updated to reflect the current state of the instrument.
- Event Register
  Transitions in a Condition Register are latched in the corresponding Event Register. The THM1176/TFM1186 only latches transitions from 0 to 1. Event Registers are cleared when read.

- Event Enable Register
  A mask indicating what bits in the Event Register are included in the Summary bit. The enable mask of the Status Byte is called the Status Enable register, and it determines which bits cause an RQS (ReQuest for Service).

5-4 USBTMC-USB488 CONTROLS

The following functions are supported directly by the USBTMC-USB488 protocol. Historically, these correspond to dedicated hardware signals in IEEE 488.1 (HPIB or GPIB).

Command	**Description**
`INITIATE_CLEAR`	Clears the device input and output buffers
`TRIGGER`	Assert bus trigger
`SRQ`	Requests service from host
`READ_STATUS_BYTE`	Read status byte
`REN_CONTROL`	Remote Enable (no effect)
`GO_TO_LOCAL`	Enable local controls (no effect)
`LOCAL_LOCKOUT`	Disable local controls (no effect)

5-5 IEEE 488.2 COMMON COMMANDS

As any IEEE 488.2 compliant instrument, the THM1176 family supports the following commands.

Command	Name	Description
`*CLS`	Clear status	Clear all event registers and queues (not enable registers) and error buffer
`*ESE <NRf>`	Program event enable	Program standard event enable register
`*ESE?`	Event enable query	Read standard event enable register
`*ESR?`	Event status query	Read standard event register and clear it
`*IDN?`	Identification query	Returns the following information: manufacturer; model; serial number; and version of electronics, probe and firmware. Note that this query returns "Arbitrary ASCII Response Data" (see IEEE488.2 standard) and cannot be followed by another query in the same command sequence.
`*OPC`	Set operation complete	Set the operation complete bit in the standard event register after all commands have been executed
`*OPC?`	Operation complete query	Returns an ASCII "1" after all commands have been executed
`*RST`	Reset	Reset device to power-on configuration
`*SRE <NRf>`	Program status enable	Program status enable register Important: you must also enable service requests on the host. See Section 5-7 for details.
`*SRE?`	Status enable query	Read status enable register
`*STB?`	Status byte query	Read status byte register
`*TRG`	Trigger	Generate bus trigger
`*TST?`	Self-test Query	Perform complete self-test, return 0 if successful, 1 if not
`*WAI`	Wait-to-Continue	Wait until previous commands have completed

5-6 SCPI COMMANDS

In the command definitions below, the following conventions are used:

`[]` optional keywords or parameters

`<>` value

The abbreviated form of each command is written in capital letters. For example, the "MEASure" command can be written as "MEASURE" or "MEAS", or, since capitalization doesn't matter, "measure" or "meas".

Each command is presented with its subcommand(s) indented below it. For example:

:FETCh		
[:SCALar]		Fetch values acquired during last MEASure, READ or INITiate
[:FLUX]		
:X?	[<digits>]	Fetch x-component of flux density measurement
[:Y]?	[<digits>]	Fetch y-component of flux density measurement

According to this table, the following commands are legal:

:FETC:SCAL:FLUX:Y?

:FETC? (same as above, omitting optional keywords)

:FETC:X? (fetches x-component of flux density measurement)

The following special parameters are recognized:

MINimum

MAXimum

DEFault

Numeric parameters usually require units. Analogously, the values returned by queries contain units, as specified by the UNIT command. In addition, some units can have prefixes:

N = nano (10^{-9})

U = micro (10^{-6})

M = milli (10^{-3})

K = kilo (10^{3})

MA = mega (10^{6})

The table below lists the units supported by the THM1176 family. Note that different models recognize different ranges of magnetic field strength units, depending on their measurement range; all model recognize T (Tesla).

Magnetic field strength		
T	M, U, N	Tesla (default)
MAHZP		Megahertz proton
GAUSS	K, M	Gauss
Other		
S	M, U	Seconds

The following tables list the legal commands for the THM1176 family, in alphabetical order.

Command	Parameters	Description
:ABORt		Reset the trigger system: - Aborts acquisition in progress - Disables trigger - Disables continuous trigger

Command	Parameters	Description
[:CALCulate] :AVERage		
:COUNt?	[MINimum | MAXimum | DEFault]	Query averaging count
:COUNt	<count> | MINimum | MAXimum | DEFault	Set averaging count

Command	Parameters	Description
:CALibration		
[:INITiate]		Initiate the offset correction procedure in zero-gauss chamber
:ZERO		Restore factory offset correction
:STATe?	[DEFault]	Query calibration state
:STATe	<boolean> | DEFault	Set calibration state: whether or not temperature and gain calibration is applied. ON by default.

Command	Parameters	Description
:DIAGnostic :UPGRade [:INITiate]		Initiate a firmware upgrade. The instrument will disconnect from the USB bus and reconnect as a DFU (Device Firmware Upgrade[1]) device, with the following alternate settings: CODE, DATA, RESERVED and HWINFO.

NOTICE
The :DIAGnostic:UPGRade:INITiate command is intended for use by the manufacturer only. It can cause your instrument to become nonoperational.

Command	Parameters	Description
:FETCh		
[:SCALar]		Fetch data values acquired during last MEASure, READ or INITiate. The following actions invalidate previously acquired data: - Reset; - Continuous trigger initiation; and - Changing trigger parameters. Return at least the requested number of significant digits.
[:FLUX]		
:X?	[<digits>]	Fetch x-component of flux density measurement <digits> min=1, max=5, def=3
[:Y]?	[<digits>]	Fetch y-component of flux density measurement <digits> min=1, max=5, def=3
:Z?	[<digits>]	Fetch z-component of flux density measurement <digits> min=1, max=5, def=3

[1] See "Universal Serial Bus Device Class Specification for Device Firmware Upgrade," Version 1.1, Aug 5, 2004, available from https://www.usb.org/sites/default/files/DFU_1.1.pdf.

:TIMestamp?		Fetch time stamp. Returns an 8-byte hexadecimal number, in ns. Note that the timer resolution is 167 ns.
:TEMPerature?		Fetch temperature. Returns unsigned integer between 0 and 64K, with arbitrary units.
:ARRay		Fetch values acquired during the last MEASure:ARRay or READ:ARRay. <size> must be no greater than the acquisition size. If FORMat is ASCii, returns a comma-separated list of values. The other parameters are as for :FETCh:SCALar.
[:FLUX]		
:X?	<size>[,<digits>]	Fetch x-component of flux density measurement <size> min=1, max=2048, def=1 <digits> min=1, max=5, def=3
[:Y]?	<size>[,<digits>]	Fetch y-component of flux density measurement <size> min=1, max=2048, def=1 <digits> min=1, max=5, def=3
:Z?	<size>[,<digits>]	Fetch z-component of flux density measurement <size> min=1, max=2048, def=1 <digits> min=1, max=5, def=3

Command	Parameters	Description
:FORMat		
[:DATA]?	[DEFault]	Query data output format
[:DATA]	ASCii | INTeger | PACKed[,<length>] | DEFault	Set format for returned flux density measurement data. – ASCii by default. – INTeger returns an IEEE488.2 definite-length block, consisting of an 8-byte header of the form "#6nnnnnn" and followed by nnnnnn bytes of binary data. The data consists of a 32-bit big-endian signed integer for each flux density value, containing the 16-bit big-endian raw measurement value if calibration correction is disabled, or otherwise the flux density value in µT (THM1176-MF/HF/HFC), mG (THM1176-LF) or nT (TFM1186) – PACKed,<length> returns compressed data, where <length> is the number of bytes per sample: 1 or 2, 2 by default. The data will be returned as an IEEE488.2 definite-length block, consisting of a 7-byte header of the form "#5nnnnn" and followed by nnnnn bytes of binary data. The first byte is <length>, encoded in ASCII; the following four bytes are the first field value, in the same format as for INTeger; and the following 8- or 16-bit signed integers represent the remaining data samples, as a delta relative to the previous sample.

Command	Parameters	Description
:INITiate		
[:IMMediate]		
[:ALL]		Enable the trigger, where the trigger source, trigger count and trigger period are set with TRIGger commands
:CONTinuous?	[DEFault]	Query continuous-trigger state
:CONTinuous	<boolean> | DEFault	Set continuous-trigger mode, where the trigger is automatically re-enabled after each acquisition. OFF by default. Continuous trigger is only allowed if the TRIGger:SOURce is TIMer.

Command	Parameters	Description
:MEASure		Abort any pending triggers and perform measurements using the default acquisition parameters: - Immediate trigger - Continuous initiation off - Averaging count 1 - Calibration state on - Default range
[:SCALar]		Perform a single measurement. Set the range for the expected value if provided; auto-range if not. Return at least the requested number of significant digits.
[:FLUX]		<expected_value> min=0T, max=20T, def=0T <digits> min=1, max=5, def=3
:X?	[<expected_value>] [,<digits>]	Return x-component of flux density measurement
[:Y]?	[<expected_value>] [,<digits>]	Return y-component of flux density measurement
:Z?	[<expected_value>] [,<digits>]	Return z-component of flux density measurement
:ARRay		Perform a series of <size> measurements. The other parameters are as for :MEASure:SCALar.
[:FLUX]		<size> min=1, max=2048, def=1 <expected_value> min=0T, max=20T, def=0T <digits> min=1, max=5, def=3
:X?	<size> [,[<expected_value>] [,<digits>]]	Return x-component of flux density measurement
[:Y]?	<size> [,[<expected_value>] [,<digits>]]	Return y-component of flux density measurement
:Z?	<size> [,[<expected_value>] [,<digits>]]	Return z-component of flux density measurement

Command	Parameters	Description
:MMEMory		Read the FLASH memory
[:CATalog]?		Read the file directory. Returns: - Total bytes used - Total bytes available - File entries consisting of: - File name - File type - File size
:DATA?	<filename>	Read the contents of the given file.

Command	Parameters	Description
:READ		Abort pending triggers and perform a measurement with existing parameters. Note: cannot be used when TRIGger:SOURce is BUS.
[:SCALar]		Perform a single measurement. Set the range for the expected value if provided; use the previously selected range if not. Return at least the requested number of significant digits.
[:FLUX]		<expected_value> min=0T, max=20T, def=0T <digits> min=1, max=5, def=3
:X?	[<expected_value>] [,<digits>]	Return x-component of flux density measurement
[:Y]?	[<expected_value>] [,<digits>]	Return y-component of flux density measurement
:Z?	[<expected_value>] [,<digits>]	Return z-component of flux density measurement
:ARRay		Perform a series of <size> measurements. The other parameters are as for :READ:SCALar.
[:FLUX]		<size> min=1, max=2048, def=1 <expected_value> min=0T, max=20T, def=0T <digits> min=1, max=5, def=3
:X?	<size> [,[<expected_value>] [,<digits>]]	Return x-component of flux density measurement
[:Y]?	<size> [,[<expected_value>] [,<digits>]]	Return y-component of flux density measurement
:Z?	<size> [,[<expected_value>] [,<digits>]]	Return z-component of flux density measurement

Command	Parameters	Description
:SENSe		
[:FLUX]		
[:RANGe]		
[:UPPer]?	[MINimum | MAXimum | DEFault]	Query the current range setting
[:UPPer]	THM1176-MF: 0.1|0.3|1|3 T THM1176-HF or -HFC: 0.1|0.5|3|20 T THM1176-LF: 0.008 T TFM1186: 0.0001 T | MINimum | MAXimum | DEFault	Set the range. Select highest range by default.
:AUTO?	[DEFault]	Query the auto-ranging setting
:AUTO	<boolean>| DEFault	Set auto-ranging ON or OFF. ON by default.
:ALL?		Return a list of all the ranges supported by this instrument, in T.

Command	Parameters	Description
:STATus		
:OPERation		Query/set OPERATION register sets
[:EVENt]?		Read and clear operation event register
:CONDition?		Read operation condition register
:ENABle?		Query enable register
:ENABle	<numeric_value>	Set enable register. "0" by default.
:QUEStionable		Query/set QUEStionable register sets
[:EVENt]?		Read and clear operation event register
:CONDition?		Read operation condition register
:ENABle?		Query enable register
:ENABle	<numeric_value>	Set enable register. "0" by default.
:PRESet		Reset OPERation and QUEStionable enable registers

Command	Parameters	Description
:SYSTem		
:ERRor		
[:NEXT]?		Query error queue
:VERSion?		Query SCPI version (e.g. 1999.0)
:HELP		
:HEADers?		List all available commands.
:SYNTax?	<command_header>	List syntax for a command.
:SLEEp		Power down the acquisition electronics. Power-up is automatic at the next acquisition, but takes approximately 100 ms.

Command	Parameters	Description
:TRIGger		
:COUNt?	[MINimum | MAXimum | DEFault]	Query trigger count
:COUNt	<value> | MINimum | MAXimum | DEFault	Set the number of triggers required to complete an acquisition. <value> min=1, max=2048, def=1 Note: resets the trigger system.
:SOURce?	[DEFault]	Query trigger source
:SOURce	IMMediate | TIMer | BUS | DEFault	Trigger source: - IMMediate = no wait - TIMer = periodic trigger - BUS = USB488 TRIGGER IMMediate by default. Note: resets the trigger system.
:TIMer?	[MINimum | MAXimum | DEFault]	Query trigger timer
:TIMer	<meas_time> | MINimum | MAXimum | DEFault	Set period for periodic trigger. <meas_time> min=122 µs, max=2.79 s, def=0.1 s Note 1: resets the trigger system. Note 2: if the specified trigger period is too short, a timer overrun error will be returned when the results are fetched (see Section 8-6-4).

Command	Parameters	Description
:UNIT?	[DEFault]	Query units
:UNIT	T | MT | UT | NT | GAUSs | KGAUss | MGAUss |MAHZp | DEFault	Set units in which flux density measurements are returned if FORMat is ASCii. T by default. Note: not all models support all units. Use UNIT:ALL? to determine which units are supported.
:ALL?		Return a list of all the units supported by this instrument, followed by the divisor for each set of units. The divisor converts the instrument's base units (µT for the THM1176-MF/HF/HFC, mG for the THM1176-LF, and nT for the TFM1186) to the associated units.

5-7 PROGRAMMING HINTS

Note that National Instruments' "Measurement & Automation Explorer" (part of the full NI-VISA package) provides a very useful tool to explore the command set. Select the THM1176/TFM1186 under "System / Peripherals & Interfaces / USB Devices," and click the "Open VISA Test Panel" icon. This opens a window from which you can try all functions available through NI-VISA.

Here are a few notes on how the command set is intended to be used:

- For simple measurements with the standard settings in single-channel mode, use the MEASure? command. MEASure:ARRay? returns a time series.
- Use the UNIT and FORMat commands to change the format in which the results are returned.
- Use the READ commands for measurements with non-standard trigger parameters, or to return raw measurement data without applying calibration corrections. As with MEASure, READ:ARRay? returns a time series.
- Use the FETCh command to retrieve all data corresponding to a preceding MEASure?, READ? or INITiate command, or FETCh:ARRay for the data

corresponding to a MEASure:ARRay?, READ:ARRay?, or INITiate with TRIGger:COUNt > 1.

- For the THM1176, try to build a CALibration sequence with a zero-gauss chamber into the beginning of any lengthy measurement sequence. The THM1176 is designed to have very low offset and offset drift, but as with any Hall device, these remain a significant source of error. Note that this does not apply to the TFM1186 – See Section 2-6.
- After an INITiate command with TRIGger:SOURce = BUS, the instrument expects TRIGger:COUNt triggers before resuming normal operation. During this interval, the following commands are illegal: CALibration:INITiate, FETCh, INITiate:IMMediate:ALL, SENSe:FLUX:RANGe:UPPer, SENSe:FLUX:RANGe:AUTo. The following commands are legal, but cause an ABORt and therefore terminate the acquisition sequence: *RST, ABORt, MEASure, READ.
- INITiate:CONTinuous is used for TRIGger:SOURce = TIMer or BUS, to avoid losing triggers while data is read out.
- Using the *OPC command, you can generate a ReQuest for Service (RQS) when a measurement (or any other action) is complete. Set bit 0 of the Standard Event Enable register and the ESB (Event Summary Bit) in the Status Enable register. Now, the execution of an *OPC command will generate an RQS.
- Alternatively, set bit 4 (MAV = Message AVailable) in the Status Enable register and append the *OPC? command to the previous commands. This will generate an RQS because *OPC? places a "1" on the output.
- If you program the instrument to generate an RQS, it is **very important** to Enable Service Requests on the host. This posts a read on the appropriate USB endpoint, the Interrupt endpoint. In the USB protocol, the host initiates all transfers; so if the host has not posted a read, the instrument cannot complete its RQS transfer. This will block the Interrupt endpoint, and any other commands using this endpoint – notably the USBTMC-USB488 Read Status Byte function – will fail.

- Be sure to check the status after every command. The Standard Event, OPERation and QUEStionable Status registers provide a general idea of what went wrong, and the status message on the Error/Event Queue (retrieved by SYSTem:ERRor?) provides a detailed diagnostic. See Chapter 8-Error Codes for the exact interpretation of these error messages. It may be convenient to set up the Enable bits to generate a ReQuest for Service (RQS) when an error is encountered.

REFERENCE
6-Technical Specifications

6-1 MEASUREMENT

Ranges: - THM1176-MF: - THM1176-HF: - THM1176-HFC: - THM1176-LF: - TFM1186:	 100 mT, 300 mT, 1 T, 3 T 100 mT, 500 mT, 3T, 20T (calibrated to 14.1 T) 100 mT, 500 mT, 3T, 20T (calibrated to 1.5 T) 8.0 mT 100 µT *Notes: Ranging may be performed automatically or manually.*
Data output:	- B_x, B_y, B_z (ASCII or binary, single point or array, calibrated or not) - Temperature (uncalibrated) - Time stamp (167 ns resolution)
Units: - THM1176-MF/HF/HFC: - THM1176-LF: - TFM1186:	 T, mT, µT, G, kG, MHz p (proton NMR frequency) T, mT, µT, G, mG T, mT, µT, nT, G, mG
Sample rate: - Immediate trigger (default): - Timed trigger: - Bus trigger (via USB):	 Approx. 6.8 kSa/s (free-running, until internal buffer is full) Into internal buffer: 0.36 Sa/s to 5.3 kSa/s (jitter ~ 0.2 µs std. dev.) During USB readout: 0.36 Sa/s to 2.3 kSa/s (jitter ~ 1.2 µs std. dev.) Up to approx. 400 Hz (until internal buffer is full) *Notes: 1 sample = (B_x, B_y, B_z); Internal buffer size = 4096 samples*
Bandwidth:	DC to 1 kHz
Resolution: - THM1176-MF: - THM1176-HF/HFC: - THM1176-LF: - TFM1186:	 0.1 mT 0.3 mT 2 µT 4 nT *Notes: Averaging of N measurements improves the resolution by approximately √N.*
Accuracy: - THM1176-MF/HF/HFC: - THM1176-LF: - TFM1186:	 ±1 % of reading or specified resolution, whichever is greater ±20 µT ±0.5% of reading and ±100 nT *Notes: The accuracy is given for arbitrary field orientation; typically it is x10 better along the primary axes.*

User offset correction:	To be performed before each series of measurements, in Zero Gauss Chamber supplied *Notes: Does not apply to TFM1186 – see Section 2-6.*

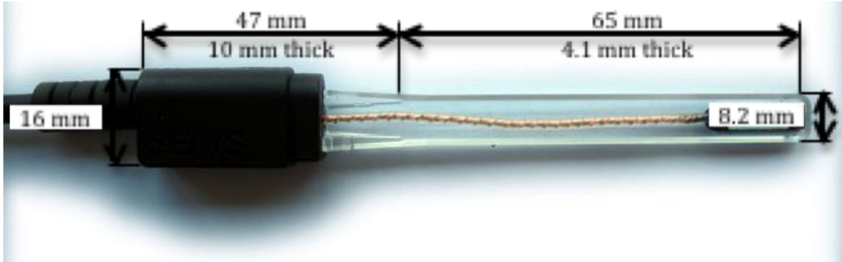
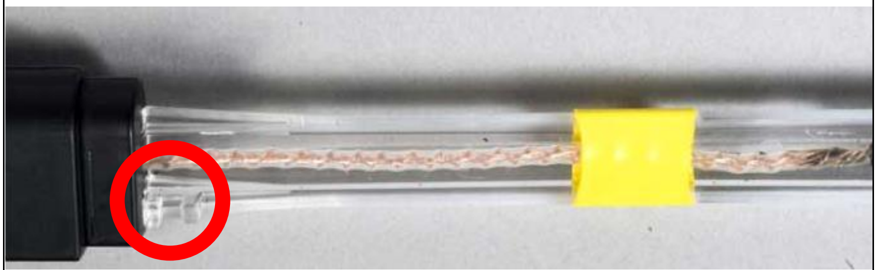
6-2 INTERFACE

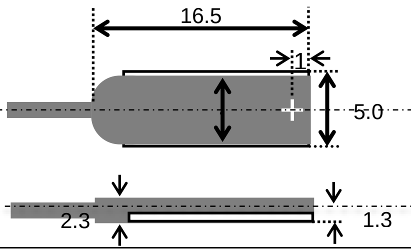
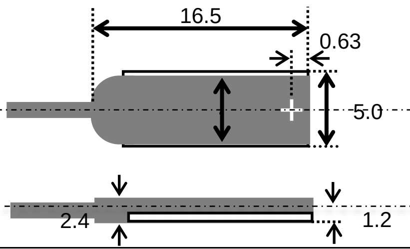
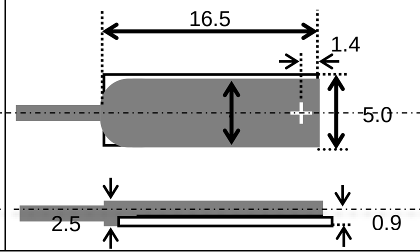
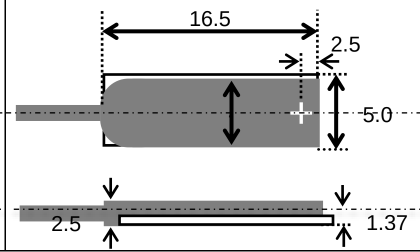
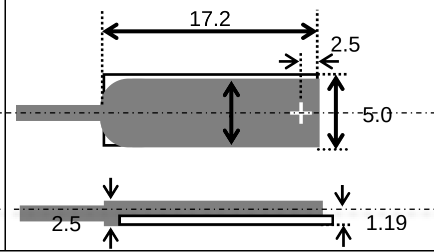
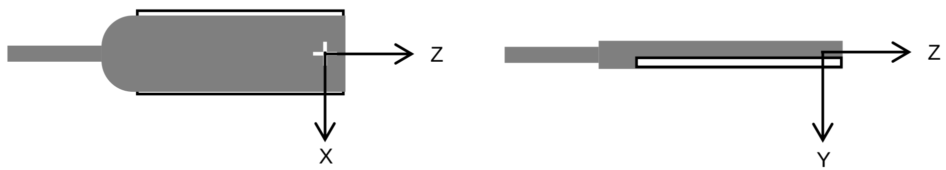
Interface:	USB 2.0, full speed (12 Mbps)
Class / USB driver:	USBTMC (USB Test & Measurement Class) / USB488 DFU (Device Firmware Upgrade)
Protocol:	IEEE 488.2, SCPI (Standard Commands for Programmable Instruments)
Connector:	USB Type A
Power:	USB bus-powered, 4.3V to 5.25V 35 mA min (idle, power-saver on), 90 mA max
Wake-up time from power-saver:	100 ms

6-3 OPERATING CONDITIONS

Operating temperature:	0°C to +40°C
Storage temperature:	-20°C to +60°C
Operating magnetic field:	Instrument electronics: 3 T max

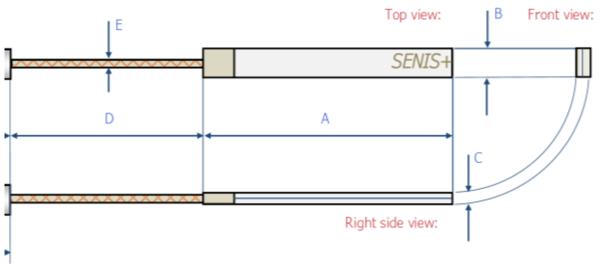
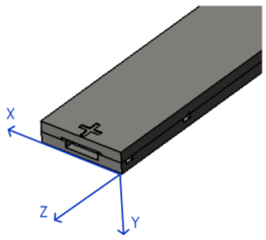
6-4 MECHANICAL – THM1176-MF/HF

Dimensions:	
- Instrument electronics:	76 x 22.5 x 14 mm^3
- Probe with housing:	113 x 16 x 10 mm^3
- Probe without housing:	
Cable length:	
- THM1176-MF:	3 m, optionally 6 m
- THM1176-LF:	6 m
	Notes: Includes 1 m of USB cable.
Weight:	160 g (3 m cable); 290 g (6 m cable)
Stationary mounting point:	 For M2.5 screw (not included). Note: to avoid breaking the mounting point, use a spacer and do not over-tighten the screw.

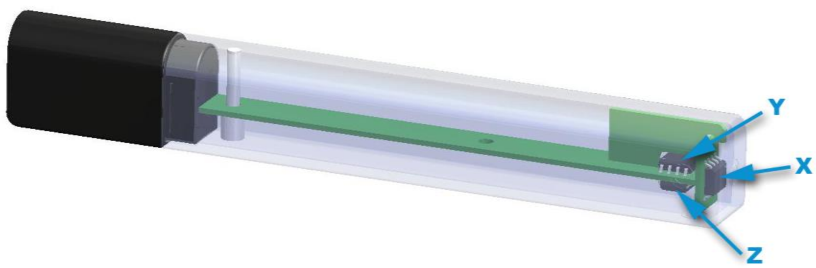
<table>
<tr><th colspan="5">Sensor dimensions</th></tr>
<tr><th>THM1176-HF</th><th colspan="4">THM1176-MF</th></tr>
<tr><td>Probe version C1[2]</td><td>Probe version A0[2,3]</td><td>Probe version A1[2,3]</td><td>Probe version B0[2]</td><td>Probe version B1[2]</td></tr>
<tr>
<td>Notes:
"+" marks the centre of the field sensitive volume.
All dimensions are in mm.
Tolerances are ± 0.1mm
</td>
<td>Notes:
"+" marks the centre of the field sensitive volume.
All dimensions are in mm.
Tolerances are ± 0.1mm
</td>
<td>Notes:
"+" marks the centre of the field sensitive volume.
All dimensions are in mm.
Tolerances are ± 0.1mm, except the 2.5mm thickness which is ± 0.3mm.
</td>
<td>Notes:
"+" marks the centre of the field sensitive volume.
All dimensions are in mm.
Tolerances are ± 0.1mm
</td>
<td>Notes:
"+" marks the centre of the field sensitive volume.
All dimensions are in mm.
Tolerances are ± 0.1mm
</td>
</tr>
<tr><td colspan="5"></td></tr>
<tr><td></td><td></td><td colspan="2"></td><td></td></tr>
<tr><td>Ceramic length : 14mm</td><td>Ceramic length : 14mm</td><td colspan="2">Ceramic length : 16.5mm</td><td>PCB length : 17.2mm</td></tr>
<tr><td>Sensitive volume : 150μmx150μmx10μm</td><td colspan="4">Sensitive volume : 200μmx200μmx5μm</td></tr>
</table>

[2] The probe version is part of the descriptor returned by the *IDN? query, displayed by the THM1176 software in the "Info" field. See Section 5-5.
[3] Some units were incorrectly programmed as probe version "C1". This will be corrected at the next factory calibration; in the meantime, the two may be distinguished visually.

6-5 MECHANICAL – THM1176-HFC

Dimensions:	
- Instrument electronics:	76 x 22.5 x 14 mm^3
- Probe dimensions:	 A = 8.0 ± 0.2 mm B = 2.0 ± 0.5 mm C = 0.5 + 0.05/-0.00 mm D = 50 ± 1 mm E = Ø 0.8 ± 0.1 mm
- Field sensitive point:	150 µm x 150 µm x 10 µm
Cable length:	3 m, optionally 6 m *Notes: Includes 1 m of USB cable.*
Weight:	150 g (3 m cable); 280 g (6 m cable)
Location of field sensitive point:	Marked by "+" above. X = 1.0 ± 0.1 mm Y = -0.25 +0.05/-0.00 mm Z = -0.3 ± 0.05 mm 

6-6 MECHANICAL – THM1176-LF

Dimensions: - Instrument electronics: - Probe with housing: - Field sensitive point:	 76 x 22.5 x 14 mm^3 113 x 16 x 10 mm^3 6 x 3.4 x 3 mm
Cable length:	3 m, optionally 6 m *Notes: Includes 1 m of USB cable.*
Weight:	160 g (3 m cable); 290 g (6 m cable)
Sensor locations:	

6-7 MECHANICAL – TFM1186

Dimensions: - Instrument electronics: - Probe housing:	 76 x 22.5 x 14 mm^3 70 x 30 x 32 mm^3
Cable length:	3 m *Notes: Includes 1 m of USB cable.*
Weight:	310 g
Sensor package:	

6-8 SOFTWARE

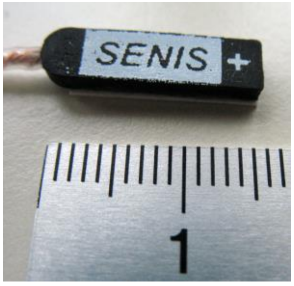
Software functions:	Windows, macOS or Linux Meter mode: • Vector components, magnitude and oscillations • Numeric, plot, compass, vector and table displays Spectrum mode: • Spectral plot of vector components, magnitude or oscillations • Table of spectral peaks AC Analysis mode: • RMS, Peak-peak, Standard Deviation • Plot, numeric and table displays Mapping mode: • Manual or mechanized mapping • Numeric, plot, table and vector plot display Exposure limits: graphic overlays and alarms Control of range, units, trigger, acquisition & display rates, oversampling Auto-ranging, Hold, Max and Alarm functions Zero offset correction Save and replay from memory or disk Save and restore settings Context-sensitive help

6-9 WARRANTY, CALIBRATION, CERTIFICATION AND MAINTENANCE

Warranty	2 years
Recommended calibration interval:	18 months (3-Axis Hall Probe only) Note that for logistical reasons, Metrolab recalibrates the THM1176 in batches. Four weeks in the year are fixed to perform batch calibrations: Week 10, Week 24, Week 37, Week 50 To benefit from the discounted pricing for this batch operation, you must ensure that your instrument arrives at Metrolab the week before.
Certification:	CE approved
Maintenance:	Firmware and software upgradable by end user

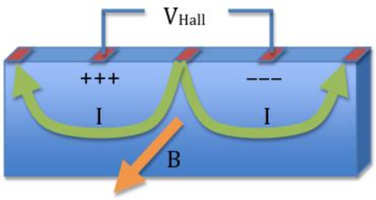
REFERENCE
7- THM1176-MF/HF/HFC Sensor Details

This chapter is adapted from an article by Philip Keller of Metrolab in the June/July 2008 issue of Magnetics Business & Technology (http://www.MagneticsMagazine.com).

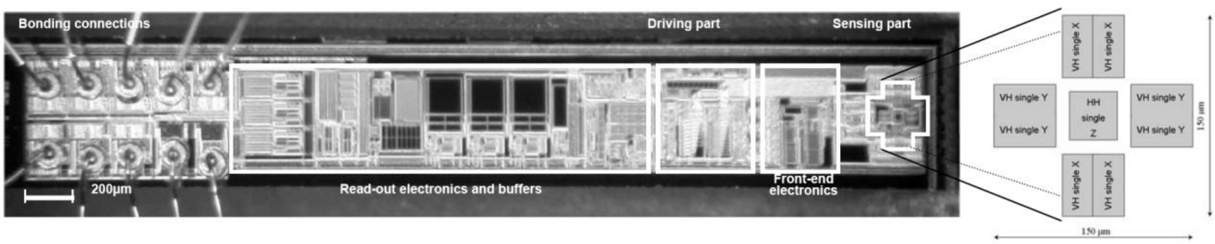


To measure the total field, we need three orthogonally oriented Hall sensors. Typically, three individual sensors are glued into a cube, roughly five to ten millimeters on a side. But now there is another way: a single IC containing one conventional planar Hall element and two sets of "vertical" Hall elements.

The vertical elements can be thought of as plates of N-type silicon inserted vertically into a P-type substrate. If a current is injected into the center terminal and extracted from the two end terminals, the currents in the two halves of the plate flow in opposite directions, resulting in a Hall voltage on the remaining terminals.

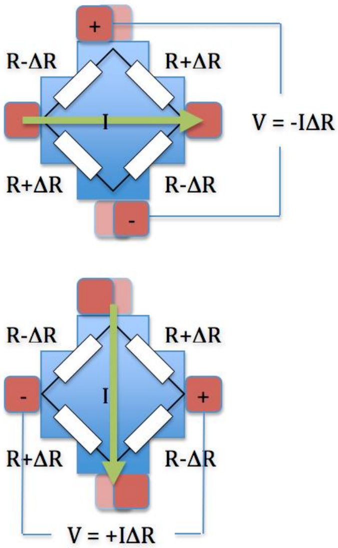


A team at the EPFL in Switzerland, led by Dr. Popovic, applied this technique to design a 3-axis sensor on an IC, called the MAG3D. The array of Hall elements measures 150 x 150 x 10 µm^3 – a million-fold reduction in active volume compared to a conventional approach! This allows precise position determination as well as consistent measurements of all three components even in highly inhomogeneous fields.



But MAG3D contains much more than the Hall elements. To build a Hall magnetometer, we need to supply a current and measure a voltage. By increasing the current and/or amplifying the voltage, one can increase the sensitivity. All this is done on the IC; the external electronics only supplies 5V power and two digital lines to select one of four ranges. This represents a tremendous simplification of the magnetometer as a whole. (Image courtesy of Senis GmbH)

But there's more… All Hall magnetometers suffer from measurement offset – in other words, the instrument measures a non-zero result even in a zero field. What's more, this offset varies with time and temperature. One should calibrate the instrument in a zero-gauss chamber before each use, and the instrument has to continuously correct the measurement for temperature variations. Even so, offset remains a significant source of error.



Where does offset come from? One common source is misalignment of the terminals. As shown in the figure, the effect can be modeled with a resistance network, where the longer current paths result in higher resistances, and vice versa. In our example, the resulting offset voltage would be negative. But if we exchange the current and voltage leads, thereby functionally rotating the Hall element by 90°, the offset voltage becomes positive. It is important to note that the Hall voltage is unaffected by this rotation.

The MAG3D exploits this effect in two ways. The "spinning current" technique, where the voltage and current leads are rapidly switched back and forth and the results averaged, compensates for manufacturing imperfections such as terminal misalignment. In addition, by wiring orthogonally oriented pairs of sensors in series, the MAG3D increases its sensitivity while at the same time compensating for dynamic offset errors. This includes the planar Hall effect, whose magnitude changes sign when the current direction is rotated by 90°. The combination of these techniques results in a sensor with significantly reduced offset, offset drift, and sensitivity to planar Hall effect.

REFERENCE
8-Error Codes

Error codes returned by the USB Interface are numbered according to the SCPI standard.[4] Sections 21.8.9 through 21.8.16 of Volume 2 of the SCPI manual, "Command Reference", provide a generic description of all possible error codes. In general, the codes are between -800 and 300. This chapter describes only the error codes produced by the THM1176/TFM1186, and the circumstances that might produce each error.

In addition to the SCPI errors, the THM1176 Application Programming Interface might produce additional errors, in the range of -1073807360 to -1073807192 and 1073676290 to 1073676457 (0xBFFF00xx and 3FFF00xx – the former are errors and the latter are warnings). These are VISA error codes, and are not documented here. See the LabVIEW on-line help under "VISA Error Codes," or right-click on the error indicator and select "Explain error."

8-1 0: NO ERROR

Zero indicates no error.

8-2 -100: COMMAND ERRORS

8-2-1 -102: Syntax error

The command header did not match any of the known commands.

8-2-2 -104: Data type error

A parameter within the command was of a type invalid for the command.

8-2-3 -115: Unexpected number of parameters

The wrong number of parameters was given in the command.

8-2-4 -123: Exponent too large

The command contains a numeric parameter that was too large to be stored internally. This occurs if the value has an exponent greater than ±43.

8-2-5 -151: Invalid string data

The parameters in the command contain an unmatched single or double quote.

[4] Standard Commands for Programmable Instruments – see Section 5-1 for the complete reference.

8-2-6 -171: Invalid expression

The parameters in the command contain an unmatched bracket.

8-3 -200: EXECUTION ERRORS

8-3-1 -221: Settings conflict

Indicates that a legal program data element was parsed but could not be executed due to the current device state:

- Starting an acquisition when trigger is not enabled;
- Sending a bus trigger when trigger is not enabled, when the trigger source is not BUS, or when the expected number of triggers have already been received;
- Sending a CALibration:INITiate, FETCh, INITiate:IMMediate:ALL, READ, or SENSe:FLUX:RANGe command when triggers were enabled in BUS trigger mode;
- Sending an INITiate:CONTinuous command when in IMMediate trigger mode;
- Sending SYSTem:SLEEp when trigger is enabled.

8-3-2 -222: Data out of range

Indicates that a legal program data element was parsed but could not be executed because the interpreted value was outside the legal range as defined by the device:

- A numeric parameter is smaller than the allowable minimum or larger than the maximum;
- A character parameter does not match one of the allowable choices;
- FETCh: fetching more data than what was acquired;
- FORMat[:DATa] : <length> specified for ASCii or INTeger ;
- MEASure, READ: the <expected_value> is too large;
- MMEMory:DATa: the file does not exist;
- SENSe: the requested range does not exist; or
- SYSTem:HELP: requesting help for a non-existent command.

8-3-3 -225: Out of memory

The device has insufficient memory to perform the requested operation:

- when writing the new User Offset Zero file to Flash.

8-4 -400: QUERY ERRORS

8-4-1 -400: Query error

Generic query error:

- Device being cleared when query was received.

On the THM1176/TFM1186, no other conditions should generate this error. If this is not the case, please report to Metrolab the circumstances under which you received this error.

8-4-2 -410: Query INTERRUPTED

The host has sent a new command before finishing reading the response to a preceding query.

8-4-3 -420: Query UNTERMINATED

The host is trying to read a response without having sent a complete query.

8-4-4 -440: Query UNTERMINATED after indefinite response

Indicates that a query was received in the same program message after a query requesting an indefinite response was executed. On the THM1176/TFM1186, the only command returning an indefinite response ("Arbitrary ASCII Response Data") is *IDN.

8-5 100: INSTRUMENT-DEPENDENT COMMAND ERRORS

8-5-1 101: Invalid value in list

One or more values in a numeric list parameter are invalid, e.g. floating point when not allowed.

8-5-2 103: Wrong units for parameter

A parameter within the command has the wrong type of units for the command.

8-6 200: INSTRUMENT-DEPENDENT EXECUTION ERRORS

8-6-1 200: Software Error

The firmware has encountered an unexpected error:

- the User Offset Zero file has been corrupted;
- the ADC driver returned an unknown error code;
- the command parser or dispatcher returned an unknown error code;
- encountered an error formatting a result;
- could not open one of the data files file;
- unable to perform reset;
- encountered an unknown choice for character data;
- encountered something other than a value, MINimum, MAXimum or DEFault for a numeric parameter;
- encountered something other than a Boolean or DEFault for a Boolean parameter; or
- encountered an unknown parameter type.

Please report to Metrolab the circumstances under which you received this error.

8-6-2 204: Data buffer was overrun

In timed-trigger mode, data was lost because the read-out did not keep up with the acquisition.

8-6-3 205: Measurements were over-range

The field value exceeded the selected range.

8-6-4 206: Timer was overrun

In timed trigger mode, a measurement was still in progress when the timer to start the next measurement expired. The next measurement was skipped.

8-6-5 207: Bad data compression

When returning data in PACKed FORMat, the true dynamic range of the data could not be accurately represented by the delta values. The maximum delta value was used, while attempting to correct the error on the subsequent sample(s). It is recommended to use a lesser degree of compression.