User Manual

MG-01

AMR 3-axis Geophysical Vector Magnetometer

Rev. 1.2 – 28 Apr 2024

BENEV®

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Used symbols

Symbol	Meaning
	Action related to software performance
NOTE:	Supplementary information
CAUTION:	Important information
WARNING:	Information with exceptional importance

Safety

NOTE: Read this manual before using MG-01 magnetometer.

WARNING: This device should be installed in places far from urban infrastructure. Take all necessary precautions to put all supply cables and data lines in such a way that they will be safe from thunder strikes in the time of storm! Direct thunder strike on the instrument or its supply cables will destroy it and can lead to severe damages on nearby electronic equipment!

CAUTION: Do not expose the magnetometer to impacts or supply voltages beyond the limits specified in the documentation! Use this instrument only for its intended purposes and strictly observe the operating instructions!

Warranty

Benev Science & Technology Ltd. warrants that this product will be free from defects in materials and workmanship for a period of two (2) years from the date of shipment. If any such product proves defective during this warranty period, *Benev Science & Technology Ltd.*, at its option, will repair the defective product without charge for parts and labor, or will replace it.

It is customer's responsibility to notify us in the event of a defect occurring within the warranty period, as well as packing preparation and payment of the transportation costs to the our office. *Benev Science & Technology Ltd.* bears the transportation costs of delivering the repaired or replaced product back to the customer.

This warranty shall not apply to any defect, failure or damage caused by improper use or improper or inadequate maintenance and care. *Benev Science & Technology Ltd.* shall not be obligated to furnish service under this warranty in the following cases:

– The product has been disassembled, modified, or repaired by persons who have not been explicitly authorized for this by *Benev Science & Technology Ltd.* and in the event of damage or replacement of warranty stickers.

– The product has been under impacts beyond the limits specified in its documentation or has been used in conjunction with defective products or such that are not in compliance with the quality and safety standards.

– In the case of natural disaster, such as fire, earthquake, flood, etc.

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1. Overview

MG-01 is a new 3-axial digital vector magnetometer based on anisotropic magnetoresistive (AMR) sensor technology. With its modern and compact design, reliability and low cost, it is the world's first representative of a new generation of scientific instruments. The magnetometer is intended to be used in the geophysical research areas for monitoring and recording the Earth's magnetic field. The AMR technology allows having low power consumption, low noise, high operation stability, and miniature sizes. These characteristics make MG-01 an exceptionally suitable choice for geomagnetic recording observatories and on-board satellite missions as a worthy competitor of a long-time serving classical fluxgate vector magnetometers.

1.1 Basic features

Features
Anisotropic magnetoresistive (AMR) sensors
Completely digital design ensures high accuracy and low noise measurements
Precise internal automatic temperature stabilization
Galvanically isolated digital interface
USB HID implementation (no need for driver installation)
Windows based GUI application for device operation monitoring and data recording
Low power consumption
Compact and robust aluminum shielded enclosures

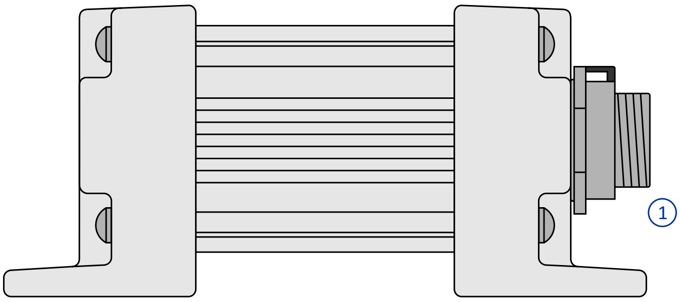
1.2 Applications

- Earth's magnetic field monitoring and recording
- Space research

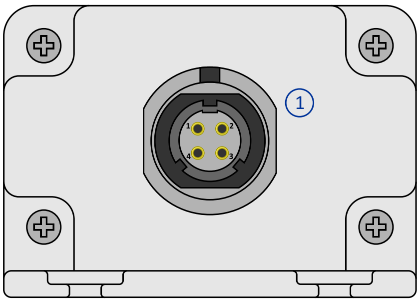
2. MG-01

2.1 MG-01 parts

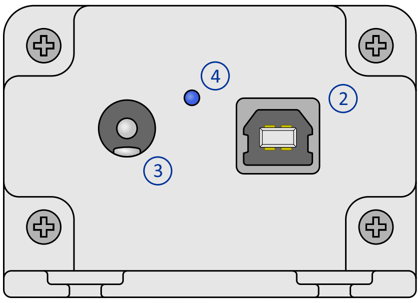
MG-01 Interface module (side view)



MG-01 Interface module
(Front panel)

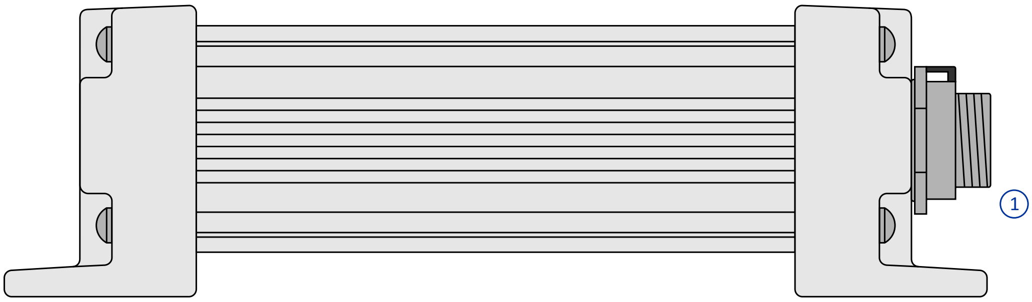


MG-01 Interface module
(Back panel)

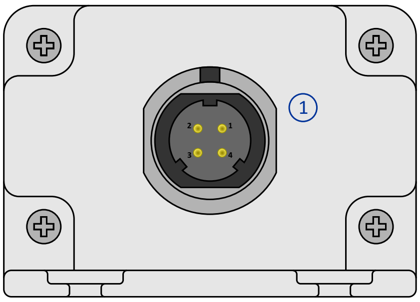


1. Cable connector
2. USB connector
3. Power supply
4. Status LED

MG-01 Sensor head (side view)



MG-01 Sensor head
(Front panel)



1. Cable connector

MG-01 consists of two basic units: a non-magnetic Sensor head (SH) and an Interface module (IM), connected by a 4-wire shielded cable (two data lines, one DC +12 ÷ 24 V power line and one GND line). The two ends of the cable shield are connected to the PCB grounds of the SH and IM respectively (see Appendix A). All magnetic measurements are made by SH and the numerical results are sent to the IM through the cable as digital packets. After each measurement request, IM receives data bytes sent by SH and resends them back to the computer through the standard USB interface. IM is attached to the PC as a USB Human Interface Device (HID). Therefore, there is no need for a special driver to be installed. A DC power supply is connected to the IM.

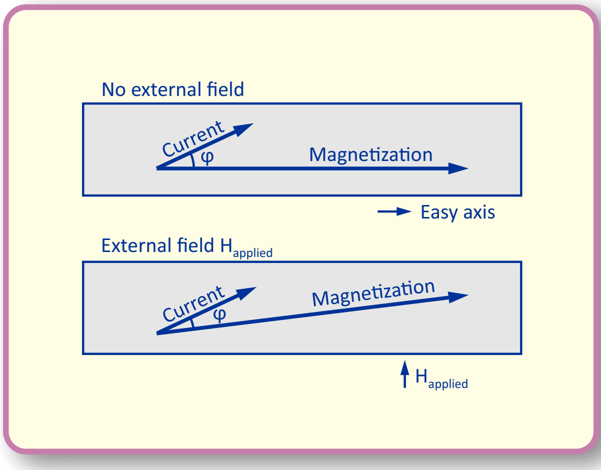
⚠ NOTE: PC's communication with MG-01 is through a Windows based GUI application StudioMG (see part 3 of this manual).

⚠ NOTE: SH has an automatic internal temperature control of the three magnetic sensors. Its work is precisely controlled through the StudioMG software (see part 3.6).

⚠ NOTE: SH, along with the cable and power supply on the one side and USB connection to the PC on the other, are fully galvanically isolated.

2.2 Anisotropic magnetoresistance

Magnetoresistance is the dependence of the electrical resistance in some materials from the applied magnetic field. Anisotropy, on the other side, we have when a given property is manifested differently in different directions. Therefore, anisotropic magnetoresistance (AMR) is a property demonstrated by some ferromagnetic materials, consisting of the dependence of electrical resistance on the angle between the direction of the electric current and the vector of magnetization.

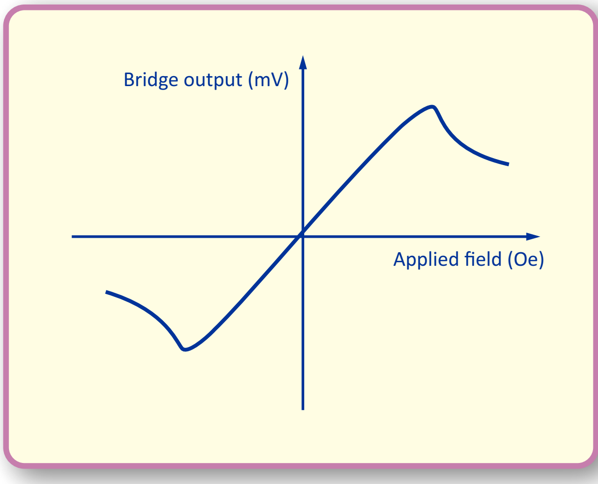


Megnetoresistive effect.

A typical AMR based sensor element is made of Permalloy (NiFe) thin film deposited onto a silicon substrate. During the fabrication process, the film is deposited in a strong magnetic field. This field sets the preferred orientation, or easy axis, of the material magnetization vector, which is set parallel to the length of the resistor element. Using the so-called “Barber pole” pattern, the current is forced to flow on an angle φ = 45° to the easy axis, and the output transfer function of the element is moved towards the linear region.

When an external magnetic field is applied perpendicular to this axis, it makes the material magnetization vector to rotate and thus, changes the angle φ. That will cause the element’s resistance to vary.

Usually, four such elements are combined to form a Wheatstone resistor bridge with a typical bridge resistance of about 1 kOhm. This configuration improves the output transfer function linearity and also compensates for some of the temperature dependencies.



Bridge output transfer function.

2.3 Technical specifications

Performance	
AMR sensors	Honeywell HMC1001, HMC1002
Orthogonal axes	x, y, z
Range (on each axis)	±75000 nT
Bandwidth (-3 dB)	DC ÷ 20 Hz
Sensitivity @ 1 S/s	0.015 nT/ADU
Noise RMS spectral density @ 1 Hz	0.05 nT/√Hz
SNR @ 1 S/s	124 dB
ADC effective resolution @ 1 S/s	20.5 bit
Absolute accuracy(1)	~ 1nT
Max sampling rate	10 S/s
Time ranges	0.1 s, 0.2 s, 0.5 s, 1 s, 2 s, 5 s, 10 s, 20 s, 30 s, 60 s
Internal temperature stabilization accuracy @ 1 S/s (RMS)	0.003 °C
Internal temperature stabilization warm-up time(2)	10 ÷ 15 min
Temperature coefficient	0.35 nT/°C

(1) Depends on the calibration procedure
(2) Depends on the difference between the internal temperature stabilization set point and ambient temperature.

Electrical	
Supply voltage	DC 12 ÷ 24 V
Digital data lines voltage	0 V / 3.3 V
Max current consumption	260 mA
Nominal current consumption(1)	90 ÷ 120 mA
Nominal power consumption(1)	~1 W
Max cable length	100 m

(1) Depends on the difference between the internal temperature stabilization set point and ambient temperature.

Mechanical	
Enclosure (Sensor head)	Aluminum, IP67, electrically shielded
Enclosure (Interface module)	Aluminum, electrically shielded
Connector (Sensor head)	WEiPU, SP1312/P4N
Connector (Interface module)	WEiPU, SP1312/S4N
Cable connectors	WEiPU, SP1310/P4IN, SP1310/S4IN
DC power jack diameter	ϕ 5.5 / 2.1 mm
Dimensions (Sensor head)	136 x 55 x 40 mm
Dimensions (Interface module)	85 x 55 x 40 mm
Weight (Sensor head)	215 g
Weight (Interface module)	145 g
Fixing points (Sensor head)	4 x M4 (non-magnetic)
Fixing points (Interface module)	4 x M4

Environmental	
Operating temperature range	-20 ÷ 50 °C
Humidity (relative)	10 ÷ 80 % (non–condensing)

2.4 Choosing an installation place

WARNING: *This device should be installed in places far from urban infrastructure. Take all necessary precautions to put all supply cables and data lines in such a way that they will be safe from thunder strikes in the time of storm! Direct thunder strike on the instrument or its supply cables will destroy it and can lead to severe damages on nearby electronic equipment!*

MG-01 is a scientific magnetometer intended to serve as a long-term recording instrument of the three vector components of the Earth's magnetic field. With its exceptional accuracy and sensitivity, MG-01 has special demands on installation site magnetic properties and environmental conditions. Choosing an appropriate place is not an easy task and requires a high degree of professional skills. Many factors can play a significant role in magnetometer operation and thus in the quality of the collected data. The big importance when choosing an installation place becomes clear especially if we take into account that MG-01 should be perfectly operational in time for decades.

As a non-magnetic unit responsible for all measurements, the Sensor head should be mounted in a place clean from any magnetic contaminations in the vicinity of the instrument. It is also important to have stable environmental conditions, free of disturbances, especially the disturbances in the ambient temperature. For that reason, it is a good choice to put the Sensor head in the non-magnetic house in a place without direct sunlight or in the small isolated shaft under the ground, where the temperature is nearly constant through the day and night. Furthermore, it is possible to put the Sensor head unit in a small non-magnetic room equipped with some form of air conditioning to stabilize the ambient temperature. The Sensor head unit has an automatic active internal temperature stabilization, capable of decreasing the sensor's temperature coefficient to the values below 1 nT/°C, but also, it is a good practice for some form of ambient temperature control to be available too.

The Interface module has no special installation demands and can be mounted in any place where the standard PC equipment is available. For example, in any room with an operator's access provided.

In any case, selecting a good site for MG-01 installation is a delicate task and should be accomplished in accordance with the specific user's demands. The above notes should be regarded only as general guidance rules. For more information, we strongly suggest the user read the recommendations about geomagnetic observatory site selection described in the IAGA's "Guide for Magnetic Measurements and Observatory Practice" and "Guide for Magnetic Repeat Station Surveys" at *https://iaga-aiga.org*

3. StudioMG

StudioMG is a compact and easy-to-use Windows based GUI application intended for continuous geomagnetic data acquisition and automatic recording, monitoring of the operation and setting basic working parameters of the MG-01 magnetometer. Optimized user interface and simplified work with the application allow for a quick visual check of the collected data and instrument performance. You can download the software from the tech info section on the product's page: *https://benev.biz/en/geophysical-vector-magnetometers.html*

NOTE: StudioMG cannot be used as a scientific analysis software and does not include any data processing math tools.

3.1 System requirements

Requrements	
Operating system	Windows XP*, Vista, 7, 8, 8.1, 10; 32-bit / 64-bit
CPU	1 GHz or better; 32-bit / 64-bit
RAM	1 GB or more
Screen resolution	1024 x 768 or higher
Hard disk free space	10 GB** or more
USB	2.0, 3.0 or 3.1 single port
Adobe Acrobat Reader	Version 9.0 or higher

* Windows XP requires .NET Framework 2.0 or higher to be installed.
** Needed for data storage.

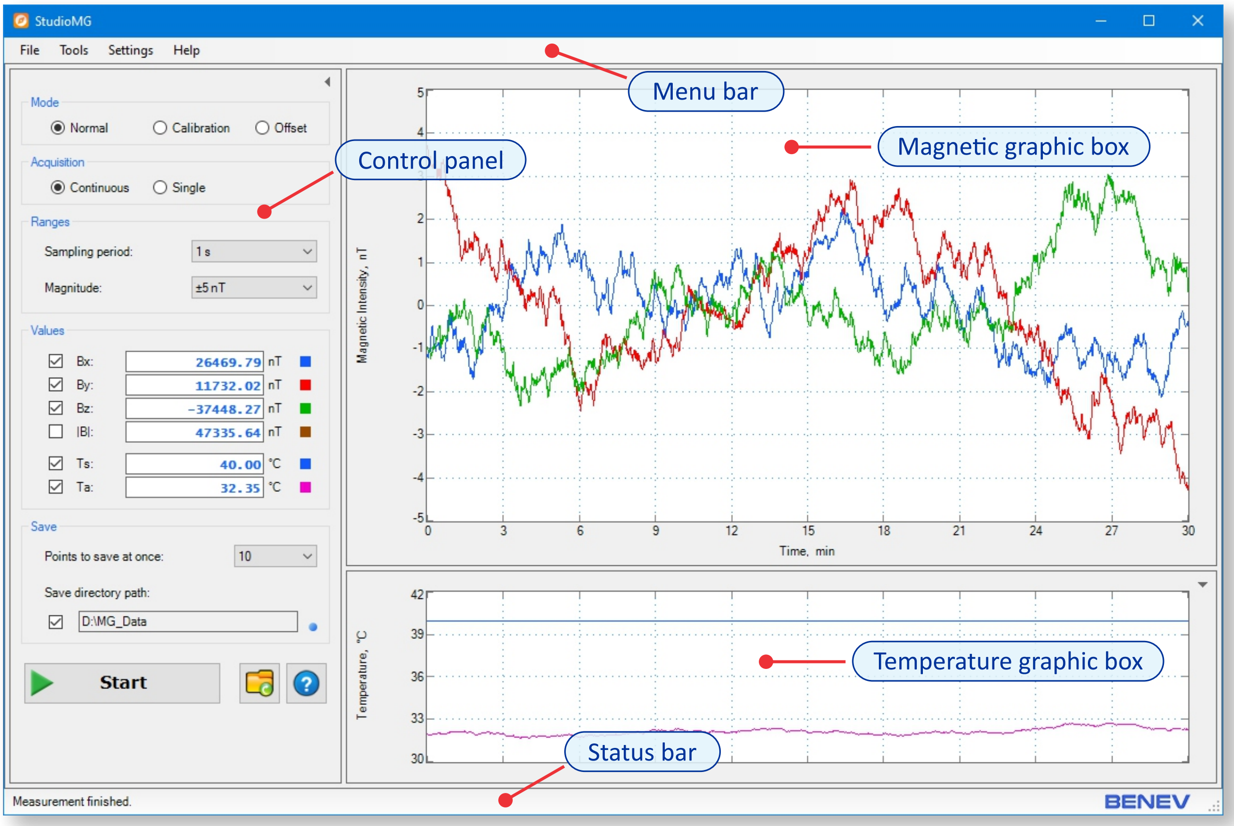
3.2 Application installation

StudioMG does not need to be installed at all. Just unpack the StudioMG.zip file somewhere on your system, for example, in the C:\Program Files\StudioMG and put a shortcut to the application .exe file on your Desktop or Start menu. That's all.

NOTE: Do not change the structure and content of the unpacked zip archive.

3.3 Main screen

StudioMG's main screen is shown on the figure below.



StudioMG main screen.

3.4 Using StudioMG to communicate with MG-01

In the *Mode* section of Control panel you can select one of three basic working modes:

– *Normal (default)*. MG-01 internally transforms collected magnetic data using calibration coefficients (see section 3.5).

– *Calibration*. Measurement data are not transformed internally and can be calibrated in the postprocessing steps.

– *Offset*. Collected data represent internal offset values of the three magnetic sensors in nT (not to confuse with three components of the bias calibration vector).

NOTE: The *Offset* mode is for instrumental testing only and normally, should not be used by the user. As an indicator of proper device operation, the offset values should be in the range of hundreds to a few thousand of nT and should remain relatively constant when the surrounding magnetic field changes significantly.

In the *Acquisition* section of the Control panel you can select:

– *Continuous (default)*. MG-01 measures data continuously.

– *Single*. On every click on *Start/Stop* button only a single data point is taken and measurement is stopped until next *Start/Stop* button click.

In the *Ranges* section, you can select the measurement sampling period and the vertical axis magnitude for the Magnetic graphic box. The vertical scale of the Temperature graphic box is automatically calculated on every acquisition step and does not depend on the selected magnitude value. To make collected magnetic data always displayed around zero line on the screen, StudioMG internally subtracts the mean values before drawing new data. Selecting different magnitudes for the Magnetic graphic box changes only the vertical scale of the graph. That is for visual purposes only and does not change the original data recorded to file.

NOTE: When you select a sampling period value, StudioMG automatically calculates the time span on the horizontal axis, taking into account maintaining data length to be approximately 1800 - 2000 points on every component's graph.

In the *Values* section, you can see current data numerical values. By clicking on the check box on the left, you can choose which data are visible in the graphic boxes.

In the *Save* section of the Control panel, you can select how many points will be saved at once. By clicking on the check box on the left, you can choose whether to record automatically collected data or not. In the text box, the directory path for the data files storage is shown. StudioMG automatically determines your system drive and makes a folder named "MG_Data" in the root. For example, "C:\MG_Data". So, be sure to have enough free space on your system's drive for data record storage.

NOTE: The exact moment of the file data recording is indicated by a single turning of the save indicator right to the text box.

NOTE: In the MG_Data directory, StudioMG automatically creates subfolders with the names showing the year and month of the record. The year-folder name format is "yyyy" and the month-folder name is "MMM". In every month folder, data are saved into text files with names of the form "ddMMMyyyy.txt". For example, data on 15 August 2021 will be in the file with the full path "C:\MG_Data\2021\Aug\15Aug2021.txt". For more information, see Appendix A.

NOTE: Infernally, StudioMG keeps the time of all data in UTC (Universal Time Coordinated) no matter your time zone or time format. Thus, the time in the data files is always UTC. The only thing you should take care of is to keep your system's time synchronized.

From the *File* menu you can choose to:

– Open an existing file with magnetometer data.

– Take a snapshot of the entire application screen an save it as an image file.

NOTE: You can choose to close or to open the Control panel and Temperature graphic box by clicking on the small arrow button in the upper right corner. The Magnetic graphic box is always visible.

3.5 Setting calibration coefficients

MG-01 is a scientific instrument, and one of the most important procedures to get the magnetometer operating correctly is the calibration procedure. But what exactly mean to calibrate a given instrument? And how does this relate to the case of scientific equipment? To say it simply, calibration is the process of finding the known connection between some physical quantity and the output readings of the measurement device designed to measure this quantity. In other words, to understand how much the output readings differ from the standard quantity values on the instrument's input and what is the acceptable level, or the tolerance, of that difference. Calibration methods development is a long and gradual process which considerations should begin even in the stage of the preliminary instrumental design. In the case of scientific devices, calibration is an even more complicated and delicate task because scientific instruments, by their very conception, are intended to work on the frontier of today's level of knowledge. And a geophysical magnetometer is not an exception.

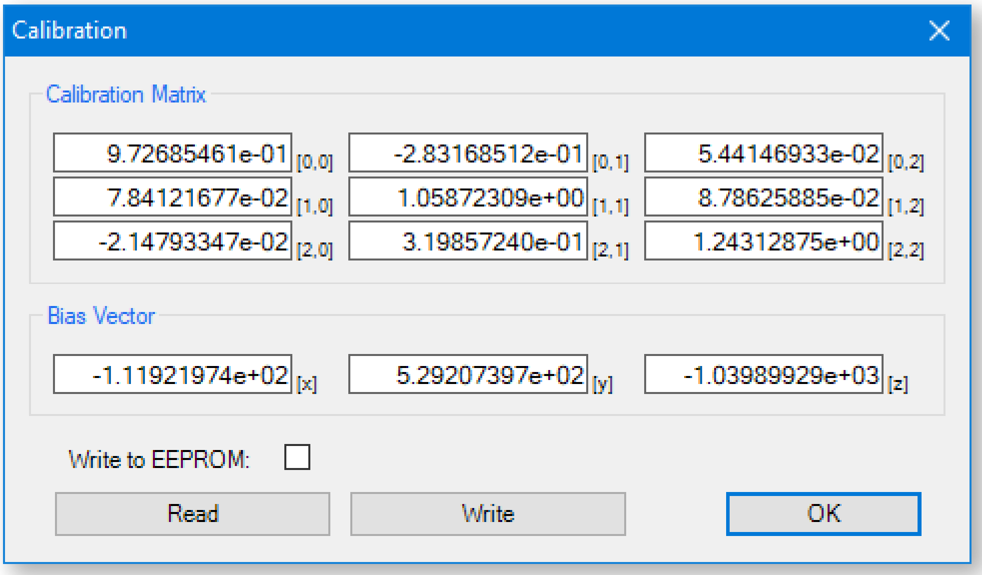
The full calibration of a three-axis vector magnetometer is subject to intense research work last decades. With the development of new magnetic sensor technologies, advances in calibration methods are continuously in progress. Scientific literature has a huge amount of publications dedicated to this problem. Despite the fact that many achievements have been done, the geophysical vector magnetometer calibration is still a really challenging task. So, the choice of exactly which one method you would use for MG-01 calibration and how it will be implemented in practice is up to you and depends on your scientific knowledge, professional skills and, of course, of available supporting equipment.

When in *Normal* mode, MG-01 uses calibration coefficients written in its memory to make a transformation of the measured magnetic field values. The applied model is linear. We have the following basic equation:

$$\mathbf{h_{tr}} = \mathbf{A} * (\mathbf{h_m} - \mathbf{b})$$

Here $\mathbf{h_{tr}}$ is the true geomagnetic field vector, $\mathbf{h_m}$ is the vector of raw magnetic data, **A** is a 3x3 square calibration matrix and **b** is a 3-component bias vector. Using this equation, MG-01 calculates the true vector value on every single measurement step in real-time and sends the result to the PC. When in *Calibration* mode, MG-01 returns only the raw geomagnetic vector data without any additional transformation. This can be used for applying more sophisticated calibration models during post-acquisition data processing.

StudioMG offers a specially designed tool for quick and easy setup of linear model's calibration coefficients in MG-01 memory.



Calibration coefficients dialog screen.

Click on *Tools → Calibration* to show the calibration coefficients dialog box. By clicking on the *Read* button, you can see current values written in MG-01's EEPROM memory. You can change them any time. To save the new values in the memory, click on the *Write* button. To store them permanently in EEPROM, be sure the *Write to EEPROM* check box is in a checked state before clicking on the *Write* button.

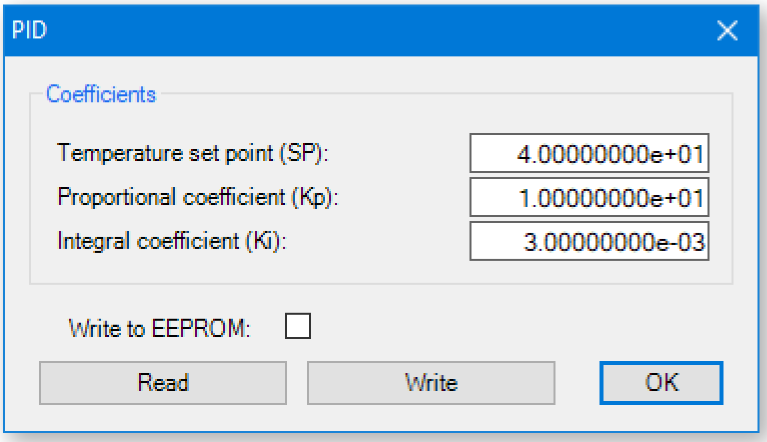
NOTE: If you want to implement some other calibration model, for example, a non-linear model, you can collect and record data always been in a *Calibration* mode. Or, you can write an identity matrix (one with 1's on its main diagonal and all other elements are 0's) as a calibration matrix and a zero-vector as a bias to the device EEPROM. In this case, *Calibration* and *Normal* modes become equivalent, and you can do the calibration on a recorded data archive as a postprocessing procedure.

NOTE: When StudioMG is working, the *Read* and *Write* buttons in the Calibration dialog are inactive. So, first, you should stop the current data measurement by clicking on the *Start/Stop* button in the Control panel and then reopen and use the Calibration dialog.

NOTE: MG-01 is manufactured with the identity calibration matrix and zero bias vector written in the EEPROM.

3.6 Setting coefficients for automatic temperature stabilization control

MG-01 has an automatic internal temperature stabilization of the three magnetic sensors. Using this approach, the temperature coefficient is decreased to values below 1 nT/°C (see MG-01's technical specifications). The active algorithm is based on the classical Proportional-Integral-Derivative (PID) method and implements only proportional and integral terms. StudioMG offers a special tool for a quick and easy setup of PID coefficients in MG-01's memory.



PID coefficients dialog screen.

Click on *Tools → PID* to show the temperature stabilization dialog box. By clicking on the *Read* button, you can see the current values written in MG-01's EEPROM memory. You can change them any time. To save the new values in the memory, click on the *Write* button. To store them permanently in EEPROM, be sure the *Write to EEPROM* check box is in a checked state before clicking on the *Write* button.

NOTE: The specific values of temperature set point (SP), proportional (Kp) and integral (Ki) coefficients depend on the temperature environment in which MG-01 operates. A good choice for SP is to be 5 to 10 °C above the maximal ambient temperature. By varying the Kp value, you can control the algorithm's responsiveness to the disturbances. By changing the Ki value, you can determine how many oscillations occur before the set point temperature has been reached.

NOTE: Setting SP too high will increase MG-01's power consumption.

NOTE: MG-01 is manufactured with Kp = 10 and Ki = 0.003 written in the device's EEPROM.

NOTE: When StudioMG is working, the *Read* and *Write* buttons in the PID dialog are inactive. So, first, you should stop the current data measurement by clicking on the *Start/Stop* button in the Control panel and then reopen and use the PID dialog.

3.7 Multilingual support

StudioMG is an application designed with built-in multilingual support .

To change the current application language:

- From the Main menu click on *Settings → Language* select the language you prefer.
- In the popup dialog box, confirm your selection and StudioMG will automatically close and restart with the new language settings.

NOTE: When the application is starting for the first time on your computer, the default language is *English*.

NOTE: The application help file launches in the language version corresponding to the current application language.

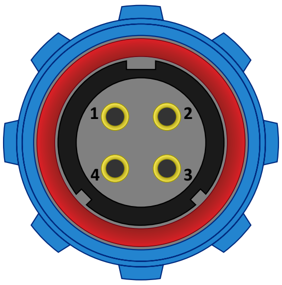
Appendix A: StudioMG data record file format

StudioMG records collected data in the text files. Values measured on every step are written in a single line. The file has no header or any other additional information. The line's structure is shown in the table below.

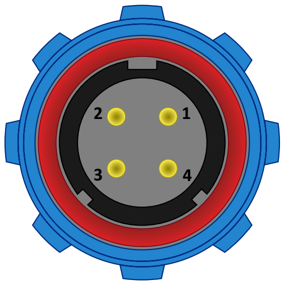
Position	Value	Format
0 ÷ 13	Magnetic component Bx in nT	±X.XXXXXXXe±XX
14	Space	
15 ÷ 28	Magnetic component By in nT	±X.XXXXXXXe±XX
29	Space	
30 ÷ 43	Magnetic component Bz in nT	±X.XXXXXXXe±XX
44	Space	
45 ÷ 58	Magnetic norm |B| in nT	±X.XXXXXXXe±XX
59	Space	
60 ÷ 71	Sensor temperature Ts in °C	±X.XXXXXe±XX
72	Space	
73 ÷ 84	Ambient temperature Ta in °C	±X.XXXXXe±XX
85	Space	
86 ÷ 94	Date	dd-MMM-yy
95	Space	
96 ÷ 106	Time (UTC)	HH:mm:ss.ss

NOTE: StudioMG does not implement any IAGA's standard file format.

Appendix B: Cable connections



WEiPU SP1310/S4IN



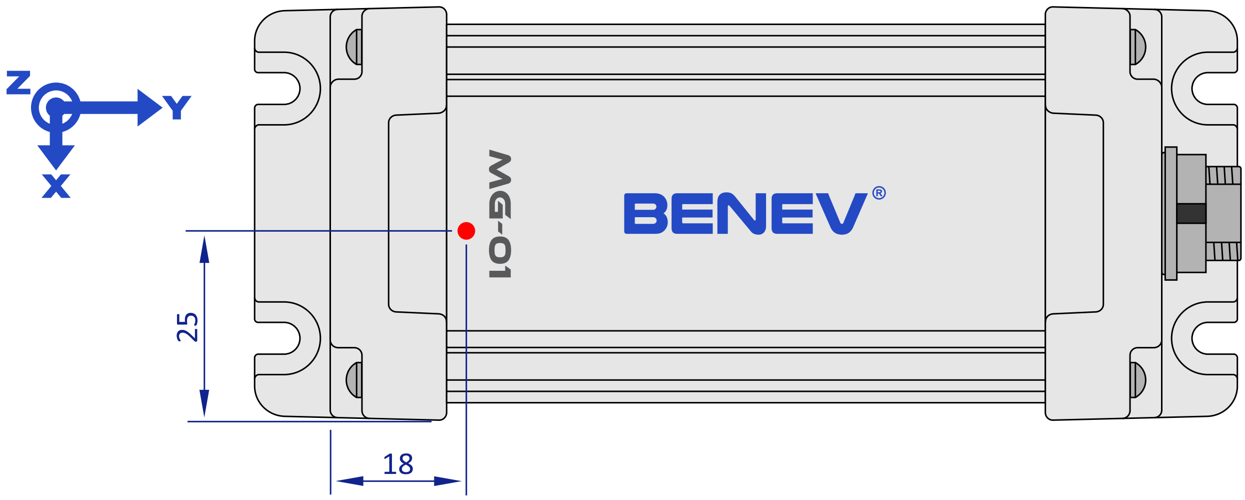
WEiPU SP1310/P4IN

SP1310/S4	SP1310/P4	Name	Voltage
Pin 1	Pin 1	RX	0 V / 3.3 V
Pin 2	Pin 2	TX	0 V / 3.3 V
Pin 3	Pin 3	+12 V	12 ÷ 24 V
Pin 4	Pin 4	GND	0 V

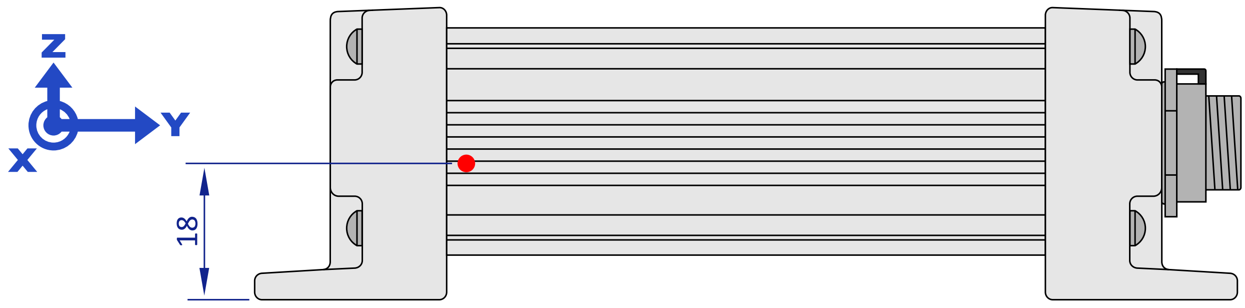
NOTE: Cable shield is connected to the GND (Pin 4) on both ends.

Appendix C: Sensor triad position and orientation

Sensor Head (top view)



Sensor Head (side view)

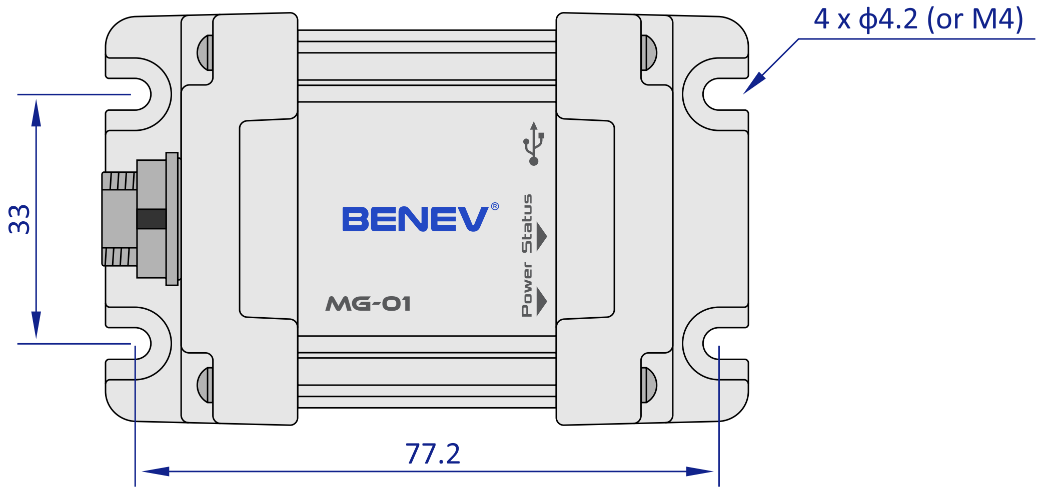


⚠ NOTE: All dimensions in mm.

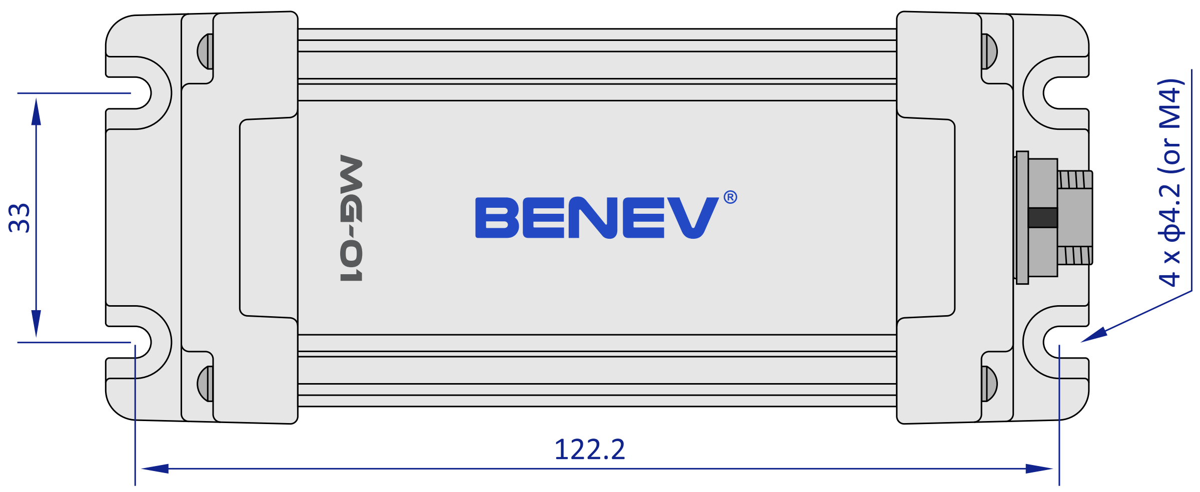
⚠ NOTE: Sensor triad position and orientation is also shown on the bottom side of the Sensor head enclosure.

Appendix D: Mounting drawings

Interface Module



Sensor Head



NOTE: All dimensions in mm.

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