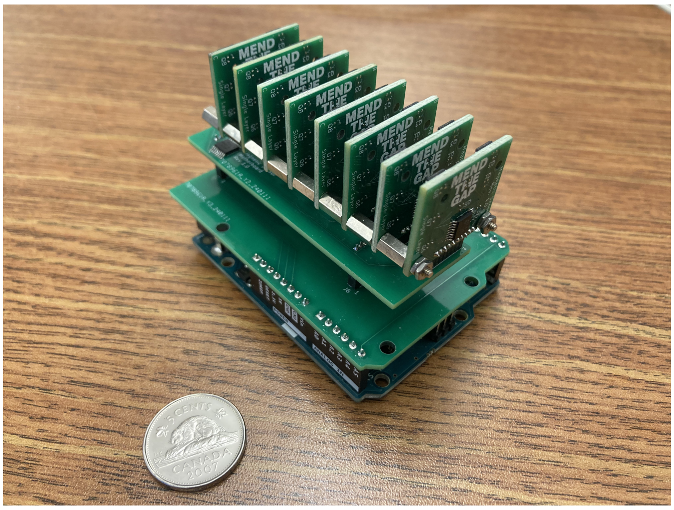


Figure 1: Fully Assembled 8-Layer Sensor Array

Features and Benefits

This device features the following capabilities:

- 5 V_{cc} operation
- Full 3-axis (x,y,z) magnetic field and temperature sensing with 12-bit resolution
- Variable sensing element geometries and configurations, with up to 8 installable sensing fins
- 8 sensing elements per sensing fin, with automatic element discovery and initialization
- Measurement rates up to approximately 350Hz at 115200 baud
- Sensing range of up to 200mT per axis, or an absolute maximum of approximately 350mT.
- Temperature field sensing of up to 120°C
- Simple Serial-Port interface with well-documented measurement format
- Pre-labelled indexing positions for positioning the sensing elements at fixed locations relative to magnetic sources

Device Description

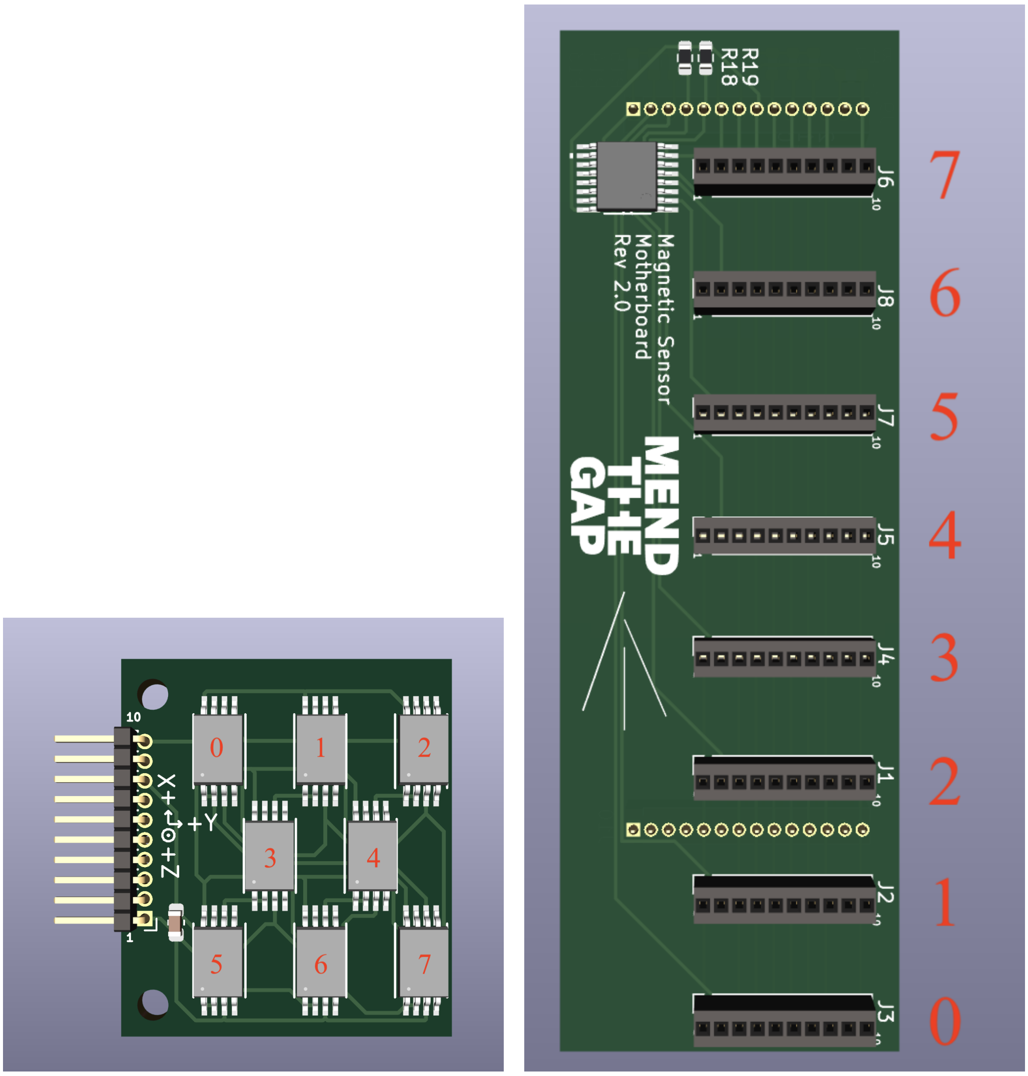
This device provides a variable-geometry configuration of up to 64 full 3-axis magnetic field sensing elements packed into a $21 \times 24 \times 60$mm sensing volume. Utilizing the `ALS31313KLEATR-2000` Hall-Effect sensor to provide 3-axis magnetic field and temperature sensing, this device allows for densely packed field measurements of complex magnetic sources. With all three field axes, full directionality and magnitude information about the measured fields can be extracted.

The individual sensing fins each contain a total of 8 sensing elements, and up to 8 sensing fins are supported at once. The device implements automatic device discovery and initialization, so fins can be installed in any layer while still uniquely mapping between sensing elements and physical locations. Individual sensing fins are rigidly fixed in place via both pin header-socket connections and M.2 spacers to ensure tightly controlled positioning of the sensing elements.

Each sensing element within the sensor array is uniquely identified by a LayerIndex and DeviceIndex pairing, derived as shown in Figure 2. From this unique identifier pair, the unique I^2C address of each sensing element is derived according to Equation 1.

$$\texttt{Address} = 2^4 \cdot \texttt{LayerIndex} + \texttt{DeviceIndex} + 8 \tag{1}$$

The four corners of the sensing fins are labelled with an indexing indicator, one of either `A`, `B`, `C`, or `D`. See Table 4 for positioning details referenced from each of these indexing locations, and Table 5 for the distances between sensing elements. Each sensing fin indicates the orientation of the co-ordinate system for which these distances apply.



(a) Sensing Fin DeviceIndex Ordering (b) Motherboard LayerIndex Ordering

Figure 2: JSMP001 DeviceIndex and LayerIndex Ordering Definition

Motherboard and Daughterboard Pin Descriptors

The individual sensing fins, referred to here as *daughterboards*, connect to the full sensing element via a 10-pin header with 0.05" pitch pins. The 10 pins of this connector must connect to the signals described in Table 1.

The motherboard into which all of the sensing fins connect provides a 14-pin header with 0.05" pin pitch. The 14 pins of this connector must connect to the signals described in Table 2.

Pin Number	Label	Description
1	`GND`	Ground Pin
2	`DSE`	Device-Select Enable. When low, the device-select multiplexer is enabled and devices can be communicated with. Requires external pull-up resistor to 5V.
3	`SDA`	I^2C data line. Requires external pull-up resistor to 3.3V
4	`5V`	$5V$ power connection for device-select multiplexer
5	`DSADDR0`	Device Select address line 0. Connects to `ADDR0` of the multiplexer. Requires external pull-down resistor.
6	`DSADDR1`	Device Select address line 1. Connects to `ADDR1` of the multiplexer. Requires external pull-down resistor.
7	`DSADDR2`	Device Select address line 2. Connects to `ADDR2` of the multiplexer. Requires external pull-down resistor.
8	`3V3`	$3.3V$ power supply for hall-effect sensors and I^2C communications
9	`N.C.`	No-Connect. Connects to nothing on the sensing fin
10	`SCL`	I^2C clock line. Requires external pull-up resistor to 3.3V

Table 1: Sensing Fin Pin Connector Description

An `Arduino Uno` shield is provided along with the motherboard which provides a simple and seamless connection to a standard `Arduino Uno` micro-controller. These pin definitions are only useful if a non-standard interface to either the sensing fins or motherboard is desired.

Pin Number	Label	Description
1	`LSADDR2`	Layer Select address line 2. Connects to `ADDR1` of the layer-select multiplexer. Does not require external pull-down resistor.
2	`LSADDR1`	Layer Select address line 1. Connects to `ADDR1` of the layer-select multiplexer. Does not require external pull-down resistor.
3	`LSADDR0`	Layer Select address line 0. Connects to `ADDR0` of the layer-select multiplexer. Does not require external pull-down resistor.
4	`DSE`	Device-Select Enable. When low, the device-select multiplexer is enabled and devices can be communicated with. Does not require external pull-up resistor to 5V.
5	`LSE`	Layer-Select Enable. When low, the layer-select multiplexer is enabled and devices can be communicated with. Does not require external pull-up resistor to 5V.
6	`GND`	Ground Pin
7	`SDA`	I^2C data line. Does not require external pull-up resistor
8	`5V`	$5V$ power connection for multiplexers
9	`DSADDR0`	Device Select address line 0. Connects to `ADDR0` of the per-layer multiplexers. Does not require external pull-down resistor.
10	`DSADDR1`	Device Select address line 1. Connects to `ADDR1` of the per-layer multiplexers. Does not require external pull-down resistor.
11	`DSADDR2`	Device Select address line 2. Connects to `ADDR2` of the per-layer multiplexers. Does not require external pull-down resistor.
12	`3V3`	$3.3V$ power supply for hall-effect sensors and I^2C communications
13	`N.C.`	No-Connect. Connects to nothing on the motherboard
14	`SCL`	I^2C clock line. Does not require external pull-up resistor to 3.3V

Table 2: Motherboard Pin Connector Description

Device Specifications and Ratings

Characteristic	Symbol	Notes	Rating	Unit
Supply Voltage	V_{cc}		5.0	V
Operating Ambient Temperature	T_A		-40 to 85	°C
EEPROM Write Count	—	Maximum number of EEPROM writes for ALS31313	1000	Writes
Magnetic Sensing Range	B_{in}	Per Axis	-200.0 to 200.0	mT
Temperature Sensing Range	T_{in}		-125 to 175	°C
I^2C Clock Speed	f_{I^2C}		1	MHz
Serial Baud Rate	f_{Serial}	Using `Arduino Uno` reference implementation	115200	bd
Sensing Rate	f_{sense}	Per axis, per ALS31313	2000	Hz

Table 3: JSMP001 Maximum and Nominal Ratings

Indexing Corner	X Position (mm)	Y Position (mm)	Z Position (mm)
`A`	-5.964	6.342	2.250
`B`	-5.964	-14.994	2.250
`C`	18.420	-14.994	2.250
`D`	18.420	6.342	2.250

Table 4: Sensing Element (0,0) Positions from Layer 0 Indexing Corners

	X (mm)	Y (mm)	Z (mm)
Intra-Row Pitch	—	6.500	—
Inter-Row Pitch	6.750	3.250	—
Inter-Layer Pitch	—	—	8.600

Table 5: Sensing Element Spacing

Constituent Integrated Circuits

This sensor array consists if heavily reliant on the ALS31313 3-Axis Linear Hall-Effect Sensor, and the SN74LV4051A 8-Channel Analog De/Multiplexer. These links provide access to the data-sheets for these components for reference.

Accompanying Firmware & Software

A reference implementation of `Arduino Uno` firmware to operate this sensor can be found here. This can be compiled and uploaded using the standard `Arduino` IDE, or via `arduino-cli` by compiling the `Magnetic-Probe.ino` sketch. This reference firmware contains a `DEBUG` mode, where the operation of the sensor is instrumented with thorough logging to allow inspection of the program and hardware state during operation. This can be enabled either by defining the `DEBUG` symbol at the top of the sketch, or compiling with the additional `-DDEBUG` flag. This mode can be turned off either by undefining this macro, defining the `NDEBUG` macro, or compiling with the `-DNDEBUG` flag.

A reference implementation of a visualization tool for the measurements produced by this sensor can be found here. This reference implementation is designed to work with the reference firmware, reading the measured values written to the Serial Port of the `Arduino Uno`. This implementation generates a real-time visualization of the fields, as well as recording the raw and formatted measurements values as read from the sensor array.

Reference Implementation Measurement Format

While not intrinsically required to be in any particular format, a de-facto measurement format is provided within the reference implementation of the `Arduino Uno`-based firmware. In this reference implementation, the magnetic field and temperature readings are combined and written to the Serial port, along with other information to identify a particular sensing element within the device. The format for a single measurement written out is as shown in Table 6.

The start byte is utilized to differentiate between a measurement and a log message reported by the device. All measurement transmissions over the Serial port begin with a `NUL` byte, while this is forbidden for log messages.

Offset (Bytes)	Length (Bytes)	Value	Format
0	1	Start Byte	Always 0x00
1	1	I^2C Address	Unsigned 7-bit with 0x00-0x07 Reserved - $[8, 127]$
2	1	Layer Index	Unsigned 3-bit $[0, 7]$
3	1	Device Index	Unsigned 3-bit $[0, 7]$
4	2	Magnetic Field (X)	Little-Endian Signed 12-bit $[-2048, 2047]$
6	2	Magnetic Field (Y)	Little-Endian Signed 12-bit $[-2048, 2047]$
8	2	Magnetic Field (Z)	Little-Endian Signed 12-bit $[-2048, 2047]$
10	2	Temperature	Little-Endian Unsigned 12-bit $[0, 4095]$
12	4	Timestamp	Little-Endian Unsigned 32-bit. Result of `Arduino Uno` `micros()` function
16	2	Stop Bytes	Always 0xAA, 0x55

Table 6: Reference Firmware Implementation Measurement Format

Hardware Design Files

This design is not intended to remain closed, and all hardware design files are available upon request. Please email jsadden@ece.ubc.ca to request up-to-date design files for the sensing fins, motherboard, or `Arduino Uno` shield.

Change Log

Date	Revision	Description
2024-02-15	1.0	Revision 1.0 Document Creation
2024-02-22	1.1	Adding reference implementation measurement formatting

Table 7: JSMP001 Data-Sheet Change Log