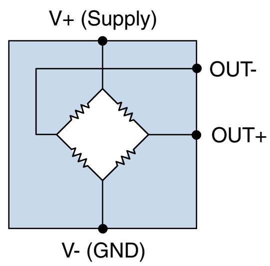
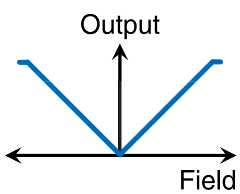
AA/AB-Series Analog Magnetic Sensors

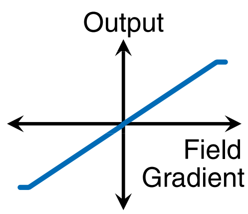
Equivalent Circuit



Idealized Transfer Functions



AA-Series
Magnetometer
Transfer Function



AB-Series
Gradiometer
Transfer Function

Features

- Magnetometer and gradiometer configurations
- Field ranges from <<0.1 mT to >400 mT
- Ultrasensitive, high-field, and low-hysteresis versions
- Wheatstone bridge analog outputs
- Operation to near-zero voltage
- Up to 1 MHz bandwidth
- Up to 150°C operating temperature
- ULLGA4, TDFN6, MSOP8, and SOIC8 packages

Applications

- Motion, speed, and position control
- Low-field sensing
- Motor commutator sensors
- Noncontact current sensing

Description

NVE’s analog GMR sensors have high sensitivity, excellent temperature stability, and small size. Their versatility and wide sensing range makes them an excellent choice for a variety of analog sensing applications including industrial and automotive position, speed, and current sensors.

The sensors are configured as inherently temperature-compensating Wheatstone bridges.

AA-Series sensors are magnetometers, which detect absolute magnetic field. AB-Series sensors are differential gradiometers, which detect field gradients.

Three magnetometer subtypes are available: the standard AA-Series; the ultrasensitive “H” subtype; the high-field, kilooersted range “K” subtype, and the low-hysteresis “L” subtype.

Packages are as small as an ultraminiature 1.1 x 1.1 mm ULLGA4.

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Absolute Maximum Ratings

<table>
<tr><th colspan="2">Parameter</th><th>Symbol</th><th>Min.</th><th>Max.</th><th>Units</th></tr>
<tr><td rowspan="2">Supply voltage</td><td>AAxxx/ABxxx/AAL002</td><td rowspan="2">V_{CC}</td><td></td><td>24</td><td rowspan="2">Volts</td></tr>
<tr><td>AAHxxx/AAKxxx/ABHxxx/
AAL004/AAL024</td><td></td><td>12</td></tr>
<tr><td rowspan="2">Operating temperature</td><td>AAxxx/AAKxxx/ABxxx/AALxxx</td><td rowspan="2"></td><td rowspan="2">−50</td><td>125</td><td>°C</td></tr>
<tr><td>AAHxxx/ABHxxx</td><td>150</td><td>°C</td></tr>
<tr><td rowspan="2">Storage temperature</td><td>AAxxx/AAKxx/ABxxx/AALxxx</td><td></td><td>−65</td><td>135</td><td rowspan="2">°C</td></tr>
<tr><td>AAHxxx/ABHxxx</td><td></td><td>−65</td><td>150</td></tr>
<tr><td colspan="2">ESD (Human Body Model)</td><td></td><td></td><td>400</td><td>Volts</td></tr>
<tr><td colspan="2">Applied magnetic field</td><td>H</td><td></td><td>Unlimited</td><td>Tesla</td></tr>
<tr><td colspan="2">Voltage from sensor connections to center pad
(applies to TDFN package only)</td><td></td><td></td><td>63</td><td>Volts DC</td></tr>
</table>

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Operating Specifications

Parameter		Symbol	Min.	Typ.	Max.	Units	Test Condition
Supply voltage	AAHxxx/AAKxxx/ ABHxxx/AAL004	V_{CC}	<1		12	Volts	Maximum limited by power dissipation
	AAxxx/ABxxx/AAL002				24		
Operating temperature	AAKxxx	T_{MIN}; T_{MAX}	−40		85	°C	
	AAxxx/ABxxx/AALxxx		−50		125		
	AAHxxx/ABHxxx				150		
Electrical offset	AAxxx/AAKxxx/AALxxx/ABxxx	V_O	−4		+4	mV/V	
	AAHxxx/ABHxxx		−5		+5		
Output at maximum field	AAxxx/ABxxx	$V_{OUT\text{-}MAX}$		60		mV/V	
	AAHxxx/ABHxxx			40			
	AAKxxx		19	25			
	AALxxx			45			
Nonlinearity	AAxxx/AAKxxx/ABxxx/AAL002				2	%	Unipolar field sweep
	AAHxxx/ABHxxx/AAL0x4			4			
Hysteresis	AAHxxx/ABHxxx			15		%	
	AAxxx/AAKxxx/ABxxx				4		
	AALxxx				2		
Resistance tolerance			−20		+20	%	25°C
Resistance vs. temperature	AAxxx/ABxxx	TC_R		+0.14		%/°C	No applied field
	AAHxxx/AAKxxx/ AALxxx/ABHxxx			+0.11			
Output temperature coefficient	AAxxx/ABxxx	$TC_{O\text{-}I}$		+0.03		%/°C	Constant-current supply
	AAHxxx/ABHxxx			-0.28			
	AAKxxx			+0.13			
	AALxxx			−0.28			
	AAxxx/ABxxx	$TC_{O\text{-}V}$		−0.1		%/°C	Constant-voltage supply
	AAHxxx/ABHxxx			-0.40			
	AAKxxx			−0.3			
	AALxxx			−0.4			
	AAKxxx	TC_{HSAT}		−0.19		%/°C	
Frequency bandwidth	AAKxxx	f_{MAX}	DC		50	kHz	−3 dB bandwidth
	AAxxx/AAHxxx				75	kHz	
	AALxxx				500	kHz	
	ABxxx/ABHxxx				1	MHz	
Junction–Ambient thermal resistance	ULLGA4 (-14 suffix)	θ_{JA}		500		°C/W	Soldered to double-sided board; free air
	TDFN6 (-10 suffix)			320			
	MSOP8 (-00 suffix)			320			
	SOIC8 (-02 suffix)			240			
Power Dissipation	ULLGA4 (-14 suffix)	P_D		100		mW	
	TDFN6 (-10 suffix)			500			
	MSOP8 (-00 suffix)			500			
	SOIC8 (-02 suffix)			675			

Operation

Sensor Subtypes
There are four AA/AB-Series subtypes, as summarized in the table below. "H" subtypes are designed for very high sensitivity, and "K" types have low sensitivity and high saturation for high-field sensing. "L" types offer low hysteresis. AAH-Series parts also have a 150°C maximum temperature specification.

Parameter	AAxxx/ ABxxx	AAHxxx/ ABHxxx	AAKxxx	AALxxx
Field Sensitivity	High	Very High	Low	High
Operating Field Range	High	Low	Very High	Medium
Hysteresis	Medium	High	Medium	Low
Max. Temperature	High	Very High	Commercial	High

Magnetometer Operation
AA-Series sensors are ***magnetometers***, which detect the absolute magnetic field.

Direction of Sensitivity
Unlike Hall effect or other sensors, the direction of sensitivity of GMR sensors is in the plane of the package, which more convenient for many applications. Two permanent magnet orientations that will activate the sensor are shown in Figure 1:

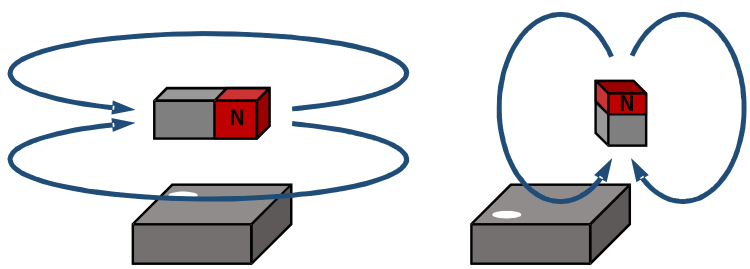

Figure 1. Planar magnetic sensitivity.

Omnipolar
AA-Series sensors are "omnipolar," meaning the output is equally sensitive to either magnetic field polarity and the output is always a positive voltage:

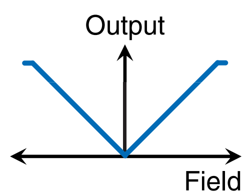

Figure 2. The omnipolar response of AA-Series sensors.

Standard and Cross-Axis Axis Directional Sensitivity
The standard axis of sensitivity is along the part axis, but there are some parts available with cross-axis sensitivity, and AAKxxx sensors are not directionally sensitive in the IC plane, and are therefore sensitive in both standard and cross-axis axis directions.

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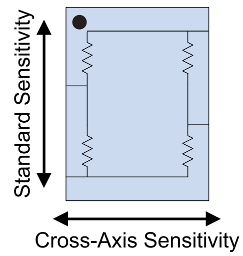

Figure 3. Standard versus cross-axis-sensitivity for AA-Series sensors.

Gradiometer Operation
AB-Series sensors are differential ***gradiometers*** that reject common mode magnetic fields, making them ideal for high magnetic noise environments such as near electric motors or current-carrying wires. The devices are sensitive to a field gradient along the part axis.

The figure below shows a typical gradiometer response:

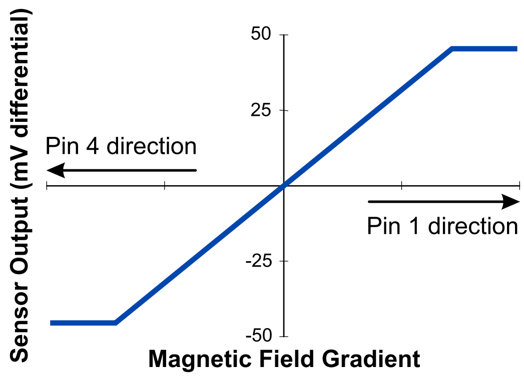

Figure 4. Typical AB-Series gradiometer response.

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Typical Performance Graphs

Figures 5–7 show the response of three types of high-sensitivity models. The standard version, the AA002, has excellent temperature stability, especially with constant-current drive. The **AAH002** has very high sensitivity but more temperature dependence, and the **AA**L002 offers low hysteresis at the expense of more temperature dependence:

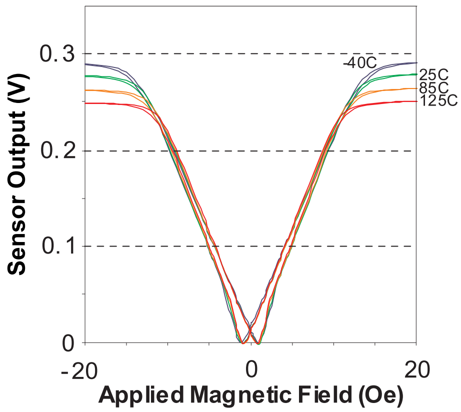

Figure 5a. Typical AA002 output with 1 mA constant-current drive.

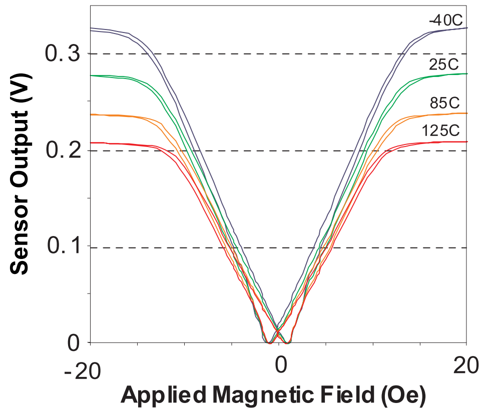

Figure 5b. Typical AA002 output with a 5V supply.

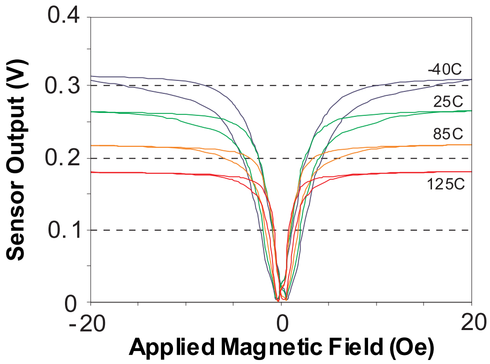

Figure 6a. Typical AAH002 output with 2.28 mA constant-current drive.

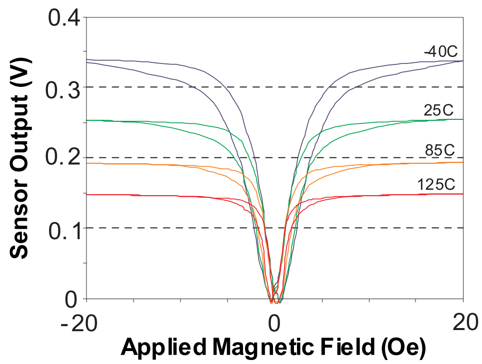

Figure 6b. Typical AAH002 output with a 5V supply.

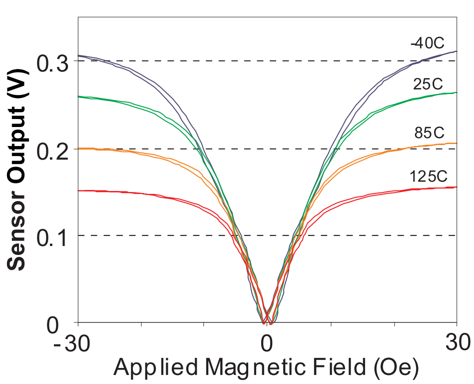

Figure 7a. Typical AAL002 output with 1 mA constant-current drive.

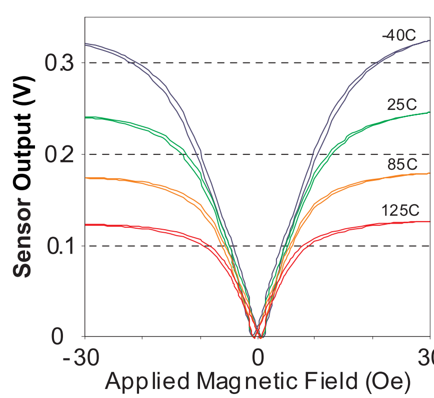

Figure 7b. Typical AAL002 output with a 5V supply.

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Figure 8 shows the typical ouput of an AAK001 high-field sensor. The sensor responds from zero field to 400 mT (4 kOe), and is are highly linear from (40 to 250 mT) (400 to 2.5 kOe). The saturation field is dependant on temperature, but sensitivity is quite stable with temperature.

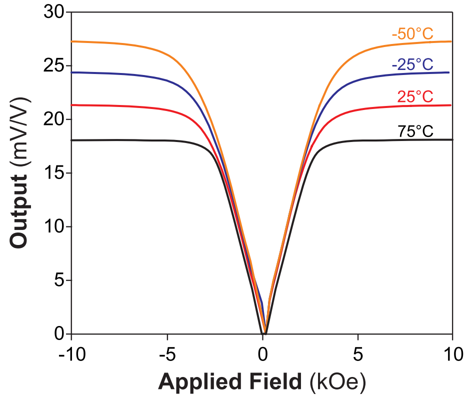

Figure 8. AAK001 high-field sensor output.

Illustrative Applications

Traditional Differential Amplifier

Traditional differential amplifiers use low-cost op-amps to provide a single-ended analog output. The circuit below has a gain of 20, which provides a full-scale output at slightly less than the sensor's saturation. A low-cost, low bias current op amp allows large resistors to avoid loading the sensor bridge. The 250 KΩ input resistors are 100 times the 2.5 KΩ sensor output impedance to avoid loading.

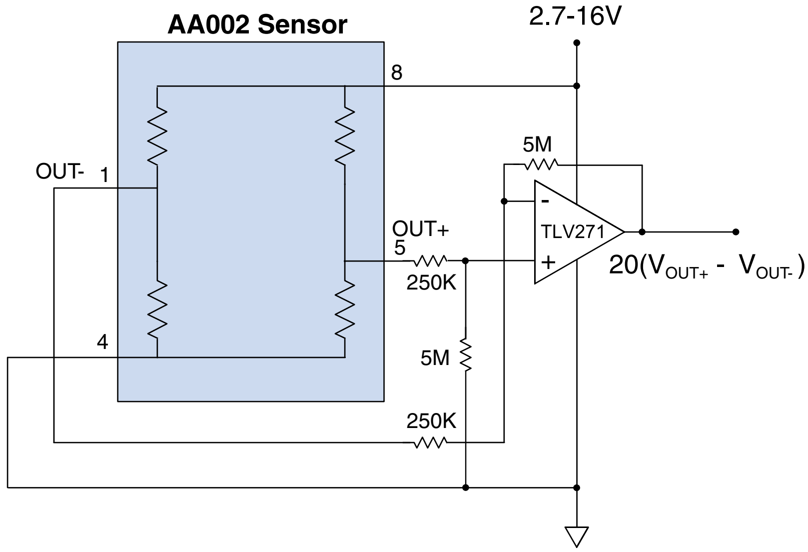

Figure 9. Traditional op-amp differential amplifier.

Sensor Instrumentation Amplifier

Instrumentation amplifiers such as the INA826 are popular bridge sensor preamplifiers because they have a low component count and have excellent common-mode rejection ratios without needing to match resistors. These amplifiers can run on single or dual supplies. AC coupling can be used for small, dynamic signals.

The circuit below has a gain of 20. The general equation for the output voltage is:

$$V_{OUT} = (1+ 49.4K / R_G)V_{IN} + V_{REF}\ ;\ \ V_{IN} = V_{OUT+} - V_{OUT-}$$

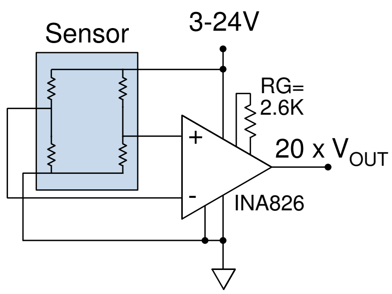

Figure 10. Single-ended analog sensor instrumentation amplifier.

Note that the instrumentation amplifier has a minimum output of 0.1V, so to detect very low fields on a single supply, an offset can be provided by using a non-zero V_{REF}.

Constant-Current Sensor Drive

Using a constant current rather than conventional constant voltage sensor supply can significantly improve temperature stability of AAxxx/ABxxx sensors. AA00x sensors, for example, have an output temperature coefficient (TC_{O-I}) of 0.03%/°C with constant current, versus –0.1%/°C with constant voltage (TC_{O-V}).

A simple constant-current supply is illustrated below:

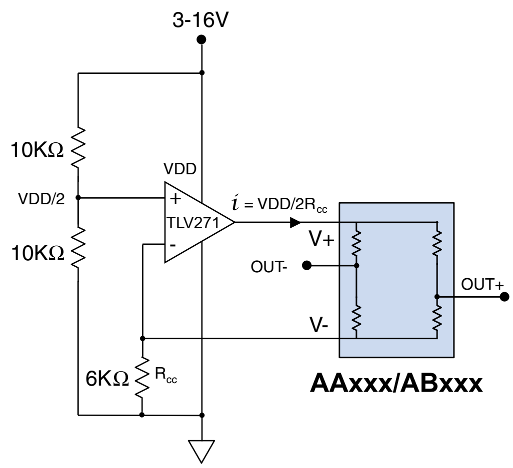

Figure 11. Constant-current supply.

The supply current for the circuit above is $V_{cc}/2R_{cc}$. R_{cc} can be set to the maximum sensor bridge resistance (e.g., 6 KΩ for many sensors) to provide the highest possible output without saturating the op-amp. The sensor will be driven with 1 mA for a 12 V supply in the circuit above. Op-amp or instrumentation amplifiers such as those illustrated in Figures 9 and 10 can be used with constant-current supplies to provide an amplified, single-ended output.

Variable Threshold Magnetic Switch

NVE offers AD-Series factory-set GMR Switches, but AA-Series analog sensors can be used for special thresholds or hysteresis, or for variable thresholds. In this circuit, the threshold is varied by changing R_G, which sets the gain of the differential amplifier. The 1 MΩ resistor sets the threshold hysteresis:

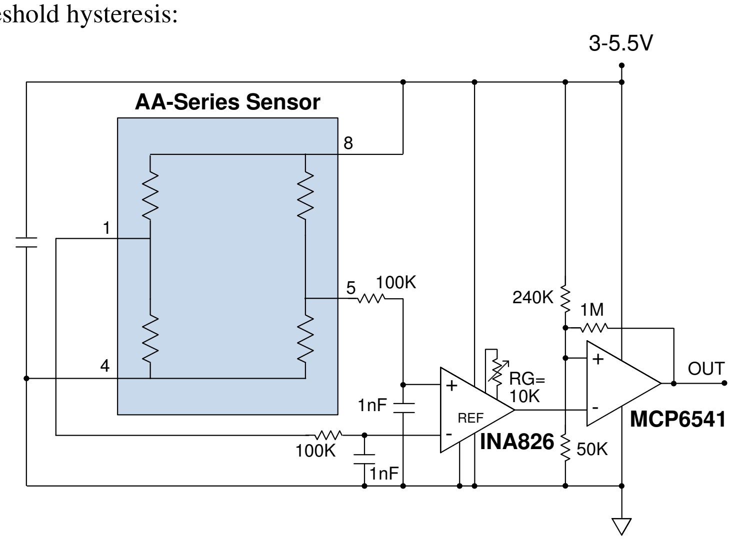

Figure 12. Variable threshold magnetic switch.

LED Field-Strength Indicator

The op-amp circuit in Figure 13 below can be used to change the brightness of an LED to indicate magnetic field strength at a glance:

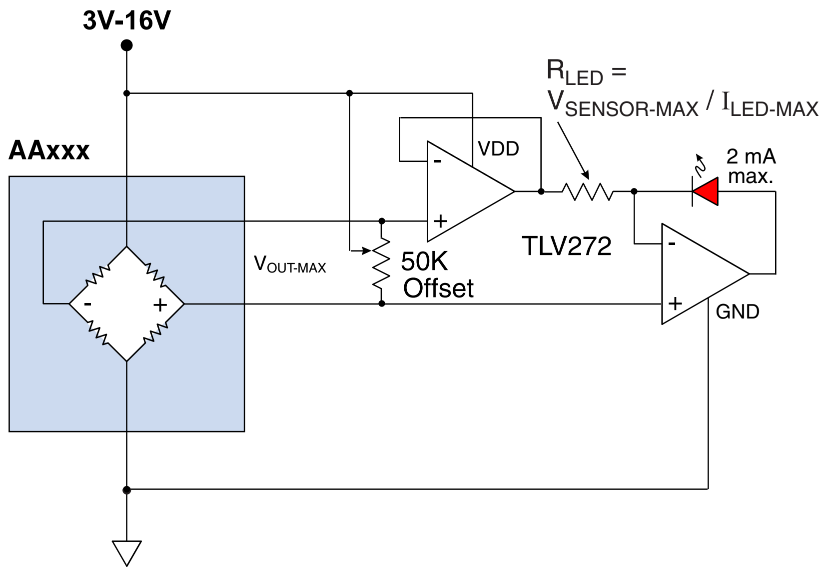

Figure 13. LED brightness indicates the magnetic field.

The LED current is proportional to the sensor output:

$$I_{LED} = (V_{OUT+} - V_{OUT-}) / R_{LED}$$

The maximum LED current can be set to the maximum sensor output. For example, for an AAK001, typical $V_{OUT\text{-}MAX}$ is 25 mV/V, so for a three-volt supply the maximum is approximately 75 mV. For a high-efficiency with a forward current of 2 mA, R_{LED} = 75 mV / 2 mA = 38Ω.

The 50 KΩ potentiometer is optional, to correct for sensor offset or to set the minimum field to turn on the LED.

The 16-volt maximum supply voltage noted in Figure 13 is limited by the op-amp selected, but note that some sensors have a 12-volt maximum supply rating. The three-volt minimum supply is to provide enough voltage to turn on the LED; the sensors can operate on lower voltages.

Noncontact Current Sensing

AA-Series sensors are often used to measure the current over a circuit board trace. The sensor measures the current by detecting the magnetic field generated by the current through the trace.

The AAL024 is ideal for this application because its cross-axis sensitivity provides sensitivity to a current trace directly under the part, and its low hysteresis provides repeatability. The AA003-02 is popular for overcurrent protection where hysteresis is needed and high accuracy is not required.

Typical current sensing configurations are shown below:

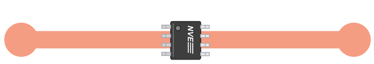

Figure 14a. 0.09" (2.3 mm) trace (0 – 10 A with an AA003 sensor)

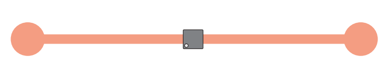

Figure 14b. 0.05" (1.3 mm) trace (0 – 5 A with an AAL024 sensor).

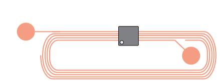

Figure 14c. Five turns of 0.0055" (0.14 mm) trace (0 – 1 A with an AAL024 sensor).

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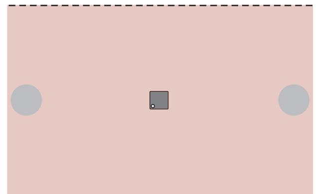

Figure 14d. 1" (25 mm) trace on the bottom side of the PCB (0 – 50 A with an AAL024 sensor).

For the geometry shown in Figure 15 and narrow traces with, the magnetic field generate can be approximated by Ampere's law:

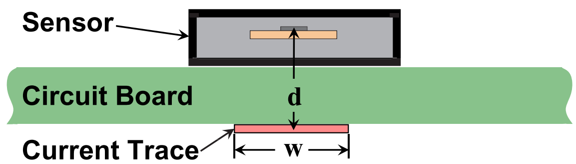

Figure 15. The geometry of current-sensing over a circuit board trace.

$$H = \frac{2I}{d}$$ [“H” in oersteds, “I” in amps, and “d” in millimeters]

The trace can also be run on the top side of the PCB for more current sensitivity.

More precise calculations can be made by breaking the trace into a finite element array of thin traces, and calculating the field from each array element. We have a free, Web-based application with a finite-element model to estimate magnetic fields and sensor outputs in this application:

www.nve.com/spec/calculators.php#tabs-Current-Sensing

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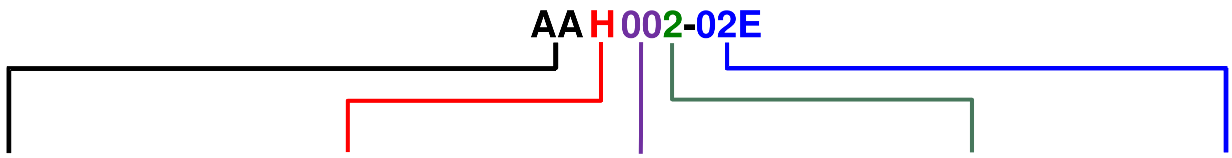
Part Numbering



Base Part
AA = Analog Magnetometer Sensors
AB = Analog Gradiometers

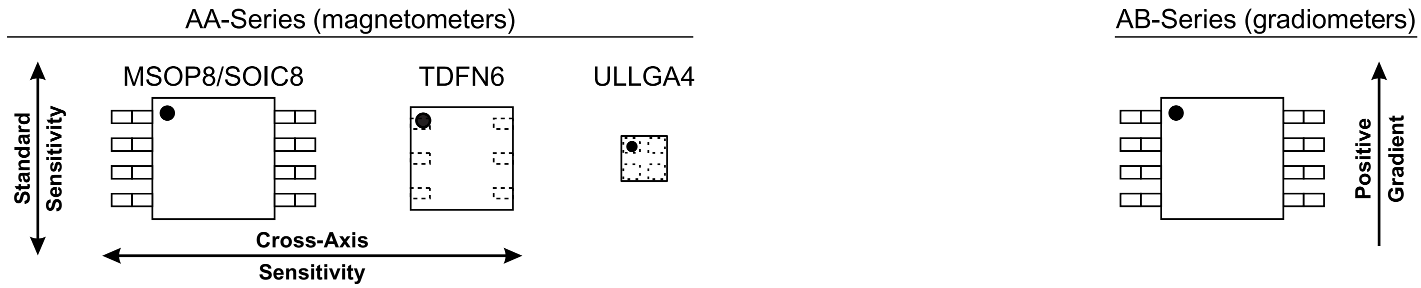
Subtype
Blank = Standard
H = High sensitivity
K = High field
L = Low hysteresis

Sensitivity Direction
00 = Standard
02 = Cross-Axis

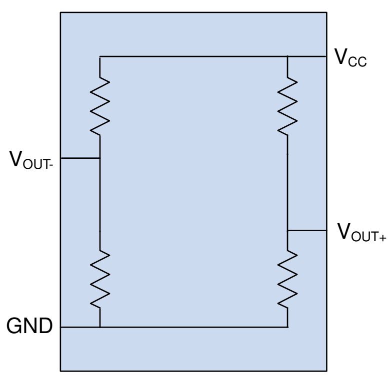
Sensitivity Code

Package Type
00 = MSOP8
02 = SOIC8
10 = TDFN6
14 = ULLGA4
E = RoHS

Direction of Sensitivity



Pinouts



AA-Series Pinout						
Sensitivity						
Standard (AAX00x-xx)			Cross-Axis (AAX02x-xx)			
ULLGA	MSOP/ SOIC	TDFN	MSOP/ SOIC	TDFN	Symbol	Description
3	1	1	5	4	V_{OUT-}	Negative bridge output (decreases with increasing field).
	2 3	2	2 3	2	NC	No internal connection.
4	4	3	4	3	V-/GND	Negative supply or ground.
1	5	4	1	1	V_{OUT+}	Positive bridge output (increases with field).
	6 7	5	6 7	5	NC	No internal connection.
2	8	6	8	6	V+	Positive supply voltage.
		Center Pad		Center Pad	NC	Internally connected to leadframe

AB-Series Pinout		
Pin	Symbol	Description
1	V_{OUT-}	Negative bridge output (decreases with gradient).
2 3	NC	No internal connection.
4	V-/GND	Negative supply or ground.
5	V_{OUT+}	Positive bridge output (increases with gradient).
6 7	NC	No internal connection.
8	V+	Positive supply.

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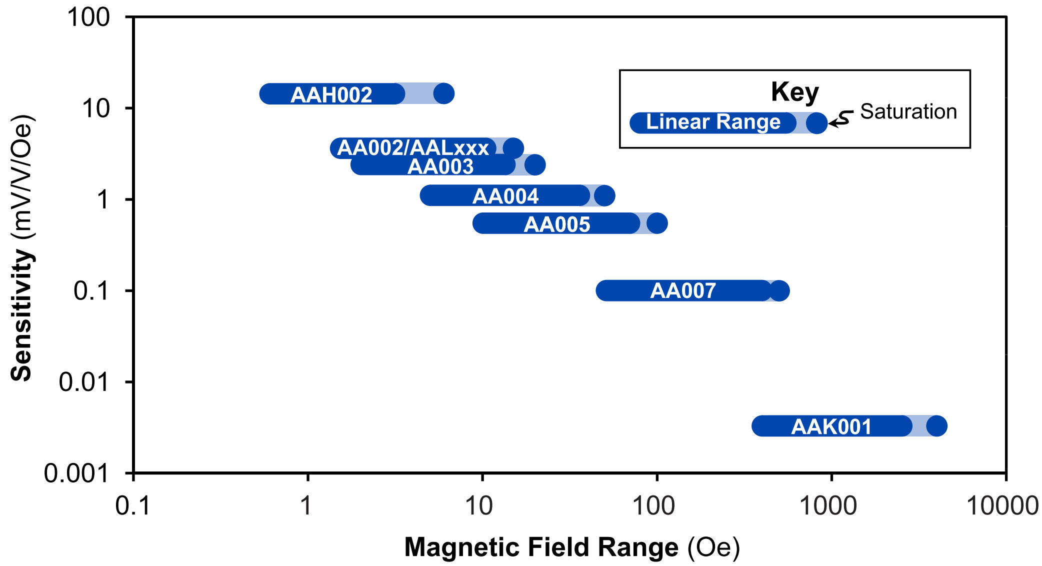
AA-Series Sensor Selector Chart



Available Parts

Magnetometers (AA-Series)										
Available Part	Linear Range (|Oe|)		Satura-tion (|Oe|)	Sensitivity (mV/V-Oe)		Max. Non-linearity (% Uni.)	Max. Hyst-eresis (% Uni.)	Max. Operating Temp.	Typ. Resist-ance	Package
	Min.	Max.		Min.	Max.					
AA002-02	1.5	10.5	15	3	4.2	2%	4%	125°C	5 kΩ	SOIC8
AA003-02	2	14	20	2	3.2	2%	4%	125°C	5 kΩ	SOIC8
AA004-00	5	35	50	0.9	1.3	2%	4%	125°C	5 kΩ	MSOP8
AA024-00	5	35	50	0.9	1.3	2%	4%	125°C	5 kΩ	MSOP8 (cross-axis)
AA004-02	5	35	50	0.9	1.3	2%	4%	125°C	5 kΩ	SOIC8
AA005-02	10	70	100	0.45	0.65	2%	4%	125°C	5 kΩ	SOIC8
AA006-00	5	35	50	0.9	1.3	2%	4%	125°C	30 kΩ	MSOP8
AA006-02	5	35	50	0.9	1.3	2%	4%	125°C	30 kΩ	SOIC8
AA007-00	50	450	500	0.08	0.12	2%	4%	125°C	5 kΩ	MSOP8
AAH002-02	0.6	3	6	11	18	4%	15%	150°C	2 kΩ	SOIC8
AAH004-00	1.5	7.5	15	3.2	4.8	4%	15%	150°C	2 kΩ	MSOP8
AAL002-02	1.5	10.5	15	3	4.2	2%	2%	125°C	5.5 kΩ	SOIC8
AAL004-10	1.5	10.5	15	3	4.2	4%	2%	125°C	2.2 kΩ	TDFN6
AAL024-10	1.5	10.5	15	3	4.2	4%	2%	125°C	2.2 kΩ	TDFN6 (cross-axis)
AAK001-14	400	2500	4000	0.0025	0.004	2%	4%	85°C	3.5 kΩ	ULLGA4

Gradiometers (AB-Series)										
Available Part	Linear Range (|Oe|)		Satura-tion (|Oe|)	Sensitivity (%R/Oe)		Max. Non-linearity (% Uni.)	Max. Hyst-eresis (% Uni.)	Max. Operating Temp.	Typ. Resist-ance	Package
	Min.	Max.		Min.	Max.					
AB001-02	10	175	250	0.02	0.03	2%	4%	125°C	2.5 kΩ	SOIC8
AB001-00	10	175	250	0.02	0.03	2%	4%	125°C	2.5 kΩ	MSOP8
ABH001-00	5	40	70	0.06	0.12	4%	15%	150°C	1.2 kΩ	MSOP8

Note: 1 Oe = 0.1 mT in air.

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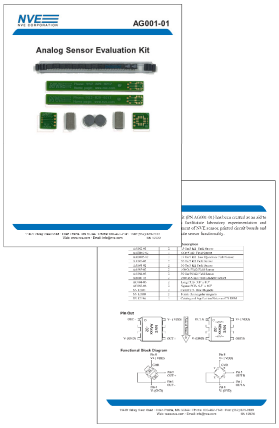
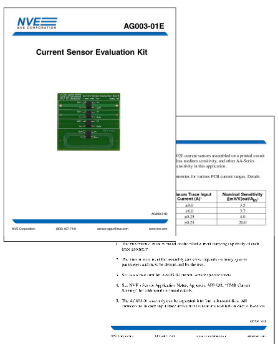
Evaluation Kits

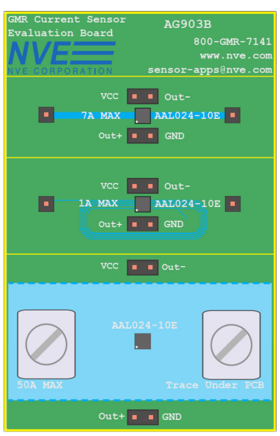
Four inexpensive evaluation kits including AA- or AB-Series analog sensors are available:



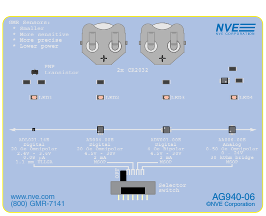
AG001-01: Analog Sensor Evaluation Kit
This kit features several types of NVE's AA and AB series parts, a selection of permanent magnets for activation or bias purposes, and circuit boards to mount the parts for testing.



AG003-01: AA003 Current Sensor Evaluation Kit
This kit features a circuit board with different trace configurations running under four AA003-02E analog sensors to evaluate the sensor as non-contact current sensors. The board supports current ranges of 0–9 amps, 0–6 amps, and 0–250 milliamps. Boards measure 2 by 1.85 inches (51 mm by 47 mm), and include four sensors.



AG903B-01: GMR Current Sensor Evaluation Kit
This board includes three AAL024-10E TDFN current sensors on a PCB with three current-trace configurations, The board supports current ranges of 0–0.75 amp, 0–5 amps, and 0–50 amps. The boards measure 1.565" x 2.915" (40 mm by 74 mm) and include sensor power and output connections, and plus connections for the current to be measured.

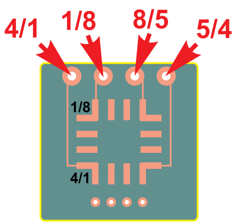


AG940-07E: Digital/Analog/Omnipolar/Bipolar Sensor Demo Board
The kit includes a demo board with our most popular digital, analog, omnipolar, and bipolar sensors, including an AA006-00E analog sensor. Each sensor drives an indicator LED. A bar magnet is included so you can see for yourself how the sensors work. The evaluation boards are 3.75 by 5 inches (95 mm by 127 mm), and are powered by two coin cells (included).

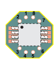
Bare Circuit Boards for Sensors

NVE offers several bare circuit boards specially designed for easy connections to surface-mount sensors. Popular PCBs are shown below (images are actual size):

AG004-06: 3" x 0.3" (75 x 8 mm) SOIC8 circuit board



AG005-06:
0.5" x 0.5" (13 mm x 13 mm)
SOIC8



AG915-06:
0.25" (6 mm) octagonal
MSOP8

AG918-06 (standard) **/ AG919-06** (cross-axis):
2" x 0.25" (50 mm x 6 mm) MSOP8

AG035-06:
1.57" x 0.25" (40 mm x 6 mm) TDFN6

AG904-06:
1.2" x 0.25" (30 mm x 6 mm)
ULLGA

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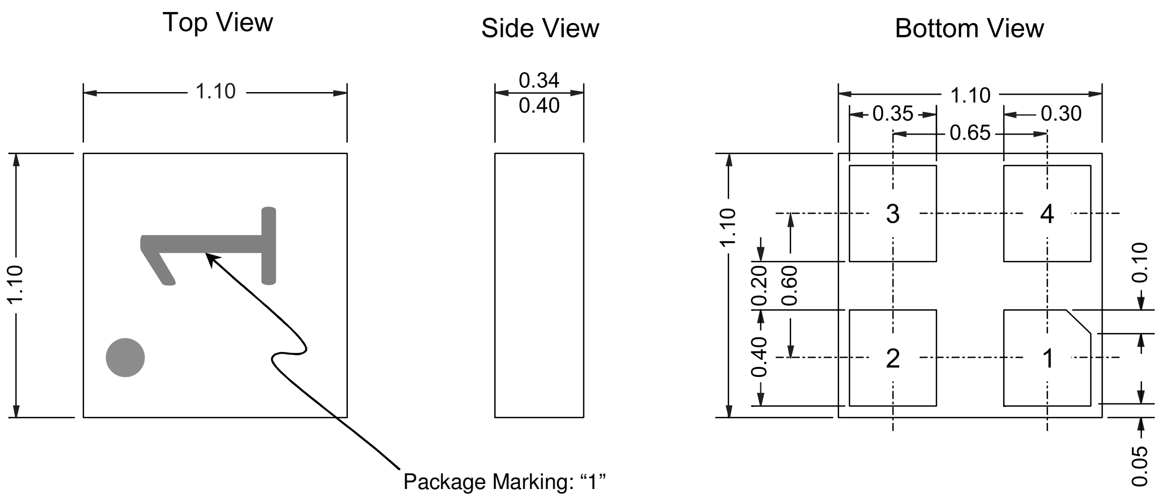
Package Drawings

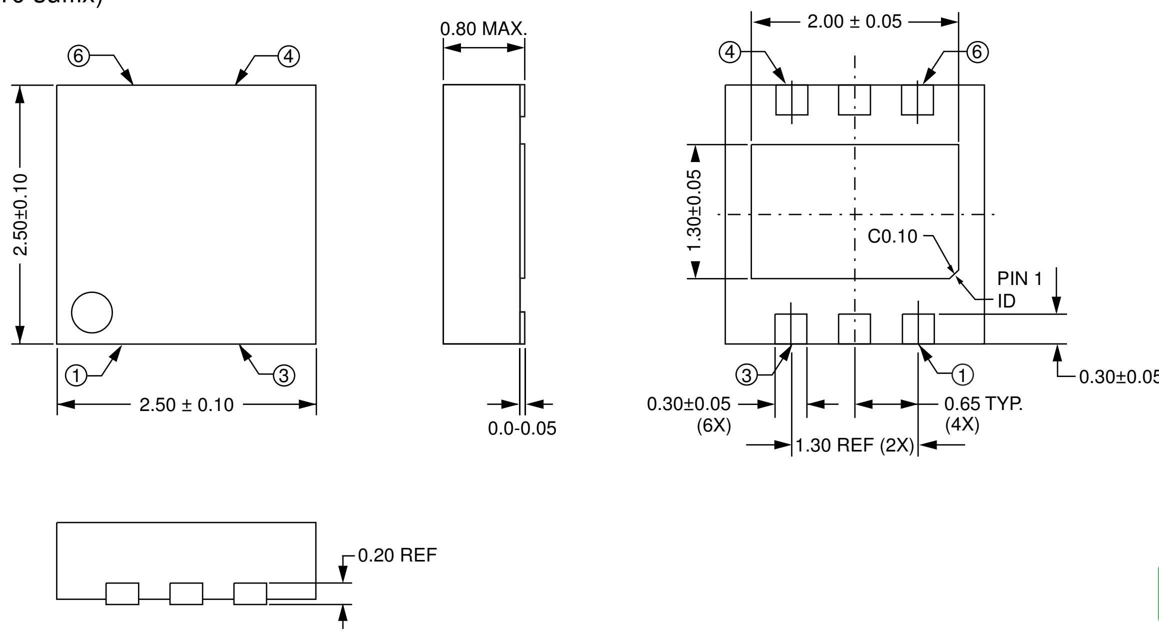
ULLGA4 (-14E suffix)



Dimensions in mm; ±0.10 mm unless otherwise noted.

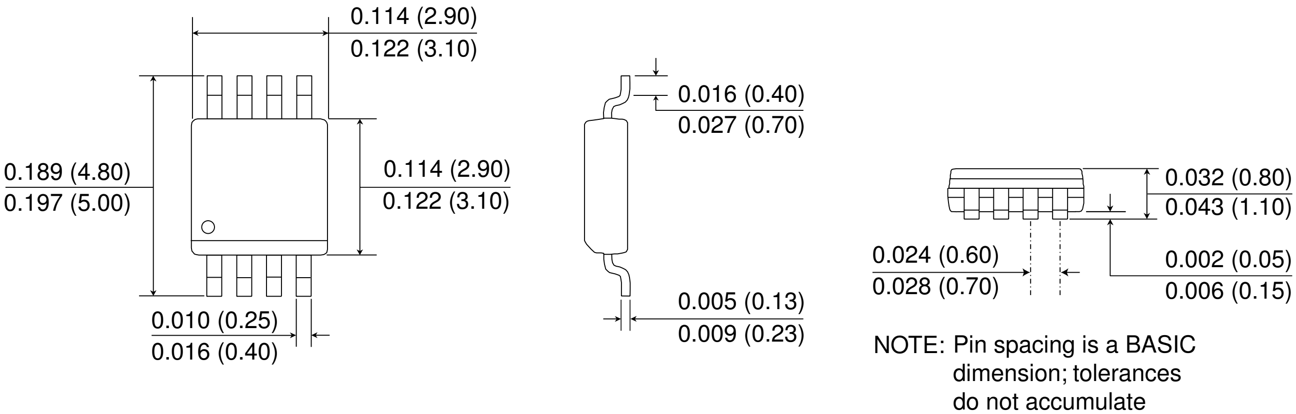
RoHS COMPLIANT

TDFN6 (-10 suffix)

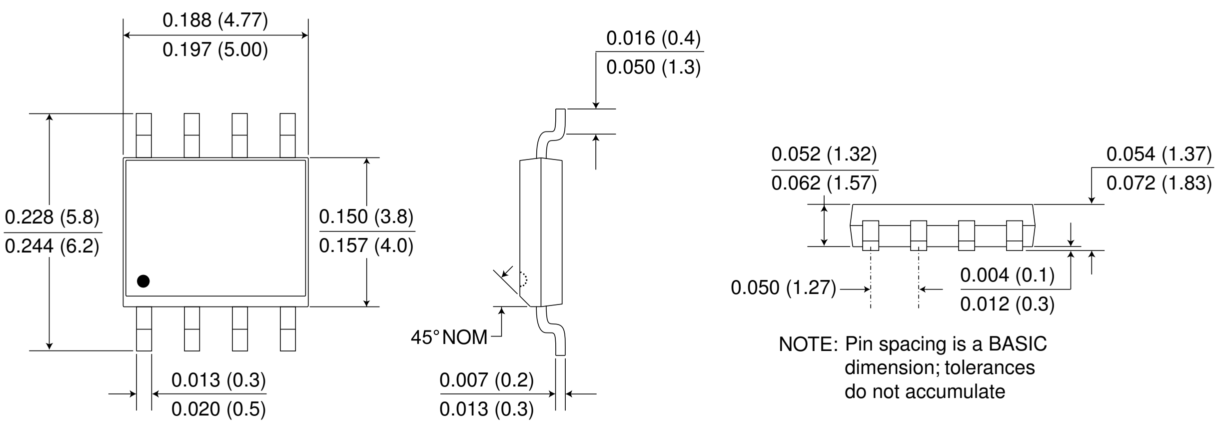


RoHS COMPLIANT

MSOP8 (-00 suffix)



SOIC8 (-02 suffix)



Soldering profiles per JEDEC J-STD-020C, MSL 1.

Revision History

SB-00-059-G
July 2019

Change
- Added SI units (mT) where appropriate.
- Added higher current-sensing trace illustration (p. 11).
- Revised AG903B-01 current sensor evaluation kit (p. 14).

SB-00-059-F
October 2018

Change
- Improved AAL-Series bandwidth specification; specified −3 dB bandwidth (p. 3).
- Added AG903B high-current evaluation kit (p. 14).

SB-00-059-E
January 2018

Change
- Added Absolute Maximum isolation specification for TDFN package (p. 2).
- Added TDFN Center Pad description (p. 12).
- Updated AAL004 and AAL024 linearity specification (p. 13).

SB-00-059-D
October 2017

Change
- Added AAK001 ultrahigh-field model.
- Added LED field-strength indicator and current-sensing applications (p. 10).
- Added AA selector chart (p. 13).
- Added Evaluation Kits (p. 14) and bare circuit boards (p. 15).
- Misc. cosmetic changes and additional illustrations.

SB-00-059-C
September 2017

Change
- Added AA007-00E high-field model.

SB-00-059-B
August 2017

Change
- Added AA024-10E and AAL024-10E cross-axis versions.

SB-00-059-A
April 2017

Change
- Initial datasheet release superseding catalog.

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