Introduction to NVE GMR Sensors

In 1988, scientists discovered the “Giant Magneto Resistive” effect—a large change in electrical resistance that occurs when thin, stacked layers of ferromagnetic and non-magnetic materials are exposed to a magnetic field. Since then, many companies have sought to develop practical applications for this intriguing technology. NVE Corporation has taken the lead by developing the first commercially available products making use of GMR technology, a line of magnetic field sensors that outperform traditional Hall Effect and AMR magnetic sensors.

NVE introduced its first analog sensor product in 1995. Since then, our product line has grown to include several variations on analog sensors, the GMR Switch™ line of precision digital sensors, and our newest products, the GT Sensors™ for gear tooth and encoder applications. In addition to these products, NVE offers printed circuit board assemblies for pneumatic cylinder position and currency detection applications as well as peripheral integrated circuits designed to work with our GMR sensors in a variety of applications. Finally, NVE remains committed to custom product developments for large and small customers in order to develop the best possible sensor for the customer’s application.

NVE magnetic sensors have significant advantages over Hall Effect and AMR sensors as shown in the following chart. In virtually every application, NVE sensors outperform the competition—often at a significantly lower installed cost.

Benefits:	GMR	HALL	AMR
Physical Size	Small	Small	Large
Signal Level	Large	Small	Medium
Sensitivity	High	Low	High
Temperature Stability	High	Low	Medium
Power Consumption	Low	Low	High
Cost	Low	Low	High

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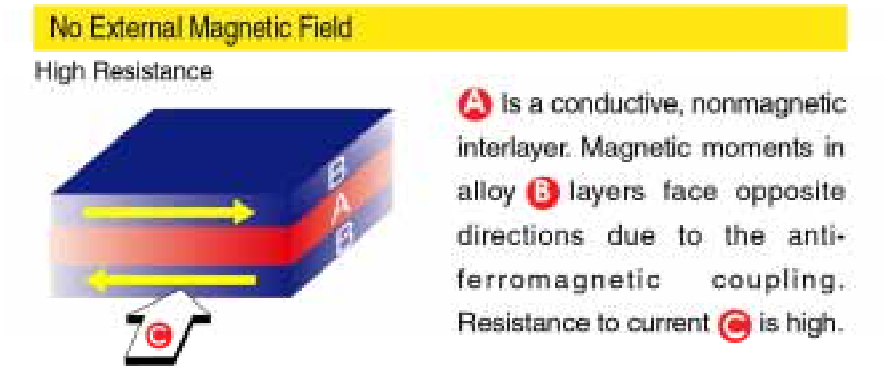
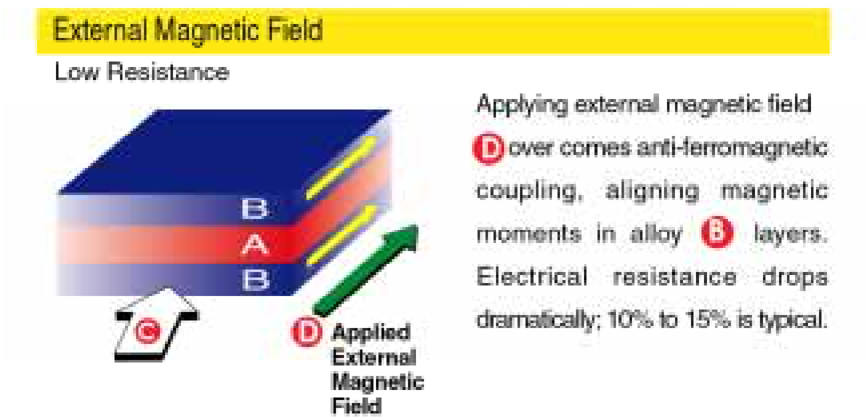
GMR Materials Overview

The heart of NVE's sensor products are the proprietary GMR materials produced in our factory. These materials are manufactured in our on-site clean room facility and are based on nickel, iron, cobalt, and copper. Various alloys of these materials are deposited in layers as thin as 15 Angstroms (five atomic layers!), and as thick as 18 microns, in order to manufacture the GMR sensor elements used in NVE's products.

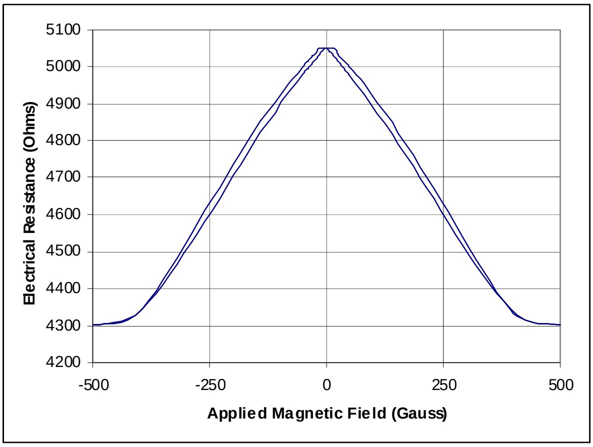
The following diagrams show how the GMR effect works in an NVE sensor using multilayer GMR material. Note that the material is sensitive in the plane of the IC, rather than orthogonally to the IC, as is the case with Hall elements.





NVE's GMR materials are noteworthy in comparison with other GMR material types in that NVE's material cannot be damaged with the application of extremely large magnetic fields. GMR materials from other sources often rely on keeping one of the magnetic layers internally magnetized, or pinned, in a specific direction, and allowing the other layer to rotate and thus provide the GMR effect. In some of these materials, an external magnetic field as small as 200 Gauss can upset this pinned layer, thus permanently damaging the sensor element. Most of NVE's GMR materials rely on anti-ferromagnetic coupling between the layers; as a result they are not affected by extremely large fields, and will resume normal operation after the large field is removed. NVE has recently introduced a production GMR material with a pinned magnetic layer, this pinned layer uses a synthetic anti-ferromagnet for the pinning, which cannot be upset at temperatures below 300ºC. As a result, NVE's pinned GMR material is not susceptible to upset problems.

The following chart shows a typical characteristic for NVE's standard multilayer GMR material:



Notice that the output characteristic is omnipolar, meaning that the material provides the same change in resistance for a directionally positive magnetic field as it does for a directionally negative field. This characteristic has advantages in certain applications.

For example, when used on a magnetic encoder wheel, a GMR sensor using this material will provide a complete sine wave output for each pole on the encoder (rather than each pole pair, as with a Hall Effect sensor), thus doubling the resolution of the output signal.

The material shown in the plot is used in most of NVE's GMR sensor products. It provides a 98% linear output from 10% to 70% of full scale, a large GMR effect (13% to 16%), a stable temperature coefficient (0.14%/°C) and temperature tolerance (+150°C), and a large magnetic field range (0 to ±300 Gauss).

In addition to manufacturing this excellent GMR material, NVE is constantly developing new GMR materials. New products have recently been introduced which use three new materials: one with double the magnetic sensitivity of the standard material, one with half the magnetic hysteresis, and one with a synthetic antiferromagnet pinned layer designed for use in magnetic saturation. Some of these new materials are suitable for operation to +225°C. Please see the application notes section of this catalog for a complete description of the GMR material types available in NVE's magnetic sensors.

NVE continues to lead the market in GMR-based magnetic sensors due to constant emphasis on developing new or improved GMR materials and frequent new product releases utilizing these improvements.

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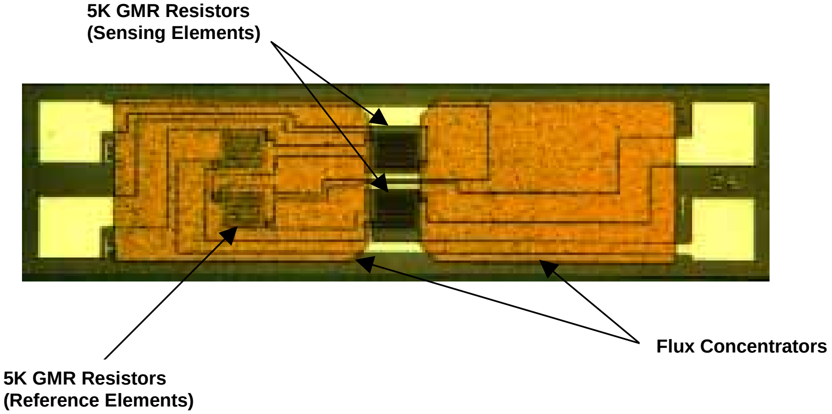
Basic Sensor Design

NVE manufactures three basic sensor element types: magnetometers, which detect the strength of the applied magnetic field, gradiometers (or differential sensors), which detect the difference in the applied magnetic field strength at two discrete points on the sensor element, and spin valve sensors, which change in output with the angular difference between the pinned layer and the free layer of the GMR material while the device is exposed to a saturating magnetic field.

These three basic sensor element types are described in the sections below.

Magnetometers

NVE's magnetometers are covered by our basic GMR material and sensor structure patents and have unique features designed to take advantage of the characteristics of GMR sensor materials. A photomicrograph of an NVE sensor element is shown below:



The size of this IC is approximately 350 microns by 1400 microns. The sensor is configured as a Wheatstone bridge. The serpentine structures in the center of the die and to the left of center under the large plated structure are 5 kΩ resistors made of GMR material.

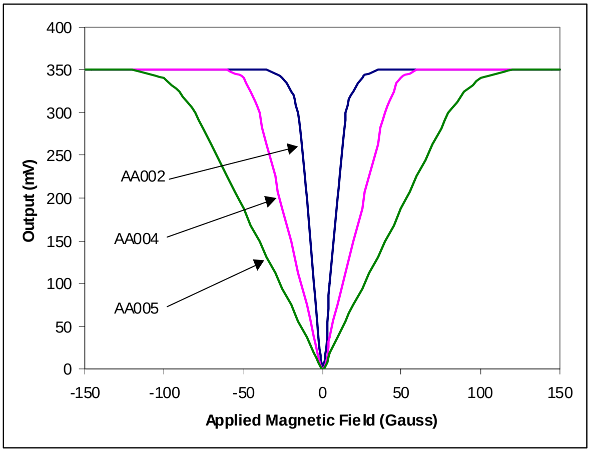
The two large plated structures shown on the die are flux concentrators. They serve two purposes. First, notice that they cover two of the resistors in the Wheatstone bridge. In this configuration the flux concentrators function as a shield for these two resistors, preventing an applied magnetic field from reaching them. Therefore, when a field is applied, the two GMR resistors in the center of the die decrease in resistance, while the two GMR resistors under the flux concentrator do not. This imbalance leads to the bridge output.

The second purpose of the flux concentrators is to vary the sensitivity of the sensor element from product to product. They work by forming a low reluctance path to the sensor elements placed between them. NVE uses a “rule of thumb” formula to calculate the effect of the flux concentrators:

Field at sensor elements ≅ (Applied Field)(60%)(FC length / gap between FCs)

For the sensor shown in the previous photo, the length of each flux concentrator is 400 microns, and the gap between the flux concentrators is 100 microns. Therefore, if the sensor is exposed to an applied field of 10 Gauss, the actual field at the sensor element will be about (10 Gauss)(0.6)(400 microns / 100 microns), or 24 Gauss.

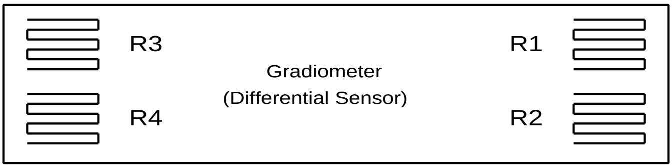
NVE uses this technique to provide GMR sensors with varying sensitivity to the applied magnetic field. The following chart shows sensitivity ranges for some of NVE’s products. Sensitivity to the magnetic field is indicated by the slope of each line:

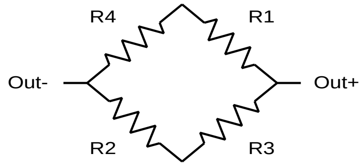


Maximum signal output from such a sensor element is typically 350 mV at 100 Gauss with a 5V power supply. This compares to an output of 5 mV under the same conditions for a Hall sensor element, and 100 mV for an AMR sensor.

Gradiometers

NVE’s gradiometers, or differential sensors, rely on the field gradient across the IC to generate an output. In fact, if one of these sensors is placed in a uniform magnetic field, its output voltage will be zero. This is because all four of the bridge resistors are exposed to the same magnetic field, so they all change resistance together. There is no shielding or flux concentration on a gradiometer. A simple representation of a gradiometer is shown in the diagram below:





Because all four bridge resistors contribute to the sensor’s output, at maximum differential field NVE’s gradiometers can provide double the output signal of our magnetometer parts—approximately 700 mV with a 5V supply. In practice, the gradient fields are typically not high enough to give this maximum signal, but signal levels of 50 mV to 200 mV are common.

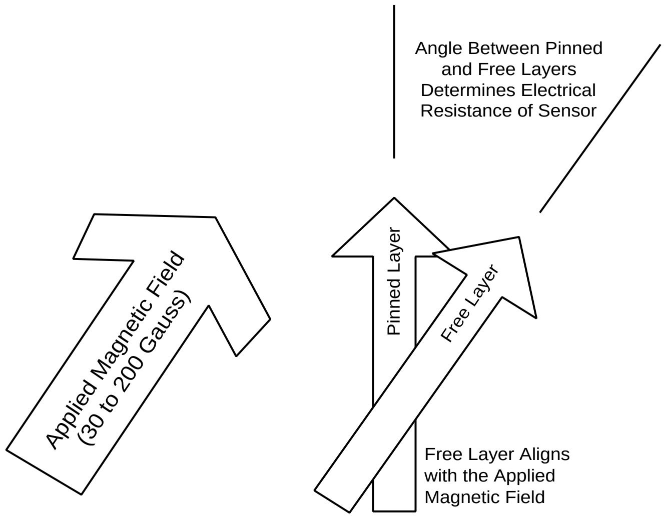
NVE’s GMR differential sensors are typically designed with two of the bridge resistors at one end of the IC, and two at the other end. The spacing between the two sets of resistors, combined with the magnetic field gradient on the IC, will determine the output signal from the sensor element. NVE offers three standard spacings for differential sensors: 0.3 mm, 0.5 mm, and 1.0 mm. If a different spacing is desired, contact NVE for development cost and schedule for a custom product.

The most popular application for differential sensors is in gear tooth or magnetic encoder detection. As these structures move or spin the magnetic field near their surface is constantly varying, generating a field gradient. A differential sensor, properly placed, can detect this movement by sensing the changing field gradient and provide an output for each gear tooth or each magnetic pole (see the GT Sensor section of this catalog for a more detailed explanation). Applications for these devices include detecting the speed and position of electric motor shafts or bearings, automotive transmission gear speeds, axle shaft speed in Anti-lock Braking Systems (ABS), or linear gear-tooth position.

Spin Valve Sensors

NVE's spin valve sensors are designed using our synthetic anti-ferromagnet pinned layer. This pinned layer is very robust, and not subject to upset or reset. The basic GMR material construction includes the pinned layer and a free layer; the free layer can be influenced by an external magnetic field in the range of 30 to 200 Gauss. The output of the sensor varies in a cosine relationship to the angle between the free layer and the pinned layer.

As long as the external field strength is in the 30 to 200 Gauss range, the free layer in the GMR material is saturated. It will therefore point in the same direction as the external field, while the pinned layer remains pointed in its fixed direction. The diagram below shows a vector concept of the device operation:

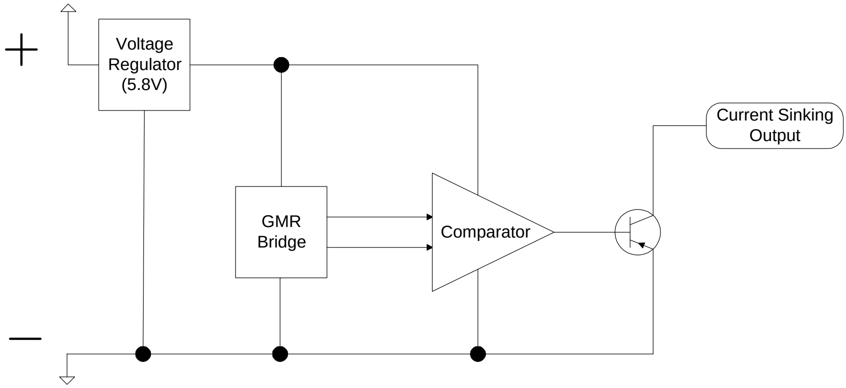


The percent change of resistance available with this GMR material is about 5%. The output is a cosine function over 360 degrees of angular movement by the external, saturating magnetic field.

Signal Processing

Adding signal processing electronics to the basic sensor element increases the functionality of NVE's sensors. The large output signal of the GMR sensor element means less circuitry, smaller signal errors, less drift, and better temperature stability compared to sensors where more amplification is required to create a usable output.

For the GMR Switch products, NVE adds a simple comparator and output transistor circuit to create the world's most precise digital magnetic sensor. For these products, no amplification of the sensor's output signal is necessary. A block diagram of this circuitry is shown in the figure below:



The GMR Switch holds its precise magnetic operate point over extreme variations in temperature and power supply voltage. This low cost product has revolutionized the industrial control position sensing market.

Taking this approach one step further, NVE's integrated GT Sensor products add low-gain amplification and magnet compensation circuitry to the basic sensor element to create a powerful gear tooth and encoder sensor at an affordable price.

NVE also offers certain peripheral IC products to help customers integrate GMR sensor elements into their systems and meet rigorous regulatory agency requirements for safety and survivability. These products include power switch ICs for switching large currents in industrial applications and voltage regulator ICs for reducing wide ranging automotive and industrial voltage supplies to manageable IC-friendly levels. Both of these product types retain a "bulletproof" appearance to the outside electrical world and resist damage from high voltage transients, reverse battery connections, and ESD/EMC events.

For applications where a unique product is required, NVE's in-house IC design group regularly does custom designs for our customers. These designs range from simple variations on NVE's existing parts to full custom chips for one-of-a-kind applications. For applications where a unique electronic functionality is required, please contact NVE.

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AA and AB-Series Analog Sensors

NVE's AA and AB-Series analog GMR sensors offer unique and unparalleled magnetic sensing capabilities. These sensors are characterized by high sensitivity to applied magnetic fields, excellent temperature stability, low power consumption, and small size. These characteristics make them suitable for use in a wide variety of applications from rugged industrial and automotive position, speed, and current sensors, to low-voltage, battery-powered sensors for use in hand-held instrumentation and implantable medical devices. The unmatched versatility of these basic magnetic sensors makes them an excellent choice for a wide range of analog sensing applications.

The AA-Series sensors use NVE's patented GMR materials and on-chip flux concentrators to provide a directionally sensitive output signal. These sensors are sensitive in one direction in the plane of the IC, with a cosine-scaled falloff in sensitivity as the sensor is rotated away from the sensitive direction. Also, these devices provide the same output for magnetic fields in the positive or negative direction along the axis of sensitivity (omnipolar output). All sensors are designed in a Wheatstone bridge configuration to provide temperature compensation. Two packages are offered, an SOIC8 and an MSOP8. These sensors are also available in die form on a special-order basis.

There are three families of NVE's basic AA-Series sensors: the standard AA-Series, the AAH-Series, and the AAL-Series. Each of these sensor families uses a different GMR material, with its own characteristics. The comparison table below summarizes the different characteristics of the GMR materials:

Parameter	AA Series	AAH Series	AAL Series
Sensitivity to Applied Fields	High	Very High	High
Field Range of Operation	High	Low	Medium
Hysteresis	Medium	High	Low
Temperature Range	High	Very High	Very High

The AB-Series sensors are differential sensor devices, or gradiometers, which take advantage of the high output characteristics of NVE's GMR materials. Two families of AB sensors are offered, the standard AB-Series and the ABH-Series. They have operational characteristics similar to the AA and AAH sensors described in the table above but with the bipolar linear output characteristics of a differential sensor.

Within these different sensor families, customers can find an excellent match to their analog sensor requirements.

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Quick Reference: AA and AB-Series

For comparison and product selection purposes, the following table lists all available AA and AB-Series analog sensors, with some of their key characteristics:

Magnetometers:

Part Number	Linear Range (|Oe[1]|)		Sensitivity (mV/V-Oe[1])		Maximum Non-linearity (% Uni.[2])	Maximum Hyster-esis (% Uni.[2])	Maximum Operating Temp (°C)	Typical Resis-tance (Ohms)	Package
	Min	**Max**	**Min**	**Max**					
AA002-02	1.5	10.5	3.0	4.2	2	4	125	5K	SOIC8
AA003-02	2.0	14	2	3.2	2	4	125	5K	SOIC8
AA004-00	5.0	35	0.9	1.3	2	4	125	5K	MSOP8
AA004-02	5.0	35	0.9	1.3	2	4	125	5K	SOIC8
AA005-02	10.0	70	0.45	0.65	2	4	125	5K	SOIC8
AA006-00	5.0	35	0.9	1.3	2	4	125	30K	MSOP8
AA006-02	5.0	35	0.9	1.3	2	4	125	30K	SOIC8
AAH002-02	0.6	3.0	11.0	18.0	6	15	150	2K	SOIC8
AAH004-00	1.5	7.5	3.2	4.8	4	15	150	2K	MSOP8
AAL002-02	1.5	10.5	3.0	4.2	2	2	150	5.5K	SOIC8

Gradiometers:

Part Number	Linear Range (|Oe[1]|)		Resistor Spacing (mm)	Maximum Non-linearity (% Uni.[2])	Maximum Hyster-esis (% Uni.[2])	Maximum Operating Temp (°C)	Typical Resis-tance (Ohms)	Package
	Min	**Max**						
AB001-02	20	200	0.5	2	4	125	2.5K	SOIC8
AB001-00	20	200	0.5	2	4	125	2.5K	MSOP8
ABH001-00	5	40	0.5	4	15	150	1.2K	MSOP8

Notes:

1. Oersted (Oe) = 1 Gauss in air.
2. Unipolar operation means exposure to magnetic fields of one polarity, for example 0 to +30 Gauss, or -2 to -50 Gauss. Bipolar operation (for example, -5 to +10 Gauss) will increase nonlinearity and hysteresis

AA Sensors

Features:

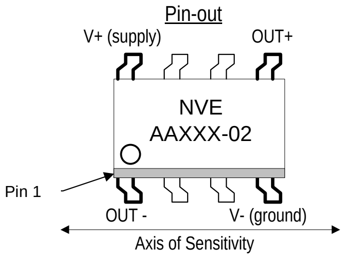
- Excellent Sensitivity to Applied Magnetic Fields
- Wheatstone Bridge Analog Output
- Operating Temperature to 125°C Continuous
- Wide Linear Range of Operation
- Near-Zero Voltage Operation
- DC to >1MHz Frequency Response
- Small, Low-Profile Surface Mount Packages

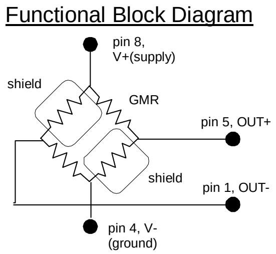
Applications:

- General Motion, Speed, and Position Sensing
- Low Power, Low Voltage Applications
- Low Field Sensing for Magnetic Media Detection
- Current Sensing

Description:

The basic AA-Series GMR sensors are general-purpose magnetometers for use in a wide variety of applications. They exhibit excellent linearity, a large output signal with applied magnetic fields, stable and linear temperature characteristics, and a purely ratiometric output.





Magnetic Characteristics:

Part Number	Saturation Field (Oe[1])	Linear Range (|Oe[1]|)		Sensitivity (mV/V-Oe[1])		Resistance (Ohms)	Package[2]	Die Size[3] (µm)
		Min	Max	Min	Max			
AA002-02	15	1.5	10.5	3.0	4.2	5K ±20%	SOIC8	436x3370
AA003-02	20	2.0	14	2	3.2	5K ±20%	SOIC8	436x3370
AA004-00	50	5	35	0.9	1.3	5K ±20%	MSOP8	411x1458
AA004-02	50	5	35	0.9	1.3	5K ±20%	SOIC8	411x1458
AA005-02	100	10	70	0.45	0.65	5K ±20%	SOIC8	411x1458
AA006-00	50	5	35	0.9	1.3	30K ±20%	MSOP8	836x1986
AA006-02	50	5	35	0.9	1.3	30K ±20%	SOIC8	836x1986