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.

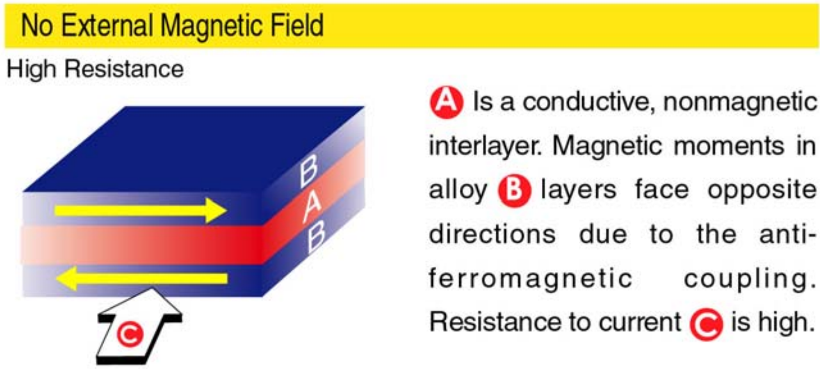
NVE magnetic sensors have significant advantages over Hall Effect and AMR sensors, as shown in the following chart. In virtually every application, NVE sensors outperform the competition – often at a significantly lower installed cost.

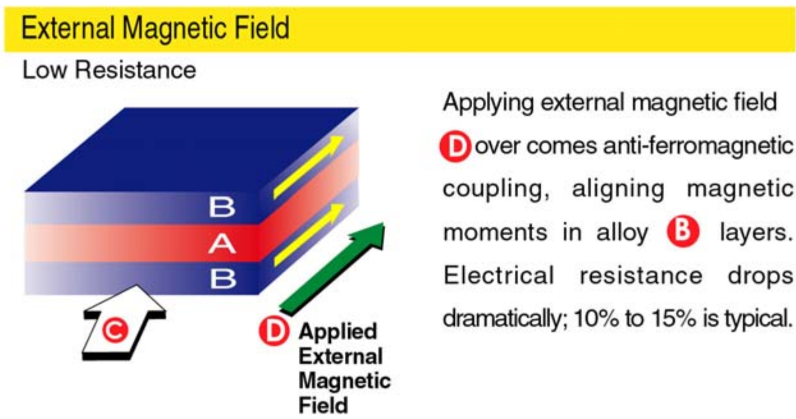
Benefits:	GMR	HALL	AMR
Physical Size	Small	Small	Large
Signal Level	Large	Small	Medium
Sensitivity	High	Low	High
Temperature Stability	High	Low	Medium
Power Consumption	Low	Low	High
Cost	Low	Low	High

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 cleanroom facility, and are based on nickel, iron, cobalt, and copper. Various alloys of these materials are deposited in layers as thin as 15 angstroms (5 atomic layers!), and as thick as 18 microns, in order to manufacture the GMR sensor elements used in NVE's products.

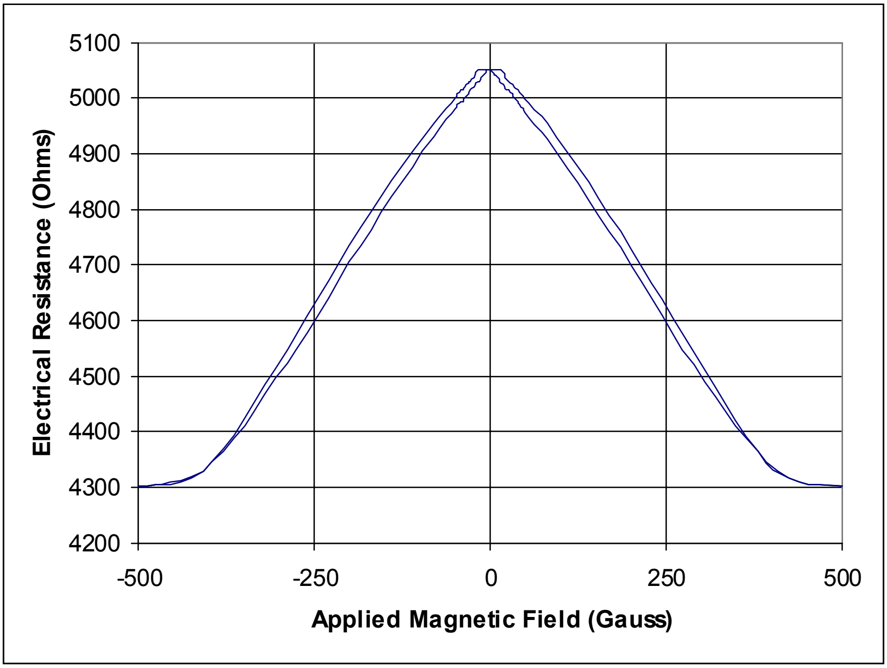
The following diagrams show how the GMR effect works in NVE's sensors. Note that the material is sensitive in the plane of the IC, rather than orthogonally to the IC, as is the case with Hall elements.





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 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. An external magnetic field as small as 200 Gauss can upset this pinned layer, thus permanently damaging the sensor element. Since NVE's materials rely on anti-ferromagnetic coupling between the layers, they are not affected by extremely large fields, and will resume normal operation after the large field is removed.

The following chart shows a typical characteristic for an NVE 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 (0.15%/°C) and temperature tolerance (+150°C), and a large magnetic field range (0 to ±300 Gauss).

In addition to manufacturing this excellent material, NVE is constantly developing new GMR materials. New products have recently been introduced which use two new materials, one with double the magnetic sensitivity of the standard material, and one with half the magnetic hysteresis. Both of these new materials are suitable for operation up to +225°C.

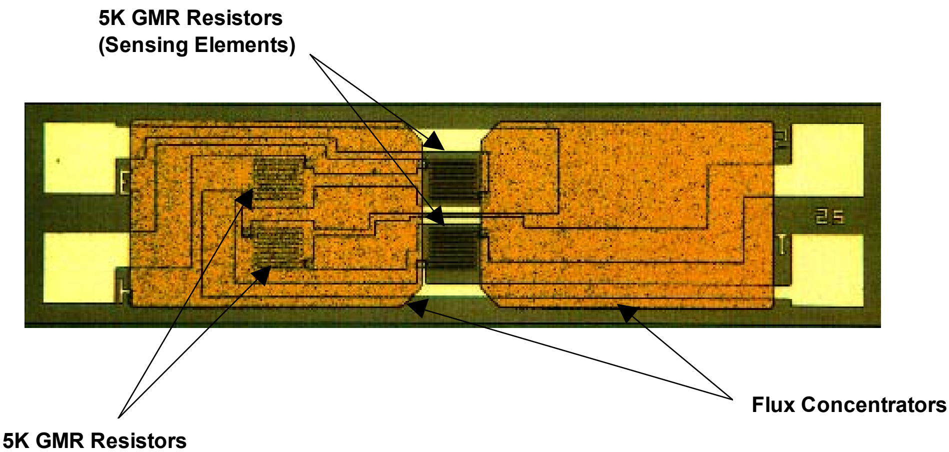
With constant emphasis on developing new and improved GMR materials, and frequent new product releases utilizing these improvements, NVE continues to lead the market in GMR-based magnetic sensors.

Basic Sensor Design

NVE manufactures two basic sensor element types: magnetometers, which detect the strength of the applied magnetic field, and gradiometers (or differential sensors), which detect the magnetic field gradient across a certain distance.

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:



ximately 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 5K resistors made of GMR material.

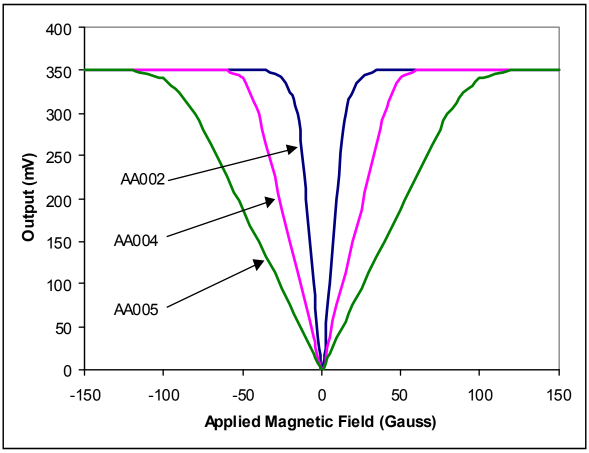
The two large plated structures shown on the die are flux concentrators. They serve two purposes. First, notice that they cover two of the resistors in the Wheatstone bridge. In this configuration the flux concentrators function as a shield for these two resistors, preventing an applied magnetic field 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.

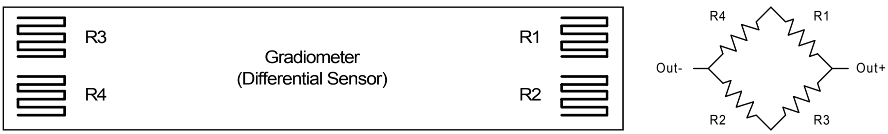
NVE uses this technique to provide GMR sensors with varying sensitivity to the applied magnetic field. The following chart shows sensitivity ranges for some of NVE's products. Sensitivity to the magnetic field is indicated by the slope of each line:



Maximum signal output from such a sensor element is typically 350mV at 100 Gauss with a 5V supply. This compares to an output of 5mV under the same conditions for a Hall sensor element, and 100mV 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 are able to contribute to the sensor's output, at maximum differential field NVE's gradiometers can provide double the output signal of our magnetometer parts, or about 700mV with a 5V supply. In actual practice the gradient fields are typically not high enough to give this maximum signal, but signal levels of 50mV to 200mV are common.

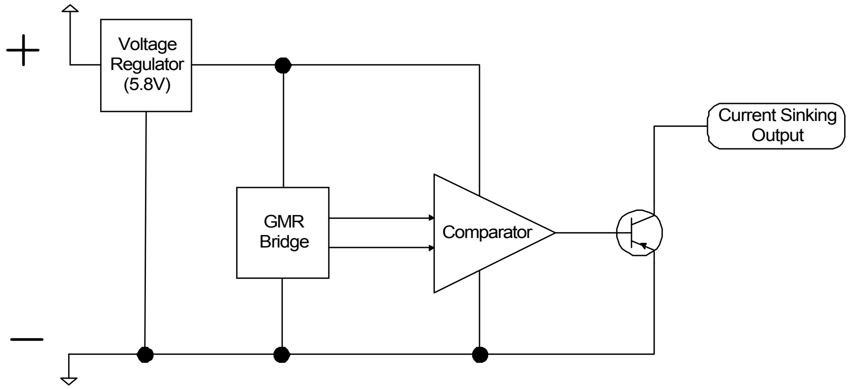
NVE's GMR differential sensors are typically designed with two of the bridge resistors at one end of the IC, and two at the other end. The spacing between the two sets of resistors, combined with the magnetic field gradient on the IC, will determine the output signal from the sensor element. NVE offers two standard spacings for differential sensors: 0.5mm and 1.0mm. 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 or axle shaft speed in Anti-lock Braking Systems (ABS), or linear gear tooth position.

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.