

## Understanding Magneto Resistance Element

by Bernie Thompson

In Lewis Carroll's story "Alice in Wonderland" a young girl notices a white rabbit running through her back yard and she starts to follow it. The rabbit then runs through a hole where Alice loses sight of it. When Alice goes through the hole in pursuit of the white rabbit, she enters a world where everything is quite different and nothing seems to make any sense. In the world of the Magneto Resistance Element (MRE) sensor many technicians may feel that they too have entered Wonderland. For example, when the MRE sensor is being used to sense wheel speed in a bearing hub and the technician is in pursuit of a wheel speed problem, he may remove the sensor and look through the sensor hole only to find there are no target teeth or tone ring to be found. Although one might think that this is why the wheel speed sensor is not working, this is the correct design for this style MRE sensor. Now let us take a closer look into the mysterious world of the MRE sensor.

Magnetoresistance was discovered in 1856 by Lord Kelvin, a prominent mathematical physicist of the time period. However, this principle was not used widely until the 1960's when it was discovered that it could be used for computer memory storage. Magnetoresistance is the ability of a material to change its electric resistance when exposed to an external magnetic field. When the force of a magnetic field is parallel to the current flow, the resistance of the conductor increases and when the magnetic field moves at a 90 degree angle to current flow, the resistance of the conductor decreases (Figure 1).

**MRE's resistivity change by angle between the current and magnetic field.**

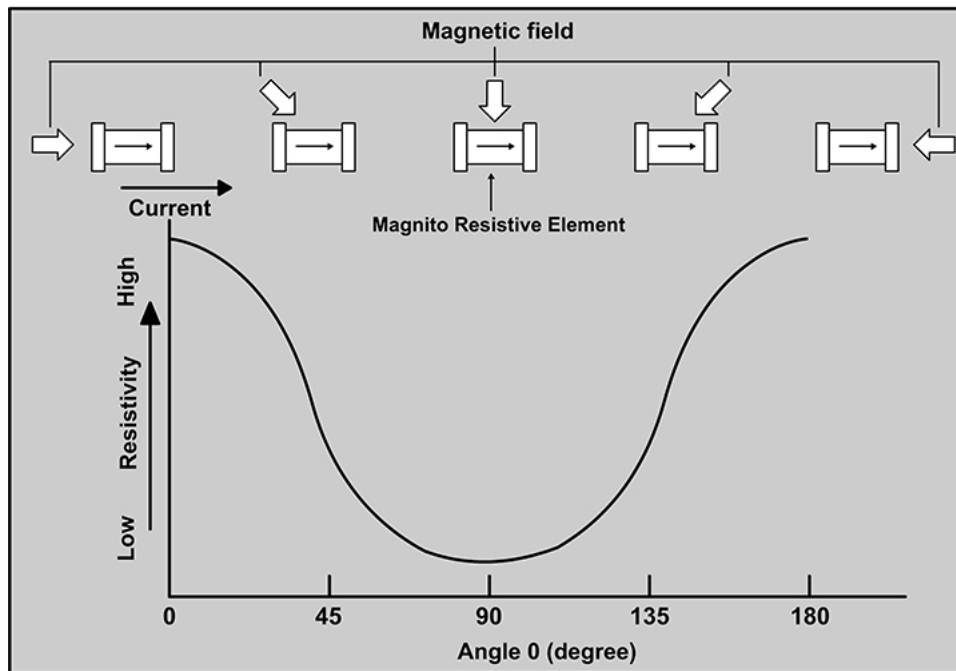


Fig. 1

This effect is referred to as The Anisotropic Magnetoresistance. Most conductors have some degree of Anisotropic Magnetoresistance, the cause of which is based on the Lorentz force. The Lorentz force acts on a moving charge in

the presence of a magnetic field. This force causes the charge carriers, electrons that are carrying the current, to move in curved paths which increases the distance and changes the speed of the carriers across the conductor. This increased distance adds resistance to the current flowing through the conductor. There is also a crowding effect that occurs as a result of the carriers being forced sideways as well as forward. This sideways movement of the carrier crowds the conductor and decreases the effective area of the conductor thus adding resistance to the conductor. The material that is used for the conductor varies depending on the application of the sensor. Ferromagnetic materials are used widely due to their magnetic properties and their ability to work in high operating temperatures. One widely used magnetic material is a nickel-iron known as Permalloys. Permalloys consist of a blend of approximately 80% nickel and 20% iron; slight traces of other magnetic metals can also be used in the alloy. Permalloys electrical resistivity generally varies within about 5% depending, on the strength and the direction of the applied magnetic field. Straight Permalloy material has a resistivity that is non-linear to the relationship of the magnetic field. In order for the magnetic field to produce a linear voltage output, a more sophisticated design is necessary. A non-magnetic material, such as aluminum, is deposited in strips at an angle of 45 degrees to the long axis of the Permalloy. These strips are referred to as barber poles. Since aluminum is more conductive than the Permalloy, the electrical current follows the aluminum strips rotating the current direction by 45 degrees, effectively changing the angle between the magnetic field and the current flow. This in turn produces a linear output in low-intensity magnetic fields. Newer thin film technology uses a combination of layered materials of indium antimonide (InSb) or metallic n-doped indium antimonide (n-InSb) to increase the magnetoresistive ability of the conductor. Thin film electrical resistivity generally ranges from 5% to 20% depending on the combination of layered materials and their orientation. With Permalloy or thin film, the sensor element is made into very thin rectangular strips. The resistivity of the element will be based on the material and the way that the element is constructed, the thickness of the element or the cross-sectional area of the element, the magnetic strength applied to the element, the magnetic angular position of the element, and the distance of the magnetic force from the element. So if a stronger magnet is used, the air gap can be significantly larger, up to 3mm, while still consistently producing accurate high resolution signals. These traits make the Magneto Resistive Element a very good choice to be used in the design of automotive sensors.

The Magneto Resistive Element has been used in the design and construction of all types of sensing devices from pressure sensing and rotational sensing to sensing the earth's magnetic field. In automotive industries, use of MRE is primarily for rotational sensing. When designing a system that will incorporate proximity sensing or non-contact sensing for rotational sensors, there are several methods that can be utilized. Passive systems such as Variable Reluctance (VR) sensors, active systems such as Hall Effect and Magneto Resistive sensors, or optical sensors. The difference between these systems is that in a passive system the sensor produces its own output whereas in semi-active or fully active systems, the electronic control module supplies current to the circuit so the sensor can produce its own output. In the past, Variable Reluctance sensors have been used predominately for sensing rotational angular position and angular speed. However, the VR sensor has many draw backs in the design requirements of modern systems. The main drawback of the VR sensor is it cannot be used to sense slow rotations per minute (RPM). The VR sensor has a very small output at slow RPM and ultimately there is a minimum speed that can be detected.. This is due to the magnetic field movement following the target wheel. If the target is moving slowly, so too is the magnetic field. This field moving across the turns of the windings in the VR sensor determines the output. The faster or quicker the magnetic field movement across the windings the greater the output of the VR sensor. In modern designs the size of this sensor is also a problem. The magnet in the VR sensor will need to be large in order for the sensor to work properly. This is reflected in the size of the sensor (Figure 2).

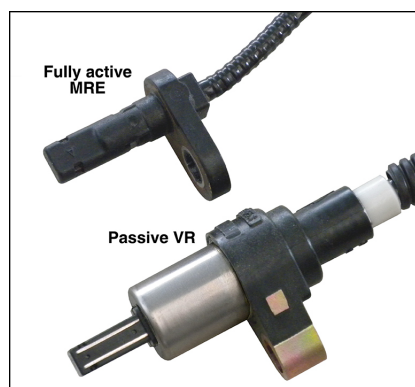


Fig. 2

In active systems, such as Hall-effect or MRE, these sensing devices have an output when stationary so the rotational speed can be tracked to zero RPM. The sensitivity of the active sensor to a magnetic field is substantially greater as well. This means that the active sensors can be packaged in a much smaller device, enabling changes to the overall design and placement of these sensors. The difference between a Hall-element and a magnetoresistive element is that the magnetoresistive element operating in a low magnetic field is 10 times more sensitive than that of the Hall-element. Electromagnetic Interference (EMI) such as voltage spikes and reverse voltage tolerance are also better with the MRE sensor. The operating working temperature of the MRE is much higher than that of that Hall-element. The benefits of MRE over all other types of sensing devices are clear and make this sensor one that you will encounter in your shop more frequently. (Figure 3)

Comparison chart of various rotation sensing systems.

Type	Sensing - type adoption criteria				
	Multi-pulse adaptability	Low rpm detection	Environmental resistivity	Operating temperature range	Cost
Reed switch	poor	good	good	good	good
Photo-coupler	good	excellent	poor	poor	fair
Variable reluctance	fair	poor	excellent	good	fair
Capacitance	good	good	poor	fair	poor
Hall device	fair	excellent	good	fair	fair
MRE	excellent	excellent	excellent	good	fair

Fig. 3

20 pulses per revolution

With the electronic revolution that has swept the automotive industry, electronic control units (ECU) are common place on modern vehicles. These control units collect data that are gathered by electrical sensors in the vehicle. The sensors take readings of physical events and convert these physical proprieties into an electrical signal that can be interpreted by a microprocessor. In the case of sensing rotational angular position and angular velocity, the microprocessor uses software to calculate the change of these signals and compares them to a mapped value ideal for the operational conditions. The microprocessor then commands changes in the controlled function in order to minimize deviation from the ideal. The MRE sensor can be used in many applications where the electronic control system is gathering data based on physical events such as steering shaft rotational position and velocity, wheel rotational velocity (both acceleration and deceleration), transmission shaft rotational position and velocity, crankshaft and camshaft rotational position, and velocity. When the MRE sensor has a second Wheatstone bridge added into the circuit, the rotational direction can be detected. This data can be used by the ECU for things such as, brake application for hill holding, steering shaft rotation for stability control, crankshaft and camshaft reverse rotation for engine auto stop and start. In each one of these sensing criteria, the magnetoresistive element will be designed into a circuit that will be best suited to the data that are gathered for control of the system by the microprocessor.. When sensing wheel speed for anti-lock brakes, traction control, and stability control systems, the MRE can take on a unique circuit configuration. There are several circuits that are in current production, one of which is shown in (Figure 4).

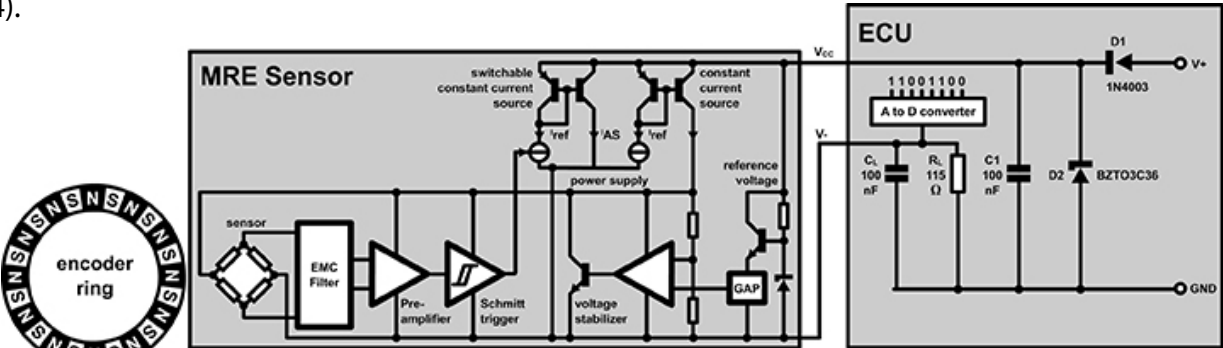


Fig. 4

In this two wire circuit, the MRE sensor is configured to read current. This is accomplished by using a voltage divider circuit that is set up between the sensor and the ECU. The circuit's constant current draw is 7mA which is increased to 14mA when it is switched on. Due to this circuit using current to sense rotation, a voltage stabilizer is needed. The voltage is stabilized by a band gap reference diode that supplies power to the sensor, amplifier, and comparator. The sensor pickup consists of four magnetoresistive elements configured into a Wheatstone bridge. In the Wheatstone bridge, a magnetic field changes the linear voltage output which is then converted to a digital output by a comparator. This digitized comparator output is fed to a Schmitt trigger, which is a digital triggering device to limit noise. As the voltage from the comparator increases, it reaches a turn on threshold or operate point. At this operating point, the Schmitt trigger changes states, which allows a voltage signal to be sent out. The release point (turn off) is set at a lower voltage than the turn on point. This transfer function controls the hysteresis (the turn on point and turn off point) of the output. The purpose of this differential is to eliminate false triggering which can be caused by minor variations from the comparator. The Schmitt trigger is turned on and this output voltage is sent to a switchable current source, which when turned on, allows 7mA of current to flow through the circuit. This switchable 7mA combines with the constant 7mA for a total current flow through the circuit of 14mA. The microprocessor has no way to read current so a resistor is placed inside the ECU. This resistor sets up a voltage divider that allows the voltage to increase to about 700mV as the current increases to about 7mA (Figure 5).

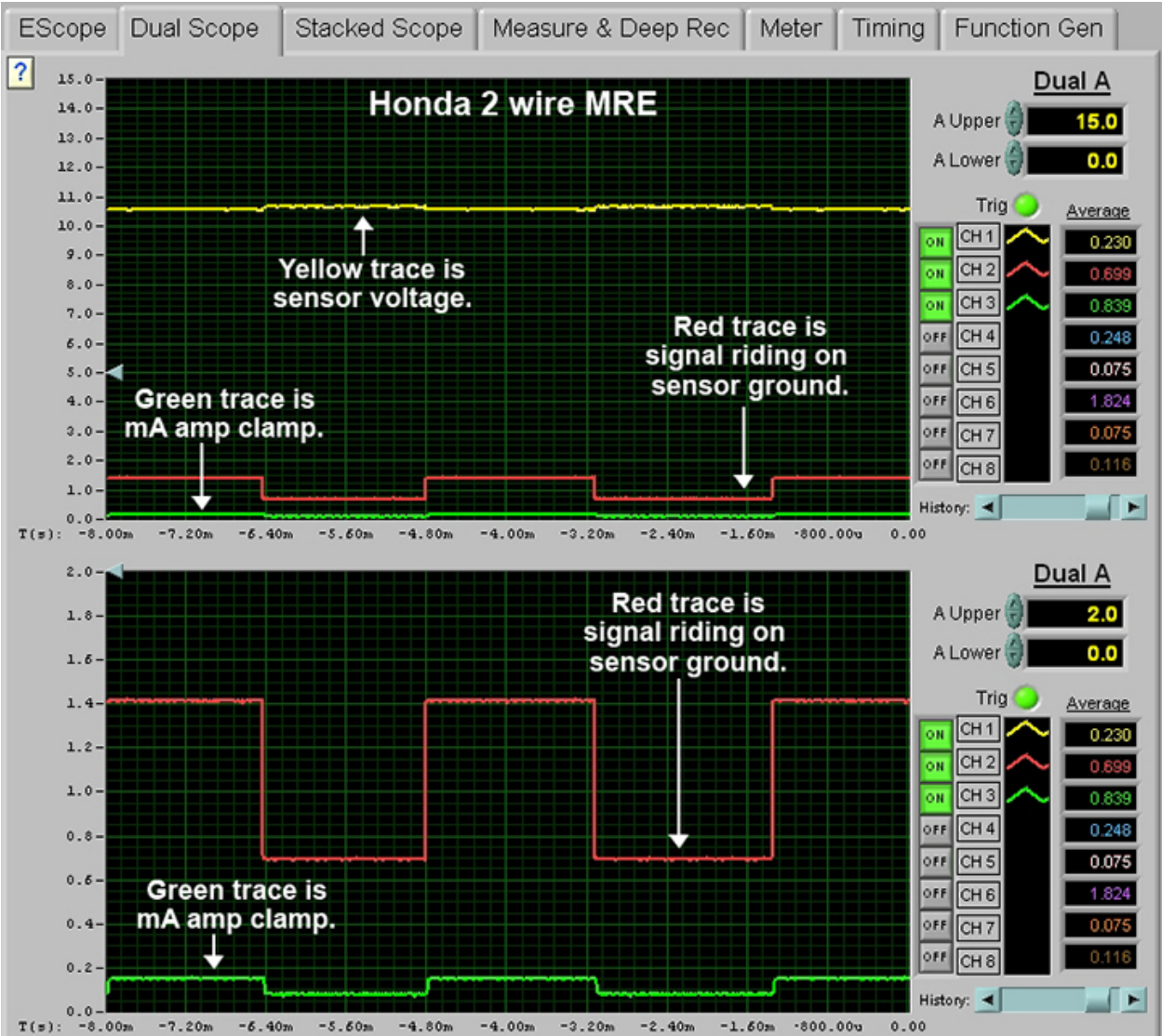


Fig. 5



This configuration is based on the ground side of the circuit. However, this basic circuit that we have discussed can also be incorporated on the power side of the circuit as in (Figure 6). The ECU uses an analog to digital converter to process this voltage change. As the magnetic field changes so does the voltage, thus allowing the ECU to track the wheel speed.



Fig. 6

It is quite possible for the technician to mistake this two wire MRE sensor for a VR sensor. If the technician checks the resistance of the MRE sensor it will show a reading of about 500,000 ohms, whereas a VR sensor will show a reading of about 800 to 1200 ohms, so it would be possible to think the sensor is bad if you do not realize which sensor with which you are working. Another source of confusion when dealing with MRE sensors is the location of the magnet. There are two types of magnets used in the design of the MRE sensor; semi-active and fully-active. In the semi-active style the magnet is located in the MRE sensor. This style MRE uses the conventional target wheel made of a ferrometallic material. As the target teeth or slots pass under the sensor the magnetic field is moved across the magnetoresistive element which changes the voltage output. This sensor's circuit can operate on a two wire current based output, as we have already discussed, or incorporate a third output wire. In this three wire sensor; one of the wires will power the sensor, one of the wires will ground the sensor, and the third wire will produce a conventional square wave signal that can either pull the voltage to ground for the signal or output voltage for the signal. In the fully-active style, the magnet is located externally. The conventional target wheel is replaced by an encoder ring that is produced with north-south magnetic fields that are embedded into an elastomeric ring that is bonded on to a steel base. The encoder ring is smaller than the bearing and is under .200 of an inch in thickness. This encoder ring is pressed onto the wheel bearing that is placed in the hub assembly. When

looking quickly at the wheel bearing, the encoder ring looks like the grease seal on the side of the bearing (Figure 7). This bearing can be installed correctly in the bearing hub with the encoder ring facing the MRE sensor or installed incorrectly with the encoder ring facing away from the MRE sensor.

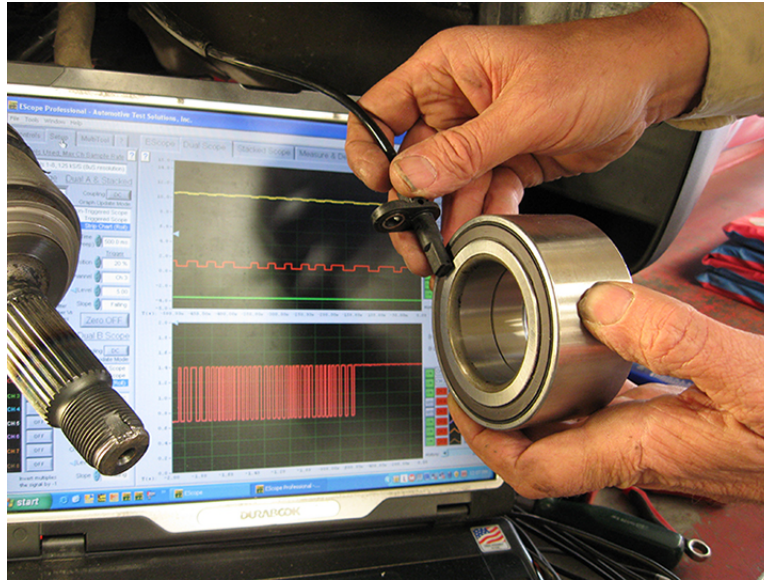


Fig. 7

When the bearing is installed with the encoder ring facing away from the MRE sensor, there will be no signal from the sensor. Therefore, it is critical that the bearing be installed correctly. To be sure which side of the bearing is the encoder, hold the outside of the bearing (the part that presses into the hub) stationary and rotate the inner bearing (part that presses on the axle). The side that moves with the inner bearing is the encoder ring and must face the MRE sensor.

When trouble shooting the MRE circuit, an oscilloscope is an essential tool as can be seen in (Figures 5-6) where the voltage level that is changing is very small and can be on the power side or the ground side. In some systems, the waveform may not be a square wave at all, but be indicated by a narrow pulse. To test the two wire semi-active MRE sensor, spin the shaft that is attached to the trigger wheel while watching the scope. If the sensor has no output signal and the power and ground voltage levels are correct, remove the sensor and move a steel object very close to the tip of the sensor. At this time if there is a signal output, the problem is with the trigger wheel and if there is no signal output the problem is in the sensor. To test a fully active two wire MRE sensor, spin the shaft that is attached to the trigger wheel while watching the scope. If the sensor has no signal output and the power and ground voltage levels are correct, remove the sensor and move a small magnet very close to the tip of the sensor (Figure 8). At this time, if there is a signal output the problem is with the encoder ring, and if there is no signal output, the problem is in the sensor.

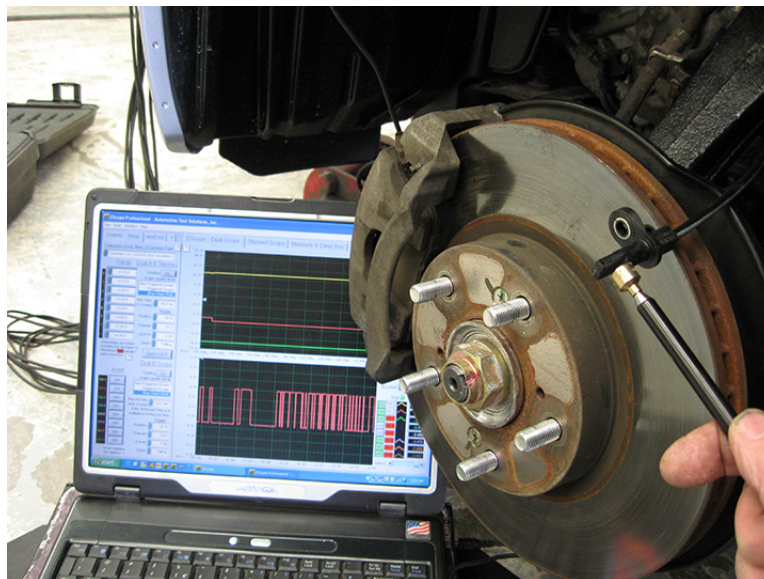


Fig. 8

The magnet that is used to test the circuit must be small because if a powerful magnet is used it can flip the magnetization of the sensor in the opposite direction. This will change the characteristics of the MRE sensor. Some sensors incorporate a bias magnet to help stabilize the sensors magnetic characteristic so this does not happen. These sensors react to very small changes in magnetic fields, so a small magnet will work fine. When the power, ground and signal voltage levels are incorrect, check for resistance in the circuit by testing the circuit for voltage drops. When there is no voltage output to the sensor from the ECU, one may think that the circuit is shorted or has a high current draw and the ECU is protecting the circuit by shutting down the voltage supply. This can be true; however, an open circuit can give the same results. When the ignition switch is turned on, the ECU completes a circuit test by watching the voltage of the signal. If this voltage is incorrect, the supply voltage is shut off, so it is important to watch the voltage during the self test in these situations. Now that you have looked through the looking glass and understand the mysterious world of the inner workings of the magneto resistive element, you too can come back from Wonderland.