

Magneto-resistive Sensors

Principles of Operation and Applications

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This application note provides an overview of the Zetex range of Magneto-resistive sensors.

The layout of a typical magneto-resistive chip (parent device 174B) is shown in Figure 1, and is for example the chip used in the ZMY20 sensor. Thin film stripes are a characteristic feature of a magneto-resistive chip. These stripes are made by photolithography and consist of Permalloy ($\text{Ni}_{81}\text{Fe}_{19}$), a magnetic material evaporated on an oxidised silicon wafer. The electrical resistivity of the stripes is changed by a magnetic field H_y due to the magneto-resistive effect. The field H_y causes a rotation of

the magnetisation in the stripe. This is shown in Figure 2. The resistivity R of a permalloy stripe depends on the angle between the directions of electric current (I) and magnetisation (M):

$$R = R_0 + \Delta R_0 \cos^2 \alpha$$

where ΔR_0 describes the strength of the magneto-resistive effect.

The maximum relative change of resistivity $\Delta R_0/R$ is approximately 2 to 3% for permalloy. The relationship between an external field H_y and angle α is

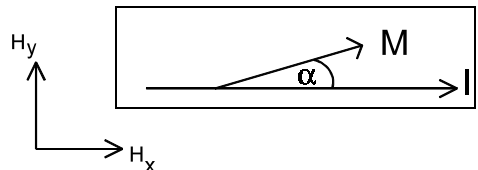


Figure 2

The magneto-resistive effect depends on the angle between the direction of electric current (I) and magnetisation (M). A rotation of the magnetisation in a permalloy stripe takes place when a magnetic field in the y -direction is applied. Without an external field the magnetisation is along the x -direction due to the shape of the stripe.

Figure 1
Magneto-resistive Magnetic Field Sensor,
(Parent Device 174B).

determined by the geometrical dimensions of the stripe and the magnetic anisotropy of permalloy. This is taken into account by introducing a field H_0 that represents the demagnetising and anisotropic field. One obtains

$$\sin^2 \alpha = \frac{H_y^2}{H_0^2} \quad \text{for } H \leq H_0$$

$$\sin^2 \alpha = 1 \quad \text{for } H \geq H_0$$

The characteristic of a magnetoresistive stripe as a field sensor is:

$$R = R_0 + \Delta R_0 \left(1 - \frac{H_y^2}{H_0^2} \right) \quad \text{for } H \leq H_0$$

A linear characteristic of the magnetoresistive sensor is required to measure a small magnetic field. The linear behaviour of the magnetoresistive sensor is achieved by using a "Barber pole" geometry. The stripes in Figure 1 are covered with aluminium bars having an inclination of 45° to the stripe axis. Aluminum has a low resistivity compared to permalloy. Therefore the Barber poles cause a change of the current direction. The angle between current and magnetisation is shifted by 45° as shown in Figure 3. The relationship between resistance and magnetic field is now

$$R = R_0 + \frac{\Delta R_0}{2} \pm \Delta R_0 \left(\frac{H_y}{H_0} \right) \sqrt{1 - \frac{H_y^2}{H_0^2}}$$

A linear characteristic of the sensor is given around $H_y^2/H_0^2 = 0$. The sign in this equation is determined by the inclination of the "Barber poles" ($\pm 45^\circ$)

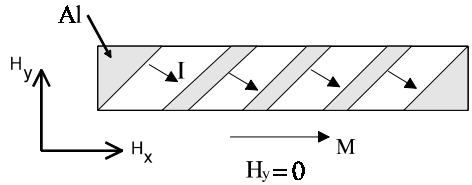


Figure 3
Covering the stripe with "Barber poles" consisting of aluminium changes the direction of the current. This does not influence the direction of magnetisation.

to the stripe axis. The characteristic of a sensor with and without Barber poles is presented in Figure 4.

The stripes of the magnetoresistive chip are arranged as a meandering pattern. They form a Wheatstone bridge which is shown schematically in Figure 5. The applied voltage is V_b . Each half bridge consists of two resistors with different "Barber pole" orientations. The voltage between the resistors of a half bridge changes upon application of a magnetic field.

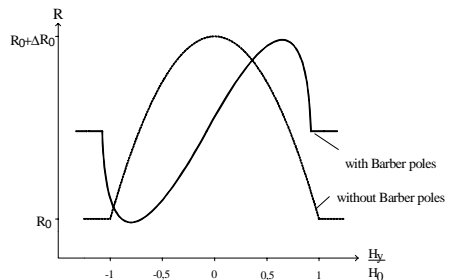


Figure 4
Characteristics of magnetoresistive sensors. The Barber pole structure enables a linear behaviour of the sensor for a small magnetic field.

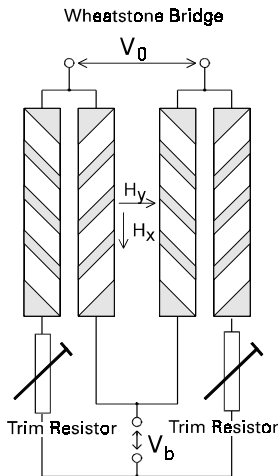


Figure 5
Wheatstone bridge of a magnetoresistive sensor with "Barber pole" structure. The bridge is balanced by laser trimming.

The resistance of one resistor increases, whilst the other resistor has a lower resistance due to the differing field characteristic. Adding a second half bridge with an opposite arrangement of "Barber poles" provides a Wheatstone bridge. The voltage difference V_0 is the output signal of the sensor. Each half bridge is trimmed to $V_b/2$ with an additional resistor in order to get an output voltage close to zero when no external field is applied. The trimming structures of the resistors in Figure 1 mark off the meander stripes on the left and right side of the chips.

Operating conditions and parameters

The shape of the stripe and the anisotropy of permalloy only define an axis along the x-direction for the magnetisation without external field H_y .

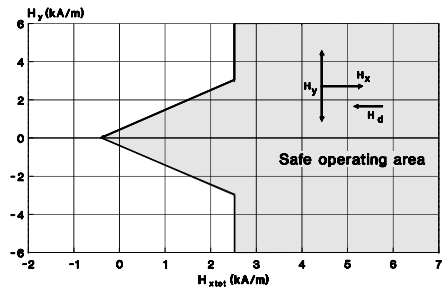


Figure 6
Safe operating area of ZMY20/ZM220.
 $H_{xtot} = H_x + H_d$; $T_{amb} = 25^\circ C$
 H_d = disturbing field.

This means that in this state the stripe can have areas with a different direction of magnetisation (magnetic domains) and the sensor does not work in a stable way. A safe operation of the sensor is achieved by applying an auxiliary field H_x . This field defines the direction of the magnetisation. The range of H_y for safe sensor operation is determined by the strength of the auxiliary field. The safe operating area (SOA) of the sensor is demonstrated in Figure 6.

The field $H_{xtot} = H_y + H_d$ determines the allowed field values for H_y , where H_d is an external disturbing field in the x-direction.

There is no limitation for H_y in the case of $H_{xtot} \geq 2.6$ kA/m (ZMY20/ZM220). A small permanent magnet is sufficient to create the auxiliary field. The magnet can be glued on the sensor package (ZMZ 20/30 or ZMY 20/30). Another option is the ZMY20M which provides a very compact sensor including an integrated magnet, and is available in a surface mount package.

The operating datasheet parameters of the Wheatstone bridge are referred to an input voltage $V_b = 1V$, due to the linear relationship between input and output voltage in this region.

The **sensitivity** S [mV/V/kA/m] of the magnetoresistive sensor is defined as the slope of the output voltage versus

external field for $-1 \text{ kA/m} \leq H_y \leq 1 \text{ kA/m}$. This parameter depends on the geometry of the permalloy meander and the auxiliary field. The latter is demonstrated in Figure 7 for $H_x = 3 \text{ kA/m}$ and $H_x = 6 \text{ kA/m}$. Note the small operating area in the case of $H_y = 0 \text{ kA/m}$. A high sensitivity of the sensor leads to a small operating area for H_y .

Further details and complete Magnetoresistive Product information is provided in the Appropriate Technical Handbook: please see Technical Publication section.

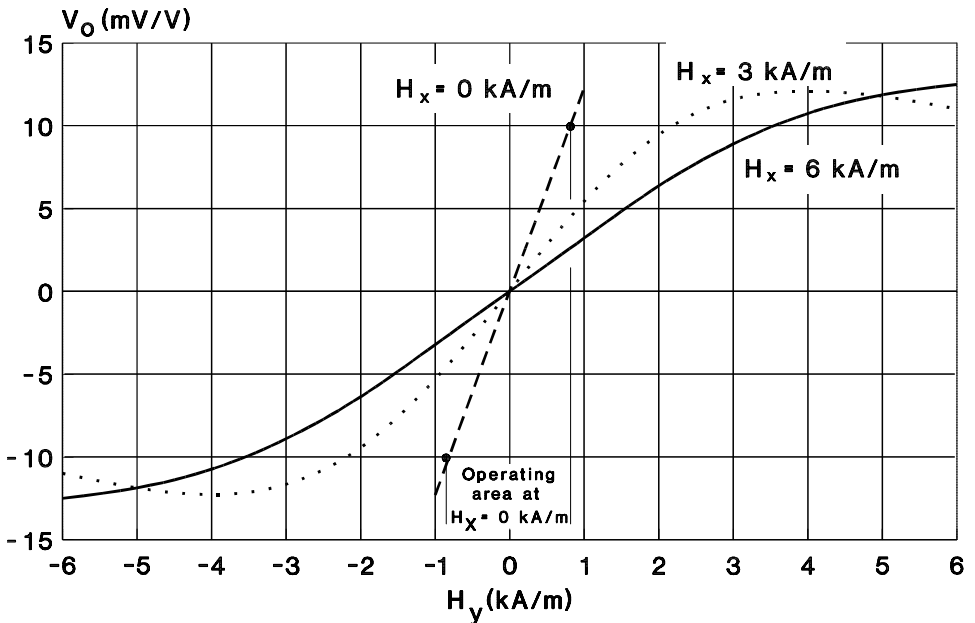


Figure 7

Sensor output characteristic of ZMY20/ZMZ20. The sensitivity of the sensor can be controlled by applying an auxiliary field H_x . This auxiliary field is necessary for sensor operation in a large field range. $V_0 = f(H_y)$; H_x -parameter; $V_B = \text{const}$; $T_{\text{amb}} = 25^\circ\text{C}$.

The Wheatstone bridge is balanced without the application of an external field ($H_y \leq 0.1$ kA/m). In this case the output voltage of the sensor is close to zero at room temperature. The deviation of the output voltage from zero is called the **offset voltage** V_{off}/V_b [mV/V]. The offset is caused by small geometric variations of the bridge which occur during the photolithographic process. The offset of the bridge is adjusted by laser trimming. The voltage output of each half bridge is $V_b/2$.

The **bridge resistance** R_{br} [%/K] of the magnetoresistive sensor depends linearly on temperature. The **temperature coefficient of bridge resistance** TCR_{br} [%/K] is positive. This is typical for metals. The **temperature coefficient of sensitivity** TCS [%/K] of the sensor is negative for $V_B = \text{const}$ (TCS_V), because the strength of the magnetoresistive effect becomes smaller with increasing temperature. In the case of $I_B = \text{const}$ (TCS_I), when the sensor is powered by a constant current supply, the temperature dependence of the sensitivity is reduced due to the linear relationship between input and output voltage. A higher bridge resistance caused by a rise in temperature leads to an increased applied voltage, partly compensating the change of sensitivity.

The Wheatstone bridge cannot fully compensate the temperature dependence of the resistors. The **temperature coefficient of offset voltage** TCV_{off} [$\mu\text{V}/\text{V}/\text{K}$] is due to local changes of resistivity in the permalloy thin film and photolithographic variations. This characteristic of the magnetoresistive sensor limits the

measurement of small magnetic fields in a wide temperature range, especially in the case of static fields. Two sensors can be selected having a comparable temperature coefficient. The offset drift is partly eliminated by using the difference of the output voltages of both sensors. Another elegant way to avoid offset drift is to invert the direction of the auxiliary field and thus inverting the output voltage of the sensor. This can be done by small coils providing an auxiliary field that can change its direction.

The **hysteresis of output voltage** V_{offH}/V_b [$\mu\text{V}/\text{V}$] describes the accuracy of the magnetoresistive sensor. The magnetisation of the permalloy stripe is not completely homogenous. There are small areas of the meander, especially at the corners of the stripes, where the magnetisation is pinned and does not correctly follow the external field. The hysteresis is measured in a magnetic field loop, where H_y goes from -3 kA/m to 3 kA/m and back to 0 kA/m ($H_x = 3$ kA/m). V_{offH}/V_b denotes the shift of the offset voltage caused by this loop.

The **maximum range of output voltage** $\Delta V_0/V_b$ [mV/V] is defined as the difference of output voltage for $\alpha = 0^\circ$ and $\alpha = 90^\circ$, where α denotes the angle between current and magnetisation of the magnetoresistive stripe. This means that $\Delta V_0/V_b$ represents the strength of the magnetoresistive effect. This parameter decreases with temperature and determines the sensitivity of the sensor.

(An example of a typical Magnetoresistive sensor datasheet, is partially reproduced in Appendix B.)

Applications

[Please refer to appendix A which summarises some graphic examples of applications for magnetoresistive sensors].

Figure 8 shows a ZMC20 current sensor being used as a basis for an overcurrent trip switch used to protect power IGBTs within a motor driver system. The circuit reacts within $3\mu\text{s}$ to prevent latch-up related failure under transient/pulse conditions, and was built within a module measuring $35 \times 20 \times 25\text{mm}$. An external $10\text{k}\Omega$ preset is required for offset adjustment. Supply voltage is $+5\text{V} \pm 10\%$ at 10mA ; output is via an open collector transistor rated at 1A , 20V ; operating temperature range is 0 to 80°C .

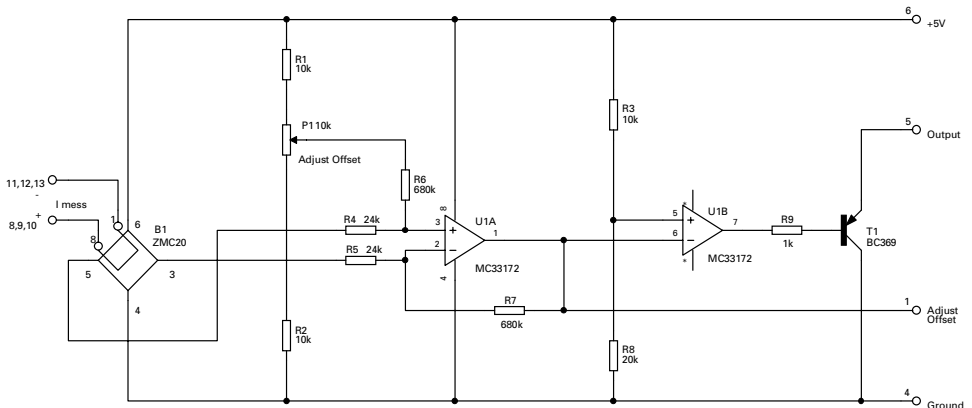


Figure 8
Overcurrent Switch using the ZMC20, for Protection of Power IGBTs.

Figure 9 provides a method for revolution measurement by reacting to a modulated magnetic field due to a rotating cog. The circuit gives a signal whose frequency is proportional to the rotational velocity of the cog, and a high level output for no rotation.

Figure 10 shows an application circuit for three-dimensional magnetic field observation. When the unit is enabled, it calibrates itself to the existing magnetic field of the earth, and then generates a warning signal if it is moved. The system employs three ZMY20 sensors (one for each dimension) and a CMOS EPROM microcontroller with an A/D converter. Similar circuits have been designed for automotive immobiliser/alarm systems that monitor the position of the vehicle by sensing the magnetic field of a movable permanent magnet. This magnet is necessary to shield the sensor

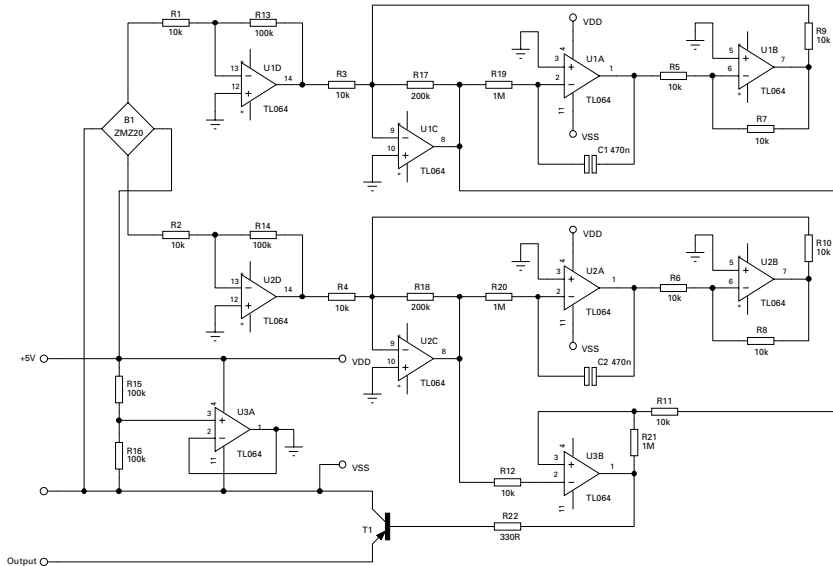
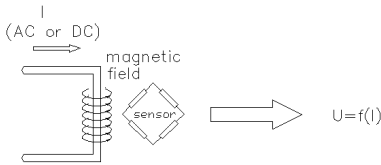


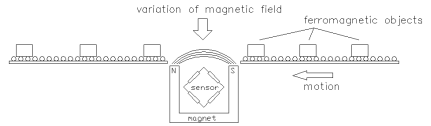
Figure 9
Sensor for Revolution Measurement.

from disturbing fields (generated by supply lines, car alternators etc.) Supporting software for these systems is available on request.

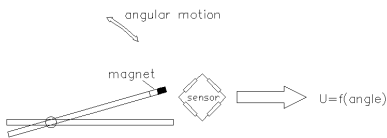
Appendix A Magnetoresistive sensor Basic Function/Application Examples.



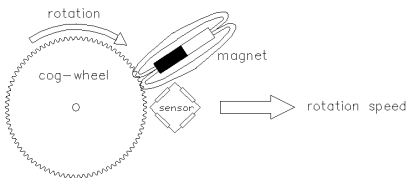
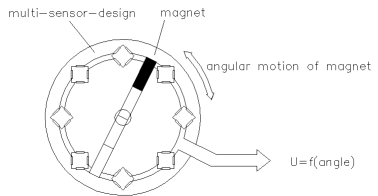
Measurement of Current (AC or DC)



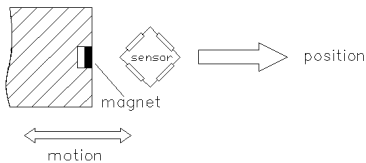
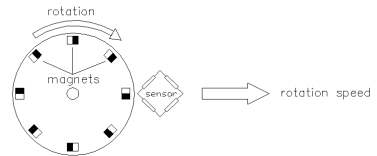
Detection of Ferromagnetic Objects



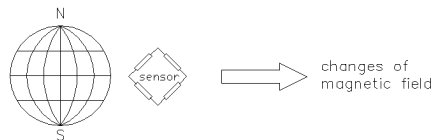
Measurement of Angular Position



Measurement of Rotation Speed



Position Sensor



Measurement of the Earth's Magnetic Field

Appendix B Partial Characterisation for ZMY20/30, ZMZ20/30 Magnetostrictive Sensors.

ELECTRICAL CHARACTERISTICS (at $T_{amb} = 25^{\circ}\text{C}$ and $H_x = 3 \text{ kA/m}$ unless otherwise stated)

Parameter	Symbol	Min.	Typ.	Max.	Unit	Test conditions
Bridge resistance ZMY20/ZMZ20 ZMY30/ZMZ30	R_{br}	1.2 2.0	1.7 3.0	2.2 4.0	$\text{k}\Omega$	
Output voltage range ZMY20/ZMZ20 ZMY30/ZMZ30	V_O/V_B	16 12	18 16	22 20	mV/V	
Open circuit sensitivity ZMY20/ZMZ20 ZMY30/ZMZ30	S	3.2 2.0	4.0 3.0	4.8 4.0	$(\text{mV/V})/(\text{kA/m})$	no disturbing field H_d allowed
Hysteresis of output voltage	V_{OH}/V_B	-	-	50	$\mu\text{V/V}$	$H_y \leq 2 \text{ kA/m}$
Offset voltage	V_{off}/V_B	-1.0	-	+1.0	mV/V	
Operating frequency	f_{max}	0	-	1	MHz	
Temperature coefficient of offset voltage	TCV_{off}	-3	-	+3	$(\mu\text{V/V})/\text{K}$	$T_{amb} = -25\dots+125^{\circ}\text{C}$
Temperature coefficient of bridge resistance	TCR_{br}	-	0.3	-	$\%/K$	$T_{amb} = -25\dots+125^{\circ}\text{C}$
Temperature coefficient of open circuit sensitivity $V_B = 5 \text{ V}$	TCS_V	-	-0.4	-	$\%/K$	$T_{amb} = -25\dots+125^{\circ}\text{C}$
Temperature coefficient of open circuit sensitivity $I_B = 3 \text{ mA}$	TCS_I	-	-0.1	-	$\%/K$	$T_{amb} = -25\dots+125^{\circ}\text{C}$