TRIAXIS MAGNETORESISTIVE (MR) SENSOR USING PERMALLOY PLATE OF DISTORTING MAGNETIC FIELD

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ABSTRACT

This paper proposes a triaxis magnetoresistive (MR) sensor of detecting not only x- and y-axes magnetic field intensities but also z-axis one, where all fields are based on the sensor coordinate system. Namely, not only azimuth but also angle of elevation of the sensor can be detected from triaxis components of geomagnetic field.

The principle is as follows: a permalloy (FeNi) plate is stood aside MR element. The plate distorts magnetic field and generates x- (or y-) component from originally z-directional field. So, the resistance of MR element changes in proportional to z-axis field intensity, provided that other axes intensities are kept constant. By contriving a processing circuit, three axes components can be separately detected.

INTRODUCTION

Recently, a navigation system of directing a user to an objective point has been installed in a mobile device such as cell phone, personal digital assistant (PDA) device, and so on. This system requires a function of detecting position and orientation of a user. While a global positioning system (GPS) is effective for detecting the position, a magnetic azimuth sensor is usable for detecting the orientation of the user: therefore, miniaturizing a magnetic sensor to the extent that it could be installed in a mobile device is desired. Magnetic azimuth sensors have been reported based on several measurement principles as follows: 1) magnetoresistive (MR) method: detecting MR resistance change due to magnetic field change [1, 2], 2) fluxgate method: using two wire coils around a soft magnetic alloy core, one is driving magnetic field and another is detecting induced current change due to magnetic field change [3], 3) magneto-impedance (MI) method: detecting change in impedance of a magnetic material with applying high-frequency current [4]. These sensors, however, are relatively large because they need three-dimensional turn coils. An azimuth sensor composed of MR elements and a planer coil, which can be fabricated by surface micromachining technique, is recently reported for the use of a mobile device [5]. Our study basically refers to this sensor and adds a triaxis function to this sensor.

Permalloy (FeNi) has been historically used for MR elements in an azimuth sensor. Permalloy resistor changes its resistance with respect to applied magnetic field, as shown in Fig. 1. To convert resistance change to voltage, Wheatstone bridge is employed for one axis measurement, as shown in Fig. 2 (note that two bridges for x- and y-directions are included in this figure). To obtain large rate of resistance change ΔR/R, bias magnetic field is applied using a planar coil, as shown in Fig. 3(a). Then, the inclination of ΔR/R per applied magnetic field change becomes steeper. Note that the bias direction for R1, R3 and that for R2, R4 are opposite, so R1, R3 decrease and R2, R4 increase, as the applied field increases, as shown in Fig. 3(b). Output voltage is expressed as (ΔR/R)E, where E is the source voltage.

The sensor shown in Fig. 2 can detect magnetic azimuth because it has two bridges for detecting magnetic fields along x- and y-axes. However, it is impossible to detect both horizontal azimuth and
angle of elevation at the same time. To detect also the angle of elevation, one more sensor should be set orthogonally to the azimuth sensor, as shown in Fig 4(a). The total sensor height is, however, increased, causing the packaging problem in mobile electronic divides. Therefore, a sensor which can detect all the three axes fields with reasonable thinness is proposed in this study, as shown in Fig. 4(b). In this figure, a permalloy (FeNi) plate is stood aside MR element. Here, magnetic field around the plate is once converged inside the plate and then released outward, generating the x-directional field on the sensor surface from originally z-directional magnetic field, as shown in the enlarged cross section in Fig 4(b).

FEM SIMULATION OF MAGNETIC FIELD

The magnetic field around a permalloy plate is simulated by using finite element method (FEM). Figures 5(a)–(c) are simulation results when magnetic field is applied in z-direction. In Fig. 5(a), the direction of magnetic field at each point is expressed as an arrow. This figure shows that the z-directional magnetic field is certainly converged in the permalloy plate and inclined to x-direction. Figure 5(b) shows the distribution of x-directional component of the magnetic flux density on x-axis. This graph shows that approximately 1/3 of the applied z-directional magnetic flux is changed to x-directional component and it rapidly decreases with distance from origin point shown in Fig. 5(a). Figure 5(c) shows that the averaged x-directional component
of magnetic flux density passing on the MR element is proportional to the applied z-directional flux density.

**DETECTING CIRCUIT**

We propose a processing circuit, which can separately detect the x-, y-, and z-components of applied magnetic field, as shown in Fig. 6. The permalloy plates are set adjoining $R_1$, $R_4$ (not adjoining $R_2$, $R_3$) on the sensor surface. Assume that $R \gg \Delta R$, where $R$ is the base resistance for $R_1$~$R_4$. Then, the potential difference between midpoints of each Wheatstone bridge is expressed as follows:

\[ V_x = \phi_d - \phi_b = -\frac{E}{2R} \left( 2\Delta R_x + \Delta R_z \right), \]  
\[ V_y = \phi_b - \phi_d = -\frac{E}{2R} \left( 2\Delta R_y + \Delta R_z \right), \]  
\[ V_z = \phi_d + \phi_b + \phi_c + \phi_d = E\left( 2 + \frac{\Delta R_z}{R} \right). \]  

According to Eqs. (1)-(3), $\Delta R_x$, $\Delta R_y$, and $\Delta R_z$ are separately obtained by knowing $V_x$, $V_y$, and $V_z$.

**FABRICATION AND CHARACTERIZATION**

The fabrication process of the proposed sensor is shown in Fig. 7. Here, MR element made of permalloy is annealed for improving its MR property. Annealing gas of $\text{H}_2$ and annealing temperature of 400°C are searched and defined by preliminary experiments. Figure 8 shows photograph of the MR sensor before and after fabricating planar coil. Permalloy plates of distorting magnetic field were bonded by adhesive resin. In future, these plates should be fabricated monolithically by using electroplating method.

The fabricated sensor is set on a magnetic field generator shown in Fig. 9. Then, the resistance of single MR element is measured by changing the applied magnetic field from -200 to 200 G along each axis of the sensor. The definition of axes is shown in Fig. 10. Note that this range is huge, considering that the geomagnetic flux density is approximately 0.4 G. The purpose of this measurement is to check the basic ability of permalloy plate to distort the magnetic field. The measurement results are shown in Fig. 11. By using a permalloy plate, the resistance changes with respect to applied flux density in z-direction by maximally 1.0%, while it does not change without the plate.

Next, the fabricated sensor is set on a rotational table, as shown in Fig. 12. In this preliminarily experiment, only one permalloy plate was set adjoining $R_1$, and the sensor was rotated around only one axis. An experiment of full characterization, in which a sensor
A bearing four permalloy plates (see Fig. 6) is rotated taking arbitrary orientation, is currently under way. The output voltage of Wheatstone bridge is measured by changing the rotational angle around each axis of the sensor at every 30 degree in geomagnetic field. The results are shown in Fig. 13. By using a permalloy plate, the normalized bridge output sinusoidally changes with respect to the rotational angle around $x$-axis. The amplitude of change is larger compared to that without the plate. The fabricated sensor using a permalloy plate is proved to surely detect triaxis magnetic field, even it is subtle geomagnetic one.

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REFERENCES