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Design and Implementation of Three axis Fluxgate Magnetometer and its Applications

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Abstract—A scientific instrument which measures the magnetic field strength and its direction is known as Magnetometer. In this article a three axis Fluxgate Magnetometer is constructed by using simple ring core and simple drive circuits instead of specialized components like Hall Effect sensors. This type of Fluxgate magnetometers is working on the principle of magnetic flux linking a coil depends on the orientation of the coil with respect to the earth's magnetic field lines. Here the three single axis fluxgate magnetometers are designed and placed perpendicular to each other on a board. The circuit is designed to produce 100 KHz frequency and to measure the Magnetic field in the range up to 7 Tesla. The sensitivity is tested through an external electromagnet. The readings are obtained in LAB-VIEW platform and the three-axis data is displayed.

Keywords: FluxGateMagnetometer, Magneticfield, Earth Magnetic field, FluxgateSensor, Magnet

I. INTRODUCTION

The Magnetometer is based on the idea that the Magnetic flux moving through a coil depends on the orientation of the coil with respect to the earth's magnetic field lines. This circuit is illustrated and intended to provide a starting point of Magnetic field Measurement and are therefore not fully optimized. Here a Three axis Fluxgate Magnetometer is designed by using Ring core which is made by Ferrite material for the higher permeability. The enameled copper wire is used to wound around the core of Drive and Detector. The Magnetic field is created by using circle magnets and Ferrite material is wound with the copper wire and excited by dc supply and different dc output voltages are induced various orientations of the Magnets. Flux gate magnetometers are very popular device preferred to measure AC and DC Field Vectors [6].

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Fluxgates are used to achieve low cost and low power consumption for the measurement [3]. A multi-core planar fluxgate can be designed for measurement of low magnetic measurements [5]. Since fluxgate magnetometer are low cost they can be co integrated along with circuitry on a die to be more power efficient than the available state of the art [4]. Calibration procedure of a fluxgate sensor can be achieved with a simple neural network [1]. A sensitive industrial grade magnetometer is very expensive and cannot be affordable for small research purposes [8]. It is capable of a resolving component of 10,000th of the earth magnetic field [9].

II. EXISTING SYSTEMS

Fluxgates are widely used sensors for magnetic field and current measurement [2]. Magnetometers can be used to obtain ground-based north [7]. At present the resolution component of fluxgate sensor are comparable with the superconducting quantum interference devices (SQUIDs) [10]. There are a variety of parameters to consider when

measuring magnetic fields. Figure 1 shows that How the Magnetic field lines are formed around the earth towards the North to South Pole. Figure 2 provides a conceptual indication of the lines of magnetic force around a bar magnet. The apparent direction of the magnetic field is depicted by arrows. The compass needle will tend to point away from the North Pole and the magnet's South Pole („S"),

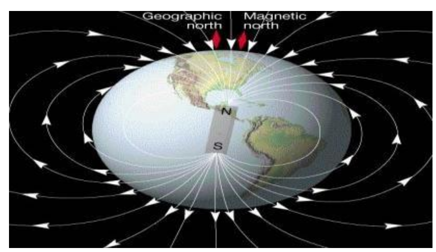

Fig. 1. Magnetic field lines around the Earth

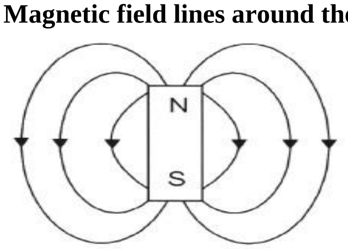

Fig. 2. Conceptual illustration of the magnetic lines of force around a permanent bar magnet.

The density of flux lines (analogous to contours on a map) or the amount of magnetism per unit area is effectively measured by magnetic flux density. Tesla (T) or webber per meter square are the common units of magnetic flux density.

The magnetic field strength will be quoted whenever necessary and is usually measured in A / m (amps / m). To concentrate on the magnetic field to be measured, all the ring core flux gates are used by highly permeable core., The magnetically saturated core will be alternatively used in opposing direction along any suitable axis. The sine or square waveform is used to drive on excitation coil normally [9]. To produce high flux due to its high permeability, the core will be channeled to prior saturation of the ambient field. The vacuum causes the flux to collapse when the core's permeability falls away from the point of saturation. The cycle will be repeated to the saturation and the ambient field alternatively Despite the magnetization reversals due to the excitation, the excitation reverses the magnetization, then the flux will be operated in the ambient field through the same direction. The flux changes will be picked up by the Detector Coil (sensor coil), which revolves around the core. The flux collapse or recovery will be indicated by the sign of induced voltage. The action of the core gating flux inside and outside the detector coil clearly indicates the name Fluxgate.

III. PROPOSED SYSTEM

To form a continuous magnetic circuit, the twin rods are connected top and bottom. It is really logical extension of ring core. [6]. They typically spread the toroidal exciting winding evenly around the ring core, the equivalent of the average winding outside and the orthogonal, walker rod core design. Since the core is isotropic, it defines the direction of the axis's feedback / sensing winding sensor. To measure the direction and strength of magnetic field three ring cores are designed and used. It is also common to use large special external feedback coils with improved field gradients; In fact, a complete three-axis system with two rings can be made in this way. With this type of sensor, the central region along all axes is completely canceled by the reaction.

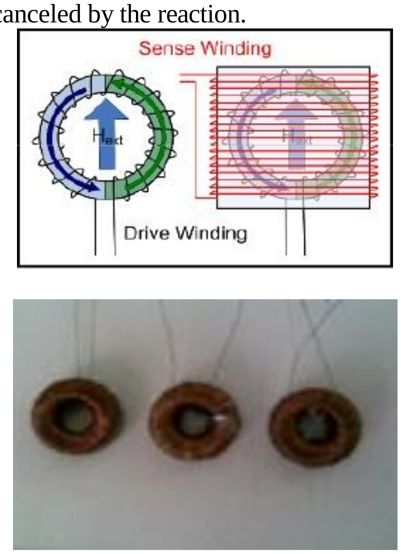

Fig. 3. Ring core Fluxgate

The ringcore can be made up of simple ferrite or tape wound core intended for more mundane electronic applications, Designs Similar to figure 3 is used on modern satellite missions for mapping magnetosphere and deep space applications. They probably have lower noise and lower power requirements than rod core devices

Table-I: Design parameters of Ring core Fluxgate

S. No	Parameters	Dimensions
01.	OD (Output Diameter)	16mm
02.	ID (Input Diameter)	12mm
03.	Thickness	7mm
04.	Copper wire	2mm
05.	Drive coil	22SWG
06.	Detector (or) sense coil	26SWG
07.	No of turns in drive coil	60turns
08.	No of turns in sense (or)Detector coil	300turns

IV. WORKING PRINCIPLE

Figure 4 shows the circuit diagram of the detector. The integrated circuit, IC 1 (a CMOS hex schmitt inverter) performs many functions within the circuit. The ICla-IClc drive coil produces short duration pulse of low frequency for L1a. ICla makes a simple square wave oscillator. The output of the oscillator is fed to the input of the ICLB via diode D2, which together with the ICLC stabilizes a retrograde mono. The output is the same as the output of ICla, but with a much shorter duty cycle. The IClc field effect transistor switches on TR1 during the period that the output is in a logic high state that L1a is driving. D5 helps mimic the switching transitors produced by Lla. The LLB is the detector coil. The height of the pulse produced by llb is partially determined by any external magnetic field present. The output from the LLB is fed to the operational amplifier IC2 through the coupling capacitor C10. Resistors R13 and R14 provide a partial-supply reference at the input of the op-amp. The diode D7 and D8 limit the amplitude of the input signal if it varies above or below the supply train.The pulse is produced by wave-det ect or buffered by 1 C2 and appears on pin 6 of the device. There are other unwanted patients besides the required pulse. These are gated out by TR2 which switches the signal to ground except for the period when the required pulse is present. The drive signal for TR2 is produced by ICld - Icle.

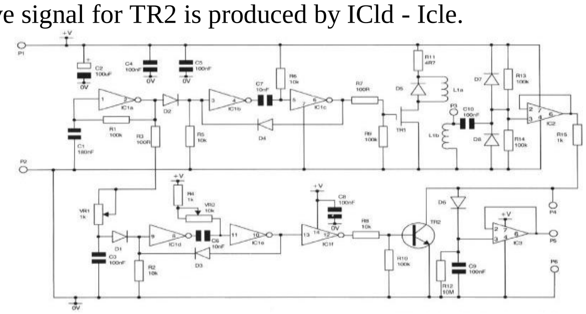

Fig. 4. Sensitive Detector Circuit Diagram

There are two preset variable resistors. The VRI together with C3 determines the point at which the mono stable formed by the ICld and ICle triggers. The pulse length produced by the VR2 detector-mines mono stable. IClf inverts the pulse output from ICle so that it makes perfect sense to drive TR2. The waveform produced at terminal P4 consists of a buffer output from the detector coil with a pulse produced by TR2 switching. This signal provides a discharge path to capacitor C9 with R12 through diode D6. The resulting DC voltage is buffered by the opera-tyle amplifier IC3 and is made available at terminal P5. The output voltage at P5 is the proper-tunnel for the magnetic flux density of any external mag- netic field to which the detector coil is exposed. The voltage is definitely offset due to half the supply reference voltage for IC2, but for relative readings this is usually not a problem.

Here the magnetic field is created by using Ferrite rod by the way of giving DC excitation or by using bar magnet or Circle magnets. The magnetic field is created to simulate in orbit conditions in three different axes.

Fig. 5. The coil which is used to create the magnetic field

Table-II: Design parameters of Magnetic Field

S. No	Parameters	Dimensions
01.	Total length	80mm
02.	Diameter	8mm
03.	No of turns	500
04.	Excitation	+8VDC

V. HARDWARE RESULTS

Fig. 6. Top view of the Three axis Fluxgate Magnetometer

Fig. 7. Three axis Fluxgate Magnetometer with its output

In this Hardware setup, three single axis fluxgate magnetometers are designed and placed at right angles to each other in same board to measure the magnetic field strength in three directions (Roll(X), Pitch(Y) and Yaw (Z)). Power supply of 9 V is given and the sensed output is taken by multi-channel oscilloscope for the different orientations of magnetic field. A Pro-circle is used to calculate accurately calibrate the Magnetic field measurement in every degree moment. The Magnets are placed on pro-circle in horizontal and vertical direction. To simulate in Orbit conditions readings are taken from 0 to 360 deg in all the three axes. The readings are tabulated in table 3 and table 4.

Table-III: Magnets Placed in Horizontal Direction

S. No	Angle(deg)	X axis(V)	Y axis(V)	Z axis(V)
Without Magnet		3.60	3.544	5.507
With Magnet		3.60	3.554	4.409
01.	0	3.60	3.554	4.409
02.	30	3.60	3.547	4.409
03.	60	3.61	3.539	4.436
04.	90	3.61	3.534	4.893
05.	120	3.60	3.538	5.620
06	150	3.60	3.542	5.786
07.	180	3.61	3.545	5.836
08.	210	3.61	3.547	5.843
09.	240	3.61	3.548	5.844
10.	270	3.60	3.551	5.776
11.	300	3.60	3.554	5.596
12.	330	3.60	3.557	4.801
13.	360	3.60	3.555	4.240

Table-IV: Magnets Placed in Vertical Direction

S.No	Angle(deg)	X axis(V)	Y axis(V)	Z axis(V)
Without Magnet		5.516	3.544	3.61
With Magnet		5.846	3.544	3.60
01.	0	5.743	3.547	3.60
02.	30	5.696	3.550	3.60
03.	60	5.775	3.546	3.60
04.	90	5.737	3.547	3.61
05.	120	5.672	3.547	3.61
06	150	5.583	3.547	3.61
07.	180	5.303	3.544	3.61
08.	210	5.390	3.543	3.61
09.	240	5.580	3.540	3.61
10.	270	5.699	3.538	3.61
11.	300	5.841	3.541	3.60
12.	330	5.901	3.546	3.60
13.	360	5.881	3.544	3.60

VI. RESULT ANALYSIS

HORIZONTAL AXIS

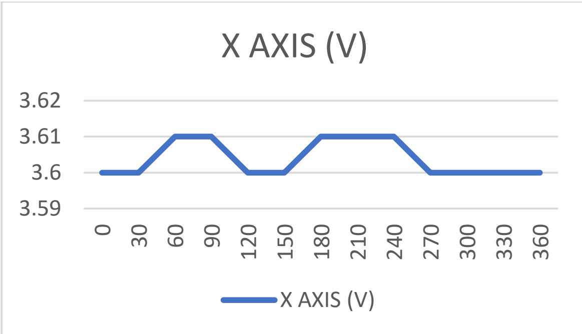

Fig. 8. Horizontal X axis

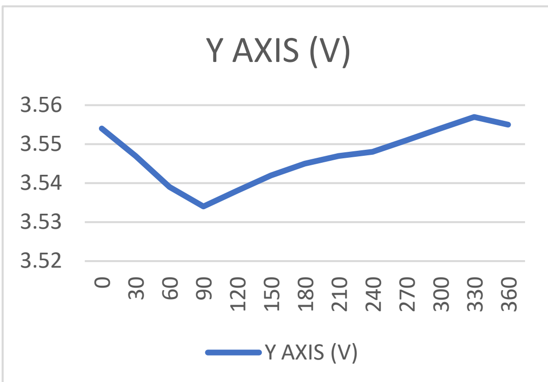

Fig. 9. Horizontal Y axis

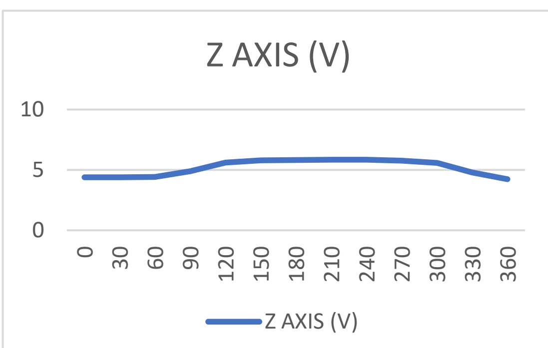

Fig. 10. Horizontal Z axis

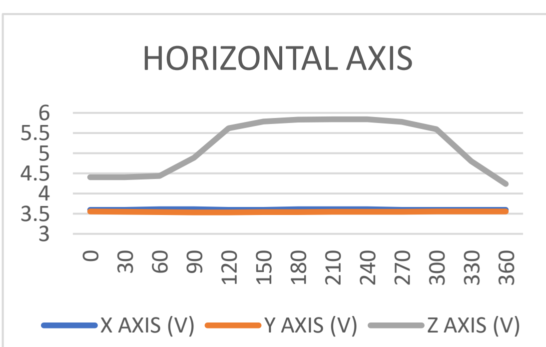

Fig. 11. Consolidated results of xyz in Horizontal direction

VERTICAL AXIS

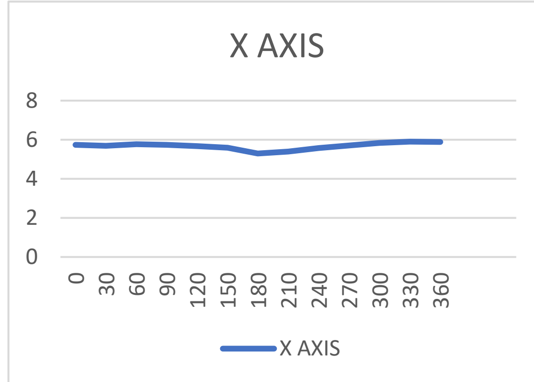

Fig. 12. Vertical X axis

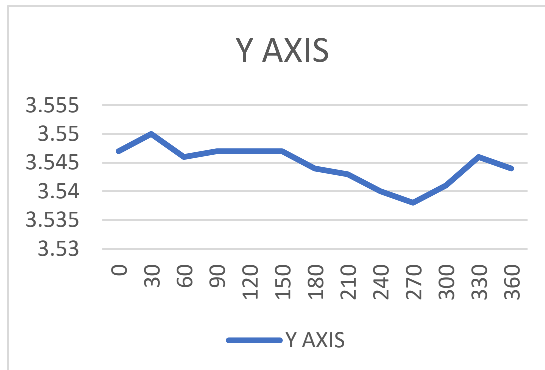

Fig. 13. Vertical Y axis

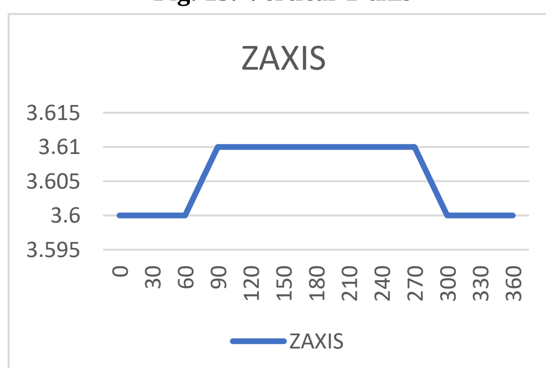

Fig. 14. Vertical Z axis

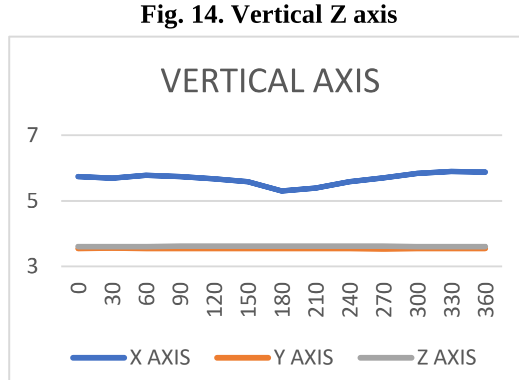

Fig. 15. Consolidated results of xyz in Vertical direction

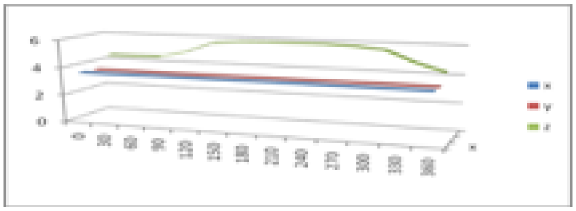

Fig. 16. Horizontal Direction

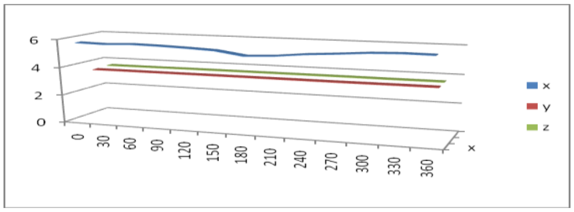

Fig. 17. Vertical Direction

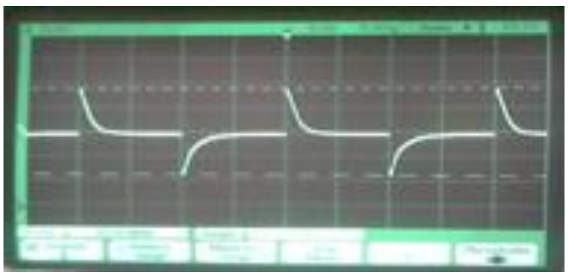

Fig. 18. Excitation Current

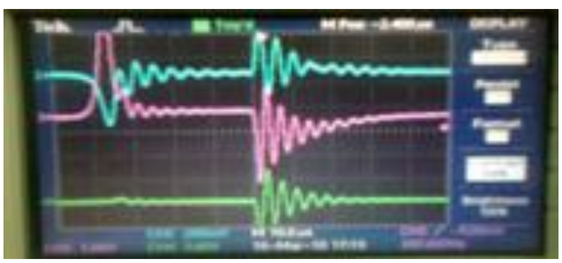

Fig. 19. Detector Coil Output Between P3 and P6

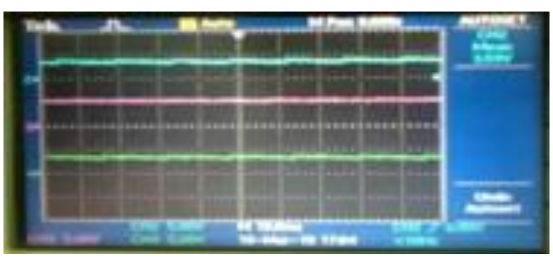

Fig. 20. Final DC output voltage between P5 and P6 Fig 9 Detector coil output for 30 KHz Square wave applied

VII. VALIDATION AND JUSTIFICATION

In this paper we have verified that high precision device can be achieved using low cost components. These Devices are used in space exploration and high-end applications, but expensive and complex to design and fabricate. This detector is a general-purpose experimental circuit and serves to illustrate how a sensitive magnetometer can be constructed form standard parts without the need for specialized components such as hall-effect devices or magneto resistors. Where improved performance is required the unit may be modified in a variety of ways; for example, to improve sensitivity linearity and stability. If a smoother DC level is required at the output of the circuit this can be achieved using an active peak detector to detect the height of the pulses produced at P4. It should be pointed out that when changing the duty cycle of the pulse driving coil, attention should be paid to current consumption and the power dissipation in the output stage of the circuit. It may be necessary to increase the power rating of R11 and fit a heat sink to TR1.

A Magnetometer using this type of arrangement can be useful when making long term measurements of the earth's magnetic field for research purpose and in navigational applications. For monitoring applications over, long periods the output voltage from the Magnetometer may be used to drive a chart recorder or data logger via the appropriate interface circuitry. It may be useful to convert the output voltage to frequency or to serial or parallel data. This is relatively simple to arrange using off the shelf voltage to frequency or analogue to digital converter ICs.

Fig. 21. HMC2003- Three axis Magnetic field Sensor

But nowadays Magnetic field Sensors are available for single axis and three-axis in the form of single chip IC named as HMC 1001, HMC 1003 and HMC 2003 etc. It is shown in figure 10. By using this IC also easy to construct a Magnetometer and is used to measure the magnetic field strength and its orientation.

VIII. FUTURE SCOPE

The area of possible developments are on the side for increased precision and accuracy of the magnetometer. This can be paired up with a Microcontroller for the application of drones and high-end devices.

IX. CONCLUSION

Hence A three axis Fluxgate Magnetometer is designed by using simple components and the magnetic field strength is measured for the different orientations of the Magnetic field or Magnets. Here for the orientations of the Magnets and Magnetic field it gives three different outputs in the three directions (Roll(X), Pitch(Y) and Yaw (Z)). In Spacecraft applications it will determine the orientation of the Spacecraft and also it is used for navigational application to determine the direction. It is also used to calibrate the Magnetic Compass as well as Unmanned autonomous vehicles.

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