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Development of A Low-Cost Microcontroller-Based Magnetic Fluxmeter

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Abstract
To measure the magnetic flux of magnetic substances, a low-cost magnetic fluxmeter based on a microcontroller was developed. The meter is made up of the HMC 1021 magnetic flux sensor, a 12 V, 60000mAH lithium battery, a pre-amplifier, a buffer, a set/reset circuit, a memory card shield, and a liquid crystal display unit. The sensors for the fluxmeter were designed and connected to the Arduino Mega 2560 using the Arduino platform C-program to ensure a correct connection with all devices. When compared to a conventional magnetic fluxmeter, performance evaluation of the created magnetic fluxmeter displayed a positive response (480 Model fluxmeter). As seen for the pure nickel magnet magnetic flux, which drops as the distance increases, the experimental result demonstrates that the magnetic flux is inversely proportional to the distance from the current-carrying conductor. The proximity distance was changed at intervals of 0-124 mm, and it is clear that the magnetic flux is rapidly decreasing; the field of a 120 mm long object is insignificant at 100 mm. As a result, the developed device can be utilized as a low-cost magnetic fluxmeter powered by a microcontroller with a digital readout.
Keywords: *Low-cost, microcontroller, magnetic, fluxmeter, measuring instrument*

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I. INTRODUCTION

Electromagnetic pollution produced by electrical devices is increasingly recognised as a new sort of pollution, equally as harmful to society as air and water pollution. The significance of electromagnetic interference has increased due to semiconductor devices working in a contaminated electromagnetic environment. To protect devices from danger from electromagnetic interference, they must frequently be insulated(Dolnka*et al*., 2017).

Semiconductors with artificially layered magnetic structures play a very important role in science and technology: space research, military applications (power electronics, actuators, current transformers, computation modules, and assemblies), security systems, high-density magnetic memory (nonvolatile memory devices, heads for magnetic data storage), non-destructive testing (magnetic tunnel junctions sensors), navigation (passive and wireless magnetic sensors), geology, and medicine (magnetic biosensors) (Białostocka*et al*., 2022). The use of a strong DC magnetic field to interfere with the proper operation of sensitive elements of an EM is one of the common forms of nondestructive testing(Illia *et al.*, 2022).

Strong magnetic fields' intense experimental conditions offer novel chances for basic scientific study, and the associated experimental tool has gained recognition as a "national weapon" for uncovering scientific secrets in the disciplines of science and technology (Ku and Shao, 2018). A strong magnetic field helped the "fractional quantum Hall effect," which received the Nobel Prize in Physics towards the end of the 20th century.

As a result of the rapid development of galvanomagnetic devices over the past few decades, a range of solid-state magnetic fluxmeters has been developed that provides information regarding the magnetic field in analogue form. However, the current trend in sensor technology necessitates the employment of silicon switching devices for measuring magnetic field strength using these devices' well-known features that are magnetic field dependant.Modern sensor technology advancements combined with microprocessor technology in recent years have allowed for the creation of instruments that can precisely measure and regulate physical quantities like speed, pressure, and temperature.For scientists and technicians working in the fields of materials science, biophysics, and magnetic levitation, precise knowledge of the magnetic field is just as crucial as other physical parameters.

Over the past few decades, magnetoresistive sensor-based semiconductor fluxmeter research and development have been crucial. The advantages of adopting integrated embedded chips, microprocessors, and microcontrollers are provided by swift advances in science and technology. In current industrial operations, including those involving vehicles, aerospace, robotics, electronics, defence applications, mobile communications, rail transportation, and medical applications, the use of microcontrollers is rising quickly (Wael*et al*., 2019). Both the manufacturer and the user can identify and operate a component more effectively with the aid of the measurement of the magnetic flux of semiconductor substrates.

A magnetic field is used to construct nanoscale semiconductor devices on a substrate or implant them into silicon-integrated circuits. With this technique, nanodevices are positioned in patterned depressions on the surface of an integrated circuit wafer using a magnetic field. The wafer is then further treated to turn the nanostructures into devices that are integrated with the underlying circuitry once the recesses have been filled with nanostructures(Sudhakar*et al*., 2004).

The magnetic storing of data on a technological surface is another example of how a flexible anisotropic magneto-resistive (AMR) sensor may be used. A read/write head was invented to gain a technique of storing crucial product information intrinsically on a component, and it was inspired by traditional hard drive magnetic storage technology (Lisa *et al*., 2015).

When a magnetic field is tilted, the flux moves throughout the environment, creating output changes in the field's magnitude, direction, or both. It is necessary to conduct compensation for the magnetic sensor's motion and tilt when a stable base is not feasible, such as in any mounting device subject to motion.

Conducting the scientific study in a strong magnetic field setting requires reliable measurement of strong magnetic fields. To obtain a stable magnetic field measurement, Wang, (2019) used the method of magnetic resonance. By reversing the magnetic field size, Wang *et al.* (2020) observed the capacitance change caused by the magnetic field generated Lorentz force to drive the flat plate regularly, with the measurement range reaching 0.05-1.50 T.

Liu, (2015) developed a national standard for superconducting strong magnetic fields and measured magnetic induction by following the path of the proton gyromagnetic ratio, a physical constant. Additionally, they achieved the measurement of magnetic induction intensity by tracing the proton gyromagnetic ratio's physical constant. However, this approach needs heavy water probes operating in strong magnetic fields with high magnetic field homogeneity.

This study makes use of a tilt-compensated magnetic sensor that can measure the strength of the magnetic flux in the area. After applying finite impulse response digital filtering, impulse-removing median filtering, tilt compensation, and execution time optimization algorithms, the system's capacity to correct for tilt in magnetic field readings is examined.

By creating and calibrating a fluxmeter with optimal sensitivity, this research aims to achieve the requisite minimum detectable magnetic field flux density of 10^{-9} Gauss.

The semiconductor magnetic flux meter is not repairable when it malfunctions due to its high cost and highly specialised nature, as was already mentioned. Therefore, in the current economic climate, it is necessary to create an instrument with a digital readout capability that is straightforward, affordable, sensitive, and easily serviceable for a long time.

II. MATERIALS AND METHODS

The developed magnetic fluxmeter consists of a sensing unit, analogue-to-digital converter, and microcontroller with an intelligent display unit as shown in the block diagram in figure 1. The developed magnetic fluxmeter is sensed by the magnetic sensor and a differential voltage output is produced which is proportional to the measured magnetic flux.The output of Op-amp is fed to a buffer which serves as a link between a non-inverting amplifier and ADC (Widlar, 1969). Unwanted high-frequency noise was removed by an analogue low-pass filter and digitalized voltage is read and processed by the microcontroller. The flux is finally displayed on a suitable digital display which is connected to the microcontroller.

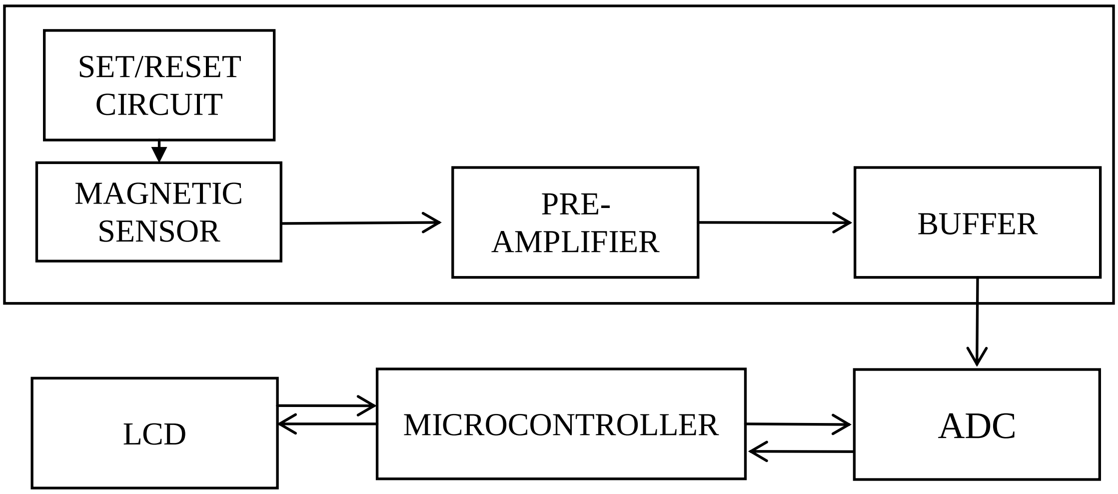

Figure 1: Block Diagram of Magnetic Fluxmeter

SET/RESET STRAP GENERATOR

The purpose of the Set/Reset (S/R) strap is to restore the MR sensor to its high sensitivity state for measuring magnetic fields. This is done by pulsing a large current through the S/R strap. The Set/Reset (S/R) strap looks like a resistance between the SR+ and SR- pins. Once the sensor is set (or reset), low noise and high sensitivity field measurements can occur. The term "set" refers to either a set or reset current. When MR sensors are exposed to a magnetic disturbing field, the sensor elements are broken up into randomly oriented magnetic domains (Figure 2a) which leads to sensitivity degrading. A current pulse (set) with a peak current above the minimum current in spec through the Set/Reset strap will generate a strong magnetic field that realigns the magnetic domains in one direction (Figure 2b). This will ensure high sensitivity and repeatable reading. A negative pulse (Reset)will rotate the magnetic domain orientation in the opposite direction (Figure 2c), and change the polarity of the sensor outputs. The state of these magnetic domains can retain for years as long as there is no magnetic disturbing field present.

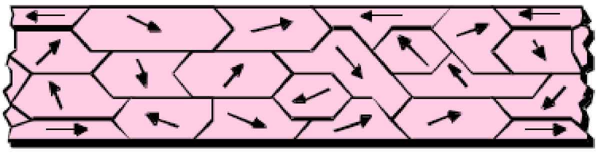

Figure 2a: Random Domain Orientations

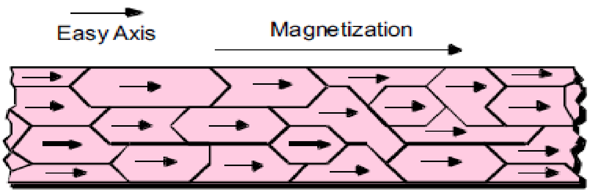

Figure 2b: After a Set Pulse

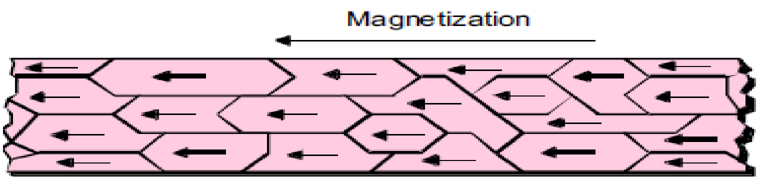

Figure 2c: After a Reset Pulse

The on-chip S/R should be pulsed with a current to realign, or "flip", the magnetic domains in the sensor. This pulse can be as short as two microseconds and on average consumes less than 1 mA dc when pulsing continuously. The duty cycle can be selected for a 2 µ-sec pulse every 50 msec, orlonger, to conserve power. The only requirement is that each pulse only drives in one direction. That is, if a +3.5 amp pulse is used to "set" the sensor, the pulse decay should not drop below zero current. Any undershoot of the current pulse will tend to "un-set" the sensor and the sensitivity willnot be optimum. Using the S/R strap, many effects can be eliminated or reduced that include: temperature drift, non-linearity errors, cross-axis effects, and loss of signal output due to the presence of high magnetic fields.

MAGNETIC SENSOR

The Honeywell HMC1021 Anisotropic Magneto-Resistive (AMR) sensors are straightforward resistive Wheatstone bridges that simply need a supply voltage to sense magnetic fields. The sensors convert any incident magnetic field in the directions of the sensitive axis to a differential voltage output when power is applied to the bridges.The sensor contains two on-chip magnetically connected straps, the offset strap, and the set/reset strap, in addition to the bridge circuitry. These straps replace the requirement for external coils to be placed around the sensors and are used for incident field modification and magnetic domain alignment. The nickel-iron (Permalloy) thinfilm used to make the magnetoresistive sensors is coated on a silicon wafer and structured as a resistive strip element. A change in the resistive elements of the bridge results in a commensurate change in voltage across the bridge outputs when there is a magnetic field present.These resistive components are arranged so that they share a sensitive axis (depicted by arrows on the pinouts), which will result in a rise in voltage as magnetic fields move in the sensitive direction. Additional sensor bridges positioned in orthogonal directions enable precise measurement of any field direction because the output only depends on the one-dimensional axis and its magnitude (the principle of anisotropy). Applications like magnetometry and compassing are possible because of the integration of sensor bridges in two and three orthogonal axes. The magneto-resistive components are shown in Figure 3 for illustration purposes.

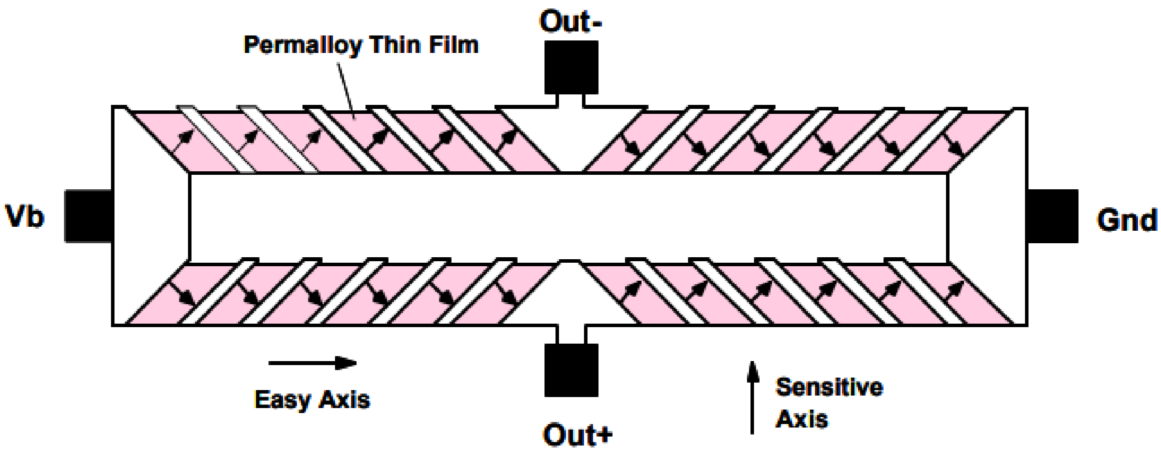

Figure 3: Magneto-Resistive Wheatstone Bridge Elements

PRE-AMPLIFICATION AND BUFFER

The pre-amplifier used is a differential amplifier as shown in Figure 4 in which the signal maintains polarity from input to the output and buffer form between the link pre-amp and ADC. The output voltage of the amplifier is given as

$$V_0 = \frac{R_f}{R_1}(V_y - V_x) \quad (1)$$

The magnetoresistivesensor (HMC 1021)is used which has a sensitivity of about 5μV/nT at 25^0C. The amplification required to produce 61.3 μV at room temperature is 13, then R_f=12.5kΩ and R_1= 1KΩ

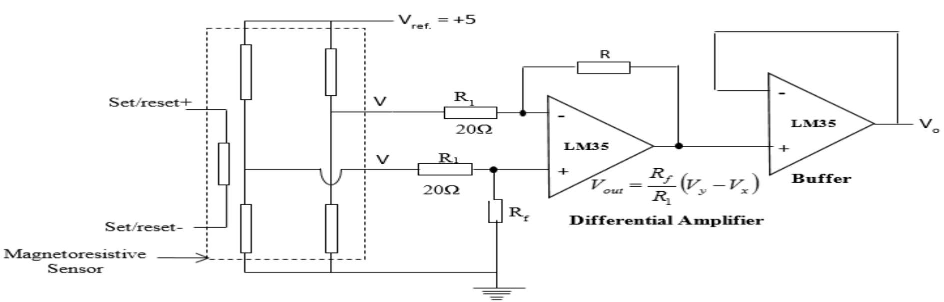

Figure 4:Pre-amplifier in Non-inverting Amplifier mode and Buffer Amplifier

MICROCONTROLLER UNIT

The selected Microcontroller for the research is the Arduino UNO. The Arduino UNO is based on the ATmega328, a low-power CMOS 8-bit microcontroller. The ATmega328 is designed to optimize power consumption versus processing speed. As shown in Figure 5, the Arduino UNO consists of 14 digital I/O pins (including six pins that can be used as pulse width modulation (PWM) outputs), six analogue inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, In-circuit serial programming (ICSP) header, and a reset button. Additionally, it can be powered through USB or with an AC-to-DC adapter or battery. Unlike preceding boards, the UNO uses Atmega16U2 programmed as a USB-to-serial. The Arduino can be described as the hub of the magnetic levitation device and will be responsible for controlling the power input of the electromagnet, retrieving data from the device's sensor, and returning the retrieved data to be plotted and displayed on an LCD.

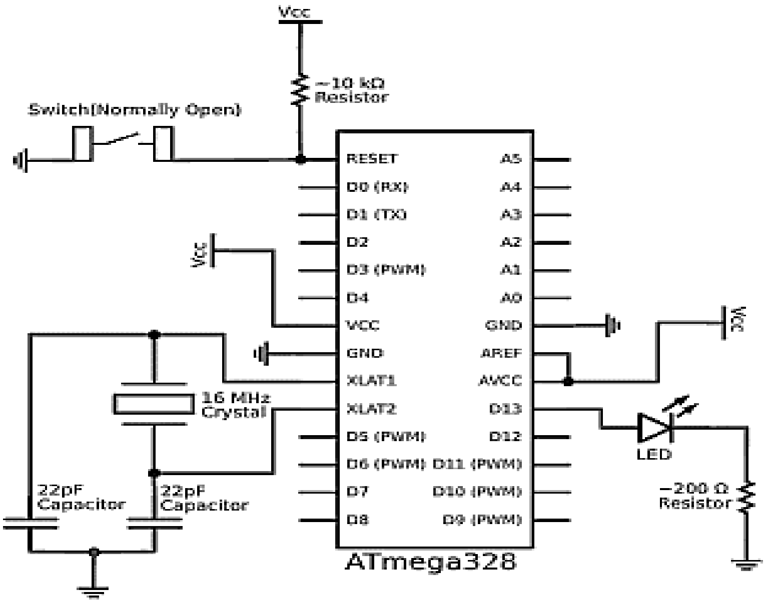

Figure 5: Implementing Circuit of ATMEGA328

CIRCUIT DESCRIPTION

The magnetic field initially forces the AMR sensor to change its resistance, which is transduced into a differential voltage signal. Then the voltage signal is amplified and the offset voltage is removed. Finally, the analogue voltage signals are converted to digital data by the analogue-to-digital converter (ADC). The offset voltage comes from the cross-axis field contribution called the "cross-axis effect;" another offset voltage comes from an unbalanced Wheatstone bridge of the AMR sensor under a zero magnetic field circumstance called a "bridge offset." A combination of other offsets originating from the signal amplifier offset control, and ADC is called a "circuit offset."

The offset voltage will seriously degrade the ADC's dynamic range after being amplified, so we must cancel it in two ways. The payload processor can determine how much offset control voltage is to be generated to cancel the dominant part of offset voltage and immediately optimize the dynamic range of the signal. Any residual offset voltage is corrected by using a special mechanism called "Set/Reset".The magnetizations of the sensor are defined as "Set-state" and "Reset-state" when the sensor has been magnetized along and against the easy-axis direction, respectively. Because a reversal of the magnetizing field polarity will not affect the offset voltages resulting from bridge offset, cross-axis effect, and circuit offset in the sensor output, we therefore can change the magnetizing of sensors between the Set-state and Reset-state can be changed alternatively and the difference of the measurements obtained in both can be found states to eliminate any residual offset.The sensors were linked to Arduino mega 2560 using Arduino platform C-program for proper communication with all devices.The proportional analogue output signal from the magnetic sensor transmits a proportional analogue signal tothe pre-amplifier circuit will be transmitted to the buffer. The buffer transmits a proportional analogue signal tothe analogue-to-digital converter which will transmit the equivalent signal output to the microcontroller to transform the proportional output signals into processed data. The processed data will be displayed on the Liquid Crystal Display and stored on the memory Secure Data Card.

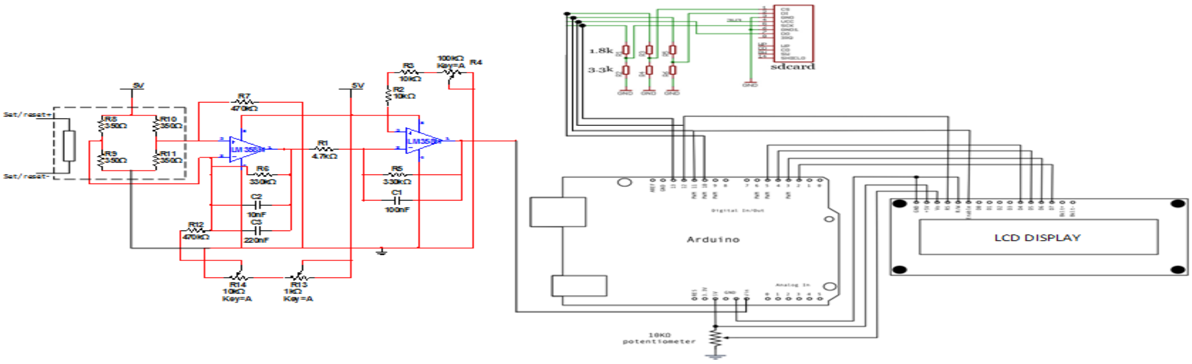

Figure 6: Complete circuit diagram of a digital magnetic Fluxmeter

TESTING OF THE DIGITAL MAGNETIC FLUXMETER

To make sure the research met the necessary criteria, the parts were momentarily mounted on a breadboard. The final transfer of components onto the Vero board, soldering the component, and linking the active circuit while precisely adhering to the schematic diagram are all included in the building process. The digital magnetic fluxmeter research is detailed below. A digital multimeter set to check for short circuit connections and continuity along copper connections had all errors found and fixed as observed in (Figure 7).

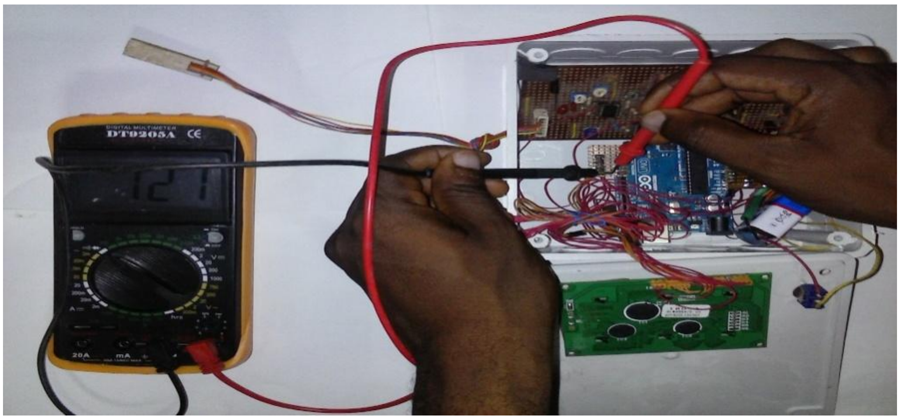

Figure 7: Test for continuity of copper wires connections

CALIBRATION OF THE DEVELOPED DIGITAL MAGNETIC FLUXMETER

A typical magnetic fluxmeter was used to calibrate the instrument.

Both the developed fluxmeter and the model 480 fluxmeter's sensors were placed close to the magnetic source at the same distance and in the same direction. Both were carefully positioned in the field, which is the right location and oriented to respond to the maximum reading without alignment errors. The constructed system was tweaked using potentiometer R_2 until the values displayed by the two systems were identical. The closeness distance was adjusted every 0 to 124 mm. A specimen of a pure nickel magnet was utilised to measure the magnetic flux in millimetres using a 480 model Fluxmeter and a built fluxmeter. The results are displayed in Table 1. The outcome of flux measurement using the newly built fluxmeter is shown in Figure 8. The field of a 120 mm long object is minimal already at a distance of 100 mm, demonstrating a very rapid drop in the magnetic flux. With good accuracy, the B-vector field is parallel to the probe. It is possible to draw a magnetic-vector field at a reasonable scale by selecting a group of points around the end of a rod magnet. The measurements from the constructed device and the 480 Model fluxmeter were compared, and the correlation coefficient between the two magnetic fluxmeters' readings was close to unity, indicating good agreement with the 480 Model fluxmeter.The calibration curve for the instrument can be obtained by plotting the difference in magnetic flux generated and the standard magnetic flux meter

Table 1: The readings of the Magnetic Fluxmeter

X (mm)	The magnetic flux of Constructed fluxmeter B (μT)	The magnetic flux of 480 Model fluxmeter B (μT)
0	68.21	68.00
5	44.02	44.50
10	37.05	35.00
15	19.21	18.50
20	14.00	14.00
25	10.23	10.00
30	08.44	08.50
35	06.16	06.50
40	05.45	05.00
45	04.25	04.21
50	03.25	03.23
55	03.02	03.03
60	02.36	02.30
65	02.19	02.11
70	02.12	02.10
75	01.25	01.32
80	01.84	01.88
85	01.73	01.73
95	00.72	00.71
100	00.61	00.60

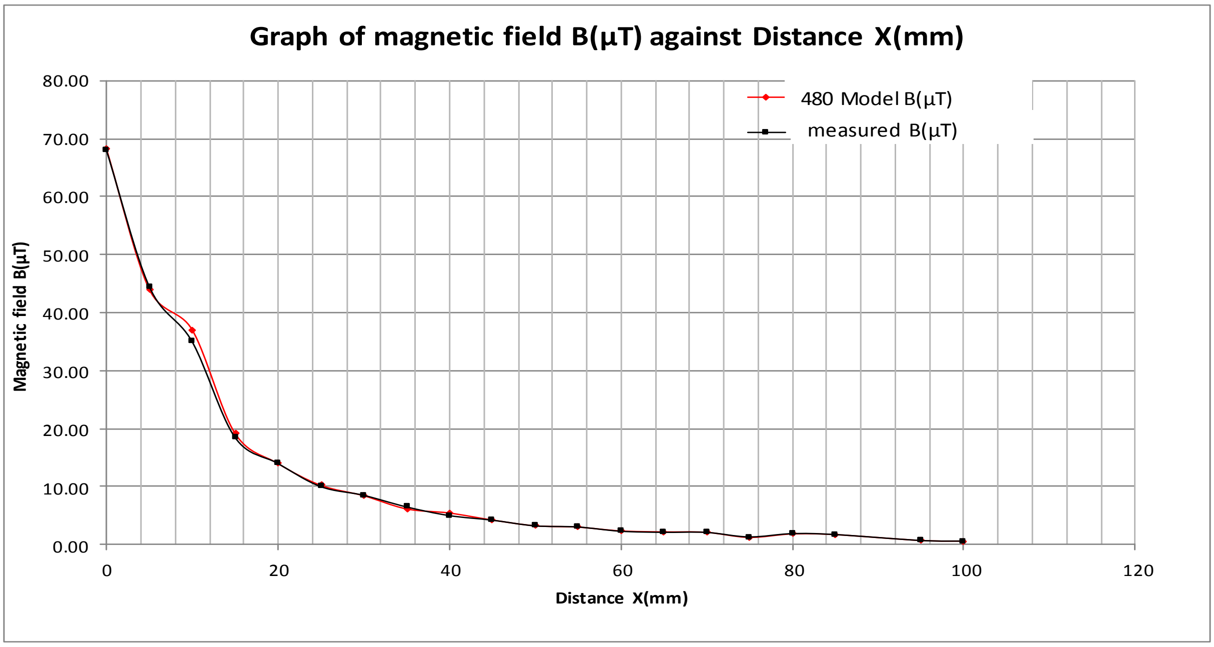

Figure 8: Graph of Magnetic Flux B (nT) versus distance X(mm)

Performance Evaluation of the Digital Magnetic Fluxmeter

On completion of the design and construction work, performance evaluation was done by measuring various types of semiconductor material which were placed near the device to check if the system responded and it was found that the magnetic flux readings increase relative to the magnetic properties of the semiconductors as observed in Figure 9.

Figure 9: Showing magnetic flux readings when the developed magnetic fluxmeter is 1cm away from the Current-carrying wire at various current flows.

III. CONCLUSION

In this work, a design was carried out and tested in accordance with the research and analysis of numerous system components. As noticed from pure nickel magnets, the magnetic flux is inversely proportional to the distance from the current-carrying conductor and decreases with distance. The magnetic flux can be controlled effectively, efficiently, reliably, and robustly by using a microprocessor. When compared to a typical magnetic fluxmeter(480 Model), the low-cost magnetic fluxmeter developed exhibits good response and appropriate great performance.Hence, designing a magnetic flux sensor that can measure three-dimensional axes will promote MRM.

REFERENCES

[1]. **Dolníka B, Rajňáka M, Cimbalaa R, Kolcunováa I, Kurimskýa J, Balogha J, Džmuraa, Petráša J, Kopčanskýb P, Timkob M, Briančinc J and Fabiánc M. (2017**) The Response of a Magnetic Fluid to Radio Frequency Electromagnetic Field. Article in ActaPhysicaPolonica Series a Volume 131, Issue 4, pp. 946-948

[2]. **Białostocka, A.M.; Klekotka, U.; Kalska-Szostko, B. (2022)** The Influence of the Substrate and External Magnetic Field Orientation on FeNi Film Growth. Energies Volume 15, Issue 3520, pp. 1-12

[3]. **Illia D., Robert G. Olsen, Viacheslav Z., Anastasiia C., Bystrík D., Oleksandr B. (2022)** Development of Effective Shielding against Electricity Meters Tampering with Strong Magnetic Fields Volume 213, Issue 108722, pp. 1-18

[4]. **Wael A. S. andBasem A. Z. (2019)** Evolution of Microcontroller-based Remote Monitoring System Applications.International Journal of Electrical and Computer Engineering. Volume 9, Issue 4, pp. 2354-2364

[5]. **SudhakarS., Vishal R. M., Anthony T. F., Martin P. L. and N.M. Ravindra (2004)** "The Magnetic Field-Assisted Assembly of Nanoscale Semiconductor Devices: ANewTechnique"Article in JOM: The Journal of the Minerals, Metals & Materials Society. Volume 56, Issue 10, pp. 32-34

[6]. **Lisa J., Daniel K., RahelK., Johannes R., PiriyaT., AnjaW., Lutz R. and Marc C. W. (2015)** Recent Developments of Magnetoresistive Sensors for Industrial Applications; Sensors Volume 15, Issue 11, pp. 28665-28689

[7]. **Widlar R. J. (1969)** "Design Techniques for Monolithic Operational Amplifier", IEEEJ. Solid State Circuits. SC-4. pp. 184-189

[8]. **Ku G.L., Shao S.F. (2018)** Steady-State Strong Magnetic Field Technology and its Scientific Significance. Sci. Technol. Rev., Volume 36, pp. 93–96

[9]. **Wang, X.F. (2019)** Weak Magnetic Field Measurements of Magnetic Resonance Samples via Atomic Magnetometers. Master's Thesis, University of Chinese Academy of Sciences, Beijing, China.

[10]. **Wang Y.Y., Xu G.B., Wang C. C., Chen X., Ma Y. M. (2020)** Structure Design and Characteristic Analysis of a Planar Torsional Micro Sensor for Strong Magnetic Field Measurement. J. Hefei Univ. Technol. (Nat. Sci.). Volume 10, pp. 1352–1356.

[11]. **Liu J.Y. (2015)** Research and Design of the Proton Precession Magnetometer Sensor. Master's Thesis, Jilin University, Changchun, China.