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Digital Gaussmeter Design and Implementation Based on Hall Effect Principle

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Abstract-In this work, the construction of Hall Effect based Digital Gaussmeter is presented and its performance is analysed. Gaussmeter is a scientific instrument for detecting and measuring the strength of magnetic field. The instrument is basically an arrangement of magnetic sensors and electronic circuit that generate data in a digital format which is implemented using ISIS Proteus Professional Electronics workbench. The instrument's design is based on the Hall Effect principle, a phenomenon characteristic of electric current, which is the variation of output voltage based on change of the input magnetic field. A digital panel voltmeter is used to display the output voltage of the sensor. This voltage is calibrated in form of flux density range. The voltage is proportionate to the magnetic field and it is a low-level signal. So it is equipped with a low noise electronic design to amplify the signal. A window discriminator circuit is used to drive a light emitting diode which shows if a magnetic field is detected by the instrument and also display the strength of the field between 0 and 3000 Gauss. The meter is robust and works very well in detecting and quantifying electromagnetic field.

Keywords: Electromagnetic field, Hall effect sensor, Gaussmeter, magnetic field, magnetic field measurement,

1. Introduction

Accuracy in magnetic field measurement is very important not only in the industry but also in the educational laboratory. In the industry, it is necessary because of the continuous need to design high precision actuators, magnetic-based instruments, magnetic switches, electric motors, coil etc. This requires instrument that can accurately measure magnetic field density. Studies on effect of electromagnetic on humans also increase the need for such high precision measuring instrument.

In academic, electromagnetic field with its sensors is very important and interesting topic in Physics and Engineering, yet because of its abstract nature, most students find the topic a bit difficult to comprehend. Electromagnetic field (combination of electric field and magnetic field) is not visible though its effect can be visibly seen. There is therefore the need to easily demonstrate its existence to students in the laboratory by detecting it, demonstrating its effect and measuring it strength.

The most common way of demonstrating magnetic field in laboratory is the use of iron filing around a bar magnet. Beyond this simple experiment, equipment and instruments needed for more in-depth study of electromagnetism are often complex, expensive and required highly skilled technician to maintain. Therefore, low-cost, simple and robust instruments with means of detecting the presence of the magnetic field around current-carrying conductor, any objects or even in an open space will in no small measure enhance students' understanding and appreciation of magnetism and its application.

There is a very strong and cordial relationship between electric and magnetic field. When current flows through a wire, magnetic field is produced or surrounds the wire. In other words, a current-carrying conductor is surrounded by magnetic field. In addition, when there is relative motion between a coil of wire and magnet, an electric voltage is produced. Magnetic sensors are needed to detect and determine the strength of magnetic field.

The strength of a magnetic field determines the amount of voltage that is induced in electro-magnetic circuit as well as the speed of electric motors among other variables. Similarly, the amount of current in a conductor also determines the strength of the magnetic field it produces. Gauss meter is an instrument for detecting and measuring the strength and direction of magnetic fields (Maciąg 2019).

Magnetic device is widely used to make a transducer; an example is speaker which is an important part of some electronics. Magnet either temporary or permanent is the major link between electrical and mechanical energy. It is a key part of electric power generator, electric motor and many other numerous devices.

Magnetic field sensors are solid state devices and have very wide applications which include power system, minerals exploration, spacecraft operation, automobile industries, weapons detections, archaeology, environmental survey, marine navigations; for speed, distance and position sensing; medical instruments, metal detections, telecommunication, current and voltage measuring instruments, instrumentation, and control applications. Magnetic field sensing play crucial role in all and many more applications mentioned above (Dewi, Panatarani and Joni 2016, Nowicki and Szewczyk 2019, Bennett et. al 2021, Lipovský.et. al. 2021; Trivedi et. al., 2022)

Each of these magnetic sensing applications presents different and specific requirements. So it is necessary to use appropriate magnetic sensor capable of meeting each applications specifics. Different magnetic sensors are designed to operate based on different principles and physical or natural phenomena. Applications specifics determine which magnetic sensor is preferable because of advantages and limitations of each type in certain application based on its sensitivities, coverage (range), bandwidth, maintenance, cost etc.

Zulfikar et. al. 2017 explore the use of smart phone (which all students are quite familiar with) that has magnetic field detector application to detect magnetic fields in any medium with a view to make students better understand and appreciate the physics' abstract topic of magnetic field. The result obtains by using this application on various smart phone differs because of difference in quality of magnetic detector in each. The process, nonetheless, the students were able to observe, compare and grasp the magnetic field interactions in different medium thereby enhancing their conceptual understanding of magnetic field.

Hejtmanek and Roubal 2019 worked to suppress noise level in gaussmeter by employing synchronous detection in a lock-in-amplifier to reduce the problem of noise. The employed amplifier helps in the suppression of unwanted signals making it easier to pick the desired signals. The gaussmeter noise reduction optimisation approach fulfils the conditions of maximum frequency bandwidth.

Beyaz and Parlak 2021 developed a low cost gaussmeter for agricultural purpose using HAL503 Hall Effect sensor, labVIEW software and microcontroller development card. The measured values of magnetic field using the developed instrument showed it is 99.6% accurate when compared to calculated values using theoretical formula.

Trivedi et. al 2022 developed a contactless means of sensing magnetic field. The field is first converted into mechanical translation and then converted it to optical signal. The optical signals are in form of laser speckles patterns reflected off on optically rough cantilever beam when the metal beam is expose to magnetic field. The magnetic field is then measured by quantifying the variations in the speckle pattern with intensity correlation algorithms. The method is capable of measuring time-changing and static magnetic field.

The aim of this work is to design and construct robust, good quality and highly sensitive locally made gauss meter for monitoring electromagnetic radiation in any human environment, in laboratory experiments and for research purposes. The instrument can detect and measure field around television set, video display terminals (VDT), field-radiating antenna, ringing phone/handset, around radio station, around current-carrying conductor etc. This electromagnetic field strength measuring instrument, will greatly aid the students' understanding and experience of the concept of electromagnetic field and its strength through laboratory experiment.

2 Materials and Methods

There are various sensing technologies or scientific principle on which the fabrication of magnetometer can be based. Some of these are: Magnetoimpedance, Magnetoinductance, Magnetoresistive, vibrating sample magnetometer (VSM), Hall Effect, Fluxgate, proton precision, SQUID (superconducting quantum interference devices), Magneto-optic Kerr effect (MOKE) etc (Araujo and Pereira 2015). Each of these technologies has different sensitivity and different way of employing magnetic sensors.

Magnetic field sensing device that are based on Hall Effect principle have better advantages of low cost, low power consumption, longer life, highly repeatable operation, high sensitivity, smaller size, wider range of measurement and capable of detecting and indicating magnetic field polarity (Ursache, Lunca and Vornicu 2019; Fatmaryanti et al. 2021).

The fabricated meter majorly consist of hall effect sensor, probe, MCP3202 12-bit analogue-to-digital (A/D) converter, microcontroller unit, a 4 × 16 LCD display and a 5V 3mA power suppy unit.

3.1 Sensor Unit

Hall effect sensor is a device used to measure the magnitude of a magnetic field. It operates on the principle discovered by Edwin Hall in 1879, where a voltage difference is created across a conductor when a magnetic field is applied perpendicular to the flow of current. Figure 1 below shows Hall Effect sensor

Figure 1: Hall effect sensor Module

Description: A typical Hall effect sensor consists of a thin strip or slab of semiconductor material (like gallium arsenide, indium arsenide, or silicon) through which a constant current flow. When a magnetic field is introduced perpendicular to the current flow, it generates a voltage difference across the semiconductor material. This voltage is directly proportional to the strength of the magnetic field.

Operation: Current Flow: The sensor has a current flowing through it, typically provided by an external power source.

Magnetic Field Influence: When a magnetic field is introduced perpendicular to the sensor, it causes a deflection in the flow of electrons due to the Lorentz force.

Voltage Output: This deflection creates a measurable voltage across the semiconductor material. The strength of the magnetic field determines the magnitude of the voltage generated.

Sensitivity: Hall effect sensors can detect very small changes in magnetic fields.

Output Signal: Analog sensors produce a continuous voltage output proportional to the magnetic field strength. Digital sensors output discrete on/off signals.
Temperature Dependence: Sensitivity can be affected by temperature changes.

Hysteresis: Some sensors might exhibit hysteresis, meaning the output can differ for the same magnetic field depending on whether the field is increasing or decreasing.

Types: There are different types like linear Hall effect sensors (for linear measurements) and digital Hall effect sensors (for detecting presence or absence of a magnetic field).

3.2 Analogue to Digital Converter Unit

The Figure 2 above is MCP3202 12-bit analogue-to-digital (A/D) converter IC is a successive approximation 12-bit A/D converter with an on-board sample-and-hold circuit. In this work, it is programmed to provide a single pseudo-differential input pair or dual single-ended inputs. Differential non-linearity (DNL) is specified at ±1 LSB, and integral nonlinearity (INL) is offered in ±1 LSB

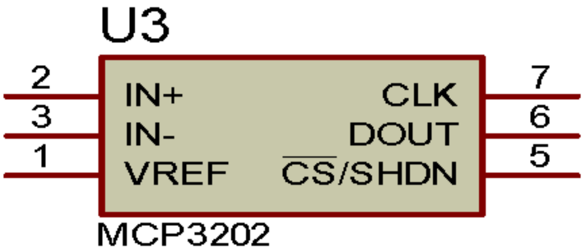

Figure 2: Schematic diagram of A/D MCP3202

(MCP3202-B) and ±2 LSB (MCP3202-C) versions. Communication with the device is done using a simple serial interface compatible with SPI protocol. The device is capable of conversion rates of up to 100kb at 5V and 50kb at 2.7V. The MCP3202 device operates over a broad voltage range of 2.7 V to 5.5V. Low-current design permits operation with typical standby and active currents of only 500nA and 375µA, respectively.

3.3 Microcontroller Circuit And LCD Unit

Arduino Uno is a board based on AT-mega328P microcontroller. The microcontroller on the board is programmed in Arduino programming language using Arduino development environment. Pins 10 through 13 of Board are connected to pins 1, 5, 6 and 7 of 12-bit ADC IC1, respectively. Pin 1 of Board is connected to RXD pin 3 of LCD. Figure 3 shows the schematics of the microcontroller unit.

3.4 Magnetic Probe

The magnetic probe used in this work consists of small coils of wire wounded around an insulating material with output voltage equal to the rate of *magnetic* flux change through the coils. Which is incorporated with Hall effect sensor module to measure DC and AC magnetic field. The analogue output of the module is connected directly to analogue input pin of the Arduino.

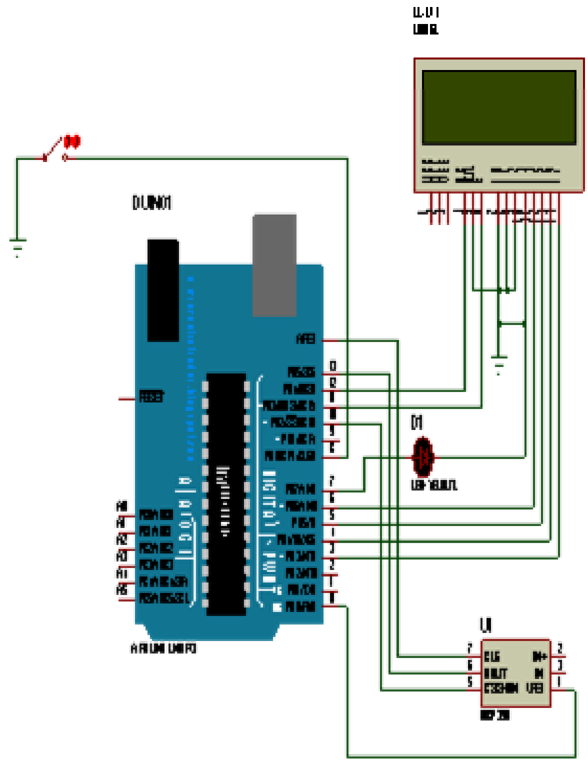

Figure 3: Microcontroller Unit (MCU) with Display Unit

4 Hall Effect Principle and Operation

The Hall Effect is a fundamental principle in physics discovered by Edwin Hall in 1879. It describes the behavior of electric charges in a conductor when exposed to a magnetic field and a current flow. Hall Effect is the production of voltage potential (Hall voltage) across a current-currying conductor or semiconductor when a magnetic field is applied or incident perpendicularly to direction of flow of the current. The Hall voltage developed is proportional to the strength of the incident magnetic field and the current. The principle of operation involves several key components:

Setup: Imagine a flat conductor, often a semiconductor material, through which a current is passing. The current flows in one direction along the conductor.

Magnetic Field Application: A perpendicular magnetic field is introduced, cutting across the conductor. This means the magnetic field is at a 90-degree angle to the direction of the current flow.

Lorentz Force: When a magnetic field intersects with a current-carrying conductor, it exerts a force on the moving charges (electrons) within the conductor. This force is known as the Lorentz force.

Electron Deflection: As the Lorentz force acts on the moving charges, it causes these charges (electrons) to experience a sideways deflection within the conductor. The extent of deflection depends on the strength and orientation of the magnetic field.

5 Operation of the Gaussmeter

Hall Effect sensor is a semiconductor transducer that operates on the principle of Hall Effect by varying its voltage output as a result of changes in magnetic field. Hall Effect based gaussmeter basically consists of magnetic probe,

Hall Effect sensor and electronic circuit. The instrument amplifies the hall sensor voltage output and gives the result on a calibrated flux density information. Figure 4 shows the simplified block diagram of the gaussmeter while figure 5 shows the circuit diagram.

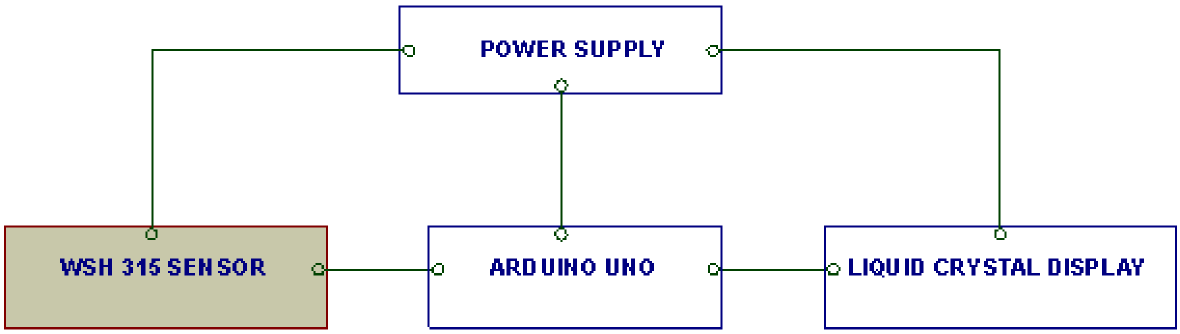

Figure 4: Simplified block diagram of the gaussmeter

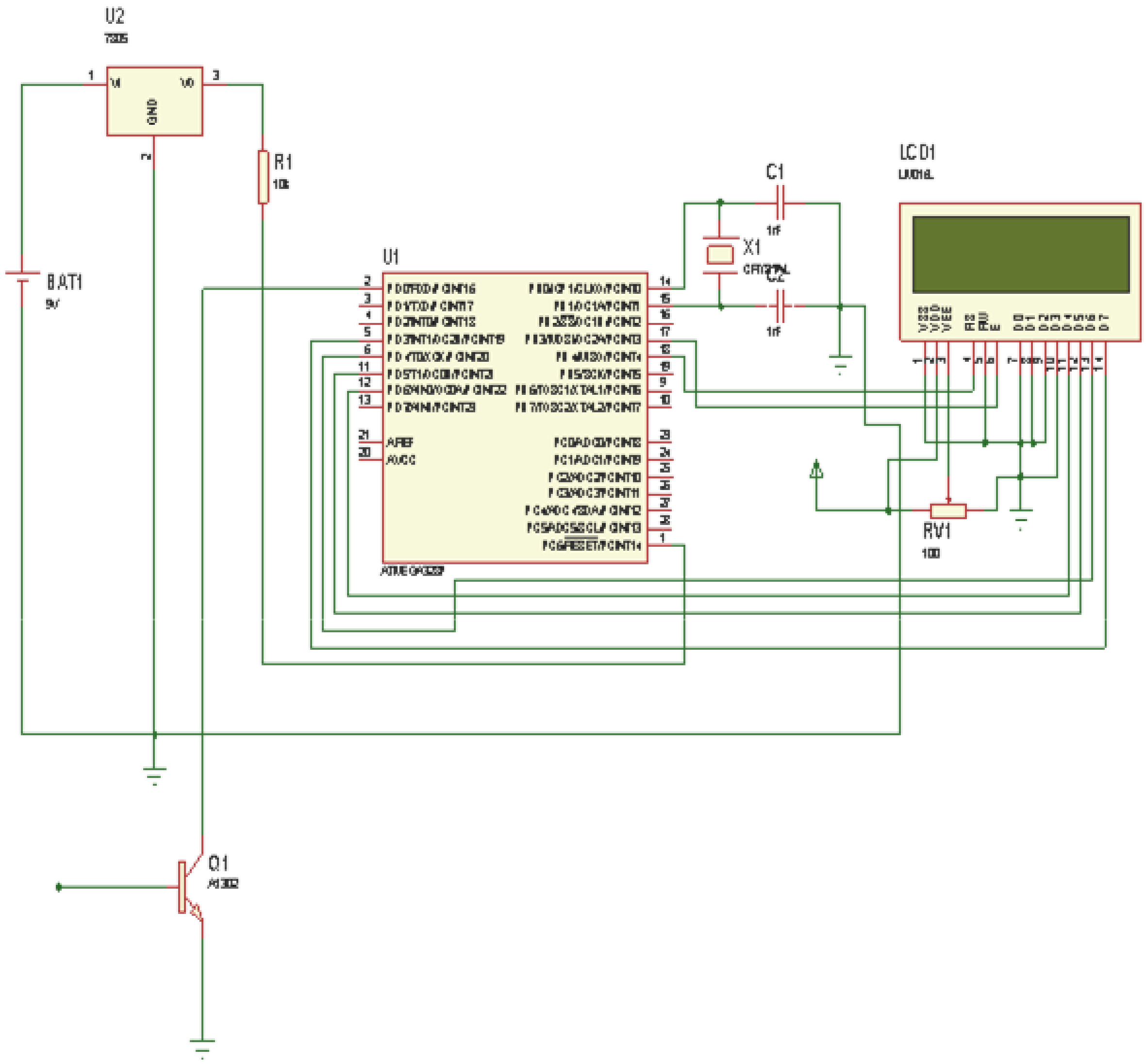

Figure 5. Complete Circuit Diagram of Gauss Meter

The operation of the instrument is coordinated and controlled by AT-mega328P microcontroller. The Hall-effect sensor WSH 315 has three pins V_{dd}, V_{out} and GND. It senses and detects presence of magnetic field and then produces voltage level that is directly proportionate to the amount of the incident or detected magnetic field strength. The voltage generated by the sensor is applied to the 12-bit MCP3202 Analog to Digital Converter ADC that is integrated into the microcontroller. The ADC is programmed to provide a single pseudo-differential input pair or dual single-ended input. The ADC is capable of 100kb/s conversion rate at 5.0V and 500nA. Figure 6 shows the prototype assembly

Figure 6: Prototype Assembly

6.0 Calibration of the Instrument

Typically, the calibration involves exposing the gauss meter to the known magnetic field generated by the reference source. The constructed meter was placed close to the reference source at a predetermined distance specified by the calibration procedure of the standard meter, the standard meter was activated to generate a stable magnetic field. And the constructed meter was used to take reading and compare it to the known value of the magnetic field produced by the reference source.

7.0 Errors and Accuracy of the Instrument

After the calibration, the accuracy of the meter was observed to be 0.1% when the reading of the constructed meter was compared with the standard one. And it was discovered that the meter have zero offset errors, because it doesn't read zero when no magnetic field is present.

8.0 Test Result and Discussion

To validate the constructed Gauss meter two small magnets were used as standard and constructed meter was used to measure the magnetic field of the two magnet and the result were compared with standard commercial gauss meter Model 5170 as shown in the table below.

Table 1: Readings of Commercial and Constructed Gaussmeter

Model 5170 Gaussmeter Reading (mT)		Constructed Gaussmeter Readings (mT)	
M1	M2	M1	M2
22.3	24.5	22.1	24.0
22.0	24.7	22.7	24.0
22.5	23.9	23.0	25.6
22.0	24.6	22.1	24.0
22.3	24.0	22.5	23.9
22.4	24.1	21.8	24.4

From the Table 1, above, it is noticeable that the result are not constant, as it vary in about 0.1% around the average value of 24.31mT (22.0 to 25.6). These variations can be as a result of thermal noise from the circuitry and the tolerance from the pull-up resistor. Also the parameter programmed remain constant. From the data sheet of the hall –effect sensor used, the scale and the sensibility for these readings were adequate.

Conclusion

A portable, low- cost, low-power consumption and highly sensitive digital gaussmeter with hall effect magnetic sensors has been built. The fabricated instrument is very useful for detecting the presence and measuring magnetic flux density on any electromagnetic and magnetic objects and surroundings within the range of 0 to 3000G (0-300mT). It is very good at performing laboratory practical and experiments for and by student in studying magnetic field and its properties. It is also very suitable for research purpose on magnetism. Its operation is very simple and straightforward. Further research can concentrate on wide range of smaller measuring capacity.

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References

Bennett, J.S.; Vyhnalek, B.E.; Greenall, H.; Bridge, E.M.; Gotardo, F.; Forstner, S.; Harris, G.I.; Miranda, F.A.; Bowen, W.P. Precision Magnetometers for Aerospace Applications: A Review. *Sensors* **2021**, *21*, 5568. https://doi.org/10.3390/s21165568

Beyaz A. and Parlak D. (2021) *Efficacy Detection of Low-Cost Hall Effect Sensor for a LabVIEW-Based Agricultural Gaussmeter* Yuzuncu Yil University Journal of Agricultural Sciences Volume 31, Issue 3, 30.09.2021 DOI: 10.29133/yyutbd.932155

Dewi S., Panatarani C, and Joni I (2016) Design and development of DC high current sensor using Hall-Effect method AIP Conference Proceedings 1712, 030006 (2016); doi: 10.1063/1.4941871

Fatmaryanti S.D., Pratiwi U., Al Hakim Y., Sriyono, Akhdinirwanto R.W, Murhadi M. (2021) *Assemble a Digital Magnetic Induction Gauge with Hall Effect Sensor UGN3503U and Node MCU ESP8266 in Classroom Laboratory.* 2nd International Conference on Education and Technology (ICETECH 2021)

Hejtmanek T. and Roubal Z. (2019) *Reducing the Noise Level in a Gaussmeter with a Hall Probe for Reliable Magnetic Impedance Tomography.* PhotonIcs & Electromagnetics Research Symposium, Spring (PIERS | SPRING), Rome, Italy, 17-20 June, 2019

Lipovský P, Draganová K, Novotňák J, Szőke Z, Fiľko M. Indoor Mapping of Magnetic Fields Using UAV Equipped with Fluxgate Magnetometer. *Sensors*. 2021; 21(12):4191. https://doi.org/10.3390/s21124191

Łukasz Maciąg (2019) *Application of portable gaussmeter for field and laboratory measurements of magnetic properities of volcanic rocks - case study from Pieniny Clippen Belt, Outer Western Carpathians, Poland.* 19th International Multidisciplinary Scientific GeoConference SGEM 2019

Maciąg Łukasz (2019) *Application of portable gaussmeter for field and laboratory measurements of magnetic properities of volcanic rocks - case study from Pieniny Clippen Belt, Outer Western Carpathians, Poland.* 19th International Multidisciplinary Scientific GeoConference SGEM 2019

Nowicki, M., & Szewczyk, R. (2019). Determination of the Location and Magnetic Moment of Ferromagnetic Objects Based on the Analysis of Magnetovision Measurements. *Sensors*, 19(2), 337.

Sedelnikov A.V., Filippov A.S., Gorozhakina A.S. (2018). *Evaluation of Calibration Accuracy of Magnetometer Sensors of Aist Small Spacecraft.* IOP Conf. Series: Journal of Physics: Conf. Series **1015** (2018) 032045 doi :10.1088/1742-6596/1015/3/032045

Trivedi V, Mahajan S., Joglekar M, Joshi N, Chhaniwal V., Dubey S., Zalevsky Z., Javidi B., Anand A. (2022) Opto-mechanical magnetometer based on laser speckle correlation. Measurement, Vol 189, 15 February 2022, 110490

Ursache Silviu, Lunca Eduard, Vornicu Silviu (2019) *DC Digital Gaussmeter Based on Linear Hall-Effect Sensor IC.* 2019 IEEE International Conference on Electromechanical and Energy System SIELMEN, 1-4, https://doi.org/10.1109/SIELMEN.2019.8905856

Vismay Trivedi, Swapnil Mahajan, Mugdha Joglekar, Nirav Joshi, Vani Chhaniwal, Satish Kumar Dubey, Zeev Zalevsky, Bahram Javidi, Arun Anand (2022) *Opto-mechanical magnetometer based on laser speckle correlation.* Elsevier Measurement Volume 189 doi.org/10.1016/j.measurement.2021.110490

Zulfikar A., Girsang D.Y, Saepuzaman D. (2017) *Analyzing Educational University Students' Conceptions through Smartphone-based PDEODE*E tasks on Magnetic Field in several mediums.* AIP Conference Proceedings 1848, 050007 (2017); https://doi.org/10.1063/1.4983963