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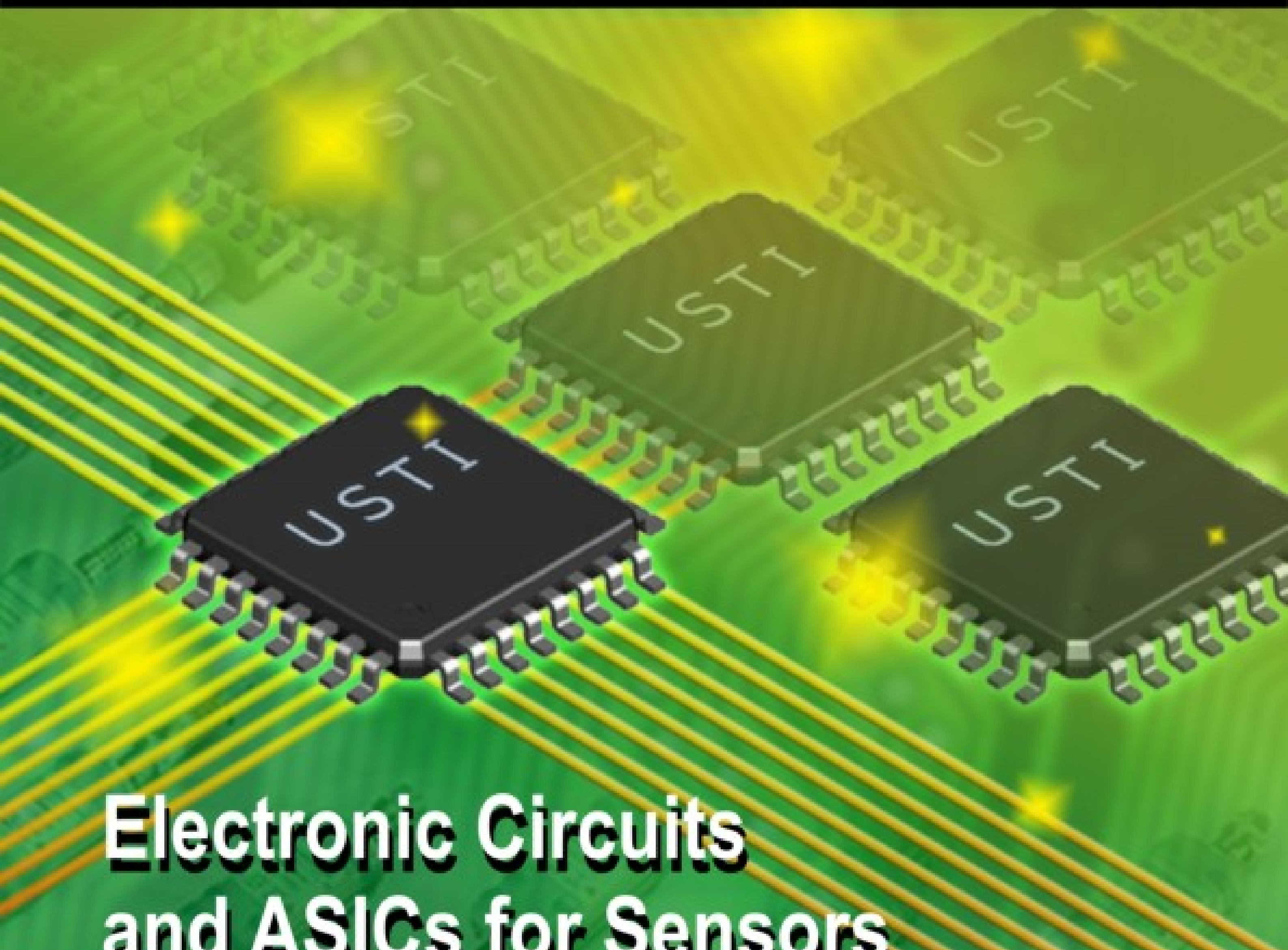

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Remote Measurement of Electric Current Using Magneto-Optic Technique

[1]Mahfoozur Rehman, [2]Basem Abdul Jalil, [3]Zaid Abdullah
School of Electric and Electronics Engineering,
Engineering Campus, Universiti Sains, Malaysia
14300-Nibong Tebal, Pinang-Malaysia
[1]Tel: +6057179536, [2,3] +6045996000
E-mail: mahfoozur_rehman@hotmail.com, mza@eng.usm.my

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Abstract: The paper deals with the development of an interesting technique which can help in the remote measurement of electrical current, using magnetic and optical devices. Major advantage of the presented technique is the isolation provided by Hall sensor as well as by the optical devices of measuring system from the actual power circuit. It will help in the repair of measuring system without closing the main circuit which is a crucial requirement of supply system. Output of the optical receiver is interfaced with the microcontroller to display the current as well as to instill intelligence to the system. It has been successfully used for the measurement of currents up to 60 A and relationship between current under measurement and output of the system is appreciably linear. *Copyright © 2008 IFSA.*

Keywords: Hall effect sensor, Fiber optic sensor, Remote measurement, Measurement of current, Microcontroller based measurement

1. Introduction

The measurement of Electrical quantities, without making contact with the circuit under test, is a very important requirement and it will avoid the closure of the main circuit during testing or making any modifications in the measuring systems. For the measurement of current and voltages, without electrical contact, current and potential transformers are used on AC circuits but they also can not fulfill the basic requirements because open circuiting of secondary winding of current transformer may create problems, and is not advised under standard practices [1]. This paper adopts Hall Effect sensor to isolate the main circuit from the measurement circuit as well as it reduces the amplitude of the signal to low value. As a second step, low level signal is converted into an optical signal with the help of LED by choosing the most linear part of the LED characteristic. Resulting optical signal is transmitted with the help of optical fiber and is finally converted into a voltage signal with the help of optical detector. Output of the optical detector is further amplified then interfaced with the microcontroller to display the current as well as intelligent steps to incorporate special warnings at the receiving end. Main circuit and measuring circuits do not have any undesirable reflections to cause any sort of damage of chips. It has been used for the measurement of currents up to 60 A successfully. With, higher rating Hall sensors/proper shunts still higher ranges may be covered. For long distance transmission, LED optical source may be replaced by Laser and multimode Optical Fiber may be replaced by single mode fiber. Currents at high voltages may be measured with out any danger to equipment and personals due to high order of isolation between power circuit and measuring system.

2. Basic Principles

In the proposed scheme, initially high values of currents are converted into low values of voltages with the help of Hall sensor [2]. The output voltage of the Hall sensor is used to forward bias the LED to produce light which is transmitted to remote place with the help of Optical Fiber. At the destination, optical signal is converted into electrical signal with the help of optical receiver circuit. Output of the optical receiver is interfaced with the microcontroller to provide intelligence as well as to display the current, under measurement, with high degree of isolation. The theoretical aspects of different devices, used in the scheme, are given below.

2.1. Magnetic Field and Current Sensing Integrated Circuits Based upon Hall Effect

The Hall Effect was discovered in 1879 by Edwin Hall. It arises from the Lorenz force experienced by a charged particle moving in a magnetic field .If the carriers are flowing in a slab of metal or semiconductor; they are deflected preferentially to one side of the slab, producing a voltage as shown in Fig. 1. Referring to Fig.1, the Hall voltage is given by, [2]

$$V_H = \frac{R_H I_X B_Z}{T}, \tag{1}$$

where R_H =Hall coeff. (m^3/C), I_X =Current through the sensor (Amp), B_Z =Flux density in sensor (Tesla), T =Plate thickness (m).

The Eq.(1) is valid for L>> W >>T, approximately, L is not much greater than W and W>>T for cases where the equation is valid, and nonlinearity in Hall coefficient can be neglected, the Hall voltage is directly proportional to the current and the magnetic flux density and inversely proportional to the thickness of the plate. The R_H is between four and five orders of magnitude larger for semiconductors than for most metals due to the fact that the carrier density is much smaller in semiconductors. This translates directly into increased sensitivity. Hall Effect devices are easy to fabricate and can be made as an intrinsic part of nearly any bipolar or MOS process. A great deal of thought has been given to realize high quality Hall devices from available active circuit processes. Allegro Micro Systems have developed a chip for the measurement of current linearly and have incorporated Different signal conditioning blocks to get linear output without the effect of noise and temperature [3]. Its block diagram is shown in Fig. 2. It has five terminals and out put is available on 3rd terminal. The relationship between output voltage is input current is appreciably linear in different temperature ranges. It has low output impedance and can be easily connected without loading problems. It will play important role in the development of remote measurement presented here.

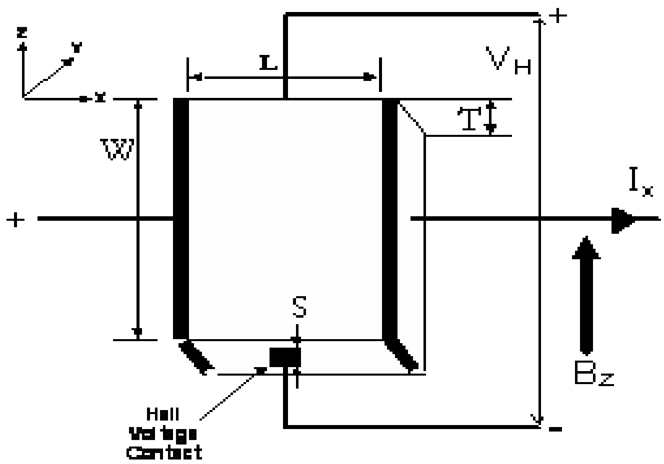

Fig. 1. Basic Hall Sensor.

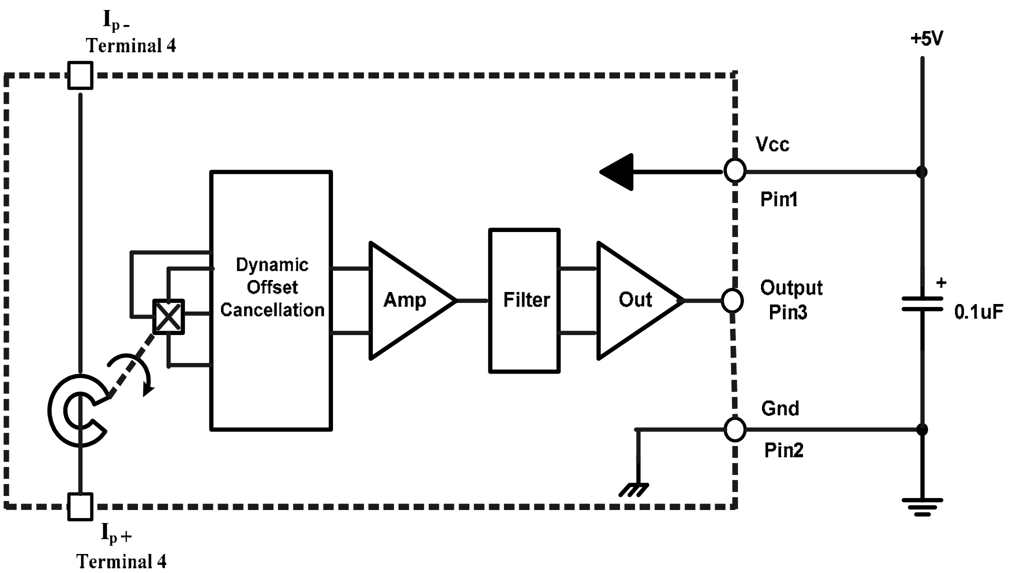

Fig. 2. Hall Sensor (Allegro Micro System).

2.2. Use of Light Emitters to Convert Electrical Signal into Optical Signal

Light Emitters convert Electrical signal into a corresponding Optical signal that can be transmitted with the help of optical fiber. A light Emitting diode is a semiconductor p-n junction that is optimized to release light of approximately the band gap energy under forward bias when electrons fall from the conduction band to the valence band. LED can work at low current densities but the emitted photons have random phases and the device is an incoherent optical source. LED is preferred over Lasers due its distinct advantages like simpler fabrication, low cost, reliability, less temperature dependence, simpler drive circuitry and linearity. These advantages combined with the development of high radiance, relatively high bandwidth devices have ensured that the LED remains an extensively used source of optical power. The power internally generated in an LED is given by following expression [4]:

$$P_{\text{int}} = \eta_{\text{int}} \frac{hcI_L}{e\lambda} \quad , \tag{2}$$

where, η_{int} = LED Internal quantum efficiency, λ = Wavelength, h = Planck constant, I_L = drive current through LED, e = charge of an electron, c = velocity of light.

However, emitted light of the LED is of main significance because it will reach the photo detector to produce current. The emitted light will be different from the internally generated light due to the effect of materials used in the fabrication of LED. Following equation gives the expression for the emitted optical power.

$$P_e = \frac{P_{\text{int}} F n^2}{4n_x^2}, \tag{3}$$

where P_e is the emitted optical power, P_{int} is the internally generated power, F is the transmission factor of the semiconductor-external interface, n is the refractive index of the optical fiber, n_x is the refractive index of material of LED.

Substituting the value of internally generated power in (3) we get

$$P_e = \frac{\eta_{\text{int}} hcI_L F.n^2}{4e\lambda n_x^2} = K_e.I_L \,. \tag{4}$$

For a particular construction, K_e is constant and emitted light may be taken proportional to load current. The drive current I_L depends upon the output voltage of the Hall sensor as discussed in previous section. If the output voltage of Hall sensor is V_H at a particular Primary current of I Amp then resulting current through the LED is

$$I_L = \frac{V_H - V_{fw}}{R_T}, \tag{5}$$

where, V_{fw} is the forward voltage of the LED.

Current given by Eq.(5) will pass through LED and will produce Optical power which may be given by following expression [4]

$$P_e = K_e I_L \tag{6}$$

This power will be launched into the multimode optical fiber by polishing the optical fiber nicely. Now the signal representing the current under measurement will travel through the Optical Fiber and in the receiver side this light will fall upon the Photo Diode and produce a current, I_D. Expression for detector current may be given by following expression:

$$I_D = \Re.P_e = \Re K_e I_L, \tag{7}$$

where I_D is the photo diode current and $\Re$ is the responsivity of the diode and may be given by following expression:

$$\Re = \frac{\eta e}{hf}, \tag{8}$$

where η is the quantum efficiency of the diode, e is the charge on the electron, h is the Plank constant, f is the frequency of the incident light.

Substituting the value of I_L in (7) we get

$$I_D = \Re K_e . \frac{V_H - V_{fw}}{R_T} . \tag{9}$$

Substituting the value of V_H in (9) we get

$$I_D = \Re . K_e \frac{1}{R_T} [\frac{R_H . I_X . B_Z}{T} - V_{fw}] . \tag{10}$$

For a particular chip we can make some assumptions and final expression may be written as follows:

$$I_D = K_1 . I_X - K_2 . \tag{11}$$

Eq. (11) shows that the relationship between I_D and I_X, may be represented by a straight line. I_D can be converted into voltage using the current to voltage converter and may be further amplified using an inverter. A summing amplifier at the end may be used to develop linear relationship between I_D and I_X as shown in Fig. 3. The output voltage of the current to voltage converter may be given by following expression:

$$V_0 = -I_D . R_F \tag{12}$$

The output of the inverter, with a gain of $-k_3$, will be

$$V_{01} = I_D K_3 . R_F \tag{13}$$

Substituting the value of I_D we get

$$V_{02} = K_3 . R_F (K_1 . I_X - K_2) \tag{14}$$

A summer amplifier is so designed that it will subtract a voltage equal to $K_3 \times R_F \times K_2$ from the voltage V_{02}. The final expression will be:

$$V_{03} = K_3 . R_F . K_1 . I_X = K_4 . I_X \tag{15}$$

Eq. (15) shows that output voltage, V_{03} of the summer will be proportional to primary current in the input circuit and relationship between V_{03} and I_X will be linear.

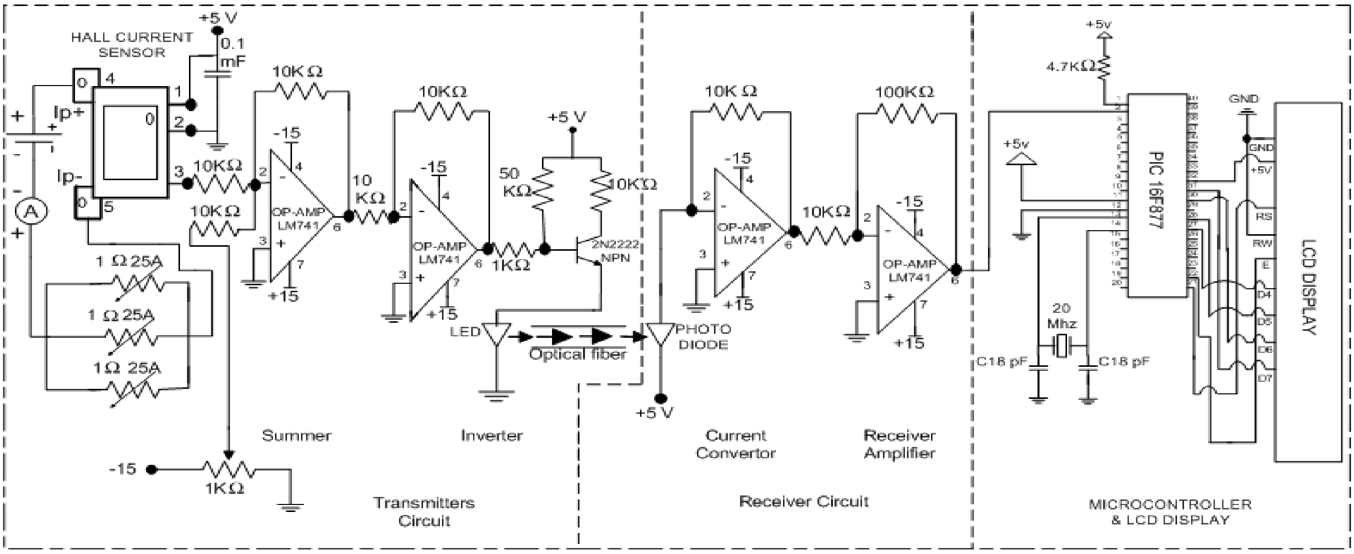

Fig. 3. Circuit diagram of the proposed technique.

3. Experimental Results

Initially, the characteristics of the Hall Sensor, Optical transmitter and optical receiver were determined and verified in the laboratory and it was found that the devices gave quite repetitive characteristics. To verify the scheme, connections were made as shown in Fig. 3. It was tested for Direct Currents due to some limitations of the equipment. To get better sensitivity, ends of the optical fiber were polished with great care and then they were fixed inside the transmitter and receiver carefully. The connections in the primary circuit were checked to avoid loose connections which may give rise to terminal heating. Constant voltage supply of 5 volts was given to the photo diode and LED to avoid noise. Current was increased in steps of 5 A and resulting output of the photo detector circuit was recorded with the help of a multimeter. Observations were repeated a number of times and at different ambient temperatures. It was observed, for the temperature variations in an air-conditioned Laboratory, there was no variation in the results.

The results are shown in Fig. 4. Same observations were repeated after interfacing the optical receiver with the microcontroller followed by the LCD display system. The results obtained are shown in Fig. 5. According to the theoretical derivations developed in Eq. (15), relationship between the current under measurement and output voltage is appreciably linear.

4. Conclusions

A novel scheme is presented for the measurement of large values of currents without making direct contact with the main power circuit. It employs the famous Hall devices for current sensing and optical sources and detectors for transmitting the signals to remote places for safe measurement. Any changes may be made in the measurement circuit, beyond the output of the of the Hall sensor, without affecting the main power circuit and hence without being affected by the high voltage of the primary circuit, due to perfect isolation. Linearity, accuracy and reliability of the measurement mainly depend upon the Hall

Sensor, transmitter and receiver. The maximum non-linearity of the Hall sensor9ACS750xCA-075) used is 5% while maximum error is 1% only [3].Accuracies of transmitter and receiver may be much better than this. Repeatability of the circuit has been tested through rigorous experimentation. With further development work, accuracy, reliability and repeatability of circuit may be improved. Complete circuit is compact, robust and can be prepared at low cost. It may be further extended for the measurement of a.c. current, and voltages and power.

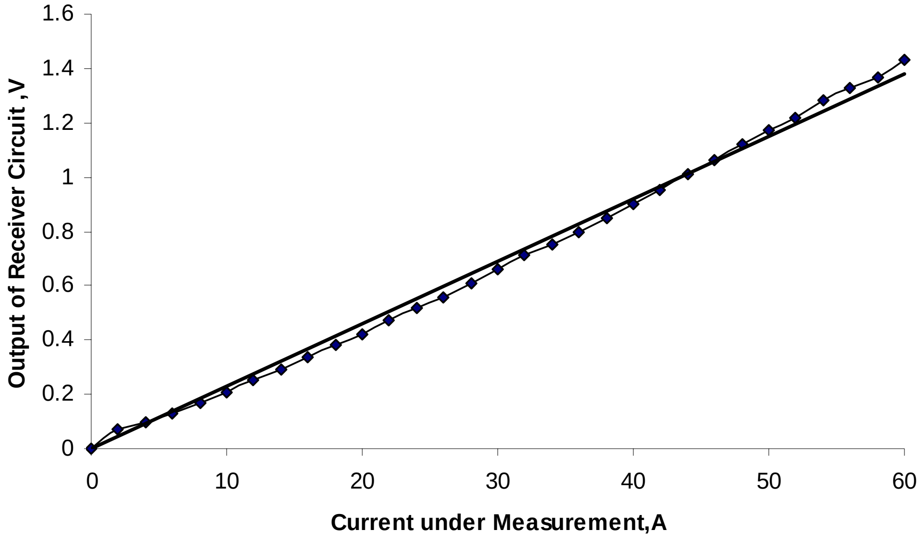

Fig. 4. Relationship between current under measurement and Output Voltage of the receiver.

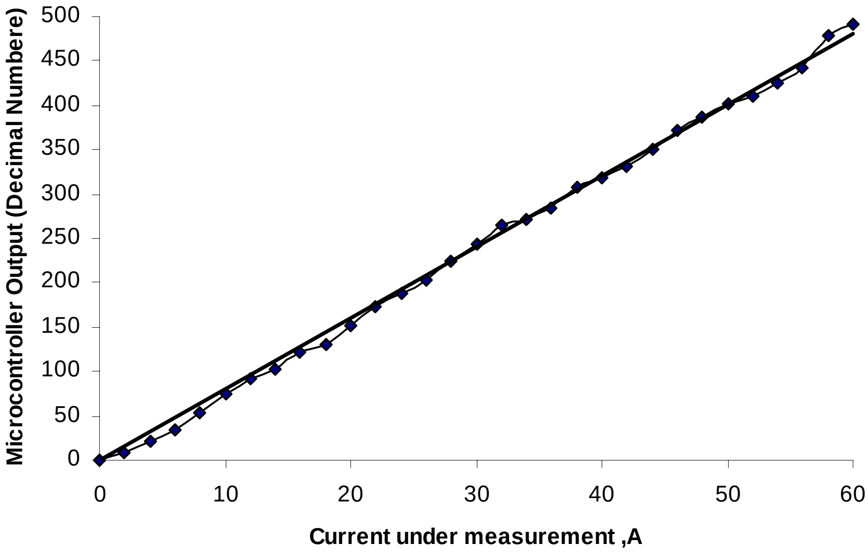

Fig. 5. Relation ship between current under measurement and microcontroller output.

Acknowledgments

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Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

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- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
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- Nanosensors;
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