TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol.12, No.5, May 2014, pp. 3713 ~ 3718
DOI: http://dx.doi.org/10.11591/telkomnika.v12i5.5004

Accurate Low-Current Measurement Circuit for Multimeters and Oscillograps

Shuqin Geng*, Chen Liu, Jinhui Wang, Ligang Hou, Ying Yuan
Department of Electronic Information and Control Engineering, Beijing University of Technology 1509#,
Beijing University of Technology,100hao, Pingleyuanlu, Chaoyang district, Beijing, China
*Corresponding author, e-mail: gengshuqin@bjut.edu.cn

Abstract

A simple and high-precision current-to-voltage (I/V) converter circuit for multimeters and oscillographs is presented in this paper. The I/V converter measures the electric current with uA and nA selectable ranges in the frequency range from direct current to 1MHz. Circuit technology is also discussed. System Architecture is presented and dual polarity power is designed. Power detector circuit is explained. Measurement data are obtained. Linearity and the error are analyzed. The typical accuracy of the µCurrent is higher by 0.085% in the µA and nA ranges. µCurrent can be used in detecting low uA and nA in current systems, chips, and modules.

Keywords: *I/V converter, low current, high precision, measurement*

1. Introduction

Accurately measuring the sleep and operating current of a microcontroller [1] and other modules of embedded systems is a common task. Numerous measurement applications of high-impedance devices such as ultrasound piezoelectronic transducers are used in “surface” microscopy [2-5]. Tuning forks, torsion oscillators, and electrostatically driven grids are types of useful experimental tools for studying the physical properties of quantum liquids and other systems at low and very low temperatures [6]. Lower supply voltages for current battery-powered circuits correspond to greater requirements for accurately measuring the supply current [7].

However, in our experiment, the end node of wireless sensor networks will not transmit or receive data when the end-node current of wireless sensor networks is monitored by multimeter. However, the end node functions well when the end-node current is not monitored. The same problem occurs the when the multimeter is changed. The reason for this phenomenon is that the burden voltage is typically specified in mV/A. The value changes with varying current ranges. Thus, the burden voltage may have 1mV/A, 1mV/mA, or 1mV/µA. Multimeters with good performances will at least decrease the value to 0.1 mV/uA. During transmission, the system current is approximately 16mA, and 4-, 4.5-, 5-, and 6-digit multimeters will decrease the value to 1.6V, thus causing dysfunction to the end-node system. Jones [1] encountered this problem in the past and designed an adapter for multimeters. However, the battery voltage directly supplies power to the circuit. Thus, a decreasing battery voltage influences measurement performance. An additional feature is the nA current range, which is not found in most multimeters. Measuring the current with probes is not convenient for oscillographs. Such as speaking voice and human body movement caused by vibration will affect the measurement instrument.

To achieve noise reduction as far as possible, current addition of vibration isolation device in the circuit, fixtures, while outside of the instrument increased shielding box to reduce the slight vibration on measurement result of external interference, the cost of higher implementation is more complex [8]. Thus, we aim to improve the design circuit in this study for convenient connection with oscillographs.

Received October 30, 2013; Revised December 20, 2013; Accepted January 7, 2014

2. System Architecture

Low-current monitor systems must have low noise, low drift, and ultra-low offset. The current measurement system architecture is shown as Figure 1. The system is consisted of a low current [9], an active current-to-voltage (I/V) converter, a battery, a low dropout (LDO), a power detector, and a dual polarity power supply. The dual polarity power supply for the I/V converter. The I/V circuit module must be highly precise. The output can be connected to multimeters or oscillographs, and the I/V circuit module has two I/V channels for changing the measurement range (uA/nA).

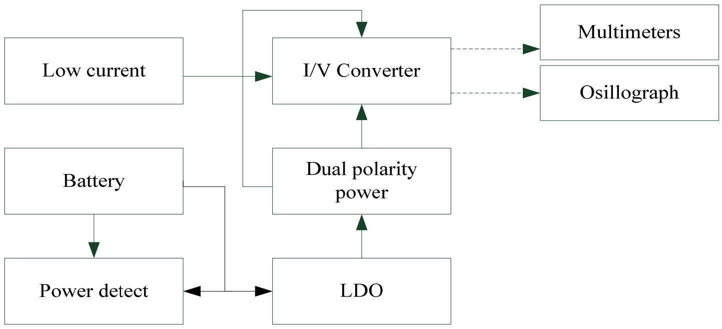

Figure 1. Block Diagram of a Low-current Adapter System for Multimeters and Oscillographs

2.1. I/V Converter Module

Figure 2 shows the schematic of a non-inverting loop amplifier. Suppose the closed-loop amplifier uses an ideal operational amplifier (op amp). An infinite open-loop gain Av causes op amps to have almost zero input differential voltage, thus, the relationship between the input and output voltages is as follows:

$$V_{out} = \left(\left(R_f \ / \ R\right) + 1\right) * V_{\text{in}} = \left(\left(49/1\right)+1\right) * V_{\text{in}} = 50V_{\text{in}} \quad (1)$$

Where the resistor R and the feedback resistor Rf can be a value of IKΩ and IMΩ, respectively, with a magnification range of 0 to 100.

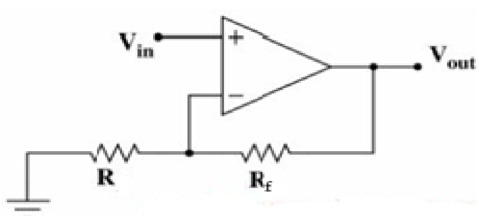

Figure 2. Schematic of a Simple

Several elements influence data accuracy, such as the noise produced by the electrometric amplifier, precision of the scaling resistor, circuit of the measured current, circuit techniques, measurement environment, and cables. The op amp input impedance is not infinite, and the resistance Rf is subject to the limits of the amplifier input impedance. The primary factors affecting the sensitivity of the micro-current measurement are op amp bias current Ib, noise-voltage, and zero-point drift. The instantaneous value of the input noise current of the amplifier is based on the current originating from constructing and circuit elements, such as leakage of insulators, cables, and printed circuit boards (PCBs) during transmission. The instantaneous value of the noise current of the amplifier is based on the current of the instantaneous value of thermal noise voltage of the scaling resistor and the instantaneous value of input noise voltage of the amplifier and the input offset voltage of the amplifier.

MAX4239 is one of the Maxim integrated products, CA in USA. It is an ultra-low offset, low noise, low drift, and ultra-high-precision amplifier that offers near-zero direct current (DC) offset and drift by patented autocorrelating zeroing techniques. This method constantly measures and compensates for the input offset, thus eliminating drift, temperature, and 1/f noise effects over time. Device feature rail-to-rail outputs, operate from a single 2.7V to 5.5V supply, and consume only 600μA. An active-low shutdown mode decreases the supply current to 0.1μA [10].

Given that an ammeter with an active I/V converter does not have the shortcomings of an ammeter with a passive I/V converter (i.e., excessive input resistance and a shunt voltage) [11], a feedback structure is selected for this low-current adapter.

Figure 3 shows the schematic of the I/V converter. A low current passes through the resistance, thus changing the current to ui. The ui then multiplies the amplification factor of MAX4239, thus resulting in Vout. Two current ranges are defined by the shunt resistor on each range and the gain of MAX4239.

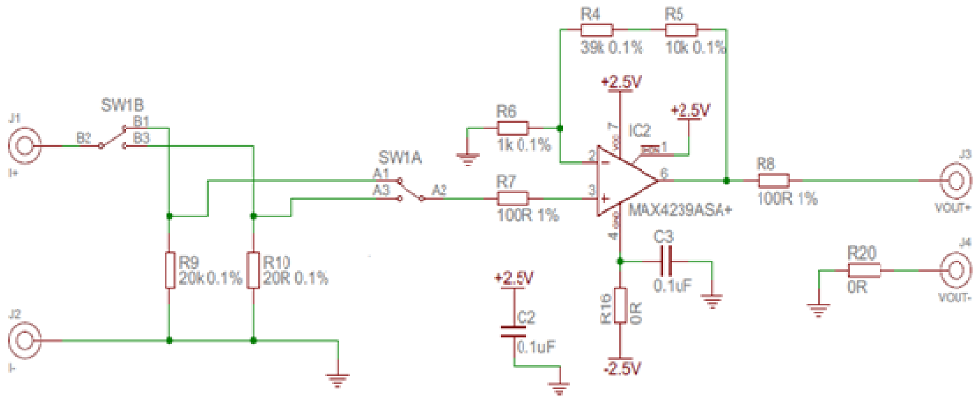

Figure 3. I/V Converter Circuit

R9 (20 K 0.1%) is the shunt resistor for the nA range, R9 provides a burden voltage of 20μV/nA (1 nA*20 K). The 20μV signal and 1mV (20 uV*50) is the input and output of MAX4239, respectively. The oscillograph or multimeter will display 1mV. R10 (20 R 0.1%) is switched in the μA range by SW1B, which provides a burden voltage of 20μV/μA (1μA*20 R). SW1A selects which shunt resistor is fed through the amplifier. Table 1 shows the current range.

Table 1. Unit of I/V and I_{in}-max

Unit	I/V	Iin-max
uA	1mV/uA	±2200uA
nA	1mV/nA	±2200nA

2.2. LDO Voltage Regulator

A stable voltage can reduce the negative effects on measurement accuracy; hence, we choose the voltage regulator chips. The HT7350 is one of the HOLTEK Taiwan Complementary Metal Oxide Semiconductor (CMOS) LDO voltage regulators. It is used in this device. This voltage regulator can deliver up to 250mA of current while consuming only 4μA of quiescent current (typical). A series of four alkaline batteries are used in this device. The device can use lithium battery, which results in low cut-off voltage. The alkaline battery is a green device, whereas lithium battery causes pollution. The input and output voltages of this device is 6 and 5 V, respectively. Both the dropout voltage and temperature coefficient are low.

2.3. Dual Polarity Power

The I/V converter needs a balanced dual polarity power. MCP6002 is one of the Microchip Technology Inc. USA, which is an op amp that has a 1MHz gain bandwidth product and a 90° phase margin (typ.). This op amp also maintains a 45° phase margin (typ.) with a 500 pF capacitive load. R1 and R2 distribute the battery voltage. MCP6002 supports rail-to-rail input and output swings. The dual polarity in this device is 2.5 and −2.5 V. This op amp is designed with the advanced CMOS process, which has a power supply range of 1.8 V to 5.5 V. The output voltage range of the MCP6002 op amp is VDD − 25 mV (min.) and VSS + 25 mV (max.) when RL = 10 kΩ and is connected to VDD/2 and VDD = 5.5V. The MCP6001/2/4 op amp is designed to prevent phase reversal when the input pins exceed the supply voltages [12].

2.4 Power Detector Design

Figure 4 shows the power and power detector schematic. Another OA of MCP6002 can detect and determine the battery voltage. When the battery energy is sufficient and the device is turned on, the output voltage of IC1B is higher than the threshold voltage of Q1. The output voltage will turn on Q1 and the green LED will become bright. When the battery voltage is low, the output voltage of IC1B will be lower than the threshold of Q1 and Q1 will be turned off. The user can change the battery when the red LED becomes bright. Three zero resistances are present and are used to make holes and interconnect components conveniently.

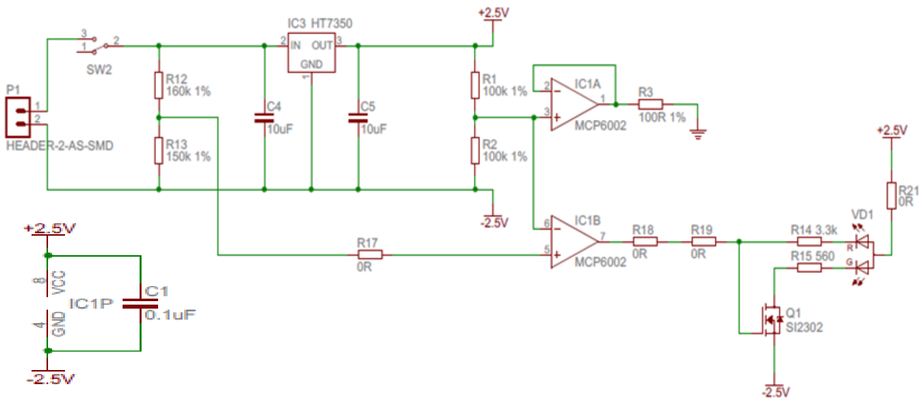

Figure 4. Power and Power Detector Schematic

2.5 Circuit Technique

Circuit technology is important for achieving high precision, measuring low currents, and choosing high-performance op amps.

Reasonable and reliable circuit elements should be selected, such as high-resistance precision and low-noise platinum resistance, tantalum capacitors for low noise, and high insulation materials such as composite-coated copper for PCB use [13, 14]. Short overhead microwave-shielded cabling can be used as input and output signal lines. PCB surface leakage effects need to be considered in applications where low input-bias current is critical. Surface leakage is caused by humidity, dust, or other contaminants on the board. The use of a guard ring around sensitive pins is the easiest way to reduce surface leakage. The guard ring is biased at the same voltage as the sensitive pins. In order to shield the circuit from electromagnetic interference, the entire circuit was enclosed within a metal shield box [15].

3. Measurements

Measurements are performed in a laboratory to determine the characteristics of the circuit performance. The Keithley Model 2400 of Keithley Instruments Inc. in U.S.A. serves as the constant current source of the I/V converter, and FLUKE 8508A reference multimeter is used as the output voltage detector. The experimental environment temperature for detecting nA and uA parameters are 18.5 and 18.9°C, respectively. We conducted five circle measurements, and each step is approximately 100uA. Figure 5 and Figure 6 show the low-current detector average experimental results of the five circles for the uA and nA parameters. The typical accuracy of the µCurrent is better than 0.085% in the µA and nA ranges. Figure 5 and 6 present the DC characteristics of the average output voltage of the I/V converter for the five circles.

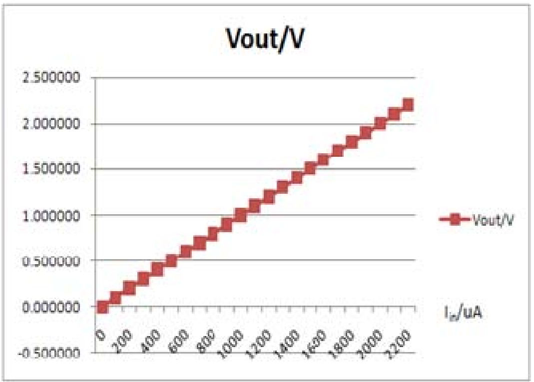

Figure 5. DC Characteristics of the I/V Converter for the Input uA Current

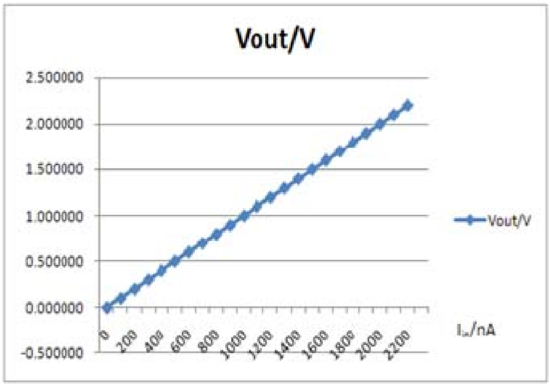

Figure 6. DC Characteristics of the I/V Converter for the Input nA Current

From Figure 5 and 6, we can see that with the I_{in} increasing, V_{out} is Linear increasing. DC characteristics of the I/V converter for the input nA and uA current is good. Method of least squares is used to fitting line [16] for the five circle measurement data. The ratio is 0.001001 for uA and 0.001000 for nA.

$$\Delta= (V_{out}/1000- I_{in})/ I_{in} \quad (2)$$

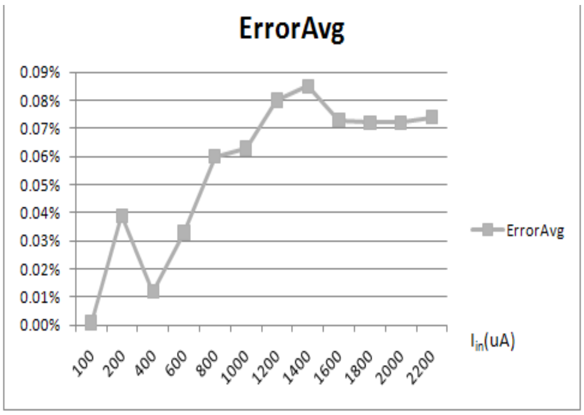

Figure 7. Error of the Input uA Current

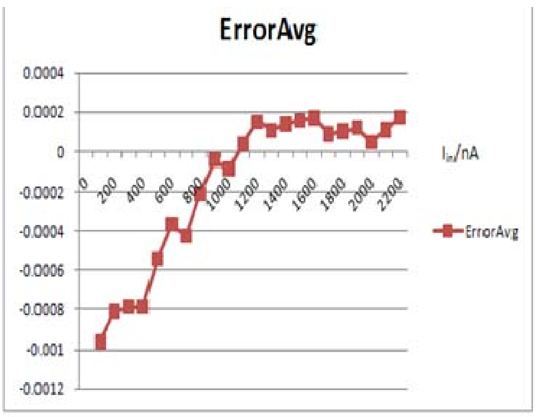

Figure 8. Error of the Input nA Current

Figure 7 shows the measurement data error rate. It is calculated by (2) with the five circiles average value of experiment data. The error rate increases with increasing input current. From Figure 7, we can see that when the input current passes the 1400uA, the error rate is about 0.072%, which is caused by the denominator increaseing faster than the numerator of (2). Phenomenon of nA is the same as the current of uA.The highest error rate △ of uA is 0.085%, which can satisfy most low-current systems. When the current of uA becomes small, the error rate is become small too, which is near the zero. From Figure 8, we can see that with the current increasing, the error rate becomes small; when the current of nA passes 1400nA, the error rate becomes less than 0.02%. However, From Figure 8, we can also see that with the current becomes small, the error rate becomes large reversely, which is caused by the precision of resistence, the offset voltage, noise and PCB leakage current. Offset adjustment circuits can be used to improve the presition.The highest error rate △ of nA is 0.1%, which can satisfy most low-current systems.

4. Conclusion

We have presented the I/V converter circuit and its technical characteristics with two-channel ranges. The essential features of the I/V converter are its simplicity and high precision with a frequency range of 1MHz. The dual polarity power and power detector is conveniently used. The measurement data are analysed and error rate is low. Circuit techniques are important for the realization of high presition of I/V converter. The highest error rate △ of uA is 0.085%, which can satisfy most low-current systems. The highest error rate △ of nA is 0.1%, which can satisfy most low-current systems. The Linearity is analized. The I/V converter is used in the detection of low uA and nA current systems, chips, and modules.

Acknowledgements

This work was supported in part by the National Natural Science Foundation of China (Grant No. 60976028 and 61204040), Beijing Municipal Natural Science Foundation (Grant No. 4123092), and Advanced Technology Foundation (Grant No. 002000514312004 and No. 002000514311013).

References

[1] David L Jones. The µCurrent A professional precision current adapter for Multimeters, 2006; 1-19.
[2] L Libioulle, A Radenovic, E Bystrenová, G Dietler. Study of Probes and Substrates for Low Temperature Atomic Force Microscopy and Biological Applications. *Acta Physica Polonica A.* 2003; 104(3-4); 373-380.
[3] A Yu Kuzin, PA Todua, VI Panov, AI Oreshkin. Reconstructed Silicon Survaces for Calibration of Scanning Tunnel Microscopes. *Measurement Techniques.* 2012; 55(7): 773-779.
[4] Francesco Forti, Michael E. Wright. Measurement of MOS Current Mismatch in the Weak Inversion Region. *IEEE Journal of Solid-StateCircuits*. 1994; 29(2): 138-142.
[5] P Pookaiyaudom, A Worapishet, FJ Lidgey, K Hayatleh, C Toumazou. Measurement of cell and bacterial activity using array-based ISFET Chemical Current-Conveyor in weak-inversion. *IEEE International Symposium on Circuits and Systems.* 2012; 2059-2062.
[6] S Holt1, P Skyba. Electrometric direct current I/V converter with wide bandwidth. *Review of Scientific Instruments*. 2012; 83: 64703-5.
[7] Lei Lin, Yuankai Liu, Wang Ping, Fang Hong. The Electric Vehicle Lithium Battery Monitoring System. *TELKOMNIKA Indonesian Journal of Electrical Engineering.* 2013; 11(4): 2247-2252.
[8] Lin W ei, Fu Changwei. Research on nA Level Current M easuring Circuit and Anti-Jamming Technology.*Micronanoelectonic Technology.* 2008; 45(7): 419-422.
[9] Yinchuan Wu, Baolong Guo, Jiatian Zhang, Zhengguo Yan. Study on Defect Detecting and Locating Method of Tubular Cylindrical Conductor. *TELKOMNIKA Indonesian Journal of Electrical Engineering.* 2013; 11(6): 3251-3258.
[10] MAX4238/MAX4239P, Handbook of MAX4238/MAX4239P.
[11] Chao-Yang Zhou ab, Hong Su a, Rui-Shi Mao a, Cheng-Fu Dong a, Yi Qian a, Jie Kong. An accurate low current measurement circuit for heavy iron beam current monitor. *Nuclear Instruments and Methods in Physics Research* B. 2012; 280: 84–87.
[12] Handbook of MCP6001/2/4.
[13] CHEN Guo-jie, XU Zhi-ming. The design of programmable weak current amplifier based on ICL7650. *Journal o f Foshan University (Natural Science Edit ion).* 2001; 19 (4): 9-11.
[14] Yu Hai-yang, Yuan Rui-ming, Wang Chang-rui, Du Yu-lei. Overview of Low Current Measurement. North China Electric Power. 2006; 11: 51-54.
[15] She Qianshun, Zhao Hongyun, Su Hong, Ma Xiaoli, LI Xiaogang. The development of a long-time current integration digitizer. *Nuclear Techniques*. 2010; 33(11): 867-870.
[16] Huilan Huang, Lingyun Wang, Yinhong Dai, Daoheng Sun. *Weak Current Detection Technique for Electrostatic Droplet Ejection*. International Workshop on Intelligent Systems and Applications. 2009; 1-5.