

ISSN 1726-5479

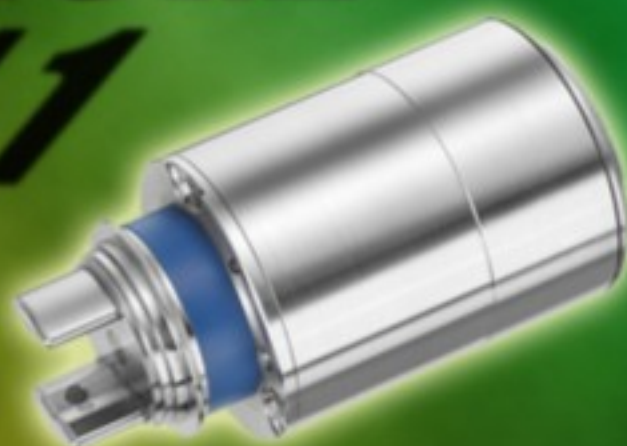
SENSORS & TRANSDUCERS

9^{vol. 96}
/08

IEEE 1451



**TEDS Sensors,
IEEE 1451 Standards**



International Frequency Sensor Association Publishing



Editor-in-Chief: professor Sergey Y. Yurish, phone: +34 696067716, fax: +34 93 4011989,
e-mail: editor@sensorsportal.com

Editors for Western Europe

Meijer, Gerard C.M., Delft University of Technology, The Netherlands
Ferrari, Vittorio, Università di Brescia, Italy

Editors for North America

Datskos, Panos G., Oak Ridge National Laboratory, USA
Fabien, J. Josse, Marquette University, USA
Katz, Evgeny, Clarkson University, USA

Editor South America

Costa-Felix, Rodrigo, Inmetro, Brazil

Editor for Eastern Europe

Sachenko, Anatoly, Ternopil State Economic University, Ukraine

Editor for Asia

Ohyama, Shinji, Tokyo Institute of Technology, Japan

Editorial Advisory Board

Abdul Rahim, Ruzairi, Universiti Teknologi, Malaysia
Ahmad, Mohd Noor, Northern University of Engineering, Malaysia
Annamalai, Karthigeyan, National Institute of Advanced Industrial Science and Technology, Japan
Arcega, Francisco, University of Zaragoza, Spain
Arguel, Philippe, CNRS, France
Ahn, Jae-Pyoung, Korea Institute of Science and Technology, Korea
Arndt, Michael, Robert Bosch GmbH, Germany
Ascoli, Giorgio, George Mason University, USA
Atalay, Selcuk, Inonu University, Turkey
Atghiaee, Ahmad, University of Tehran, Iran
Augutis, Vyngantas, Kaunas University of Technology, Lithuania
Avachit, Patil Lalchand, North Maharashtra University, India
Ayesh, Aladdin, De Montfort University, UK
Bahreyni, Behraad, University of Manitoba, Canada
Baoxian, Ye, Zhengzhou University, China
Barford, Lee, Agilent Laboratories, USA
Barlingay, Ravindra, RF Arrays Systems, India
Basu, Sukumar, Jadavpur University, India
Beck, Stephen, University of Sheffield, UK
Ben Bouzid, Sihem, Institut National de Recherche Scientifique, Tunisia
Binnie, T. David, Napier University, UK
Bischoff, Gerlinde, Inst. Analytical Chemistry, Germany
Bodas, Dhananjay, IMTEK, Germany
Borges Carval, Nuno, Universidade de Aveiro, Portugal
Bousbia-Salah, Mounir, University of Annaba, Algeria
Bouvet, Marcel, CNRS – UPMC, France
Brudzewski, Kazimierz, Warsaw University of Technology, Poland
Cai, Chenxin, Nanjing Normal University, China
Cai, Qingyun, Hunan University, China
Campanella, Luigi, University La Sapienza, Italy
Carvalho, Vitor, Minho University, Portugal
Cecelja, Franjo, Brunel University, London, UK
Cerda Belmonte, Judith, Imperial College London, UK
Chakrabarty, Chandan Kumar, Universiti Tenaga Nasional, Malaysia
Chakravorty, Dipankar, Association for the Cultivation of Science, India
Changhai, Ru, Harbin Engineering University, China
Chaudhari, Gajanan, Shri Shivaji Science College, India
Chen, Jiming, Zhejiang University, China
Chen, Rongshun, National Tsing Hua University, Taiwan
Cheng, Kuo-Sheng, National Cheng Kung University, Taiwan
Chiriac, Horia, National Institute of Research and Development, Romania
Chowdhuri, Arijit, University of Delhi, India
Chung, Wen-Yaw, Chung Yuan Christian University, Taiwan
Corres, Jesus, Universidad Publica de Navarra, Spain
Cortes, Camilo A., Universidad Nacional de Colombia, Colombia
Courtois, Christian, Université de Valenciennes, France
Cusano, Andrea, University of Sannio, Italy
D'Amico, Arnaldo, Università di Tor Vergata, Italy
De Stefano, Luca, Institute for Microelectronics and Microsystem, Italy
Deshmukh, Kiran, Shri Shivaji Mahavidyalaya, Barshi, India
Dickert, Franz L., Vienna University, Austria
Dieguez, Angel, University of Barcelona, Spain
Dimitropoulos, Panos, University of Thessaly, Greece
Ding Jian, Ning, Jiangsu University, China
Djordjevic, Alexander, City University of Hong Kong, Hong Kong
Ko, Sang Choon, Electronics and Telecommunications Research Institute,

Donato, Nicola, University of Messina, Italy
Donato, Patricio, Universidad de Mar del Plata, Argentina
Dong, Feng, Tianjin University, China
Drljaca, Predrag, Intersema Sensoric SA, Switzerland
Dubey, Venkatesh, Bournemouth University, UK
Enderle, Stefan, University of Ulm and KTB Mechatronics GmbH, Germany
Erdem, Gursan K. Arzum, Ege University, Turkey
Erkmen, Aydan M., Middle East Technical University, Turkey
Estelle, Patrice, Insa Rennes, France
Estrada, Horacio, University of North Carolina, USA
Faiz, Adil, INSA Lyon, France
Fericean, Sorin, Balluff GmbH, Germany
Fernandes, Joana M., University of Porto, Portugal
Francioso, Luca, CNR-IMM Institute for Microelectronics and Microsystems, Italy
Francis, Laurent, University Catholique de Louvain, Belgium
Fu, Weiling, South-Western Hospital, Chongqing, China
Gaura, Elena, Coventry University, UK
Geng, Yanfeng, China University of Petroleum, China
Gole, James, Georgia Institute of Technology, USA
Gong, Hao, National University of Singapore, Singapore
Gonzalez de la Rosa, Juan Jose, University of Cadiz, Spain
Grael, Annette, Goteborg University, Sweden
Graff, Mason, The University of Texas at Arlington, USA
Guan, Shan, Eastman Kodak, USA
Guillet, Bruno, University of Caen, France
Guo, Zhen, New Jersey Institute of Technology, USA
Gupta, Narendra Kumar, Napier University, UK
Hadjiloucas, Sillas, The University of Reading, UK
Hashsham, Syed, Michigan State University, USA
Hernandez, Alvaro, University of Alcalá, Spain
Hernandez, Wilmar, Universidad Politecnica de Madrid, Spain
Homentcovschi, Dorel, SUNY Binghamton, USA
Horstman, Tom, U.S. Automation Group, LLC, USA
Hsiai, Tzung (John), University of Southern California, USA
Huang, Jeng-Sheng, Chung Yuan Christian University, Taiwan
Huang, Star, National Tsing Hua University, Taiwan
Huang, Wei, PSG Design Center, USA
Hui, David, University of New Orleans, USA
Jaffrezic-Renault, Nicole, Ecole Centrale de Lyon, France
Jaime Calvo-Galleg, Jaime, Universidad de Salamanca, Spain
James, Daniel, Griffith University, Australia
Janting, Jakob, DELTA Danish Electronics, Denmark
Jiang, Liudi, University of Southampton, UK
Jiang, Wei, University of Virginia, USA
Jiao, Zheng, Shanghai University, China
John, Joachim, IMEC, Belgium
Kalach, Andrew, Voronezh Institute of Ministry of Interior, Russia
Kang, Moonho, Sunmoon University, Korea South
Kaniusas, Eugenijus, Vienna University of Technology, Austria
Katake, Anup, Texas A&M University, USA
Kausel, Wilfried, University of Music, Vienna, Austria
Kavasoglu, Nese, Mugla University, Turkey
Ke, Cathy, Tyndall National Institute, Ireland
Khan, Asif, Aligarh Muslim University, Aligarh, India
Kim, Min Young, Koh Young Technology, Inc., Korea South

Korea South

Kockar, Hakan, Balikesir University, Turkey

Kotulska, Malgorzata, Wroclaw University of Technology, Poland

Kratz, Henrik, Uppsala University, Sweden

Kumar, Arun, University of South Florida, USA

Kumar, Subodh, National Physical Laboratory, India

Kung, Chih-Hsien, Chang-Jung Christian University, Taiwan

Lacnjevac, Caslav, University of Belgrade, Serbia

Lay-Ekuakille, Aime, University of Lecce, Italy

Lee, Jang Myung, Pusan National University, Korea South

Lee, Jun Su, Amkor Technology, Inc. South Korea

Lei, Hua, National Starch and Chemical Company, USA

Li, Genxi, Nanjing University, China

Li, Hui, Shanghai Jiaotong University, China

Li, Xian-Fang, Central South University, China

Liang, Yuanchang, University of Washington, USA

Liawruangrath, Saisunee, Chiang Mai University, Thailand

Liew, Kim Meow, City University of Hong Kong, Hong Kong

Lin, Hermann, National Kaohsiung University, Taiwan

Lin, Paul, Cleveland State University, USA

Linderholm, Pontus, EPFL - Microsystems Laboratory, Switzerland

Liu, Aihua, University of Oklahoma, USA

Liu Changgeng, Louisiana State University, USA

Liu, Cheng-Hsien, National Tsing Hua University, Taiwan

Liu, Songqin, Southeast University, China

Lodeiro, Carlos, Universidade NOVA de Lisboa, Portugal

Lorenzo, Maria Encarnacio, Universidad Autonoma de Madrid, Spain

Lukasiewicz, Jerzy Pawel, Nicholas Copernicus University, Poland

Ma, Zhanfang, Northeast Normal University, China

Majstorovic, Vidosav, University of Belgrade, Serbia

Marquez, Alfredo, Centro de Investigacion en Materiales Avanzados, Mexico

Matay, Ladislav, Slovak Academy of Sciences, Slovakia

Mathur, Prafull, National Physical Laboratory, India

Maurya, D.K., Institute of Materials Research and Engineering, Singapore

Mekid, Samir, University of Manchester, UK

Melnyk, Ivan, Photon Control Inc., Canada

Mendes, Paulo, University of Minho, Portugal

Mennell, Julie, Northumbria University, UK

Mi, Bin, Boston Scientific Corporation, USA

Minas, Graca, University of Minho, Portugal

Moghavvemi, Mahmoud, University of Malaya, Malaysia

Mohammadi, Mohammad-Reza, University of Cambridge, UK

Molina Flores, Esteban, Benemérita Universidad Autónoma de Puebla, Mexico

Moradi, Majid, University of Kerman, Iran

Morello, Rosario, DIMET, University "Mediterranea" of Reggio Calabria, Italy

Mounir, Ben Ali, University of Sousse, Tunisia

Mukhopadhyay, Subhas, Massey University, New Zealand

Neelamegam, Periasamy, Sastra Deemed University, India

Neshkova, Milka, Bulgarian Academy of Sciences, Bulgaria

Oberhammer, Joachim, Royal Institute of Technology, Sweden

Ould Lahoucine, University of Guelma, Algeria

Pamidighanta, Sayanu, Bharat Electronics Limited (BEL), India

Pan, Jisheng, Institute of Materials Research & Engineering, Singapore

Park, Joon-Shik, Korea Electronics Technology Institute, Korea South

Penza, Michele, ENEA C.R., Italy

Pereira, Jose Miguel, Instituto Politecnico de Seteбал, Portugal

Petsev, Dimiter, University of New Mexico, USA

Pogacnik, Lea, University of Ljubljana, Slovenia

Post, Michael, National Research Council, Canada

Prance, Robert, University of Sussex, UK

Prasad, Ambika, Gulbarga University, India

Prateepasen, Asa, Kingmoungut's University of Technology, Thailand

Pullini, Daniele, Centro Ricerche FIAT, Italy

Pumera, Martin, National Institute for Materials Science, Japan

Radhakrishnan, S., National Chemical Laboratory, Pune, India

Rajanna, K., Indian Institute of Science, India

Ramadan, Qasem, Institute of Microelectronics, Singapore

Rao, Basuthkar, Tata Inst. of Fundamental Research, India

Raoof, Kosai, Joseph Fourier University of Grenoble, France

Reig, Candid, University of Valencia, Spain

Restivo, Maria Teresa, University of Porto, Portugal

Robert, Michel, University Henri Poincare, France

Rezazadeh, Ghader, Urmia University, Iran

Royo, Santiago, Universitat Politècnica de Catalunya, Spain

Rodriguez, Angel, Universidad Politécnica de Cataluna, Spain

Rothberg, Steve, Loughborough University, UK

Sadana, Ajit, University of Mississippi, USA

Sadeghian Marnani, Hamed, TU Delft, The Netherlands

Sandacci, Serghei, Sensor Technology Ltd., UK

Sapozhnikova, Ksenia, D.I.Mendeleyev Institute for Metrology, Russia

Saxena, Vibha, Bhabha Atomic Research Centre, Mumbai, India

Schneider, John K., Ultra-Scan Corporation, USA

Seif, Selemeni, Alabama A & M University, USA

Seifter, Achim, Los Alamos National Laboratory, USA

Sengupta, Deepak, Advance Bio-Photonics, India

Shearwood, Christopher, Nanyang Technological University, Singapore

Shin, Kyuho, Samsung Advanced Institute of Technology, Korea

Shmaliy, Yuriy, Kharkiv National University of Radio Electronics, Ukraine

Silva Girao, Pedro, Technical University of Lisbon, Portugal

Singh, V. R., National Physical Laboratory, India

Slomovitz, Daniel, UTE, Uruguay

Smith, Martin, Open University, UK

Soleymannpour, Ahmad, Damghan Basic Science University, Iran

Somani, Prakash R., Centre for Materials for Electronics Technol., India

Srinivas, Talabattula, Indian Institute of Science, Bangalore, India

Srivastava, Arvind K., Northwestern University, USA

Stefan-van Staden, Raluca-Ioana, University of Pretoria, South Africa

Sumriddetchka, Sarun, National Electronics and Computer Technology Center, Thailand

Sun, Chengliang, Polytechnic University, Hong-Kong

Sun, Dongming, Jilin University, China

Sun, Junhua, Beijing University of Aeronautics and Astronautics, China

Sun, Zhiqiang, Central South University, China

Suri, C. Raman, Institute of Microbial Technology, India

Sysoev, Victor, Saratov State Technical University, Russia

Szeczyk, Roman, Industrial Research Institute for Automation and Measurement, Poland

Tan, Ooi Kiang, Nanyang Technological University, Singapore,

Tang, Dianping, Southwest University, China

Tang, Jaw-Luen, National Chung Cheng University, Taiwan

Teker, Kasif, Frostburg State University, USA

Thumbavanam Pad, Kartik, Carnegie Mellon University, USA

Tian, Gui Yun, University of Newcastle, UK

Tsiantos, Vassilios, Technological Educational Institute of Kaval, Greece

Tsigara, Anna, National Hellenic Research Foundation, Greece

Twomey, Karen, University College Cork, Ireland

Valente, Antonio, University, Vila Real, - U.T.A.D., Portugal

Vaseashta, Ashok, Marshall University, USA

Vazques, Carmen, Carlos III University in Madrid, Spain

Vieira, Manuela, Instituto Superior de Engenharia de Lisboa, Portugal

Vigna, Benedetto, STMicroelectronics, Italy

Vrba, Radimir, Brno University of Technology, Czech Republic

Wandelt, Barbara, Technical University of Lodz, Poland

Wang, Jiangping, Xi'an Shiyou University, China

Wang, Kedong, Beihang University, China

Wang, Liang, Advanced Micro Devices, USA

Wang, Mi, University of Leeds, UK

Wang, Shinn-Fwu, Ching Yun University, Taiwan

Wang, Wei-Chih, University of Washington, USA

Wang, Wensheng, University of Pennsylvania, USA

Watson, Steven, Center for NanoSpace Technologies Inc., USA

Weiping, Yan, Dalian University of Technology, China

Wells, Stephen, Southern Company Services, USA

Wolkenberg, Andrzej, Institute of Electron Technology, Poland

Woods, R. Clive, Louisiana State University, USA

Wu, DerHo, National Pingtung University of Science and Technology, Taiwan

Wu, ZhaoYang, Hunan University, China

Xiu Tao, Ge, Chuzhou University, China

Xu, Lisheng, The Chinese University of Hong Kong, Hong Kong

Xu, Tao, University of California, Irvine, USA

Yang, Dongfang, National Research Council, Canada

Yang, Wuqiang, The University of Manchester, UK

Ymeti, Aurel, University of Twente, Netherland

Yong Zhao, Northeastern University, China

Yu, Haihu, Wuhan University of Technology, China

Yuan, Yong, Massey University, New Zealand

Yufera Garcia, Alberto, Seville University, Spain

Zagnoni, Michele, University of Southampton, UK

Zeni, Luigi, Second University of Naples, Italy

Zhong, Haoxiang, Henan Normal University, China

Zhang, Minglong, Shanghai University, China

Zhang, Quintao, University of California at Berkeley, USA

Zhang, Weiping, Shanghai Jiao Tong University, China

Zhang, Wenming, Shanghai Jiao Tong University, China

Zhou, Zhi-Gang, Tsinghua University, China

Zorzano, Luis, Universidad de La Rioja, Spain

Zourob, Mohammed, University of Cambridge, UK

Contents

Volume 96
Issue 9
September 2008

www.sensorsportal.com

ISSN 1726-5479

Research Articles

Design and Fabrication of Micromachined Absolute Micro Pressure Sensor <i>P. A. Alvi, J. Akhtar, K. M. Lal, S. A. H. Naqvi and A. Azam</i>	1
A Micromechanical Sensor of Temperature Based on Surface Plasmons Resonance <i>Juriy Hastanin, Yvon Renotte, Karl Fleury-Frenette, Serge Habraken</i>	8
Recent Advances in Lactate Estimation and Lactate Sensors for Diagnosis of Diseases <i>Suman and Ashok Kumar</i>	18
Sensitivity Evaluation of a Love Wave Sensor with Multi-guiding-layer Structure for Biochemical Application, Wen Wang, Shitang He	32
Morphological and Humidity Sensing Studies Of WO₃ Mixed With ZnO And TiO₂ Powders <i>N. K. Pandey, Anupam Tripathi, Karunesh Tiwari, Akash Roy, Amit Rai, Priyanka Awasthi, Aradhana Mishra, Alok Kumar</i>	42
A Bioelectrical Impedance Analysis Device for Monitoring Haemoglobin Status in Dengue Patients, Herlina Abdul Rahim, Fatimah Ibrahim, Mohd Nasir Taib And Ruzairi Abdul Rahim	47
Studies on Gas Sensing Performance of Pure and Li₂O-modified CdIn₂O₄ Thick Film Resistors, L. A. Patil, M. D. Mahanubhav	56
Benzene and Toluene Vapor Sensing Properties of Sr(II)-added Barium Aluminate Spinel Composites, B. Jeyaraj, L. John Kennedy, G. Sekaran and J. Judith Vijaya	68
Direct Monitoring and Control of Transformer Temperature in Order to Avoid its Breakdown Using FOS, Deepika Yadav, A. K. Nadir and Pragati Kapoor	81
Multi Channels PWM Controller for Thermoelectric Cooler Using a Programmable Logic Device and Lab-Windows CVI, Eli Flaxer	93
Study of A Modified AC Bridge Technique for Loss Angle Measurement of a Dielectric Material, S. C. Bera and D. N. Kole	104
Analysis of Programmable Voltage Source Under Power Supply Interference <i>Sheroz Khan, Salami Femi Abdulazeez, Lawal Wahab Adetunji</i>	112
Assessment of Structural Behavior of Non-corroded and Corroded RCC Beams Using Finite Element Method, Anand Parande, P. Dhayalan, M. S. Karthikeyan, K. Kumar and N. Palaniswamy	120

Authors are encouraged to submit article in MS Word (doc) and Acrobat (pdf) formats by e-mail: editor@sensorsportal.com
Please visit journal's webpage with preparation instructions: <http://www.sensorsportal.com/HTML/DIGEST/Submission.htm>

Multi Channels PWM Controller for Thermoelectric Cooler Using a Programmable Logic Device and Lab-Windows CVI

Eli FLAXER

AFEKA - Tel-Aviv Academic College of Engineering
218 Bney Efrayim Rd. 69107 Tel-Aviv, Israel
Tel.: +972-3-6449344
E-mail: flaxer@afeka.ac.il

Received: 16 July 2008 /Accepted: 15 September 2008 /Published: 30 September 2008

Abstract: We present a complete design of a multi channels PID controller for Thermoelectric Cooler (TEC) using a pulse width modulation (PWM) technique implemented by a dedicated programmable logic device (PLD) programmed by VHDL. The PID control loop is implemented by software written by National Instrument Lab-Windows CVI. Due to the fact that the implementation is by a VHDL and PLD the design is modular, as a result, the circuit is very compact in size and very low cost as compared to any commercial product. In addition, since the control loop is implemented by software running on a personal computer (PC) using a C language, it is easy to adjust the controller to various environmental conditions and for a width range of sensors like: a thermo couple (TC), thermistor, resistance temperature detectors (RTD) etc. We demonstrate the performance of this circuit as a controller for a small incubator using thermistor as the temperature sensor. *Copyright © 2008 IFSA.*

Keywords: Thermoelectric cooler, PID controller, Programmable logic

1. Introduction

Temperature control is needed for a wide range of applications. For some, a precision of ± 1 °C is satisfactory, but accurate applications require precision of ± 0.1 °C and in some cases even better. For example, the performances of electro-optics devices depend strongly on temperature; hence, these devices require high precision temperature control [1]. Analogously, in bio-tech systems a constant regulation with a precision of a 0.1 °C is satisfactory. Moreover, in several systems it is not sufficient to regulate the temperature to a constant value, but instead, an optimization procedure is required. In

systems like these, feedback control mechanisms vary the target temperature to maximize the output signal from the device under control.

Thermoelectric Coolers (TEC) [2, 3, 4] are solid state heat pumps that operate according to the Peltier effect [5] - a heating or cooling effect when an electric current passes through two conductors. A voltage applied to the free ends of two dissimilar materials creates a temperature difference. With this temperature difference, Peltier cooling will cause heat to move from one end to the other. The heat pumping capacity of a cooler is proportional to the current and the number of pairs of n- and p- type elements.

In this work we present a complete design of a multi channels PID controller for TEC, implemented by a dedicated programmable logic device (PLD) that is programmed by very high-speed integrated circuit hardware description language (VHDL). The PID control loop is implemented by software written by National Instrument [6] Lab-Windows CVI. We introduce, in detail, the design of a 4 channels controller and then explain how to expand it to 32 channels. The design is modular due to the fact that the implementation is by a VHDL and PLD. As a result, the circuit is very compact in size and at very low cost.

2. Design Considerations

The controller, presented here, was developed to operate with a variety TECs, at a wide temperature range, with variety sensors like: thermo couple (TC), thermistor, and resistance temperature detectors (RTD). The controller is connected to a personal computer (PC) via the standard parallel port - to set the outputs power and monitoring the actual temperature, while the PID control loop is implemented by software on the PC. To achieve a compact design with high efficiency, we used a high frequency PWM technique with a small coil filter. High frequency PWM technique combines the advantages of high efficiency energy transfer and a very low ripple at the output. As mentioned above, the TEC heat pump capacity is proportional to the current flow through the device, this means that by inverting the current direction, one converts the cooler to a heater and vice versa. To improve the controller performance, we drive the TEC with a bi-directional current, switched by full-bridge solid-state devices.

3. Electronic Circuit

Fig. 1 is the circuit diagram of the 4 channels controller. The major device in the circuit is U_1 - the digital control unit, which is comprised of one Complex Programmable Logic Device (CPLD) timed by a 25 MHz clock - U_3 . The CPLD was programmed on board through JTAG (J_2), and implements the following:

1. Communicating with a PC in Enhance Parallel Port (EPP) mode thru J_1 .
2. Controlling the data acquisition unit - U_2 .
3. Implementing the multi channels 256 levels PWM controller.

The PWM outputs of the CPLD are connected to the full bridge power devices - U_4 and U_5 . The bridge - L298 - converts the TTL logic level to power pulses of up to 36 V and up to 2.5 A. The outputs of the bridge are filtered by low pass filters (L_3 - L_{10} and C_9 - C_{16}) in order to achieve a DC level on the TECs that are connected to JP_5 - JP_8 .

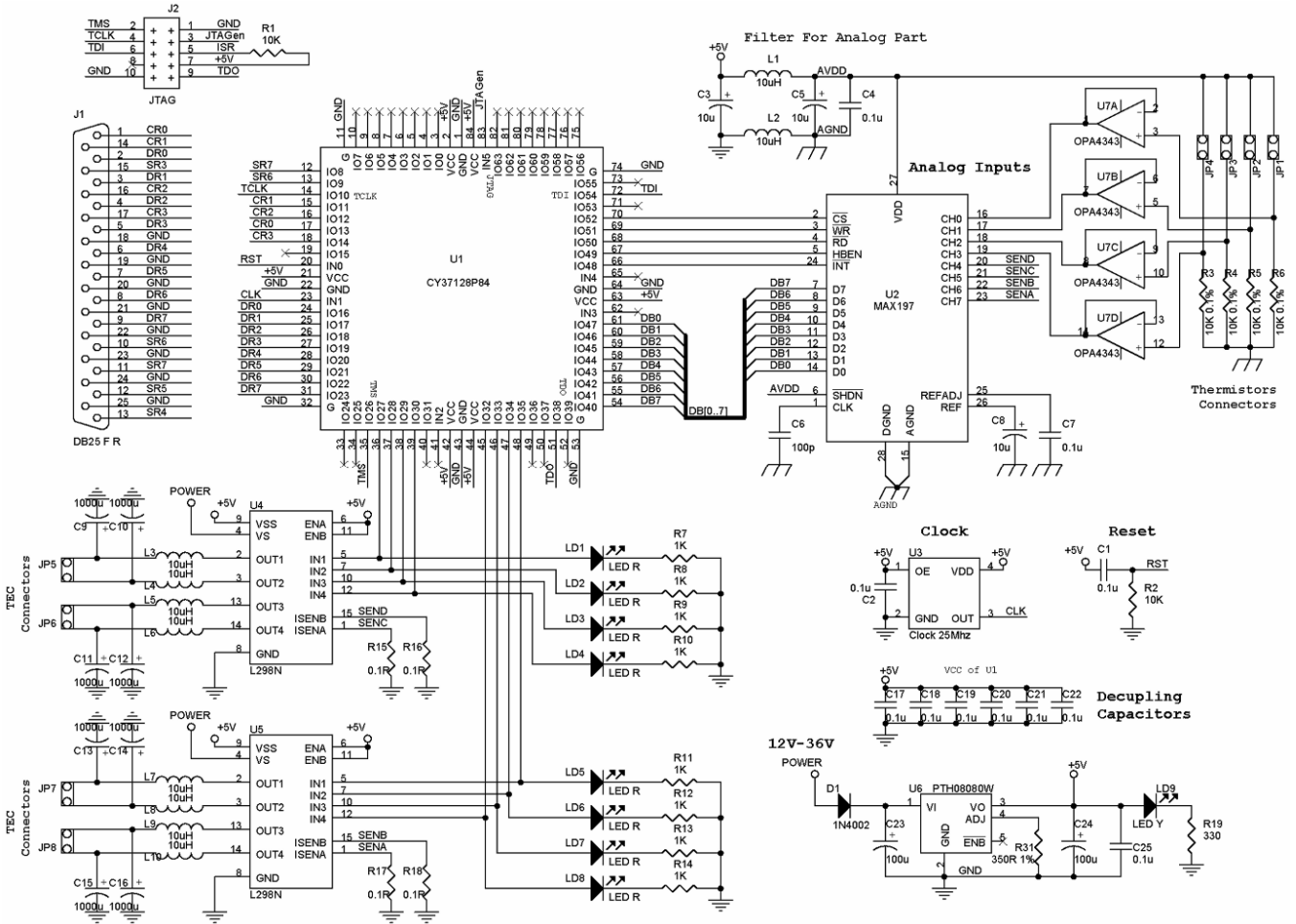


Fig. 1. The controller circuit diagram.

The temperatures of the regulated objects, attached to the TECs are sampled by Negative Temperature Coefficient (NTC) thermistors [7] that are connected to JP₁-JP₄. The room temperature resistance of the sampling thermistor is 10 kΩ while its B_{25/100}-Constant is 3988 K which leads to a resistance of 32.65 KΩ at 0 °C and 0.68 KΩ at 100 °C. Each thermistor is serially connected to a 10 KΩ 0.1% reference resistor (R₃-R₆) and both form a voltage divider whose configuration depends on the temperature of the object. The output voltage of this divider V_M - runs between 0 V-5 V ruling by the expression $5V \cdot \{R_{25}/(R_{25}+R_K)\}$. Where R_K - the thermistor resistance at temperature T_K - is defined by $R_K = R_{25} \cdot \exp \{B \cdot (1/T_K - 1/T_{25})\}$. If we defined:

$$\alpha \equiv R_K/R_{25} = \exp \{B \cdot (1/T_K - 1/T_{25})\} \quad (1)$$

and

$$\beta \equiv R_{25}/(R_{25}+R_K) \quad (2)$$

It is easy to see that $\alpha = 1/\beta - 1$, thus the transformation between the temperature and the measuring voltage V_M is:

$$1/T_K = 1/T_{25} + 1/B \cdot \ln(1/\beta - 1), \quad (3)$$

where $\beta = V_M / 5V$.

The data acquisition unit – U_2 is made of a single Analog to Digital Converter (DAC) that operates with an internal reference and clock. The MAX197 [8] is a multi range, 12 bit data acquisition system, which requires only a single +5 V supply for operation. This converter provides 8 analog input channels that are independently software programmable for a variety of ranges: ± 10 V, ± 5 V, 0 V to +10 V, or 0 V to +5 V, while the input is protected against an over voltage of ± 16.5 V. This converter supports an 8 + 4 bits parallel interface to a microprocessor, and an internal reference of 4.096 V. Four channels of this unit are connected to thermistors to monitor the temperature, while the other channels monitor the TEC's currents. Since the converter inputs current is several hundreds micro ampere, we buffered the inputs by U_7 - single-supply, rail-to-rail, CMOS operational amplifiers.

U_6 is a DC to DC converter that accepts 12 V-18 V in its input and converts it to 5 V on the output. In order to work with voltage above 18 V, one must replace this converter by others that work with 36 V.

4. Chipset Design

Digital designs are increasingly based on programmable logic devices. These devices are very flexible, inexpensive, and replace many basic logic parts with a single high-density device. The designs become very compact, small in size, and ultra-fast. There are several methods to design, synthesize, and simulate the content of the programmable logic: Hardware Description Language (HDL) as Verilog and VHDL, Schematic Editors, and more. This design is implemented by VHDL using Synplify 8.5 [9] to synthesize and Active-HDL 6.3 [10] to simulate the CPLD.

Our device - CY37128P84 from Cypress Semiconductor [11] - includes all the logic of the circuit and functions as a chipset of the system. Since the parallel port does not include an address bus, we must read or write any data in two cycles, first writing the address and afterwards reading or writing the relevant data. Moreover, due to the fact that the parallel port data bus consists of only 8 bits, while the converters resolution is of 12 bits, each analog data should map on 2 addresses in the chipset; low byte and high byte. By using this architecture each register in the chipset has its own local address:

- 0 – ADCL : read-low byte of ADC.
- 1 – ADCH : read-high byte of ADC.
- 2 – ADCS : write-start conversion / read-end of conversion.
- 3 – PWM1 : write-PWM1 duty cycle.
- 4 – PWM2 : write-PWM2 duty cycle.
- 5 – PWM3 : write-PWM3 duty cycle.
- 6 – PWM4 : write-PWM4 duty cycle.
- 7 – ENABLE : write-enable to the 8 PWM outputs.

The internal architecture of the CPLD is based on the state machine that is shown in Fig. 2.

At IDLE state, the machine is waiting for an Address Strobe (nA) or a Data Strobe (nD). If nA is detected, the machine starts an address write cycles, or, if nD is detected, the machine starts a data read/write cycle. At an ASTB state, the relevant address is saved in the internal register. At an STB state, the machine sets the proper chip selection to the peripheral, while the nWrite signal determines the cycle mode - write data or read data. At WRn and RD1 states, the machine transfers the specified data between the peripherals and the register, as can be seen in Fig. 2.

The implementation of the four bipolar PWM channels in VHDL is very simple. Fig. 3 shows a VHDL list in one process that implements all the PWM channels. The clock (clk) is 25 MHz while the counter (cnt) is 8 bits, thus, the modulation frequency is about 100 kHz ($25 \text{ MHz} / 2^8$).

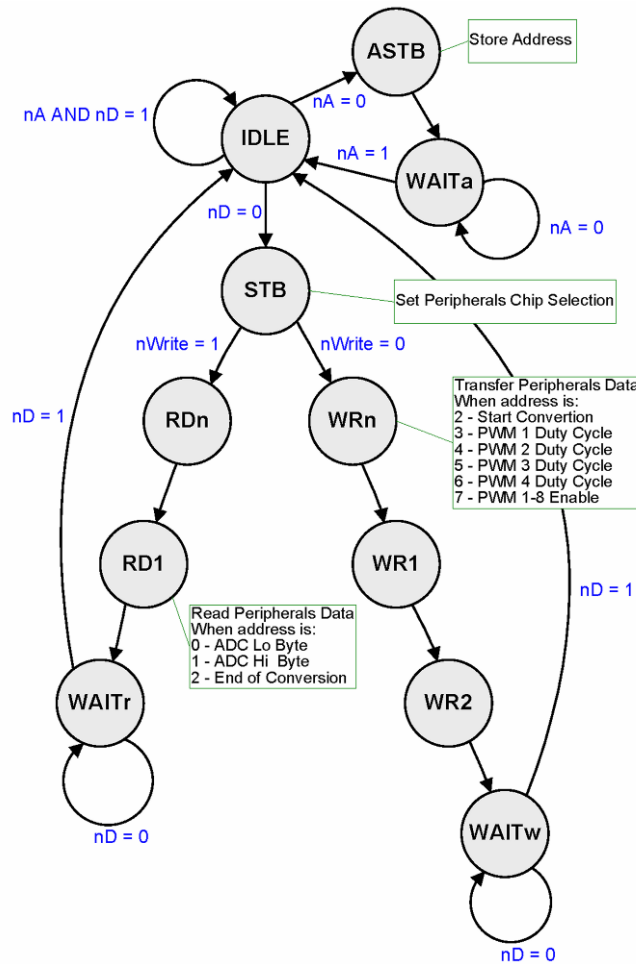


Fig. 2. The chipset state machines diagram.

```

-----
PwmUpdate: process (clk)
  variable T: boolean;
begin
  if Rising Edge (clk) then
    Cnt <= Cnt + 1;
  end if;
  for k in 0 to 7 loop
    T := (Cnt < Duty(k/2)) and (PWMen(k) = '1');
    PWM(k) <= std_logic(T);
  end loop;
end process;
-----

```

Fig. 3. A VHDL list in one process that implements the all PWM channels.

5. Drivers and Software

The communication between the PC and the chipset is achieved by a simple protocol. From the programmer's point of view, one needs three low-level functions (drivers): setAddress, writeData, and

readData to establish communication between the PC and the chipset. Above this low-level layer, the user needs a data acquisition library to translate the digital data to a real value (duty-cycle, temperature, etc.). These functions can be written in an assembly, C or any other high level language. We used C language to write both the low-level drivers and the data acquisition library. Fig. 4 and Fig. 5 show the low-level drivers that communicate with the parallel port in EPP mode and the data acquisition library.

```
#include <utility.h>
// Base address of parallel port
static unsigned Base = 0x378;
static const int idle = 0x04;
/*****/
void resetCard()
{
    outp(Base+2, 0x00);
    outp(Base+2, idle);
}
/*****/
void setAddr(int addr)
{
    outp(Base+3, addr);
}
/*****/
void writeData(int data)
{
    outp(Base+4, data);
}
/*****/
int readData()
{
    return(inp(Base+4));
}
/*****/
```

Fig. 4. The low-level drivers to communicate with the parallel port in EPP mode.

For the PC to control the system, we built a Graphical User Interface (GUI) using a National Instrument LabWindows CVI, as shown in Fig. 6. In this panel one sees a four strip chart - one for each control channel, targets temperature, PID coefficients, control type, TECs current, and sampled interval. The control type can choose from a list that includes: Open-Loop, On-Off, Proportional, Integral, Differential, as well as any of their combinations. As mentioned above, the PID loop is implemented by software, this means that the compensation expression is very flexible and in principal can even be a non-linear expression. The type of compensation and coefficient values should be determined by the user, as this will depend on the thermal response of the object and the TEC properties [12, 13, 14].

```

typedef unsigned char byte;

#include "EppDriver.h"

#define READ_TIME_OUT    1000
#define TIME_OUT_ERROR   -1.0
#define MAX_VOLT_IN      5.00

#define ADCL              0x00
#define ADCH              0x01
#define ADCS              0x02
#define PWM1              0x03
#define PWM2              0x04
#define PWM3              0x05
#define PWM4              0x06
#define ENABLE            0x07
/*****/
double AnalogIn(byte Chan)
{
    #define    BIP        0    // 1 - Bipolar    0 - Unipolar
    #define    RNG        0    // 1 - 10V        0 - 5V
    #define    ACQ        0    // 0 - Internal Acquisition
    #define    PD10       1    // Normal Operation & Internal Clock

    short temp;
    byte lo, hi;
    int time = READ_TIME_OUT;
    setAddr(ADCS);
    writeData((PD10<<6) | (ACQ<<5) | (RNG<<4) | (BIP<<3) | (Chan&0x07));

    while (readData() & 0x01) // Wait for Int
        if (time-- == 0) return (TIME_OUT_ERROR);

    setAddr(ADCL);
    lo = readData();
    setAddr(ADCH);
    hi = readData();

    temp = (short)((hi<<8) | lo);
    temp <= 4; temp >= 4; // expand the sign bit
    return( (double)(temp * MAX_VOLT_IN / 4096.0) );
}
/*****/
void PwmWriteDutyCycle(char Chan, byte Duty)
{
    setAddr(PWM1+Chan-1);
    writeData(Duty);
}
/*****/
void PWMAEnable(char Ena)
{
    setAddr(ENABLE);
    writeData(Ena);
}
/*****/

```

Fig. 5. The C language data acquisition library.

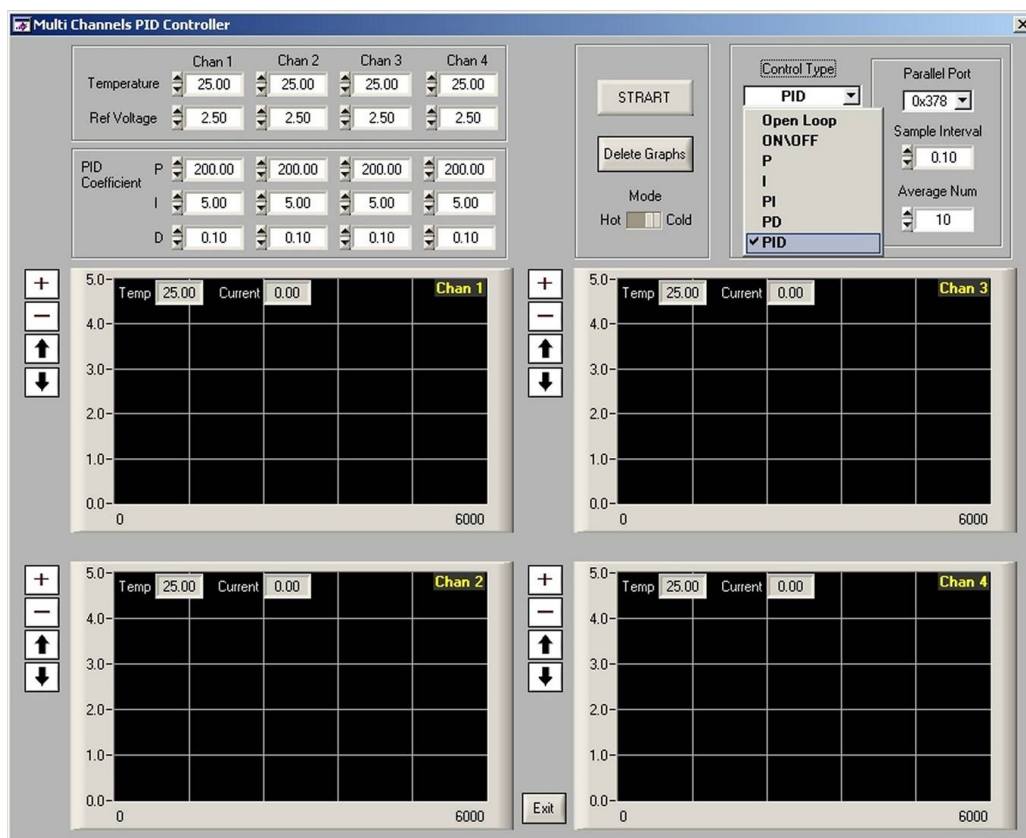


Fig. 6. The Graphical User Interface of the control program consists: four strip chart - one for each control channel, targets temperature, PID coefficients, control type, TEC current, and sampled interval. The control type can choose from a list that includes: Open-Loop, On-Off, Proportional, Integral, Differential, as well as any of these combinations.

Fig. 7 is the programming list of the PID compensation loop that receives the error and calculates the compensation value in duty cycle units (-250 to +250). In all cases we send the absolute value of this value to the PWM controller, while the sign determines the direction of the current in the bridge.

The analog acquisition time of the controller is about 20 μ s – much faster than the feedback-sampled interval, thus, there is no difficulty in simultaneously controlling all 4 channels. Moreover, since the loop sampling time is very short, we can average the sampled data 10 times for each point (to reduce the noise) and still then freeing the personal computer resources for other applications.

6. Expanding to 32 Channels

As one can understand, the design described above consists of 4 channels. Since we implemented the design by VHDL and PLD, it is therefore very simple to expand this controller to include more channels – using stronger CPLD. In order to expand the controller to 32 channels one is required to adjust the following:

- Replace the programmable logic device - U₁ by a stronger one – CY37512.
- Duplicate the entire analog and power units 8 times, using common data bus and separate chip selects.
- Expand the address register in the chipset to 64 addresses instead of 8 addresses.
- Change the loop index – K – in Fig. 3 from 7 to 63.
- Expand the commands in states WRn and RD1 of the state machine for 64 addresses.

```

/*****
int PID2Pwm(double pid)
{
    if (pid > 250.0) return (250);
    if (pid < -250.0) return (-250);
    return ((int)pid);
}
*****/
/*****
int CalculatePID(double err, int mode)
{
    static double eP, eI, eD;
    static double lasterr, divErr;

    if(mode==8) //ON\OFF
        return ((err>0.0) ? 200 : -200);

    sumErr += err*dt;
    divErr = (err-lasterr)/dt;
    lasterr = err;

    eP=eI=eD=0.0;
    if(mode & (1<<0)) //P
        eP = xP*err;

    if(mode & (1<<1)) //I
        eI = xI*sumErr;

    if(mode & (1<<2)) //D
        eD = xD*divErr;

    return (PID2Pwm(eP+eI+eD));
}
*****/

```

Fig. 7. The programming list of the PID compensation loop that gets the error and calculates the compensation value in duty cycle units (-250 to +250).

As a result, the overall circuit is very compact in size (20 cm²/channel) and very low in cost (10\$ per channel) as compared to any commercial product.

7. Results

The controller, described here, can be used by any system that basically requires 1 to 32 channels of temperature control. We used the controller to regulate the temperature of water, including bacteria, in 2 inches Petri dish. We used a 1 inch 15V/2A TEC [15] as a heater/cooler element; when a 25x25x0.4 mm piece of copper with a heat capacity of $\sim 1 \text{ J/C}^\circ$ is attached to the cold side of a TEC while its hot side is attached to the heat sink. The Petri dish is clamped to the copper piece when the temperature of this copper is sampled by the thermistor [7].

Fig. 8 shows a typical temperature time response produced by the TEC, at room temperature of 25 °C, when applying a 37 °C as the target temperature and using PID control. The feedback sampled interval was 0.1 sec and the data acquisition averaging is 10. The figure and data analysis show that the accuracy is better than 0.1°C while the stabilization time is about 2 minutes.

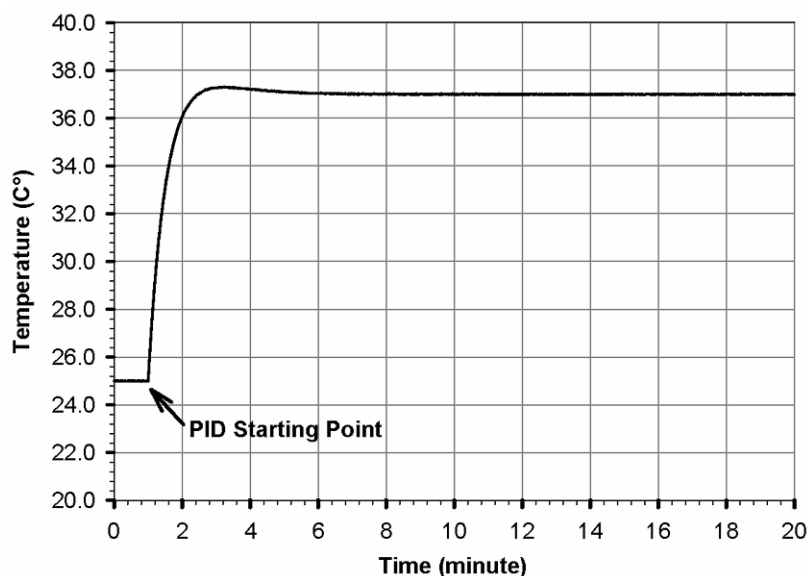


Fig. 8. A typical temperature time response produced by a TEC connected to the controller, at room temperature of 25 °C, when setting 37 °C as the target temperature. This figure shows that the stabilization time is about 2 minutes while the accuracy is around 0.1 °C.

8. Conclusion

In conclusion, we have demonstrated the complete design of a multi channels (4-32) PID controller for TEC that compatible to the several kinds of temperature sensors which can be used for systems that involve several channels of temperature control governed by a personal computer. Since we implemented the digital design by VHDL and PLD, it was therefore very simple to expand this controller to 32 channels, at the same time keeping the circuit very compact in size and at a very low cost compared to any commercial product.

Acknowledgment

I wish to thank Boris Fisherman for his help in building the setup of this experiment.

References

- [1]. E. Flaxer, *Rev. Sci. Instrum.*, 74, 2003, p. 3862.
- [2]. D. M. Rowe, *CRC Handbook of Thermoelectrics*, ISBN 0849301467, *CRC Press*, 1995.
- [3]. J. Sharp, H. J. Goldsmid, George Nolas, Julian Goldsmid, *Thermoelectrics: Basic Principles and New Materials Developments*, ISBN 354041245X, *Springer Verlag*, 2001.
- [4]. Marlow Industries, Inc, <http://www.marlow.com>
- [5]. Mark W. Zemansky, Richard H. Dittman, *Heat and Thermodynamics*, ISBN 0-07-072808-9, *McGraw-Hill*, NY, 1981, pp. 431-438.
- [6]. National Instrument: <http://www.ni.com>
- [7]. Thermistors model - Epcos B57703M0103G040.
- [8]. Maxim: <http://www.maxim-ic.com>
- [9]. Synplicity: <http://www.synplicity.com>
- [10]. Aldec: <http://www.aldec.com>
- [11]. Cypress Semiconductor: <http://www.cypress.com>
- [12]. Richard C. Dorf, Robert H. Bishop, *Modern Control System*, ISBN 0-201-84559-8, *Addison Wesley*, NY, 1995, pp. 662-670.

- [13].John J. D'Azzo, Constantine H. Houpis, Linear Control System, ISBN 0-07-113295-3, *McGraw-Hill*, NY, 1995, pp. 352-366.
- [14].John Van De Vegte, Feedback Control System, ISBN 0-13-191503-7, *Prentice_Hall*, NJ, 1994, pp. 246-257.
- [15].TEC model - Melcor CP 0.8-127-06.

2008 Copyright ©, International Frequency Sensor Association (IFSA). All rights reserved.
(<http://www.sensorsportal.com>)



SENSORS WEB PORTAL 

- **MEMS**
- **NEMS**
- **NANOSENSORS**
- **SMART SENSORS**



All about SENSORS
<http://www.sensorsportal.com>

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 addition, 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:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

Submission of papers

Articles should be written in English. Authors are invited to submit by e-mail editor@sensorsportal.com 6-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation instructions, paper example and template of manuscript are available from the journal's webpage: <http://www.sensorsportal.com/HTML/DIGEST/Submission.htm> Authors must follow the instructions strictly when submitting their manuscripts.

Advertising Information

Advertising orders and enquires may be sent to sales@sensorsportal.com Please download also our media kit: http://www.sensorsportal.com/DOWNLOADS/Media_Kit_2008.pdf



Smart Sensors Systems Design

A five-day advanced engineering course
10-14 November 2008, Barcelona, Spain



General Information

This course is suitable for engineers who design different digital and intelligent sensors, data acquisition, and measurement systems. It is also useful for researchers, graduate and post graduate students. Course will be taught in English.

Course Description

An advanced engineering course describes modern developments and trends in the field of smart sensor systems and digital sensors design.

After a general overview of data acquisition methods, modern smart, digital and quasi-digital sensors, smart systems details are discussed. A systematic approach towards the design of low-cost high-performance smart sensors systems with self-adaptation and self-identification possibilities is presented.

Contact Person

Susana Escriche
Fundació UPC. Edifici Vèrtex
Plaça Eusebi Güell, 6, 08034 Barcelona
Tel.: +34 93 401 08 94
E-mail: susana.escriche@fundacio.upc.edu

Course Instructor

Prof. Sergey Y. Yurish,
Centre de Disseny d'Equips Industrials (CDEI),
Universitat Politècnica de Catalunya (UPC-Barcelona)
Tel.: + 34 93 401 74 37, fax: + 34 93 401 19 89
E-mail: syurish@sensorsportal.com

Online Registration:

http://www.sensorsportal.com/HTML/SSSD_Course_2008.htm

Deadline for Registration:

31 October, 2008



www.sensorsportal.com