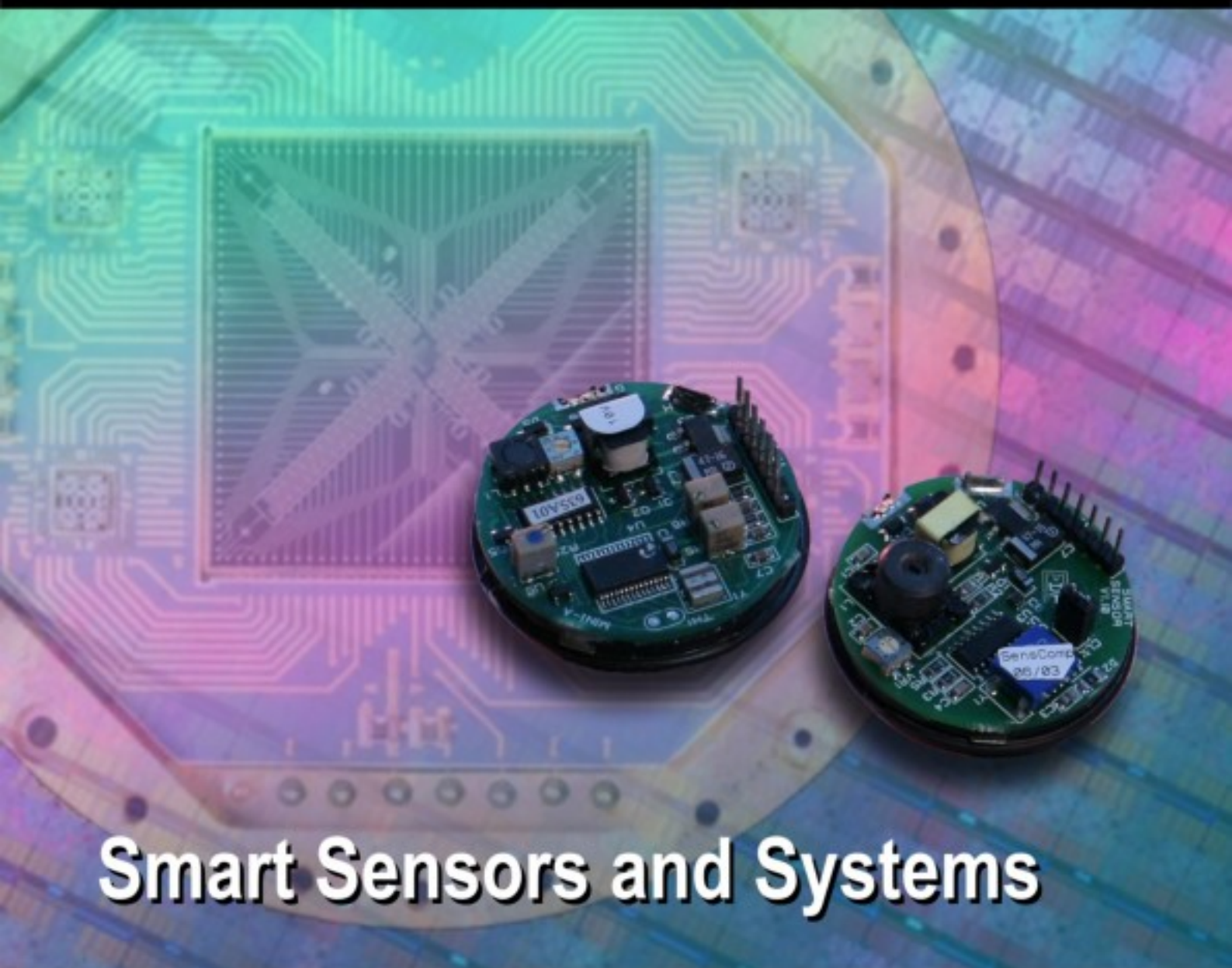


ISSN 1726-5479

# SENSORS & TRANSDUCERS

vol. 102  
**3**/09



## Smart Sensors and Systems

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

**Editor South America**

Costa-Felix, Rodrigo, Inmetro, Brazil

**Editor for Eastern Europe**

Sachenko, Anatoly, Ternopil State Economic University, Ukraine

**Editors for North America**

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

**Editor for Asia**

Ohyama, Shinji, Tokyo Institute of Technology, Japan

**Editor for Asia-Pacific**

Mukhopadhyay, Subhas, Massey University, New Zealand

## Editorial Advisory Board

**Abdul Rahim, Ruzairi**, Universiti Teknologi, Malaysia  
**Ahmad, Mohd Noor**, Nothern 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, Vyantas**, 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  
**Benachaiba, Chellali**, Universitaire de Bechar, Algeria  
**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  
**Chiang, Jeffrey (Cheng-Ta)**, Industrial Technol. Research Institute, 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**, Universite 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

**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, Venketesh**, 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 Alcala, Spain  
**Hernandez, Wilmar**, Universidad Politecnica de Madrid, Spain  
**Homentcovski, 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**, Kyungpook National University, Korea South  
**Sandacci, Serghei**, Sensor Technology Ltd., UK

- Ko, Sang Choon**, Electronics and Telecommunications Research Institute, 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, Saisune**, 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
- Lukaszewicz, 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
- Mulla, Imtiaz Sirajuddin**, National Chemical Laboratory, Pune, India
- Neelamegam, Periasamy**, Sastra Deemed University, India
- Neshkova, Milka**, Bulgarian Academy of Sciences, Bulgaria
- Oberhammer, Joachim**, Royal Institute of Technology, Sweden
- Ould Lahoucine, Cherif**, 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 Setebal, Portugal
- Petsev, Dimitar**, 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
- Raouf, 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 Cataluña, Spain
- Rothberg, Steve**, Loughborough University, UK
- Sadana, Ajit**, University of Mississippi, USA
- Sadeghian Marnani, Hamed**, TU Delft, The Netherlands
- 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
- Shankar, B. Baliga**, General Monitors Transnational, USA
- 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
- Szewczyk, 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
- Vazquez, 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, Netherlands
- Yong Zhao**, Northeastern University, China
- Yu, Haihu**, Wuhan University of Technology, China
- Yuan, Yong**, Massey University, New Zealand
- Yufra 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 102  
Issue 3  
March 2009

[www.sensorsportal.com](http://www.sensorsportal.com)

ISSN 1726-5479

## Research Articles

<b>Smart Sensor Systems: Book Review</b> .....	I
<b>Design of a Smart and High Precision Industrial Temperature Measurement and Monitoring System Using K-type Thermocouple and SPI-compatible Temperature Sensor</b> <i>Utpal Sarma, Digbijoy Chakraborty, P. K. Boruah</i> .....	1
<b>IEEE 1451.0-2007 Compatible Smart Sensor Readout with Error Compensation Using FPGA</b> <i>J. Kamala and B. Umamaheswari</i> .....	10
<b>Predicting the Deflections of Micromachined Electrostatic Actuators Using Artificial Neural Network (ANN)</b> <i>Hing Wah Lee, Mohd. Ismahadi Syono and Ishak Hj. Abd. Azid</i> .....	22
<b>Conception and Development of a Portable Electronic Nose System for Classification of Raw Milk Using Principal Component Analysis Approach</b> <i>Hing Wah Lee, Mohd. Ismahadi Syono and Ishak Hj. Abd. Azid</i> .....	33
<b>Viscosity Measurement Using Microcontroller to Study the Thermal Degradation of Edible Oil</b> <i>Neelameagam Periyasamy, Rubalya Valantina Sathianathan and Murugananthan Krishnamoorthy</i> .....	45
<b>Problems of Terminology in the Field of Measuring Instruments with Elements of Artificial Intelligence</b> <i>Roald Taymanov, Ksenia Sapozhnikova</i> .....	51
<b>Microcontroller Based Closed Loop PMDC Motor Position Control System</b> <i>Subrata Chattopadhyay, Utpal Chakraborty, Arindam Bhakta and Sagarika Pal</i> .....	62
<b>Discrete Time Sliding Mode Control Using Fast Output Sampling Feedback for Piezoelectric Actuated Structures</b> <i>L. R. Karl Marx, M. Umapathy, A. Girija, D. Ezhilarasi</i> .....	71
<b>A Particle Swarm Optimization of Natural Ventilation Parameters in a Greenhouse with Continuous Roof Vents</b> <i>Abdelhafid Hasni, Belkacem Draoui, Thierry Boulard, Rachid Taibi and Brahim Dennai</i> .....	84
<b>Experimental and Computational Study of Two-phase (Air–Palm Oil) Flow through Pipe and Control Valve in Series</b> <i>Arivazhagan M., Pugalenth, Krishna Karthik K., Rani Hemamalini, Sundaram S.</i> .....	94
<b>The Effect on Pressure Drop across Control Valve for Two Phase Flow (Air-Water)</b> <i>Arivazhagan M, Krishna Karthik K, Sundaram S</i> .....	105
<b>RBIC-Lite – a Family of Signal Conditioning ICs of ZMD</b> <i>Krauss Gudrun, Krauss Mathias</i> .....	115

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

International Frequency Sensor Association (IFSA).

## Design of a Smart and High Precision Industrial Temperature Measurement and Monitoring System Using K-type Thermocouple and SPI-compatible Temperature Sensor

Utpal Sarma, Digbijoy Chakraborty, P. K. Boruah

Department of Instrumentation and USIC, Gauhati University, Guwahati-781014, India

E-mail: [utpalsarma@gauhati.ac.in](mailto:utpalsarma@gauhati.ac.in)

*Received: 7 November 2008 /Accepted: 24 March 2009 /Published: 31 March 2009*

---

**Abstract:** This paper describes the design of a smart and high accuracy industrial temperature measurement and monitoring system using K-type thermocouple (TC). Normally errors are introduced due to non linear response of the thermocouple. We have linearised the amplified thermoemf using least square polynomial fitting algorithm. The reference junction temperature compensation is done by temperature to digital converter TMP121. Four temperature ranges are selected such that it can be implemented to a 12-bit ADC which operates from a 5 Volt DC source. The description of the system and accuracy obtained in four different temperature ranges is discussed. *Copyright © 2009 IFSA.*

**Keywords:** Sensor linearisation, Smart sensor, Data acquisition circuits

---

### 1. Introduction

Temperature is one of the most important variables in industrial process monitoring and control. Based on the demand of accuracy, resolution, environment suitability, range of operation different sensors is used for temperature measurement. Thermocouples are one of the most popular and reliable sensors, which have a very wide range of operation and can be applied to many different industrial environments. The first intricacy with TC for high accuracy measurement is that there is no fixed relationship for temperature and emf produced. So look-up table [4, 7] is one of the options. Look-up tables require many calibration points, whose number can be reduced by interpolating between them. Calculating the inverse of the function (polynomial fit) that relates the input and the output requires us first to determine that function; which needs many reference inputs again. Storage need is smaller than

that for the look-up table method [3]. In smart sensor application, this polynomial [9] fit can be done within STIM (Smart Transducer Interface module) [5, 8] or by the host PC.

The second problem is that it needs automatic room temperature compensation. Here, we employ a temperature to digital converter, TMP121 which has SPI-interface.

### **1.1. Smart Sensors**

STIM (Smart Transducer Interface module) is one of the components of smart sensor [5, 8]. When TC is taken as dumb sensor, signal conditioner in STIM amplifies the thermo emf linearly. The analog signal is then converted to digital form. A processor processes this digital data. The digital data is also linearly varying with temperature. But TC output is quite non-linear [6]. So the temperature corresponding to this analog as well as digital signal will have large errors, which affects the accuracy. The required relation between this conditioned emf and temperature is derived applying the polynomial-fitting algorithm to the amplified thermoemf. The increase in accuracy thus obtained is observed. The polynomial for temperature are calculated for four different ranges viz 0-200 °C, 0-490 °C, 0-990 °C and 0-1200 °C (i.e. for full range) such that it is compatible with 12-bit resolution ADC (ADS1286, Texas Instruments) that runs with 5 V dc source. We have used NIST-90 data for K-type thermocouple.

### **1.2. Reference Junction Compensation**

For TCs reference junction temperature compensation is done by different methods, viz, using diode sensor [11], PT-100 [12] etc. In all these cases signal conditioning is necessary. In the present case for cold junction temperature compensation we have used a pre-calibrated temperature to digital converter which eliminates the necessity of taking into account the response of other detectors. The pre-calibrated temperature to digital converter removes this problem.

## **2. System Description**

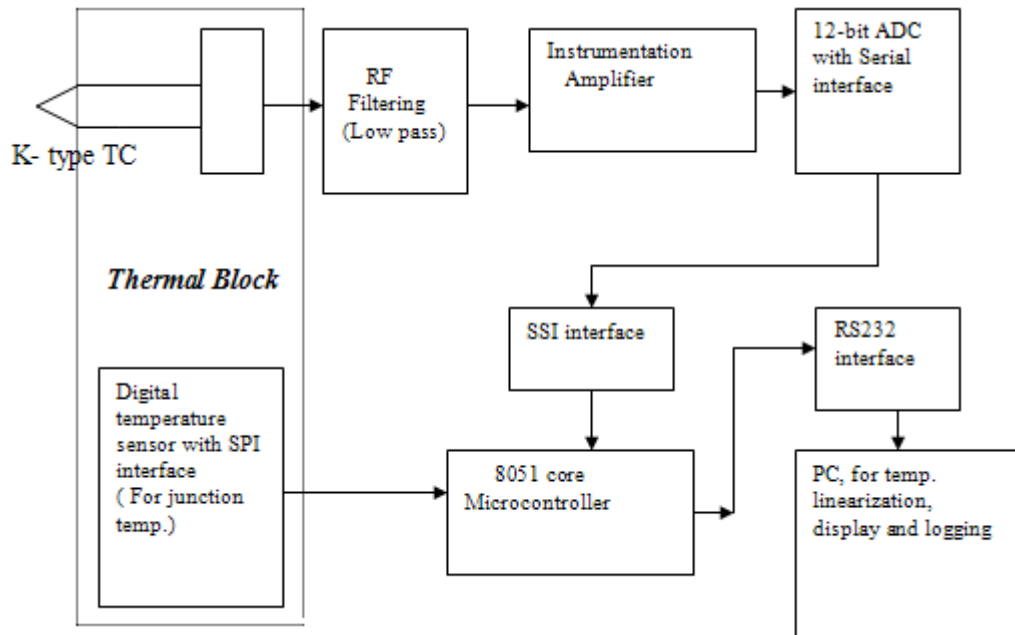
The basic block diagram of the system is shown in Fig. 1.

### **2.1. Analog Part**

The bath temperature is read by a K-type TC. Thermoemf is filtered with a low pass (10 Hz) filter. This signal is amplified with required gain with a variable gain instrumentation amplifier (INA110 from Texas Instruments) with high CMRR (106 dB). The gain of the instrumentation amplifier available is 10, 100, 200, and 500. The polynomial is fitted for these gains at four temperature ranges.

### **2.2. Digital Part**

The amplified thermoemf is digitized by a serial interfaced 12-bit ADC (ADS1286). This is interfaced with an 8051 core microcontroller (AT89c2051) with SSI interface. This serial ADC operates with no missing code, low power consumption (typically 250  $\mu$ A) and occupies less board space (8 pin PDIP). Reading of data and its processing is controlled by a firmware developed for this purpose. The firmware also sends the data serially to PC via RS232. MAX 232 is used for TTL to RS232 logic level translator.



**Fig. 1.** Block Diagram of the System.

The junction temperature is read from SPI interfaced temperature to digital temperature sensor. This reduces errors arising from trimming potentiometers, different response of TC and reference junction temperature sensor (like diode, RTD etc.) as it is pre calibrated. The temperature is given by  $T = (\text{Temp. calculated from polynomial i.e. linearised temp.}) + (\text{Temp. of reference junction read from TMP121})$ . Both parts are independently processed so this difference in temperature dependence will not cause any error.

Using the in built UART of the microcontroller the digital data is transmitted to the host PC via RS232.

### 2.3. Program for the Host PC

The program in the host PC written in Visual Basic performs the following tasks

- i. Receive 4 bytes of digital data through COM port
- ii. Separates 2 bytes for junction temperature and 2 bytes for reference junction.
- iii. The first two byte is converted to temperature with the help of the co-efficient of the required polynomial
- iv. Corrected temperature is calculated, displayed and stored onto the HDD.

## 3. Method of Analysis

For the K-type TC (wire type) the highest temperature extends up to 1372°C. The maximum input for a common ADC with 12-bit resolution is 4095 mV. Calculations are made for four different full scale temperature ranges. For each range of temperature the amplifier gain is set as required.

The least square polynomial fitting algorithm is used to find the co-relation of temperature and amplified thermoemf.

For different ranges the value of the coefficients of the polynomial are shown in the Table 1.

**Table 1.** Coefficients of the polynomial.

Range→	0-1200 <sup>0</sup> C	0-990 <sup>0</sup> C	0-490 <sup>0</sup> C	0-100 <sup>0</sup> C
Gain of the amplifier→	500	200	100	10
B0→	-0.06004	1.21526	1.31842	1.09043
B1→	0.05113	0.11706	0.23218	2.34351
B2→	$-2.26645 \times 10^{-6}$	$5.83249 \times 10^{-6}$	$3.0638 \times 10^{-5}$	0.00259
B3→	$6.91094 \times 10^{-10}$	$-1.96266 \times 10^{-9}$	$-2.57368 \times 10^{-8}$	$-2.15713 \times 10^{-5}$
B4→	$-6.20159 \times 10^{-14}$	$1.86137 \times 10^{-13}$	$8.81474 \times 10^{-12}$	$7.12748 \times 10^{-8}$
B5→	NA	NA	$-1.36369 \times 10^{-15}$	$-1.0448 \times 10^{-10}$
B6→	NA	NA	$8.15768 \times 10^{-20}$	$5.8838 \times 10^{-14}$

- B0---B6 are coefficients
- NA→ Not applied

**Table 2.** Value of the coefficients for linear fit.

Range	0-1200 <sup>0</sup> C	0-990 <sup>0</sup> C	0-490 <sup>0</sup> C	0-100 <sup>0</sup> C
Gain of the amplifier	500	200	100	10
B0	0.27183	1.42097	3.79725	-5.56053
B1	0.04887	0.12153	0.23996	2.45668

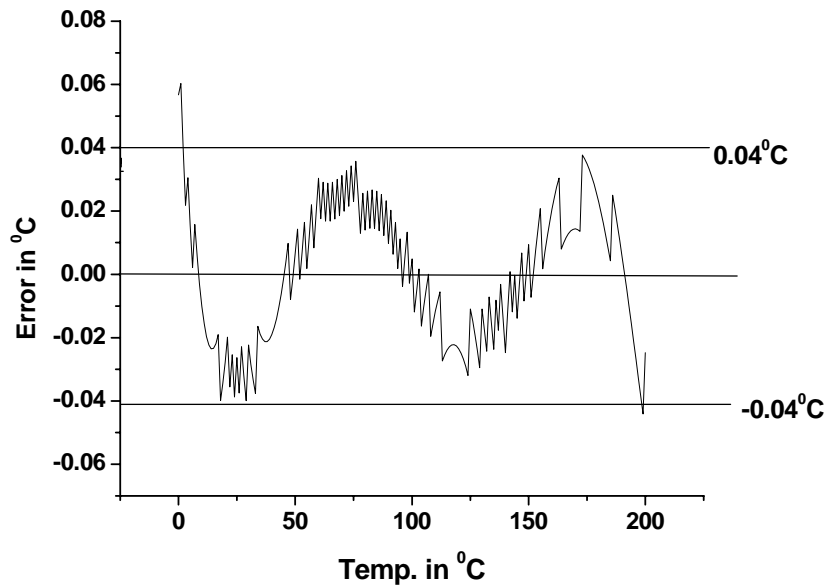
**Table 3.** Value of the errors.

Temperature Range	Maximum error in polynomial (in <sup>0</sup> C)			Maximum error in linear regression (in <sup>0</sup> C)		
	Reference Fig.	Positive	Negative	Reference Fig.	Positive	Negative
0 <sup>0</sup> C-200 <sup>0</sup> C	Fig. 2	0.04	-0.04	Fig. 3	0.83	-0.5
0 <sup>0</sup> C-490 <sup>0</sup> C	Fig. 4	0.62	-1.2	Fig. 5	1.9	-3.2
0 <sup>0</sup> C-990 <sup>0</sup> C	Fig. 6	0.68	-1.3	Fig. 7	5.1	-3.97
0 <sup>0</sup> C-1200 <sup>0</sup> C	Fig. 8	0.59	0.4	Fig. 9	1.3	-18.0

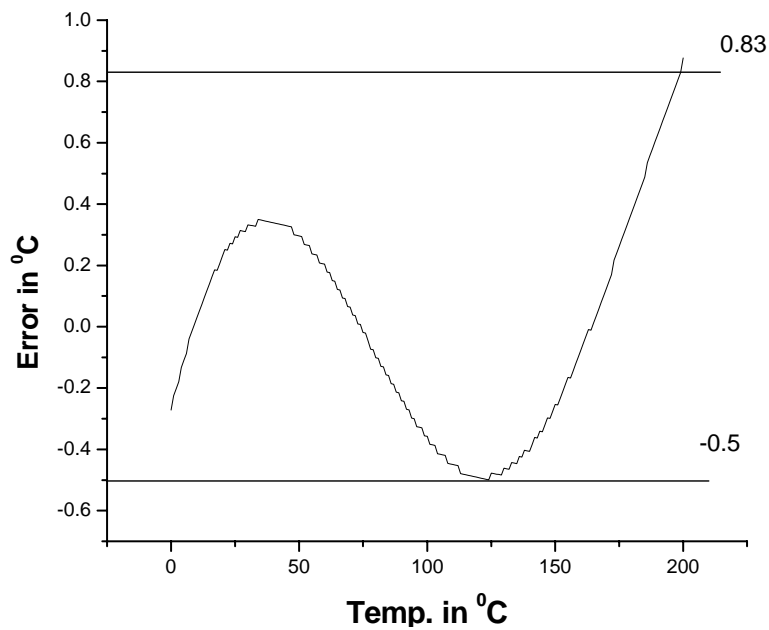
### 3.1. Range 0<sup>0</sup>C -200<sup>0</sup>C

For 0 <sup>0</sup>C -200 <sup>0</sup>C the gain of the amplifier is found to be 500 for getting full scale at 200 <sup>0</sup>C. The polynomial regression is done for temperature with the amplified thermo emf i.e. 500 times the TC output a fourth order polynomial is fitted for those data points. The temperature is recalculated from the polynomial and the variation of error with actual temperature is observed (Fig. 2). It is found that maximum error in fourth order polynomial regression is +/- 0.04 <sup>0</sup>C, but in linear regression it is found to be +0.83 <sup>0</sup>C to -0.5 <sup>0</sup>C (Fig. 3).





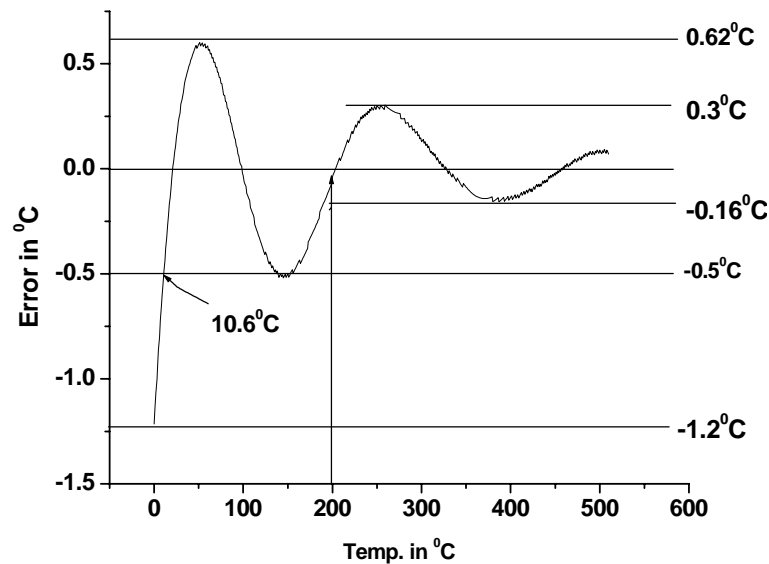
**Fig. 2.** Error curve for the range 0 °C -200 °C with polynomial fitting.



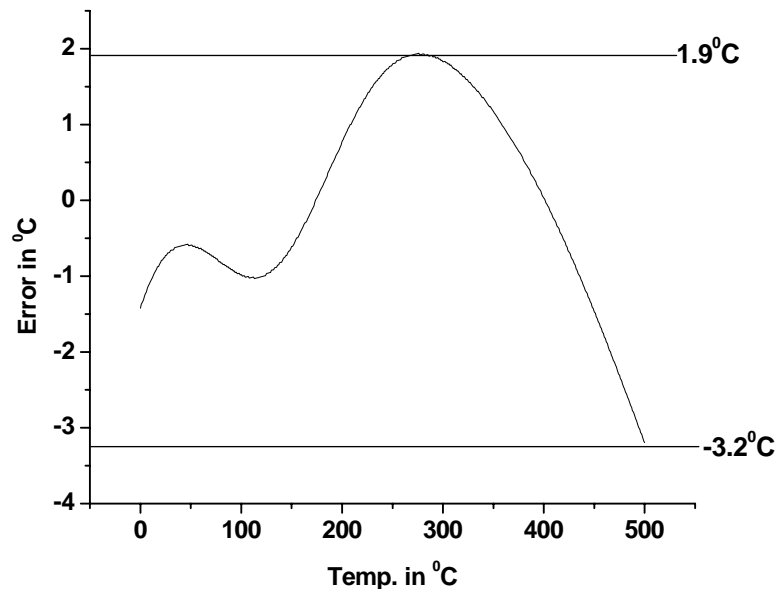
**Fig. 3.** Error curve for the range 0 °C -200 °C with linear fitting.

### 3.2. Range 0 °C -490 °C

For 0 °C -490 °C the required gain of the amplifier is found to be 200 for getting full scale at 400 °C. The polynomial regression is calculated in the same way, only the thermo emf is multiplied by 200. A fourth order polynomial is fitted for those data points. The temperature is recalculated from the polynomial and the variation of error with temperature is observed (Fig. 4). It is found that maximum error in fourth order polynomial regression is 0.62 °C to -1.2 °C, but above 10.6 °C the error reduces to +0.62 °C to -0.5 °C and above 200 °C it becomes +0.3 to -0.16 °C. In linear regression it is found to be +1.9 °C to -3.2 °C (Fig. 5).



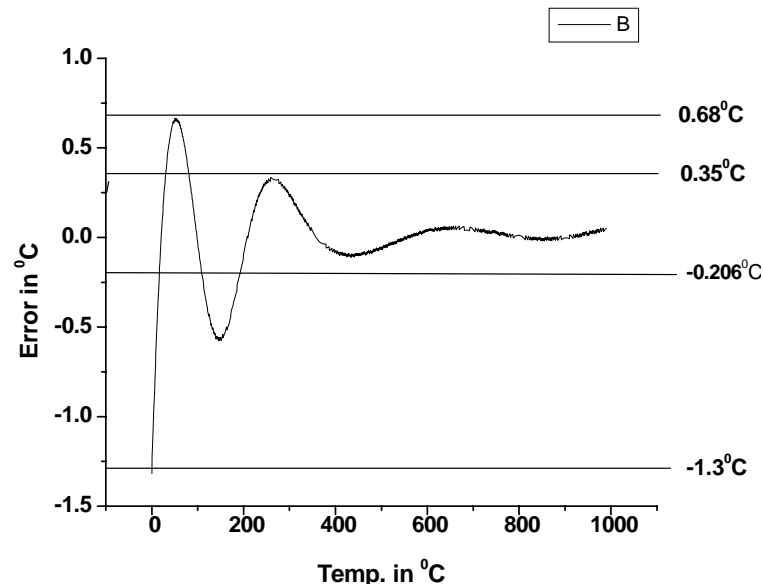
**Fig. 4.** Error curve for the range 0 °C -490 °C with polynomial fitting.



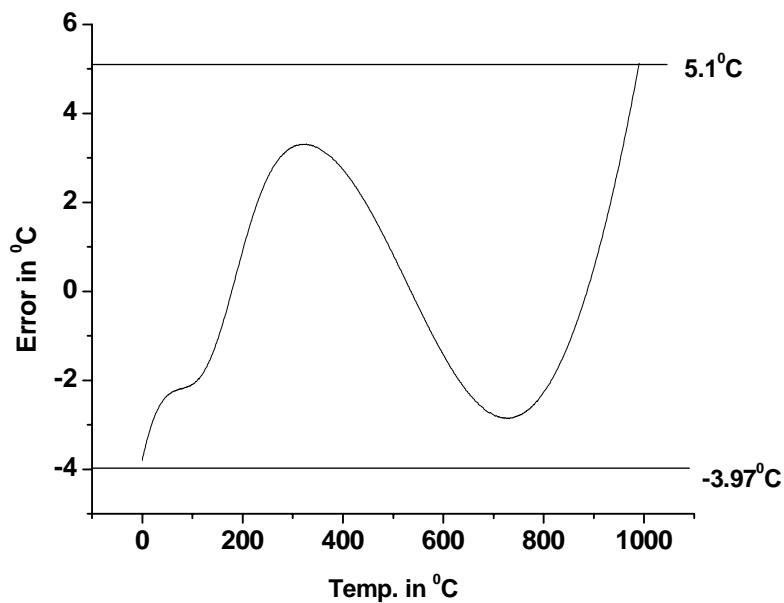
**Fig. 5.** Error curve for the range 0 °C -490 °C with linear fitting.

### 3.3. Range 0°C -990°C

For 0 °C -990 °C the required gain of the amplifier is found be 100 for getting full scale at 990 °C. The polynomial regression is calculated in the same way only the thermo emf is multiplied by 100. A sixth order polynomial is fitted for those data points .Sixth order is chosen for minimizing the error at higher temperatures. The temperature is recalculated from the polynomial and the variation of error with temperature is observed (Fig. 6). It is found that maximum error in sixth order polynomial regression is 0.68 °C to -1.3 °C, but in linear regression it is found to be +5.11 °C to -3.8 °C (Fig. 7). Here it is found that the maximum error is -1.3 °C at around 0 °C and decreases for higher temperatures. At temperature above 200 °C it shows a limiting error of 0.35 °C to -0.206 °C.



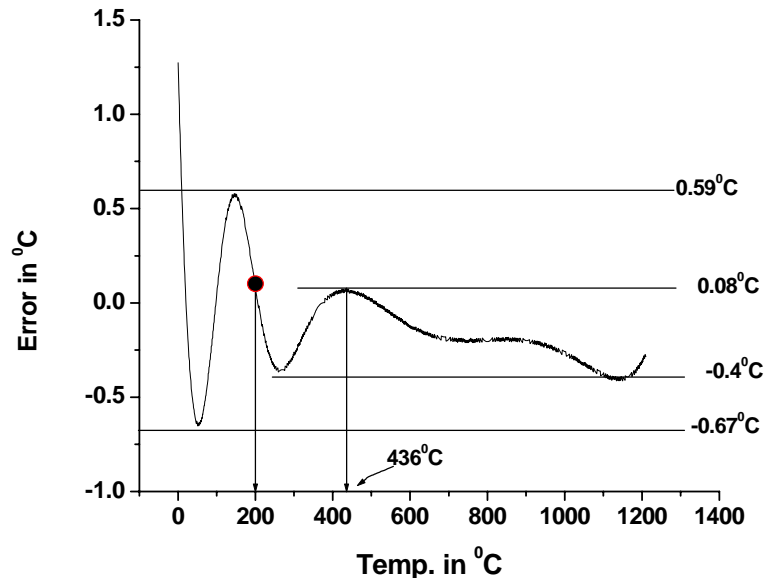
**Fig. 6.** Error curve for the range 0°C -990°C with polynomial fitting.



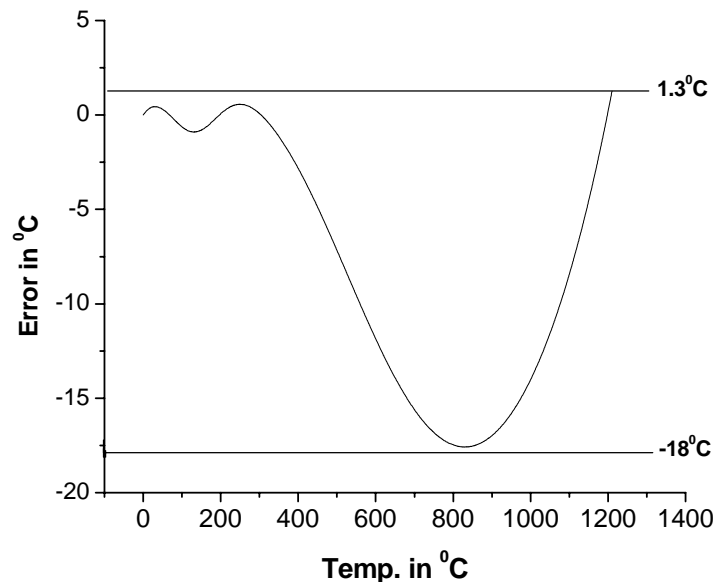
**Fig. 7.** Error curve for the range 0°C -990°C with linear fitting.

### 3.4. Range 0°C -1200°C

For 0 °C -1200 °C the required gain of the amplifier will be 10 for getting full scale at 1200 °C. The polynomial regression is calculated in the same way, only the thermo emf is multiplied by 10. A sixth order polynomial is fitted for those data points (Fig. 1). Sixth order is chosen for minimizing the error at higher temperatures. The temperature is recalculated from the polynomial and the variation of error with temperature is observed (Fig. 8). It is found that maximum error in sixth order polynomial regression is +0.59 °C to -0.67 °C, but in linear regression it is found to be 1.3 °C to -18.0 °C. Here it is found that the maximum error is 0.59 °C at around 0 °C and decreases for higher temperatures. At temperature above 200 °C it shows a maximum error of 0.08 °C to -0.4 °C (Fig. 9).



**Fig. 8.** Error curve for the range 0 °C -1200 °C with polynomial fitting.



**Fig. 9.** Error curve for the range 0 °C -1200 °C with linear fitting.

## 2. 4. Conclusion

The well known method of polynomial fitting is used for thermocouple based temperature measurement system. The accuracy obtained improves by a factor of 17 at 200 °C range, 11 from 200 °C to 400 °C in 400 °C range, 16 from 400 °C to 990 °C in 990 °C range and 40 from 436 °C to 1200 °C in 1200 °C range. The observed accuracy is dependant on temperature range. Such a system has been successfully implemented in smart transducer interface module. This method can also be applied for other sensors with nonlinear characteristics.

Use of temperature to digital converter reduces errors arising out of difference of response between TC and reference junction compensation sensor. This also reduces the parts count like ADC, amplifier for reference junction compensation sensor and therefore reduces the cost.

## Acknowledgement

The authors gratefully acknowledge the support from Texas Instruments, USA under their free sample program.

## References

- [1]. Sylvain Poussier, Hassan Rabah and Serge Weber, *IEEE Sensors Journal*, Vol. 4, No. 2, 2004, p. 262.
- [2]. L. A. Pipes and R. Harvill, *Applied Mathematics for Engineers and Physicist*, Third Edition, *McGraw-Hill International Editions*, pp. 562-565.
- [3]. TECH NOTE # 204 Custom Calibration Correction for the AI-2000 Smart Transmitter Issued August 1991, Accutech A Division of Adaptive Instruments Corporation 577 Main Street, Hudson, MA 01749.
- [4]. Sandip Pal, A. Rakshit, *Sensors and Actuators A*, 112, 2004, p. 381.
- [5]. K. Lee, IEEE 1451, A standard in support of smart transducer networking, in *Proceedings of the Technology Conference on IEEE Instrumentation and Measurement*, Baltimore, MD, USA, 1-4 May 2000.
- [6]. Mark W. Zemansky and R. H. Dittman, *Heat and Thermodynamics*, Sixth edition, *McGraw Hill International Book Company*, p. 21.
- [7]. Josep Jordana and Ramon Pallas-Areny, Optimal Two-point Static Calibration of Measurement Systems with Quadratic Response, *IMTC 2M4 - Instrumentation and Measurement Technology Conference*, Como Italy, 18-20 May 2004.
- [8]. IEEE Standard for a Smart Transducer Interface for Sensors and Actuators - Network Capable Application Processor (NCAP) Information Model, IEEE Instrumentation and Measurement Society.
- [9]. Marin Marinov et al., *27<sup>th</sup> Intel Spring Seminar on Electronics Technology*, IEEE, 2004, p. 410.
- [10]. V. Shubha and T. G. Ramesh, *J. Phys. E: Sci. Instrum.*, 19, 1986.
- [11]. Datasheet of INA114 from Texas Instruments (<http://www.ti.com>).
- [12]. Datasheet of ADS1286 from Texas Instruments (<http://www.ti.com>).

---

2009 Copyright ©, International Frequency Sensor Association (IFSA). All rights reserved.  
(<http://www.sensorsportal.com>)



**Universal Frequency-to-Digital Converter  
(UFDC-1 and UFDC-1M-16)  
in MLF (5 x 5 x 1 mm) package**

**SMALL WORLD -  
BIG FEATURES**

SWP, Inc., Toronto, Ontario, Canada,  
Tel. +34 696067716, fax: +34 93 4011989, e-mail: [sales@sensorsportal.com](mailto:sales@sensorsportal.com)  
[http://www.sensorsportal.com/HTML/E-SHOP/PRODUCTS\\_4/UFDC\\_1.htm](http://www.sensorsportal.com/HTML/E-SHOP/PRODUCTS_4/UFDC_1.htm)



## 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:

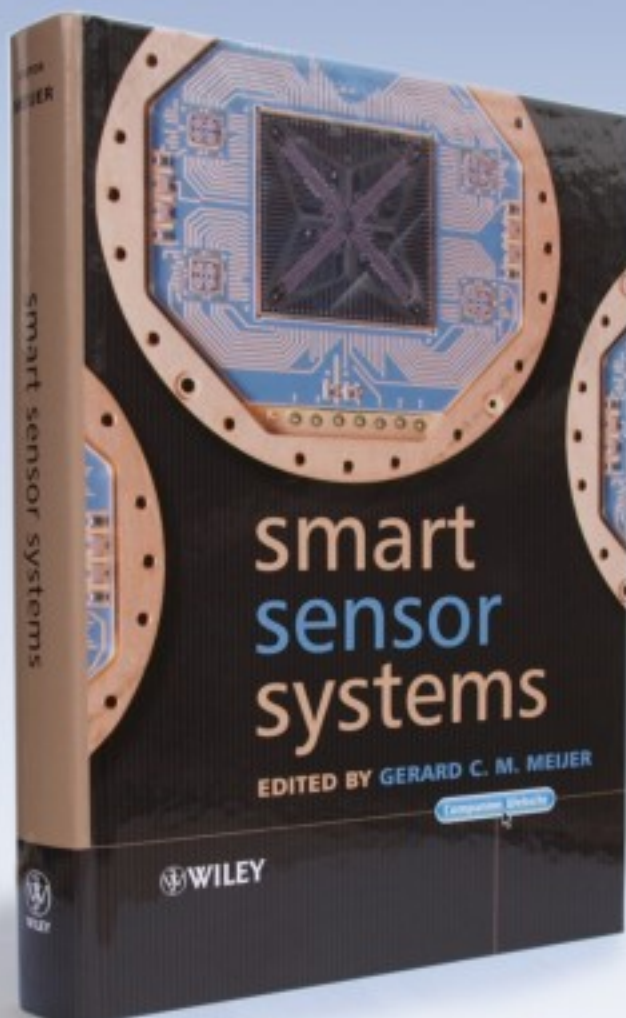
- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors 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](mailto: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](mailto:sales@sensorsportal.com) Please download also our media kit: [http://www.sensorsportal.com/DOWNLOADS/Media\\_Kit\\_2008.pdf](http://www.sensorsportal.com/DOWNLOADS/Media_Kit_2008.pdf)



**'Written by an internationally-recognized team of experts, this book reviews recent developments in the field of smart sensors systems, providing complete coverage of all important systems aspects. It takes a multidisciplinary approach to the understanding, design and use of smart sensor systems, their building blocks and methods of signal processing.'**



**Order online:**

[http://www.sensorsportal.com/HTML/BOOKSTORE/Smart\\_Sensor\\_Systems.htm](http://www.sensorsportal.com/HTML/BOOKSTORE/Smart_Sensor_Systems.htm)

**[www.sensorsportal.com](http://www.sensorsportal.com)**