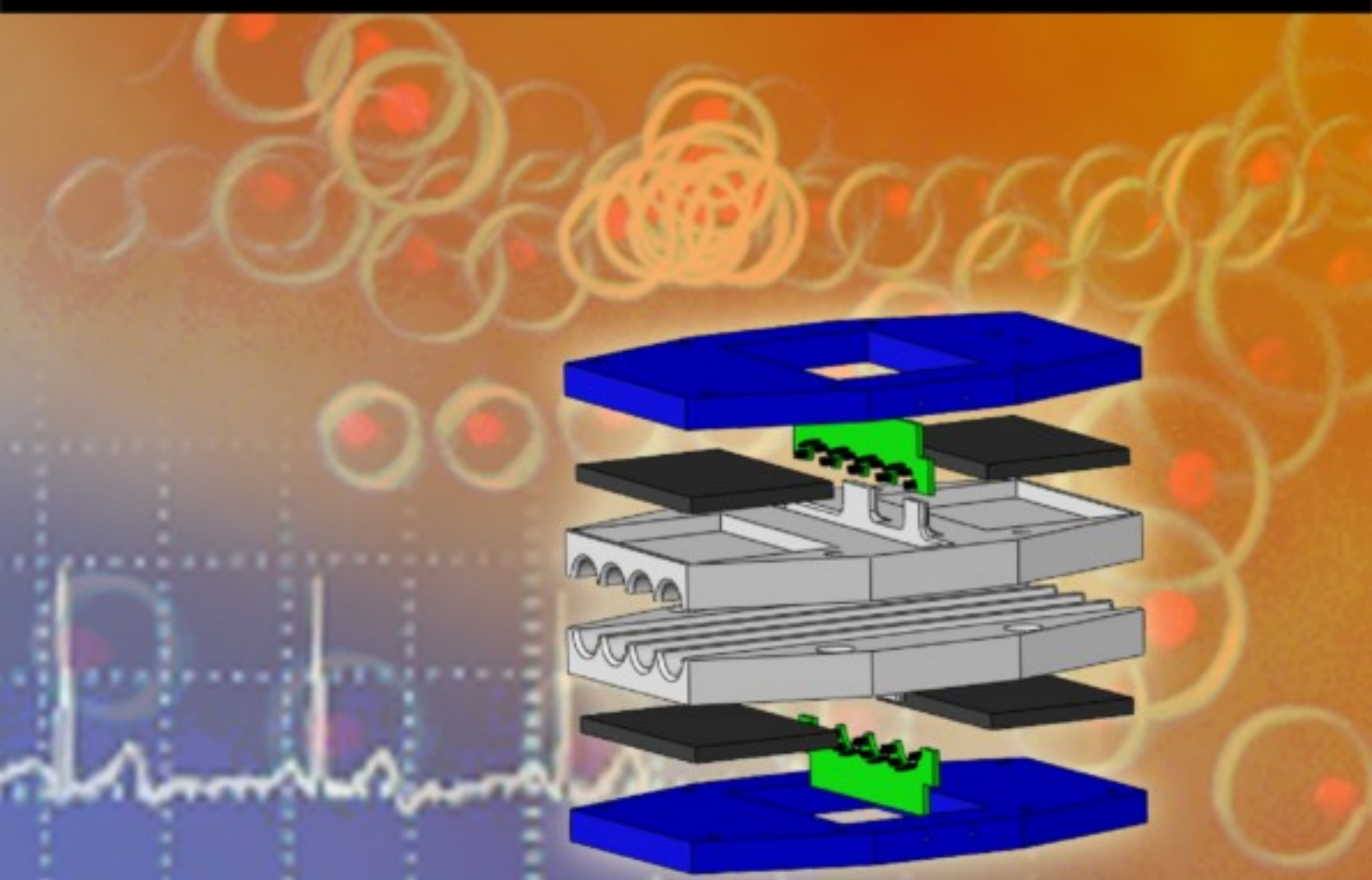


ISSN 1726-5749

# SENSORS & TRANSDUCERS

# 12

vol. 9  
Special  
/10



## Modern Sensing Technologies III

International Frequency Sensor Association Publishing



**Editors-in-Chief:** professor Sergey Y. Yurish, tel.: +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**, Northern University of Engineering, Malaysia  
**Annamalai, Karthikeyan**, 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  
**Baliga, Shankar, B.**, General Motors Transnational, USA  
**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  
**Benachiba, Chellali**, Université 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  
**Chavali, Murthy**, N.I. Center for Higher Education, (N.I. University), 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**, 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, Jianning**, Jiangsu Polytechnic University, China  
**Djordjevic, Alexandar**, 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**, Univ. 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  
**Granel, 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  
**Haider, Mohammad R.**, Sonoma State University, USA  
**Hashsham, Syed**, Michigan State University, USA  
**Hasni, Abdelhafid**, Bechar University, Algeria  
**Hernandez, Alvaro**, University of Alcala, 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  
**Khelfaoui, Rachid**, Université de Bechar, Algeria  
**Khan, Asif**, Aligarh Muslim University, Aligarh, India  
**Kim, Min Young**, Kyungpook National University, Korea South  
**Ko, Sang Choon**, Electronics. and Telecom. Research Inst., 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**, University of Vigo, Spain  
**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**, University "Mediterranea" of Reggio Calabria, Italy  
**Mounir, Ben Ali**, University of Sousse, Tunisia  
**Mulla, Imtiaz Sirajuddin**, National Chemical Laboratory, Pune, India  
**Nabok, Aleksey**, Sheffield Hallam University, UK  
**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 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 Cataluña, 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  
**Schneider, John K.**, Ultra-Scan Corporation, USA  
**Sengupta, Deepak**, Advance Bio-Photonics, India  
**Shah, Kriyang**, La Trobe University, Australia  
**Sapozhnikova, Ksenia**, D.I.Mendeleyev Institute for Metrology, Russia  
**Saxena, Vibha**, Bhabha Atomic Research Centre, Mumbai, India  
**Seif, Selemanni**, Alabama A & M University, USA  
**Seifter, Achim**, Los Alamos National Laboratory, USA  
**Silva Girao, Pedro**, Technical University of Lisbon, Portugal  
**Singh, V. R.**, National Physical Laboratory, India  
**Slomovitz, Daniel**, UTE, Uruguay  
**Smith, Martin**, Open University, UK  
**Soleymanpour, 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 Inst. 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  
**Thirunavukkarasu, I.**, Manipal University Karnataka, India  
**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  
**Vanga, Raghav Rao**, Summit Technology Services, Inc., USA  
**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**, Pacific Northwest National Laboratory, 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 Univ. 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, Shuang-Hua**, Loughborough University, UK  
**Yang, Wuqiang**, The University of Manchester, UK  
**Yang, Xiaoling**, University of Georgia, Athens, GA, USA  
**Yaping Dan**, Harvard University, USA  
**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  
**Zakaria, Zulkarnay**, University Malaysia Perlis, Malaysia  
**Zagnoni, Michele**, University of Southampton, UK  
**Zamani, Cyrus**, Universitat de Barcelona, Spain  
**Zeni, Luigi**, Second University of Naples, Italy  
**Zhang, Minglong**, Shanghai University, China  
**Zhang, Qintao**, University of California at Berkeley, USA  
**Zhang, Weiping**, Shanghai Jiao Tong University, China  
**Zhang, Wenming**, Shanghai Jiao Tong University, China  
**Zhang, Xueji**, World Precision Instruments, Inc., USA  
**Zhong, Haoxiang**, Henan Normal University, China  
**Zhu, Qing**, Fujifilm Dimatix, Inc., USA  
**Zorzano, Luis**, Universidad de La Rioja, Spain  
**Zourob, Mohammed**, University of Cambridge, UK

# Contents

Volume 9  
Special Issue  
December 2010

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

ISSN 1726-5479

## Research Articles

### Modern Sensing Technologies - III

*Subhas Chandra Mukhopadhyay, Aime Lay-Ekuakille, Anton Fuchs* ..... I

### Composition and Detection Rate of a Symmetry Axis Localization Algorithm for Digital Images

*Norbert Eidenberger, Daniel C. H. Schleicher and Bernhard G. Zagar* ..... 1

### Formulation and Characterization of Cu Doped ZnO Thick Films as LPG Gas Sensor

*A. V. Patil, C. G. Dighavkar, S. K. Sonawane, S. J. Patil and R. Y. Borse* ..... 11

### Characterization of Microbubble Contrast Agents for Echographic Imaging through Time-Scheduled Size Distribution Measurements

*Francesco Conversano, Roberto Franchini and Sergio Casciaro* ..... 21

### Production and Characterisation of Multifunctional Textile for Masonry Retrofitting and Health Monitoring

*Angela Coricciati, Paolo Corvaglia, Alessandro Largo, Michele Arturo Caponero, Giovanni Fardin* ..... 28

### Al-doped TiO<sub>2</sub> Thick Film Resistors as H<sub>2</sub>S Gas Sensor

*Chandrakant Dighavkar, Arun Patil, Sunil Patil and Ratan Borse* ..... 39

### Ultrasound Signal Analysis Applied to Determine the Optimal Contrast Dose for Echographic Examinations

*Roberto Franchini, Francesco Conversano, Antonio Greco, Raffaella Verrienti, Sergio Casciaro* .... 48

### Extended Phase Accordance Method: A Real-time and Accurate Technique for Estimating Position and Velocity of Moving Objects using Ultrasonic Communication

*Tomohiko Sato, Shigeki Nakamura, Masanori Sugimoto and Hiromichi Hashizume* ..... 56

### Magneto-inductive Sensors for Metallic Ropes in Lift Application

*Aldo Canova, Francesco Ficili and Daniel Rossi* ..... 71

### Studies on Gas Sensing Performance of Pure and Surface Chrominated Indium Oxide Thick Film Resistors

*D. N. Chavan, V. B. Gaikwad, S. D. Shinde, D. D. Kajale, G. E. Patil, G. H. Jain* ..... 82

### Effect of Annealing Temperature on Gas Sensing Performance of SnO<sub>2</sub> Thin Films Prepared by Spray Pyrolysis

*G. E. Patil, D. D. Kajale, S. D. Shinde, R. H. Bari, D. N. Chavan, V. B. Gaikwad, G. H. Jain* ..... 96

### Measurement Using Conductive Polymeric Fibers in a Wearable Sensor Platform

*Ram Manoj Sarda, Thomas Donnelly, Mansour Taherinahzadhi and Michael Haji-Sheikh* ..... 109

### Three Dimensional Measurement of Aquatic Organisms Using a Single Video Camera

*Kikuhito Kawasue, Satoshi Nagatomo and Yuichiro Oya* ..... 118

127



## **Pain Sensing System for Animals**

*Ibrahim Al-Bahadly, Subhas Mukhopadhyay and Khalil Alkhumaisi .....*

## **Experimental Assessment of a Pneumatic Level-sensing Method for Closed Tanks Applied to Water and Wooden Pellets**

*Gert Holler, Rudolf Brunnader, Bernhard Schweighofer, Hannes Wegleiter .....* 151

## **Synthesis and Characterization of Nanostructured ZnO Thick Film Gas Sensors Prepared by Screen Printing Method**

*R. Y. Borse and V. T. Salunke .....* 161

## **Sensitivity Limits of a Magnetometer with an Air-core Pickup Coil**

*Kunihisa Tashiro, Shin-ichiro Inoue and Hiroyuki Wakiwaka .....* 171

## **A Survey on Unobtrusive Measurements of the Cardiovascular Function and their Practical Implementation in Wheelchairs**

*Eduardo Pinheiro, Octavian Postolache, Pedro Girão .....* 182

## **Multi-Sensor SLAM Approach for Robot Navigation**

*Sid Ahmed Berrabah, Yvan Baudoin, Hichem Sahli .....* 200

## **ZigBee Test Harness: An Innovative Tool for ZigBee Node Testing**

*Andrea Ranalli, Claudio Borean .....* 214

## **Effect of Firing Temperature on the Composition and Structural Parameters of Screen Printed ZrO<sub>2</sub> Thick Film Sensors**

*S. J. Patil, A. V. Patil, C. G. Dighavkar, R. Y. Borse .....* 223

## **Wide-band Induction Magnetometers Stability**

*Vira Pronenko and Yevhen Vasiliev .....* 233

## **Experimental Performance Measurements of Home Photovoltaic Plants: A Case Study**

*C. Calò, C. Chiffi, G. D'Aniello, A. Lay-Ekuakille, P. Vergallo, A. Trotta .....* 240

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).

## **Call for Books Proposals** **Sensors, MEMS, Measuring instrumentation, etc.**

International Frequency Sensor Association Publishing



### **Benefits and rewards of being an IFSA author:**

#### **1) Royalties.**

Today IFSA offers most high royalty in the world: you will receive 50 % of each book sold in comparison with 8-11 % from other publishers, and get payment on monthly basis compared with other publishers' yearly basis.

#### **2) Quick Publication.**

IFSA recognizes the value to our customers of timely information, so we produce your book quickly: 2 months publishing schedule compared with other publishers' 5-18-month schedule.

#### **3) The Best Targeted Marketing and Promotion.**

As a leading online publisher in sensors related fields, IFSA and its Sensors Web Portal has a great expertise and experience to market and promote your book worldwide. An extensive marketing plan will be developed for each new book, including intensive promotions in IFSA's media: journal, magazine, newsletter and online bookstore at Sensors Web Portal.

#### **4) Published Format: pdf (Acrobat).**

When you publish with IFSA your book will never go out of print and can be delivered to customers in a few minutes.

You are invited kindly to share in the benefits of being an IFSA author and to submit your book proposal or/and a sample chapter for review by e-mail to [editor@sensorsportal.com](mailto:editor@sensorsportal.com). These proposals may include technical references, application engineering handbooks, monographs, guides and textbooks. Also edited survey books, state-of-the art or state-of-the-technology, are of interest to us.





## The Third International Conference on Bioinformatics, Biocomputational Systems and Biotechnologies

### BIOTECHNO 2011

May 22-27, 2011 - Venice, Italy



#### Tracks:

#### A. Bioinformatics, chemoinformatics, neuroinformatics and applications

- Bioinformatics
- Advanced biocomputation technologies
- Chemoinformatics
- Bioimaging
- Neuroinformatics

#### B. Computational systems

- Bio-ontologies and semantics
- Biocomputing
- Genetics
- Molecular and Cellular Biology
- Microbiology

#### C. Biotechnologies and biomanufacturing

- Fundamentals in biotechnologies
- Biodevices
- Biomedical technologies
- Biological technologies
- Biomanufacturing

#### Important deadlines:

Submission (full paper)	January 10, 2011
Notification	February 20, 2011
Registration	March 5, 2011
Camera ready	March 20, 2011

<http://www.iaria.org/conferences2011/BIOTECHNO11.html>



## The Seventh International Conference on Networking and Services

### ICNS 2011

May 22-27, 2011 - Venice, Italy



#### Important deadlines:

Submission (full paper)	January 10, 2011
Notification	February 20, 2011
Registration	March 5, 2011
Camera ready	March 20, 2011

<http://www.iaria.org/conferences2011/ICNS11.html>

#### Tracks:

- ENCOT: Emerging Network Communications and Technologies
- COMAN: Network Control and Management
- SERVI: Multi-technology service deployment and assurance
- NGNUS: Next Generation Networks and Ubiquitous Services
- MPQSI: Multi Provider QoS/SLA Internetworking
- GRIDNS: Grid Networks and Services
- EDNA: Emergency Services and Disaster Recovery of Networks and Applications
- IPv6DFI: Deploying the Future Infrastructure
- IPDy: Internet Packet Dynamics
- GOBS: GRID over Optical Burst Switching Networks



## The Sixth International Conference on Systems

### ICONS 2011

January 23-28, 2011 - St. Maarten,  
The Netherlands Antilles



#### Important deadlines:

Submission (full paper)	September 25, 2010
Notification	October 20, 2010
Registration	November 5, 2010
Camera ready	November 5, 2010

<http://www.iaria.org/conferences2011/ICONS11.html>

#### Tracks:

- Systems' theory and practice
- System engineering
- System instrumentation
- Embedded systems and systems-on-the-chip
- Target-oriented systems [emulation, simulation, prediction, etc.]
- Specialized systems [sensor-based, mobile, multimedia, biometrics, etc.]
- Validation systems
- Security and protection systems
- Advanced systems [expert, tutoring, self-adapting, interactive, etc.]
- Application-oriented systems [content, eHealth, radar, financial, vehicular, etc.]
- Safety in industrial systems
- Complex Systems

## Sensitivity Limits of a Magnetometer with an Air-core Pickup Coil

**Kunihisa Tashiro, Shin-ichiro Inoue and Hiroyuki Wakiwaka**

Department of Electrical and Electronic Engineering,  
Shinshu University, Nagano wakasato 4-17-1, 380-8553, Japan  
Tel.: +81-26-269-5216  
E-mail: [tashiro@shinshu-u.ac.jp](mailto:tashiro@shinshu-u.ac.jp)

*Received: 27 September 2010 /Accepted: 30 November 2010 /Published: 30 December 2010*

---

**Abstract:** Sensitivity limits of magnetometers with air-core pickup coils are considered through three basic principles, Faraday's law, the definition of inductance and Ohm's law. This paper presents two simple equivalent circuit models for voltage detection and current detection, and describes their sensitivity with eight parameters. Both models require different methodology for optimal pickup coil design. The calculated results are in agreement with experimental results, and illustrate the advantages of magnetometers based on current detection model. *Copyright © 2010 IFSA.*

**Keywords:** Induction magnetometer, Air-core coil, Detection model, Equivalent circuit, Sensitivity limits.

---

### 1. Introduction

A magnetometer with a coil is capable to use two methods [1]. The first method is based on Faraday's law that the induced voltage across the coil is proportional to the derivative of the flux linkage. The second method is based on the definition of self-inductance [1-13]. Though most previous works mention magnetometers through Faraday's law, an approach from the definition of self-inductance is important when the target of the magnetic field is weak and of low-frequency. One reason is the necessity of an ideal analogue integrator which does not have  $1/f$  noise, dc drift, and a limitation in gain [2]. A fluxgate magnetometer uses a change in the magnetic permeability of the core material at a few tens of kHz, in which a low-frequency flux linkage transfers to the modulated high frequency signal. This sensor is able to detect a DC magnetic field, but the modulation frequency limits the upper frequency. A change in magnetic permeability of the magnetic material also produces Barkhausen noise, and increases the white noise level of the magnetometer.



We have been developing induction magnetometers based on definition of inductance [9-13]. Our proposed design of the pickup coil is based on a Brooks coil [14]. This shape of the coil can achieve maximum inductance for a given length of winding wire, and the estimation error of the inductance is less than 3 % [12]. Induction magnetometers have the ability to detect weak magnetic fields from extremely low frequencies to those in the audible range (0.01 Hz ~ 10 kHz). Although induction magnetometers were proposed in several papers [1-7], the technical details were usually not described.

Because the nature of the coil is the fundamental basis of electromagnetism, the principles of induction magnetometers are easy to understand. However, the optimization of the design with numerous parameters is not easy. In order to simplify the design for the general shape of a pickup coil, we pay attention to the important relationships between flux linkage, current and voltage. In this paper, we find out four operation modes of a magnetometer which can be categorized with two detection models and two frequency ranges. The equivalent circuits for operation modes are based on Faraday's law, the definition of inductance, and Ohm's law. Because the sensitivity can be described with eight parameters for the modes, we can discuss the parameter dependencies. From those considerations, simplified descriptions of the sensitivity allow us to understand the merits of induction magnetometers. Some experimental results also show the validity of the models.

## 2. Air-core Coil

### 3.1 Model

We assume an air-core pickup of rectangular cross section. The self-inductance of the coil  $L$  [H] can be defined by the following equation [14, 15]:

$$L = P_0 a n^2 \text{ [H]}, \quad (1)$$

where  $a$  [m] is the mean radius,  $n$  is the number of turns, and  $P_0$  [H/m] is the coil coefficient defined by the coil shape. For examples, the value of  $P_0$  for an ideal solenoid coil with finite length is determined by the product of the circular constant  $\pi$ , permeability of vacuum in H/m, length to diameter ratio of the coil, and the Nagaoka coefficient. If the ratio of a coil length, inner diameter, and outer diameter is constant, the value of  $P_0$  becomes constant. The ratio of Brooks coil is 1:2:4. This shape of coil can achieve maximum inductance for a given length of winding wire, and the estimation error of the inductance is less than 3 % [12]. The value of  $P_0$  for a Brooks coil can be described as follows:

$$P_0 = 1.6994 \times 10^{-6} \text{ H/m}. \quad (2)$$

The resistance of the coil can be expressed by following equation:

$$R = 2\pi a n \rho / s \text{ } [\Omega], \quad (3)$$

where  $\rho$  [ $\Omega$ m] is the resistivity of the wire and  $s$  is the cross section of the wire. Assuming that a homogeneous magnetic flux  $B$  [T] is crossed with the mean cross section area  $S$  [ $\text{m}^2$ ] and the number of turns  $n$ ,  $\Phi$  leads to the relationships:

$$S = \pi a^2 \text{ } [\text{m}^2], \quad (4)$$

$$\Phi = nSB = \pi n a^2 B \text{ } [\text{Wb}]. \quad (5)$$



### 3.2. Faraday's Law

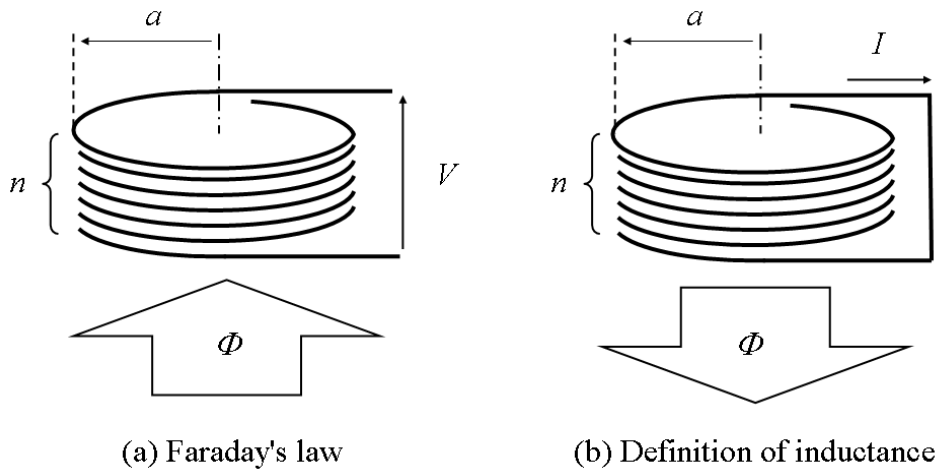
Fig. 1(a) shows a model based on Faraday's law. We assume that a homogeneous magnetic flux of  $f$  [Hz] is crossed with the coil. From (5) and Faraday's law, the induced voltage  $V$  [V] is expressed by the following equation:

$$V = (d\Phi / dt) = j2\pi^2 f n a^2 B \text{ [V]}, \quad (6)$$

where  $j$  is an imaginary number. When we measure the voltage and integrate it with an ideal integrator, we can obtain the waveform of the magnetic flux density. The normalized voltage  $V/B$  can be expressed by the following equation:

$$V/B = j2\pi^2 f n a^2 \text{ [V/T]}. \quad (7)$$

It is proportional to  $f$ ,  $n$ , and  $a^2$ . It should be noted that the value does not depend on  $L$  if we don't consider current in the circuit.



**Fig. 1.** Faraday's law and the definition of inductance.

### 2.2. Definition of Inductance

Fig. 1(b) shows a model based on the definition of inductance. From (5) and the definition of inductance, the relationship between the current  $I$  [A] and flux linkage  $\Phi$  is expressed by the following equation:

$$\Phi = LI \text{ [Wb]}, \quad (8)$$

$$I = (nSB)/L = (\pi n a^2 B) / L \text{ [Wb]}. \quad (9)$$

From (1), the normalized current  $I/B$  can be expressed by the following equation:

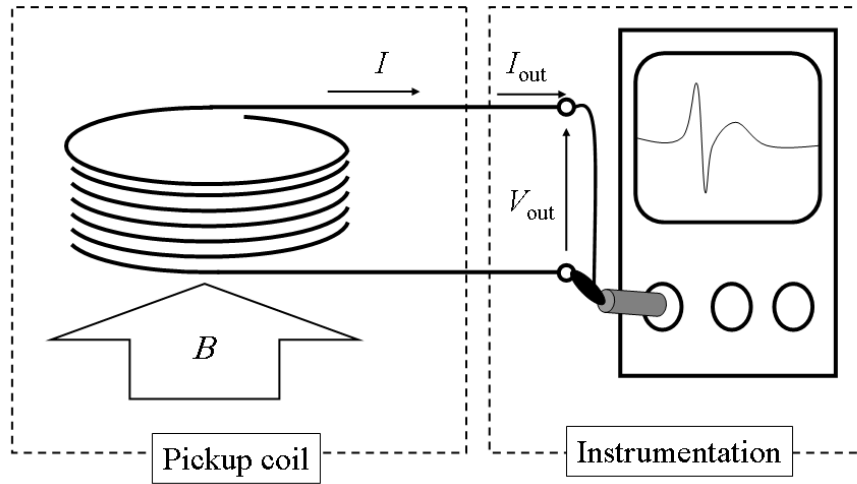
$$I/B = (\pi n a^2) / L = (\pi a) / (P_0 n) \text{ [A/T]}. \quad (10)$$

Although the value is also proportional to  $n$  and  $a^2$ , it is inversely proportional to  $L$ . It should be noted that the value does not depend on  $f$ . In the analysis of a practical magnetometer, we have to take into account the resistance of the coil.

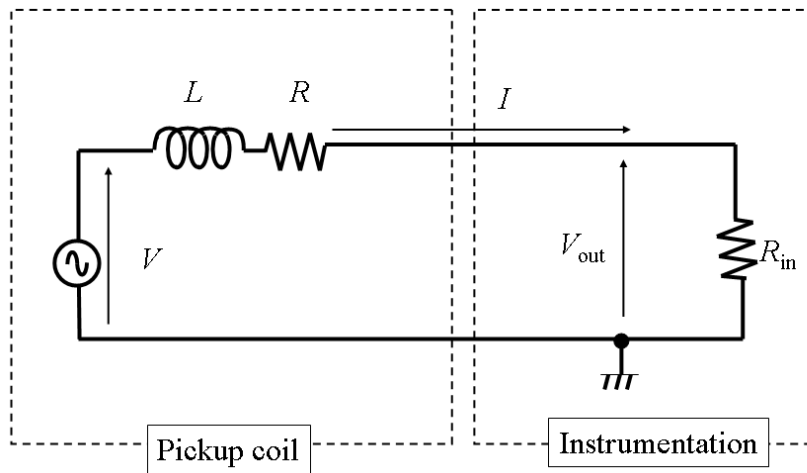
### 3. Voltage Detection Model

#### 3.1. Model

Fig. 2 (a) shows the voltage detection model. A homogeneous magnetic flux is crossed with the coil. The induced voltage is measured using an instrumentation which has an input resistance of  $R_{in}$  [ $\Omega$ ]. Based on the Thevenin's theorem, the pickup coil can be replaced with parameters of  $R$ ,  $L$ , and  $V$ . The values of those parameters are already known from (1), (3) and (7). Fig. 2(b) shows the equivalent circuits.



(a) Model.



(b) Equivalent circuit.

**Fig. 2.** Induced voltage detection model.

From the Kirchhoff's voltage law (KVL), the current  $I$  can be expressed by the following equations:

$$V = L (dI/dt) + (R + R_{in})I \text{ [V]}, \quad (11)$$

$$I = (V / (R + R_{in})) \times (1 / (1 + j(\omega L / (R + R_{in})))) \text{ [A]}. \quad (12)$$

Because the input resistance of the instrumentation is usually high as  $R_{in} \gg R$ , we rewrite (12) and define a cutoff frequency  $f_v$  [Hz] by the following equations:

$$I = (V / R_{in}) \times (1 / (1 + j(\omega L / R_{in}))) \text{ [A]}, \quad (13)$$

$$f_v = R_{in} / (2\pi L) \text{ [Hz]}. \quad (14)$$

In this model, the input current to the instrumentation  $I_{out}$  [A] is  $I$ . From (1), (13) and (14),  $I_{out}$  can be written as follows:

$$I_{out} = I = (V / R_{in}) \times (1 / (1 + j(f / f_v))) \text{ [A]}. \quad (15)$$

### 3.2. Low Frequency Region ( $f \ll f_v$ )

When the frequency  $f$  is much smaller than  $f_v$ , we can approximate (15) as follows:

$$I_{out} = V / R_{in} \text{ [A]}. \quad (16)$$

Based on Ohm's law, the input voltage of the instrumentation  $V_{out}$  is the product of  $I_{out}$  and  $R_{in}$ . From (6) and (16), the values of  $I_{out}/B$  and  $V_{out}/B$  can be expressed by the following equations:

$$I_{out} / B = j2\pi^2 f n a^2 / R_{in} \text{ [A/T]}, \quad (17)$$

$$V_{out} / B = j2\pi^2 f n a^2 \text{ [V/T]}. \quad (18)$$

In this paper, we call  $|V_{out}/B|$  the sensitivity of magnetometer. This result shows that the sensitivity in the condition is defined by Faraday's law as same as (7). The value is proportional to  $f$ ,  $n$ , and  $a^2$ , and does not depend on  $L$ .

### 3.3. High Frequency Region ( $f \gg f_v$ )

When the frequency  $f$  is much larger than  $f_v$ , we can approximate (15) as follows:

$$I_{out} = -j (f_v / f) \times (V / R_{in}) \text{ [A]}. \quad (19)$$

From (1), (6), (14), (19) and Ohm's law, we can derive the following equations:

$$I_{out} / B = (\pi n a^2) / L \text{ [A/T]}, \quad (20)$$

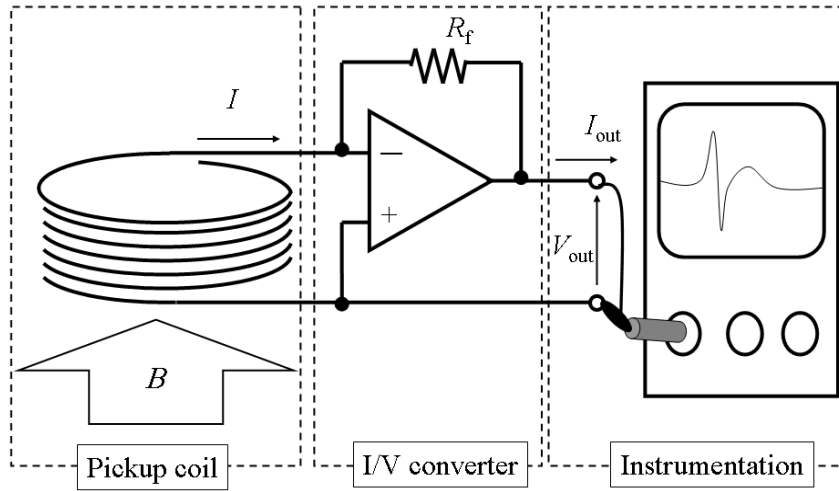
$$V_{out} / B = (\pi n a^2 R_{in}) / L = (\pi a R_{in}) / (P_0 n) \text{ [V/T]}. \quad (21)$$

In this paper, we call  $|I_{out}/B|$  the transfer ratio of the magnetometer. This result shows that the transfer ratio in those conditions is defined by the definition of inductance the same as (10). The sensitivity of the magnetometer is proportional to  $a^2$ ,  $n$ ,  $1/L$ . It does not depend on  $f$ . From (21), it seems that the sensitivity becomes infinity if  $R_{in}$  is infinity. However, (21) is not approved for a finite frequency because  $f_v$  is also infinity, and the sensitivity can only be expressed by (18). In practice, the  $R_{in}$  is finite value. It should be noted that the inductance of the pickup coil should be considered when the target frequency is high.

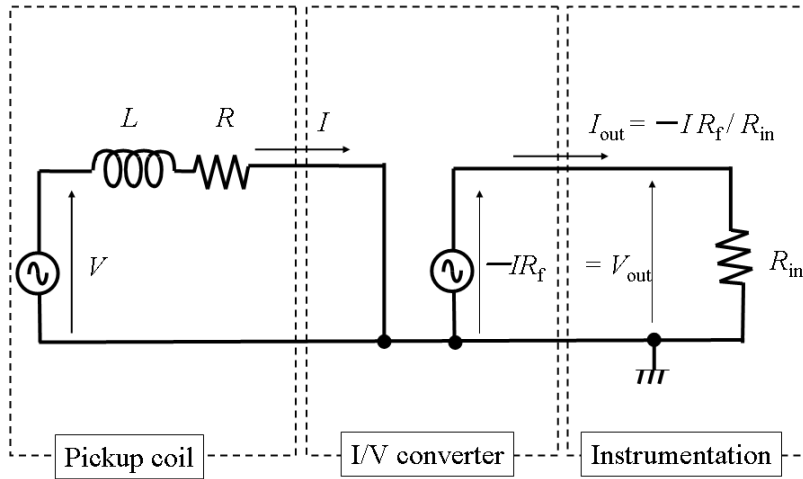
## 4. Current Detection Model

### 4.1. Model

**Fig. 3(a)** shows the current detection model with a current-to-voltage converter. Because the plus pin of the opamp is connected to the ground, the input resistance is zero and the pickup coil is in a virtual short. The output voltage of the current-to-voltage converter is the product of  $R_f$  and  $I$ . **Fig. 3(b)** shows the equivalent circuits.



(a) Model.



(b) Equivalent circuit.

**Fig. 3.** Induced current detection model.

Here, we define the cutoff frequency  $f_i$  as follows:

$$f_i = R / 2\pi L \text{ [Hz]}. \quad (22)$$

The pickup coil circuit is equivalent to Fig. 2 (b) with  $R_{in} = 0$ . From (1), (3), and (12), the current  $I$  can be expressed by the following equation:



$$I = (V / R) \times (1 / (1 + j(f / f_i))) [A]. \quad (23)$$

The input current to the instrumentation  $I_{out}$  [A] is the products of  $I$  and  $-(R_f / R_{in})$ . It can be written by the following equation:

$$I_{out} = - (R_f / R_{in}) \times (V / R) \times (1 / (1 + j(f / f_i))) [A]. \quad (24)$$

#### 4.2. Low Frequency Region ( $f \ll f_i$ )

When the frequency  $f$  is much smaller than  $f_i$ , we can approximate (24) as follows:

$$I_{out} = - (R_f / R_{in}) \times (V / R) [A]. \quad (25)$$

From (3), (6), (25) and Ohm's law, the transfer ratio and sensitivity of the magnetometer can be written by the following equations:

$$I_{out} / B = - (R_f / R_{in}) \times j 2 \pi^2 f n a^2 / R [A/T], \quad (26)$$

$$V_{out} / B = - (R_f / R) \times j 2 \pi^2 f n a^2 = - j \pi a s f R_f / \rho [V/T]. \quad (27)$$

Compared with the voltage detection model under the same frequency condition, the sensitivity is gained  $(R_f / R)$  times. In contrast, the value does not depend on  $n$ .

#### 4.3. High Frequency Region ( $f \gg f_i$ )

When the frequency  $f$  is much smaller than  $f_i$ , we can approximate (24) as follows:

$$I_{out} = j (f_i / f) \times (R_f / R_{in}) \times (V / R) [A]. \quad (28)$$

From (1), (6), (22), (28) and Ohm's law, the transfer ratio and sensitivity of the magnetometer can be written by the following equations:

$$I_{out} / B = - (R_f / R_{in}) \times (\pi n a^2) / L [A/T], \quad (29)$$

$$V_{out} / B = - (R_f \pi n a^2) / L = - \pi a R_f / (P_0 n) [V/T]. \quad (30)$$

Compared with the voltage detection model under the same frequency condition, the sensitivity is  $R_f$  times, and the sensitivity does not depend on  $R_{in}$ .

### 5. Discussion

#### 5.1. Dependence of Parameters

We have defined the four operational conditions of a magnetometer with an air-core pickup coil. The conditions were categorized by two detection models (voltage, current) and two cutoff frequencies ( $f_v, f_i$ ). The sensitivities of the magnetometer ( $V_{out}/B$ ) were described with five parameters ( $a, n, P_0, \rho, s$ ) for the coil design and three parameters ( $f, R_{in}, R_f$ ) for the electronics. Table 1 shows their relationship.

The mean radius,  $a$ , should be large to increase the sensitivities. It should be noted that the sensitivities of all conditions are proportional to  $a^2$  if  $L$  does not depend on  $a$ . However,  $L$  is proportional to  $a$  as in (1). In the voltage detection model in the low frequency region ( $f \ll f_v$ ), the sensitivity is proportional to  $a^2$  as in (18). Because the sensitivity does not depend on  $L$ , the same relationship is Faraday's law as in (7). In other conditions, the sensitivity is proportional to  $a$  as in (21), (27), and (30).

The number of turns,  $n$ , should be considered when a current exists in the pickup coil. Based on Faraday's law, the voltage transfer ratio of the pickup coil ( $V/B$ ) is proportional to  $n^2$  as in (7). In contrast, based on the definition of inductance, the current transfer ratio of the pickup coil is inversely proportional to  $n$  as in (10). Understanding this contradiction is the key point for the design of a high-sensitivity magnetometer. For a voltage detection model, an increase of  $n$  makes the sensitivity large as in (18). From (14), we should estimate  $f_v$  because the  $R_{in}$  is a finite value in practical cases. If the target frequency is higher than  $f_v$ , we have to consider the design because the sensitivity is inversely proportional to  $n$ .

Let's consider the sensitivity of current detection model in the low frequency region ( $f \ll f_i$ ). According to (27), the resistivity and cross section of the wire,  $\rho$  and  $s$ , only appear as in (27). In contrast, the sensitivity does not depend on  $n$ .

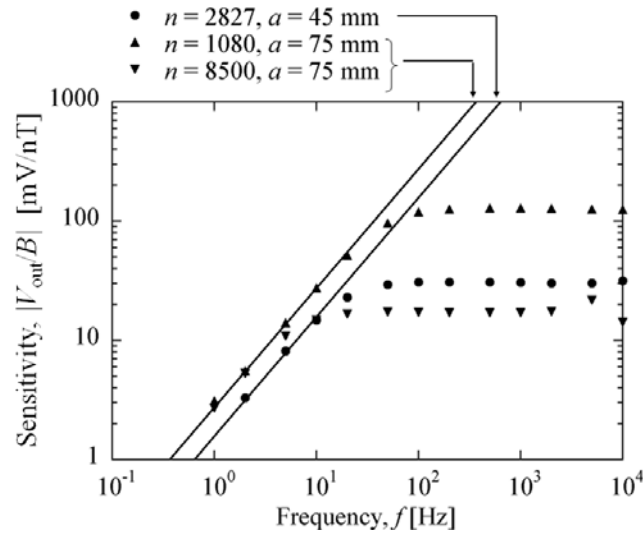
**Table 1.** Summary of parameters.

Property		Eq. number	parameter							
			$a$ [m]	$n$	$P_0$ [H/m]	$\rho$ [ $\Omega$ m]	$s$ [m <sup>2</sup> ]	$f$ [Hz]	$R_{in}$ [ $\Omega$ ]	$R_t$ [ $\Omega$ ]
Coil property	$L$ [H]	(1)	$a$	$n^2$	$P_0$					
	$R$ [ $\Omega$ ]	(3)	$a$	$n$		$\rho$	$1/s$			
Faraday's law	$ V/B $ [V/T]	(7)	$a^2$	$n$				$f$		
Definition of inductance	$ L/B $ [A/T]	(10)	$a$	$1/n$	$1/P_0$					
Induced voltage detection model	$f_v$ [Hz]	(14)	$1/a$	$1/n^2$	$1/P_0$				$R_{in}$	
	( $f \ll f_v$ ) $ V_{out}/B $ [V/T]	(18)	$a^2$	$n$				$f$		
	( $f \gg f_v$ ) $ V_{out}/B $ [V/T]	(21)	$a$	$1/n$	$1/P_0$				$R_{in}$	
Induced current detection model	$f_i$ [Hz]	(22)		$1/n$	$1/P_0$	$\rho$	$1/s$			
	( $f \ll f_i$ ) $ V_{out}/B $ [V/T]	(27)	$a$			$1/\rho$	$s$	$f$		$R_t$
	( $f \gg f_i$ ) $ V_{out}/B $ [V/T]	(30)	$a$	$1/n$	$1/P_0$					$R_t$

## 5.2. Experimental Verification

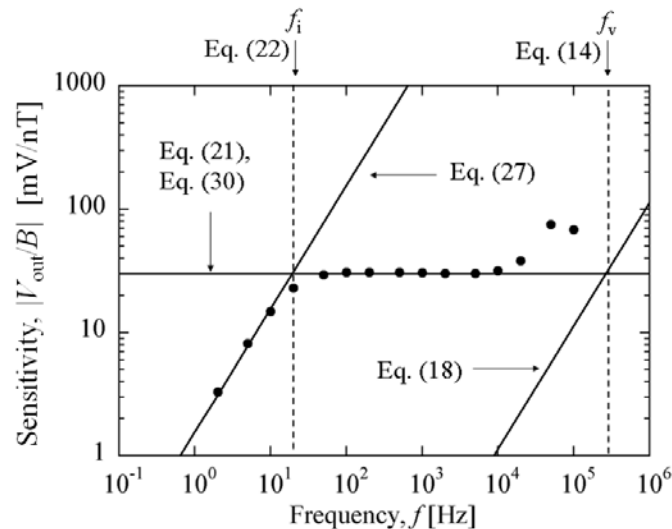
In order to confirm the behaviour of the parameter  $n$  of interest, we compared three kinds of our developed induction magnetometer. Fig. 4 shows the comparison of the measured frequency response. Plot data represents experimental results, and lines represent calculated results from (27). All of the pickup coils were Brooks coil, wound by a copper wire of 0.5 mm diameter. The same current-to-converter with  $R_t = 1 \text{ M}\Omega$  was used for the electronics. However, the parameters of  $a$  and  $n$  are different. The coil of  $a = 45 \text{ mm}$  has been developed based on an optimum design method [9]. The number of turns was defined by an optimum wire diameter of 0.5 mm. The coils of  $a = 75$  have been developed through the consideration of the space factor of the pickup coil [11]. It had been already reported that the estimated values of  $f_i$  and  $(V_{out}/B)$  in the high frequency regions were in good agreement with the measured values [12]. However, the values of  $(V_{out}/B)$  in the low frequency regions were not

discussed with theoretical approaches. The measured values in the low frequency regions were in good agreement with the calculated results from (27).



**Fig. 4.** Sensitivity as a function of frequency, as parameters of  $n$  and  $a$ . Plot data represents experimental results, and lines represent calculated results from Eq. (27).

For a clear understanding of the sensitivity limits, we compared the frequency responses of the two detection models. Fig. 5 shows the frequency response of experimental results and calculated results for the coil of  $a = 45$  mm. Plot data represents experimental results of the current detection model, and lines represent calculated results. We can see that the measured values were greater than the calculated values over 10 kHz. It had been already reported that the phenomena was due to the capacitance of the wire between the pickup coil and electronics [10]. Excluding the resonance phenomena, the validity of our proposed equations was successfully confirmed. Although, the sensitivity of the voltage detection model is proportional to  $n$ , the required  $n$  is larger than 4,000,000 to obtain the similar sensitivity of our induction magnetometer in the low frequency region. It should be also noted that for an increase of  $n$  making the sensitivity large for the voltage detection model, the value of  $R$  become large. Because the Johnson noise is proportional to  $R^{1/2}$ , the noise floor level of the magnetometer becomes worse.



**Fig. 5.** Comparison of frequency response of two models. Plot data represents experimental results of the current detection model, and lines represent calculated results. ( $a = 45$  mm,  $n = 2827$ ,  $R = 70 \Omega$ ,  $L = 0.611$  H).

### 5.3. Sensitivity Limit

The sensitivity of both detection models is limited in the high frequency region. If we assumed that  $R_f = R_{in}$ , the sensitivities can be described by the same equation as in (21) and (30). In order to simplify the equations of the sensitivity, we introduced two symbols:

$$F = 2\pi^2 f n a^2 [V/T], \quad (31)$$

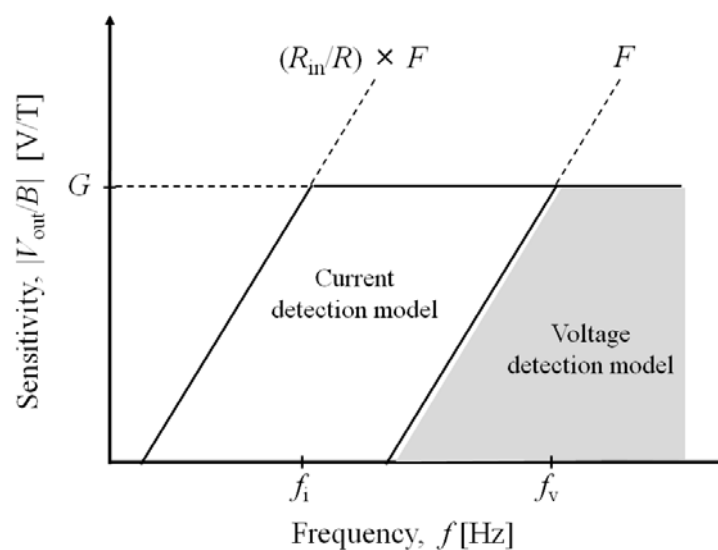
$$G = (R_f \pi n a^2) / L = (R_{in} \pi n a^2) / L [V/T]. \quad (32)$$

Fig. 6 illustrates the frequency response of the sensitivity for the two detection models. Table 2 shows a summary of the sensitivity at four operational conditions. From the results, four important tips were found.

- 1) In the low frequency region, the sensitivity of the current detection model is  $(R_f/R)$  times than that of the voltage detection model.
- 2) The limit value of the sensitivity  $G$  is inversely proportional to  $L$ .
- 3) In the current detection model, a suitable value of  $n$  exists. In the low frequency region, the sensitivity does not depend on  $n$ .
- 4) Although an increase of  $n$  makes the sensitivity large in the voltage detection model, the value of  $R$  becomes large. Because the Johnson noise is proportional to  $R^{1/2}$ , the noise floor level of the magnetometer becomes worse.

**Table 2.** Summary of the sensitivity limits.

Frequency	Detection model	
	Voltage	Current
Low	$F$	$(R_f/R) \times F$
High	$G$	$G$



**Fig. 6.** Theoretical frequency response of the sensitivity for the two detection model.



## References

- [1]. S. A. Macintyre, A portable low noise low frequency three-axis search coil magnetometer, *IEEE Trans. Magn.*, 16, 1980, pp. 761-763.
- [2]. R. J. Prance, T. D. Clark, H. Prance, Compact room-temperature induction magnetometer with superconducting quantum interference device level field sensitivity, *Rev. Sci. Instrum.*, 74, 2003, pp. 3735-3739.
- [3]. J. Lenz, and A. S. Edelstein, Magnetic sensors and their applications, *IEEE Sensors J.*, Vol. 6, No. 3, 2006, pp. 631-649.
- [4]. K. P. Estola, and J. Malmivuo, Air-core induction-coil magnetometer design, *J. Phys. E: Sci. Instrum.*, 15, 1982, pp. 1110-1113.
- [5]. V. Korepanov, R. Berkman, L. Rakhlin, Ye. Klymovych, A. Prystai, A. Marussenokov, and M. Afanassenko, Advanced field magnetometers comparative study, *Measurement*, 29, 2001, pp. 137-146.
- [6]. R. Sklyar, Superconducting induction magnetometer, *IEEE Sensors J.*, Vol. 6, No. 2, 2006, pp. 357-364.
- [7]. S. Tumanski, Induction coil sensors - a review, *Measurement Science & Technology*, Vol. 18, 2007, pp. R31-R46.
- [8]. K. Tashiro and I. Sasada, Ultra-low noise induction sensor (Preliminary studies for current sensor with magnetic shaking technique), *JSAEM Studies in Appl. Electromag. and Mech.*, 15, 2005, pp. 35-40.
- [9]. K. Tashiro, Optimal design of an air-core induction magnetometer for detecting low-frequency fields of less than 1 pT, *J. Magn. Soc. Jpn.*, 30, 2006, pp. 439-442.
- [10]. K. Tashiro, Broadband air-core Brooks-coil induction magnetometer, in *Proc. of the SICE-ICASE International Joint Conference 2006*, TA07-2, 2006.
- [11]. K. Tashiro, Proposal of coil structure for air-core induction magnetometer, in *Proc. of the IEEE Sensor 2006*, 2006, pp. 939-942.
- [12]. K. Tashiro, H. Wakiwaka, A. Kakiuchi, and A. Matsuoka, Comparative study of air-core coil design for induction magnetometer with current-to-voltage converter, in *Proc. of the 2<sup>nd</sup> International Conference on Sensing Technology (ICST' 2007)*, 2007, pp. 590-594.
- [13]. K. Tashiro, A. Kakiuchi, K. Moriizumi, and H. Wakiwaka, An Experimental Study of Stable Operating Conditions for a High-Sensitivity Induction Gradiometer, *IEEE Trans. Magn.*, Vol. 45, 2009, pp. 2784-2787.
- [14]. F. W. Grover, *Inductance Calculations*, Dover Phoenix Editions, 2004.
- [15]. K. Kajikawa and K. Kaiho, Usable range of some expression for calculation of the self-inductance of a circular coil of rectangular cross section, *TEIONKOHGAKU*, Vol. 30, 1995, pp. 324-332. (in Japanese), This article improved previous work given by J. Hak: *El. u. Maschinenb.* 51, 477, 1933).

2010 Copyright ©, International Frequency Sensor Association (IFSA). All rights reserved.  
(<http://www.sensorsportal.com>)

## Emerging MEMS 2010

### Technologies & Markets 2010 Report

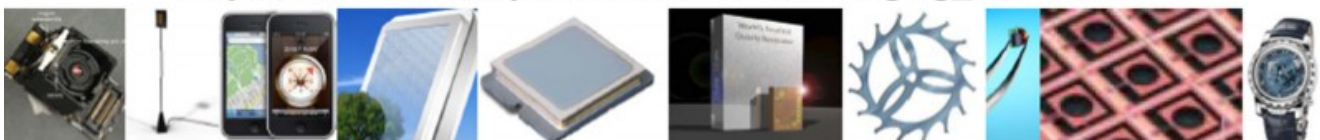
**Innovative developments in MEMS devices will add more than \$2B to the total MEMS market by 2015 !**

**This report presents a market and technical overview for MEMS-based Auto Focus, Electronic Compass, Energy Harvesting, Micro-bolometers, Micro displays, Micro fuel cells, Micro speakers, Micro structures, Microtips, Oscillators and RFID.**

**Estimated to be \$550M in 2009 a few % of the total MEMS business, Emerging MEMS markets have the potential to add \$2.2B to the overall MEMS market by 2015.**

**IFSA offers  
a SPECIAL PRICE**

**[http://www.sensorsportal.com/HTML/Emerging\\_MEMS.htm](http://www.sensorsportal.com/HTML/Emerging_MEMS.htm)**





The Second International Conference  
on Sensor Device Technologies and Applications

## SENSORDEVICES 2011

August 21-27, 2011 - French Riviera, France



**Important deadlines:**

Submission deadline	March 23, 2011
Notification	April 30, 2011
Registration	May 15, 2011
Camera ready	May 22, 2011

**Tracks:**

- Sensor devices
- Photonics
- Infrared
- Ultrasonic and Piezosensors
- Sensor device technologies
- Sensors signal conditioning and interfacing circuits
- Medical devices and sensors applications
- Sensors domain-oriented devices, technologies, and applications
- Sensor-based localization and tracking technologies

<http://www.iaria.org/conferences2011/SENSORDEVICES11.html>



The Fifth International Conference on Sensor  
Technologies and Applications

## SENSORCOMM 2011

August 21-27, 2011 - French Riviera, France



**Important deadlines:**

Submission deadline	March 23, 2011
Notification	April 30, 2011
Registration	May 15, 2011
Camera ready	May 22, 2011

**Tracks:**

- APASN: Architectures, protocols and algorithms of sensor networks
- MECSN: Energy, management and control of sensor networks
- RASQOFT: Resource allocation, services, QoS and fault tolerance in sensor networks
- PESMOSN: Performance, simulation and modelling of sensor networks
- SEMOSN: Security and monitoring of sensor networks
- SECSN: Sensor circuits and sensor devices
- RIWISN: Radio issues in wireless sensor networks
- SAPSN: Software, applications and programming of sensor networks
- DAIPSN: Data allocation and information in sensor networks
- DISN: Deployments and implementations of sensor networks
- UNWAT: Under water sensors and systems
- ENOPT: Energy optimization in wireless sensor networks

<http://www.iaria.org/conferences2011/SENSORCOMM11.html>



The Fourth International Conference on Advances  
in Circuits, Electronics and Micro-electronics

## CENICS 2011

August 21-27, 2011 - French Riviera, France



**Important deadlines:**

Submission deadline	March 23, 2011
Notification	April 30, 2011
Registration	May 15, 2011
Camera ready	May 22, 2011

**Tracks:**

- Semiconductors and applications
- Design, models and languages
- Signal processing circuits
- Arithmetic computational circuits
- Microelectronics
- Electronics technologies
- Special circuits
- Consumer electronics
- Application-oriented electronics

<http://www.iaria.org/conferences2011/CENICS11.html>

## 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. *Sensors & Transducers Journal* is indexed and abstracted very quickly by Chemical Abstracts, IndexCopernicus Journals Master List, Open J-Gate, Google Scholar, etc.

### 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.

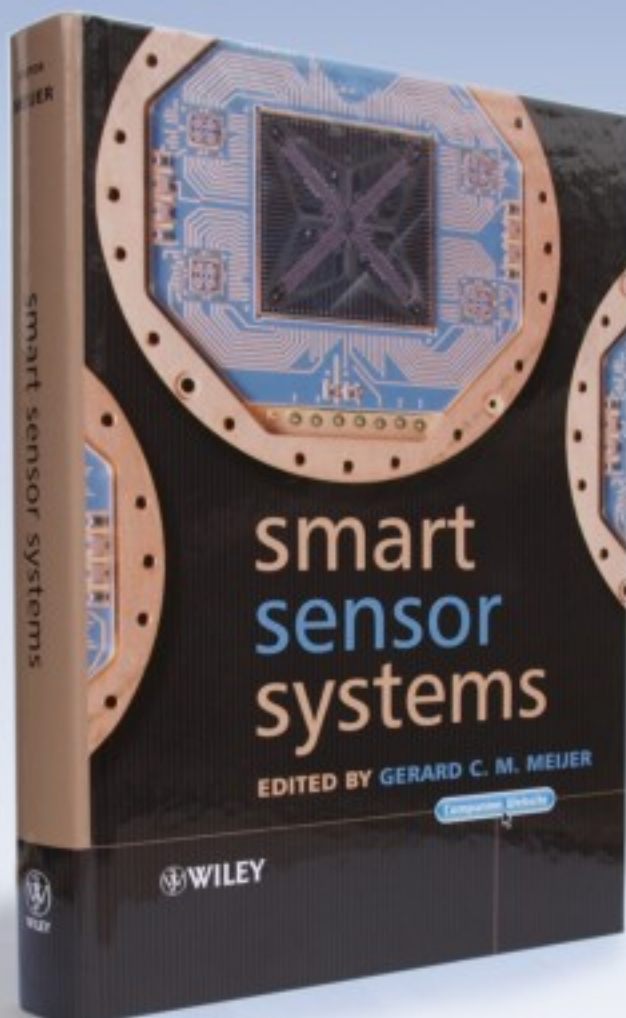
### Submission of papers

Articles should be written in English. Authors are invited to submit by e-mail [editor@sensorsportal.com](mailto:editor@sensorsportal.com) 8-14 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/Submition.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\\_2009.pdf](http://www.sensorsportal.com/DOWNLOADS/Media_Kit_2009.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)**