

ISSN 1726-5749

SENSORS & TRANSDUCERS

vol. 90
Special
4/08



Modern Sensing Technologies

International Frequency Sensor Association Publishing





Sensors & Transducers

Special Issue
April 2008

www.sensorsportal.com

ISSN 1726-5479

Editor-in-Chief: Sergey Y. Yurish

Guest Editors: Subhas Chandra Mukhopadhyay and Gourab Sen Gupta

Editors for Western Europe

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

Editors for North America

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

Editor South America

Costa-Felix, Rodrigo, Inmetro, Brazil

Editor for Eastern Europe

Sachenko, Anatoly, Ternopil State Economic University, Ukraine

Editor for Asia

Ohshima, Shinji, Tokyo Institute of Technology, Japan

Editorial Advisory Board

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

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, 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, 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
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
Hashsham, Syed, Michigan State University, USA
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
Jiao, Zheng, Shanghai University, China
John, Joachim, IMEC, Belgium
Kalach, Andrew, Voronezh Institute of Ministry of Interior, Russia
Rodriguez, Angel, Universidad Politecnica de Catalunya, Spain
Rothberg, Steve, Loughborough University, UK
Sadana, Ajit, University of Mississippi, USA

Kavasoglu, Nese, Mugla University, Turkey
Ke, Cathy, Tyndall National Institute, Ireland
Khan, Asif, Aligarh Muslim University, Aligarh, India
Kim, Min Young, Koh Young Technology, Inc., Korea South
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, Saisunee, Chiang Mai University, Thailand
Liew, Kim Meow, City University of Hong Kong, Hong Kong
Lin, Hermann, National Kaohsiung University, Taiwan
Lin, Paul, Cleveland State University, USA
Linderholm, Pontus, EPFL - Microsystems Laboratory, Switzerland
Liu, Aihua, University of Oklahoma, USA
Liu Changgeng, Louisiana State University, USA
Liu, Cheng-Hsien, National Tsing Hua University, Taiwan
Liu, Songqin, Southeast University, China
Lodeiro, Carlos, Universidade NOVA de Lisboa, Portugal
Lorenzo, Maria Encarnacio, Universidad Autonoma de Madrid, Spain
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
Mukhopadhyay, Subhas, Massey University, New Zealand
Neelamegam, Periasamy, Sastra Deemed University, India
Neshkova, Milka, Bulgarian Academy of Sciences, Bulgaria
Oberhammer, Joachim, Royal Institute of Technology, Sweden
Ould Lahoucin, 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 Seteal, 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
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
Sadeghian Marnani, Hamed, TU Delft, The Netherlands
Sandacci, Serghei, Sensor Technology Ltd., UK
Sapozhnikova, Ksenia, D.I.Mendeleyev Institute for Metrology, Russia
Saxena, Vibha, Bhabha Atomic Research Centre, Mumbai, India
Schneider, John K., Ultra-Scan Corporation, USA
Seif, Selemeni, Alabama A & M University, USA
Seifter, Achim, Los Alamos National Laboratory, USA
Sengupta, Deepak, Advance Bio-Photonics, India
Shearwood, Christopher, Nanyang Technological University, Singapore
Shin, Kyuho, Samsung Advanced Institute of Technology, Korea
Shmaliy, Yuriy, Kharkiv National University of Radio Electronics, Ukraine
Silva Girao, Pedro, Technical University of Lisbon, Portugal
Singh, V. R., National Physical Laboratory, India
Slomovitz, Daniel, UTE, Uruguay
Smith, Martin, Open University, UK
Soleymannpour, Ahmad, Damghan Basic Science University, Iran
Somani, Prakash R., Centre for Materials for Electronics Technol., India
Srinivas, Talabattula, Indian Institute of Science, Bangalore, India
Srivastava, Arvind K., Northwestern University, USA
Stefan-van Staden, Raluca-Ioana, University of Pretoria, South Africa
Sumriddetchka, Sarun, National Electronics and Computer Technology Center, Thailand
Sun, Chengliang, Polytechnic University, Hong-Kong
Sun, Dongming, Jilin University, China
Sun, Junhua, Beijing University of Aeronautics and Astronautics, China
Sun, Zhiqiang, Central South University, China
Suri, C. Raman, Institute of Microbial Technology, India
Sysoev, Victor, Saratov State Technical University, Russia
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
Vazques, Carmen, Carlos III University in Madrid, Spain
Vieira, Manuela, Instituto Superior de Engenharia de Lisboa, Portugal
Vigna, Benedetto, STMicroelectronics, Italy
Vrba, Radimir, Brno University of Technology, Czech Republic
Wandelt, Barbara, Technical University of Lodz, Poland
Wang, Jiangping, Xi'an Shiyou University, China
Wang, Kedong, Beihang University, China
Wang, Liang, Advanced Micro Devices, USA
Wang, Mi, University of Leeds, UK
Wang, Shinn-Fwu, Ching Yun University, Taiwan
Wang, Wei-Chih, University of Washington, USA
Wang, Wensheng, University of Pennsylvania, USA
Watson, Steven, Center for NanoSpace Technologies Inc., USA
Weiping, Yan, Dalian University of Technology, China
Wells, Stephen, Southern Company Services, USA
Wolkenberg, Andrzej, Institute of Electron Technology, Poland
Woods, R. Clive, Louisiana State University, USA
Wu, DerHo, National Pingtung University of Science and Technology, Taiwan
Wu, Zhaoyang, Hunan University, China
Xiu Tao, Ge, Chuzhou University, China
Xu, Lisheng, The Chinese University of Hong Kong, Hong Kong
Xu, Tao, University of California, Irvine, USA
Yang, Dongfang, National Research Council, Canada
Yang, Wuqiang, The University of Manchester, UK
Ymeti, Aurel, University of Twente, Netherland
Yu, Haihu, Wuhan University of Technology, China
Yufera Garcia, Alberto, Seville University, Spain
Zagnoni, Michele, University of Southampton, UK
Zeni, Luigi, Second University of Naples, Italy
Zhong, Haoxiang, Henan Normal University, China
Zhang, Minglong, Shanghai University, China
Zhang, Qintao, 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
Zouroh, Mohammed, University of Cambridge, UK

Contents

Volume 90
Special Issue
April 2008

www.sensorsportal.com

ISSN 1726-5479

Special Issue on Modern Sensing Technologies

Editorial

Modern Sensing Technologies

Subhas Chandra Mukhopadhyay and Gourab Sen Gupta 1

Sensors for Medical/Biological Applications

Characteristics and Application of CMC Sensors in Robotic Medical and Autonomous Systems

X. Chen, S. Yang, H. Natuhara K. Kawabe, T. Takemitsu and S. Motojima 1

SGFET as Charge Sensor: Application to Chemical and Biological Species Detection

T. Mohammed-Brahim, A.-C. Salaün, F. Le Bihan 11

Estimation of Low Concentration Magnetic Fluid Weight Density and Detection inside an Artificial Medium Using a Novel GMR Sensor

Chinthaka Gooneratne, Agnieszka Łekawa, Masayoshi Iwahara, Makiko Kakikawa and Sotoshi Yamada 27

Design of an Enhanced Electric Field Sensor Circuit in 0.18 μm CMOS for a Lab-on-a-Chip Bio-cell Detection Micro-Array

S. M. Rezaul Hasan and Siti Noorjannah Ibrahim 39

Wireless Sensors

Coexistence of Wireless Sensor Networks in Factory Automation Scenarios

Paolo Ferrari, Alessandra Flammini, Daniele Marioli, Emiliano Sisinni, Andrea Taroni 48

Wireless Passive Strain Sensor Based on Surface Acoustic Wave Devices

T. Nomura, K. Kawasaki and A. Saitoh 61

Environmental Measurement OS for a Tiny CRF-STACK Used in Wireless Network

Vasanth Iyer, G. Rammurthy, M. B. Srinivas 72

Ubiquitous Healthcare Data Analysis And Monitoring Using Multiple Wireless Sensors for Elderly Person

Sachin Bhardwaj, Dae-Seok Lee, S.C. Mukhopadhyay and Wan-Young Chung 87

Capacitive Sensors

Resistive and Capacitive Based Sensing Technologies

Winncy Y. Du and Scott W. Yelich 100

| | |
|---|-----|
| A Versatile Prototyping System for Capacitive Sensing <i>Daniel Hrach, Hubert Zangl, Anton Fuchs and Thomas Brettertklieber</i> | 117 |
| The Physical Basis of Dielectric Moisture Sensing <i>J. H. Christie and I. M. Woodhead</i> | 128 |
| Sensors Signal Processing | |
| Kalman Filter for Indirect Measurement of Electrolytic Bath State Variables: Tuning Design and Practical Aspects <i>Carlos A. Braga, João V. da Fonseca Neto, Nilton F. Nagem, Jorge A. Farid and Fábio Nogueira da Silva</i> | 139 |
| Signal Processing for the Impedance Measurement on an Electrochemical Generator <i>El-Hassane Aglzim, Amar Rouane, Mustapha Nadi and Djilali Kourtiche</i> | 150 |
| Gas Sensors | |
| Gas Sensing Performance of Pure and Modified BST Thick Film Resistor <i>G. H. Jain, V. B. Gaikwad, D. D. Kajale, R. M. Chaudhari, R. L. Patil, N. K. Pawar, M. K. Deore, S. D. Shinde and L. A. Patil</i> | 160 |
| Zirconia Oxygen Sensor for the Process Application: State-of-the-Art <i>Pavel Shuk, Ed Bailey, Ulrich Guth</i> | 174 |
| Image Sensors | |
| Measurement of Digital Camera Image Noise for Imaging Applications <i>Kenji Irie, Alan E. McKinnon, Keith Unsworth, Ian M. Woodhead</i> | 185 |
| Calibration-free Image Sensor Modelling Using Mechanistic Deconvolution <i>Shen Hin Lim, Tomonari Furukawa</i> | 195 |
| Miscellaneous | |
| Functional Link Neural Network-based Intelligent Sensors for Harsh Environments <i>Jagdish C. Patra, Goutam Chakraborty and Subhas Mukhopadhyay</i> | 209 |
| MEMS Based Pressure Sensors – Linearity and Sensitivity Issues <i>Jaspreet Singh, K. Nagachenchiah, M. M. Nayak</i> | 221 |
| Slip Validation and Prediction for Mars Exploration Rovers <i>Jeng Yen</i> | 233 |
| Actual Excitation-Based Rotor Position Sensing in Switched Reluctance Drives <i>Ibrahim Al-Bahadly</i> | 243 |
| A Portable Nuclear Magnetic Resonance Sensor System <i>R. Dykstra, M. Adams, P. T. Callaghan, A. Coy, C. D. Eccles, M. W. Hunter, T. Southern, R. L. Ward</i> | 255 |
| A Special Vibration Gyroscope <i>Wang Hong-wei, Chee Chen-jie, Teng Gong-qing, Jiang Shi-yu</i> | 267 |
| An Improved CMOS Sensor Circuit Using Parasitic Bipolar Junction Transistors for Monitoring the Freshness of Perishables <i>S. M. Rezaul Hasan and Siti Noorjannah Ibrahim</i> | 276 |

| | |
|---|-----|
| Sensing Technique Using Laser-induced Breakdown Spectroscopy Integrated with Micro-droplet Ejection System <i>Satoshi Ikezawa, Muneaki Wakamatsu, Joanna Pawlat and Toshitsugu Ueda</i> | 284 |
| A Forward Solution for RF Impedance Tomography in Wood <i>Ian Woodhead, Nobuo Sobue, Ian Platt, John Christie.....</i> | 294 |
| A Micromachined Infrared Sensor for an Infrared Focal Plane Array <i>Seong M. Cho, Woo Seok Yang, Ho Jun Ryu, Sang Hoon Cheon, Byoung-Gon Yu, Chang Auck Choi.....</i> | 302 |
| Slip Prediction through Tactile Sensing <i>Somrak Petchartee and Gareth Monkman.....</i> | 310 |
| Broadband and Improved Radiation Characteristics of Aperture-Coupled Stacked Microstrip Antenna for Mobile Communications <i>Sajal Kumar Palit.....</i> | 325 |
| The Use of Bragg Gratings in the Core and Cladding of Optical Fibres for Accurate Strain Sensing <i>Ian G. Platt and Ian M. Woodhead</i> | 333 |

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

A Forward Solution for RF Impedance Tomography in Wood

¹Ian WOODHEAD, ²Nobuo SOBUE, ¹Ian PLATT, ³John CHRISTIE

¹Lincoln Technology

Lincoln Ventures Ltd, Lincoln University, New Zealand

²Faculty of Agriculture

Shizuoka University, Shizuoka, 422-8529, Japan

³Streat Technology Ltd.

c/o Lincoln Ventures Ltd, Lincoln University, New Zealand,

E-mail: woodhead@lvl.co.nz, sobue@shizuoka.ac.jp, platti@lvl.co.nz, christij@lvl.co.nz

Received: 15 October 2007 / Accepted: 20 February 2008 / Published: 15 April 2008

Abstract: Both integral equation and differential equation methods enable modelling current and hence impedance of wood, to provide the forward solution for impedance tomography that in turn provides a measure of its internal moisture distribution. Previously, we have used a series impedance model and successfully demonstrated measurement of internal moisture distribution. Here we describe the adaptation of our integral equation method for this application. This has required an alternative calculation to model the impressed field from the segmented electrodes used in the measurements to date, and we demonstrate distortion of the anomalous field due to the presence of a wood dielectric, and the field magnitude. Further work will be required to translate the resulting field distribution from our model, to complex current and hence impedance readings, to allow completion of tomographic reconstruction using this approach. *Copyright © 2008 IFSA.*

Keywords: Impedance, Tomography, Heterogeneous, Model, Wood

1. Introduction

Water has several distinctive properties that may be used for measurement of moisture content in composite materials. One is that the bond angle of 104.47 degrees [1] between the hydrogen atoms, combines with the differing electronegativity of the hydrogen (2.1) and oxygen (3.5) atoms to result in a large polar moment. The strong polar nature of the water molecule contributes to the large relative permittivity (ϵ_r) of approximately 80 for bulk water compared to that of most dry biological and

natural materials for which ε_r is generally in the range 2 to 5 [2]. This large contrast enables dielectric measurements of composite materials to form a useful indirect measurement of volumetric moisture content (θ_v). In practice, ε_r is a curvilinear function of θ_v , whose curvature is dependent on the composite material, its texture, and its porosity which influence the interaction of the composite material with water.

ε_r arises primarily from polar molecules that store energy by elastic rotation, but contributions are also made by elastically altering bond angles, and intra-atomic contributions that are dominated by distortion of electron distribution. In the absence of an electric field, a polar substance such as water has permanent dipole moments that are randomly distributed so that no net polarization is present. The conductivity of the material and any conducting inclusions (e.g. dissociated water) dispersed within the material contribute to the dielectric loss of the mixture. The total permittivity ε comprises a real component ε' that represents the real or energy storage component of the permittivity, and ε'' the orthogonal or imaginary component that results from the conduction current contributed to by conductivity and other forms of dielectric loss.

$$\varepsilon = \varepsilon' - j\varepsilon'', \quad (1)$$

where j is $\sqrt{-1}$. Many methods of determining ε' are usefully employed for determining θ_v of composite materials. However where ε'' is large in comparison with ε' , the measurement becomes inaccurate [3]. Consequently, the choice of measurement frequency range when measuring ε' is crucial since many loss processes are frequency dependent.

For measurement of moisture content in wood, both ε' and ε'' have been explored such as described by [4], and provided the frequency is chosen to avoid the dispersive low frequency regions either or both measures may be used to provide a useful indication of moisture content.

We [5] have demonstrated the utility of applying impedance tomography to measurement of the internal moisture distribution in wood (Fig. 1), and using time domain reflectometry techniques [6]. Here we apply the electromagnetic model of [7] to the impedance tomography problem described by [5].

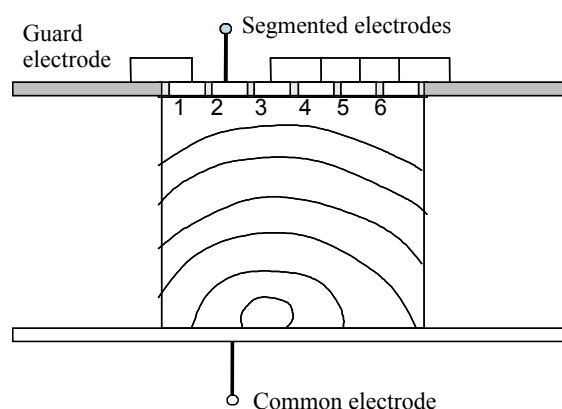


Fig. 1. Configuration of the segmented electrodes for measurement of the internal moisture distribution in wood described by Sobue and Inagaki (2007).

There are two main advantages of an integral equation model for this type of problem. The first is that since only the anomalous region (that occupied by the wood) needs to be modelled, the domain of the

problem need only include the timber cross-section and the segmented electrodes or capacitor plates (Fig. 1); the region beyond makes no contribution. Using a differential equation model, requires setting external boundary conditions, which may include the electrodes, but for accurate modelling needs to extend well beyond the region of the wood to where the field may be assumed to be zero. The second advantage of an integral equation approach is that the problem may be solved once for a given moisture distribution and for any field distribution representing different segments of the electrodes, resulting in just one forward calculation per inverse iteration. Again this contrasts with differential equation methods where one solution would be required for each capacitor electrode configuration. The approach is thus generally more favourable for inverting measurements than the otherwise more rapid differential equation methods.

We first provide some background to the integral equation approach, and then explain how we configured the impressed or incident field for application to this problem and show results from that simulation. Finally we describe the remaining work to complete the solution.

2. Theory

The polarization of a discretized zone or cell within a dielectric material may be represented by a dipole at its geometric centre. In most dielectric materials, there is no net polarization until generated by an external or impressed field. When applied to this quasi-static electric field problem where the material is considered lossless, the method of moments may be considered as the summation in each cell of the electric field contributions due to the polarization in all other cells. Using rectangular coordinates, the potential ϕ_p at point $p(x, y, z)$ generated by polarization P , is:

$$\phi_p = \frac{\tilde{P} \cdot \hat{r}}{4\pi\epsilon_0 r^2}, \quad (2)$$

where \hat{r} is a unit vector pointing from the centre of the cell to p [8], and r is the distance from the cell centre to p . In Cartesian 3-space:

$$\phi_p = \frac{\tilde{P} \cdot (\tilde{x}, \tilde{y}, \tilde{z})}{4\pi\epsilon_0 r^3}, \quad (3)$$

where \tilde{x}, \tilde{y} and \tilde{z} are the rectangular components of \tilde{r} . The potential arising from the contribution from many cells is:

$$\phi_p = \iiint \frac{\tilde{P} \cdot \hat{r}}{4\pi\epsilon_0 r^2} dv, \quad (4)$$

where dv is the differential volume over which each $\tilde{P} \cdot \hat{r}$ applies. Reverting to the single dipole case, its electric field is the space rate of change of potential ($-\nabla\phi_p$) so that from equation 3:

$$E_{px} = \frac{-\tilde{P}}{4\pi\epsilon_0 r^5} \cdot \left[\hat{x}(r^2 - 3x^2) - \hat{y}(3xy) - \hat{z}(3xz) \right] \quad (5)$$

with corresponding equations for E_{py} and E_{pz} . The above may be combined in an integral equation describing the electric field E_p at a point p :

$$\mathbf{E}_p(x, y, z) = -\nabla \left(\iiint \frac{\mathbf{P} \cdot \mathbf{r}}{4\pi\epsilon_0 r^2} dv \right) \quad (6)$$

The polarization region may now be discretized, and following the method of moments [9], we calculate the matrix of polarization vectors $P(x, y, z)$ using:

$$\begin{aligned} L(\mathbf{P}) &= -\mathbf{E}_i(x, y, z) \\ &= \mathbf{E}_p(x, y, z) - \frac{\mathbf{P}(x, y, z)}{\epsilon_0 \chi(x, y, z)}, \end{aligned} \quad (7)$$

where L is a linear operator, E_i the external impressed field and $\chi(x, y, z)$ the electric susceptibility ($\epsilon_r(x, y, z) - 1$). Equation 7 is converted to matrix form and solved for the vector of polarizations P , and the electric field strength in each cell is recovered from the polarization:

$$\mathbf{E}(x, y, z) = \frac{\mathbf{P}(x, y, z)}{\epsilon_0 \chi(x, y, z)} \quad (8)$$

The model used here employs the pseudo 3-D method [7] which effectively reduces the problem to 2-D, and uses field proximity compensation as described in [6] to obtain improved prediction of the electric field distribution.

The inputs required to solve the forward solution are:

1. A vector describing the impressed field
2. A matrix describing the complex permittivity within each cell
3. Details of the dimensionality of the problem.

While the above method applies to any impressed field distribution, in this case E_i is the vector of impressed field components arising from two planar electrodes as in Fig. 1.

3. Modelling Planar Electrodes

To calculate the field from two planar electrodes, and continuing to use rectangular coordinates, we first define a small element of the planar electrode Δx , with a line charge density ρ and calculate the potential at a point p positioned a distance $r = \sqrt{x^2 + y^2}$ from the electrode element [8]. From electrostatic theory, e.g. [8], the x -component of the potential is defined as:

$$\phi_x = \frac{\rho \Delta x}{4\pi\epsilon_0 \sqrt{x^2 + y^2}} \quad (9)$$

Since the electric field E is the gradient of the potential, i.e. $\mathbf{E} = -\nabla\phi$, and using (9) to define the potential in the x and y directions, it can be shown that the two rectangular components of the field at p may be expressed as:

$$\begin{aligned} E_x &= \frac{\rho}{4\pi\epsilon_0} \int \left((x^2 + y^2)^{-\frac{1}{2}} - x(x^2 + y^2)^{-\frac{3}{2}} \right) dx \\ E_y &= \frac{\rho}{4\pi\epsilon_0} \int -y(x^2 + y^2)^{-\frac{3}{2}} dy \end{aligned} \quad (10)$$

The integrals are taken over the surfaces of both electrodes with appropriate consideration to the sign of ρ . Then applying the theory described in Section 2, the resultant electric field may be generated. Fig. 2 shows the incident or impressed electric field, when no wood is inserted between the electrodes, when using equations 10 to provide a vector of impressed field values in the model.

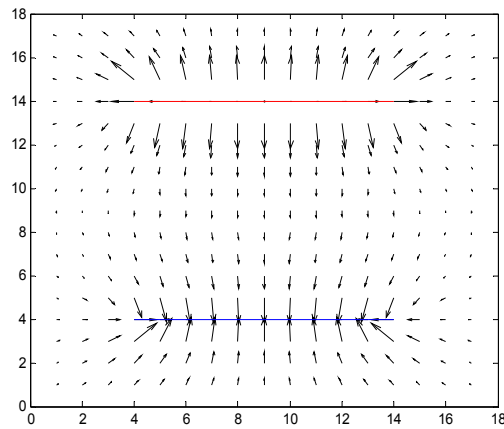


Fig. 2. Cross-sectional view (as in Fig. 1) showing the incident electric field distribution from two planar electrodes in air.

A typical result is shown in Fig. 3. In this case it arises from the forward solution applied to the region where a block of wood, $\epsilon_r = 3 + j3$, is positioned in the upper left region between the planar electrodes. It demonstrates the reduced field intensity within the wood compared with air, and the distortion of the surrounding field compared with Fig. 2. Note that in this instance, the electrodes have been defined as zero thickness, so there is an anomalous impact on the field outside the electrodes. The simplification has no effect on the field between the electrodes, with or without an included dielectric.

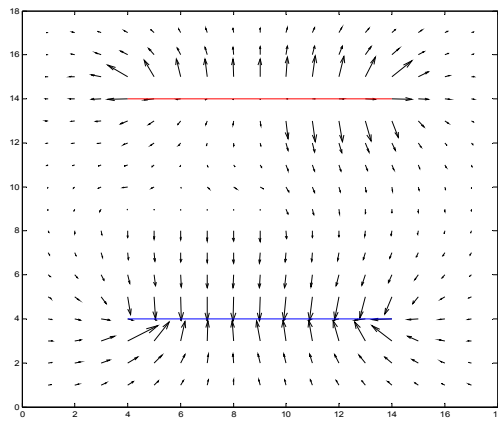


Fig. 3. Cross-sectional view (as in Fig. 2) showing the predicted electric field distribution when a block of wood is placed in the upper left region between the two planar electrodes.

4. Validation

We chose to validate the model by modelling the displacement current and hence predicting the capacitance of two planar electrodes with a PVC dielectric. A PVC block with $\epsilon_r = 3 + j0$ and with dimensions 50 by 50 by 148 mm was fitted with two self-adhesive foil electrodes of dimension 50 by

148 mm to form a capacitor. The measured capacitance, due to that of the capacitor itself plus the free-space capacitance of one plate at 250 kHz was 18.39 pF, so that the expected current from a 1V RMS source was 14.75 μ A.

The above model with a permittivity between the electrodes of $\epsilon_r = 3 + j0$, was used to calculate the electric field distribution for a potential difference between the electrodes of 1V RMS at 250 kHz. The displacement current density J_D , defined as dD/dt where D is electric displacement [11], can be written:

$$J_D = (1 + \chi)\epsilon_0 \frac{dE}{dt} \quad (11)$$

and hence the current is defined as:

$$i_D = (1 + \chi)\epsilon_0 l^2 \frac{dE}{dt} \quad (12)$$

where l is the edge length of the cubic cells. dE/dt for each cell was taken as the RMS value of the maximum dE/dt at 250 kHz, ωE . Since the forward solution represents the electrodes as sheet charge sources rather than conductors, the field and hence current outside the electrodes is affected by the dielectric between the electrodes. Hence the simulated displacement current has been taken as the sum of the total current with $\epsilon_r = 1 + j0$ and the difference between the current integrated along the inner face of the electrodes for the conditions $\epsilon_r = 3 + j0$ and $\epsilon_r = 1 + j0$. This provided a value of 15.14 μ A, compared with the 14.75 μ A value derived from measurements.

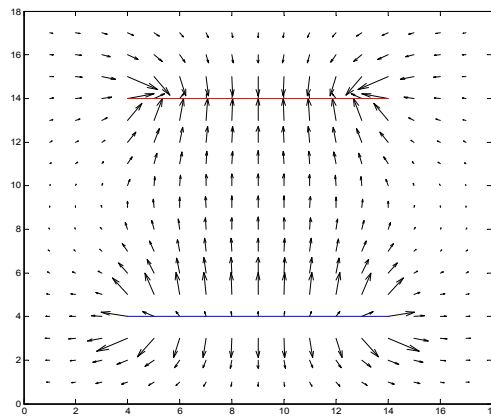


Fig. 4. Predicted displacement current for PVC dielectric between two planar electrodes.

5. Measurements in Wood

The validated forward solution described above is the major remaining step in providing a new impedance tomography method for measurement of moisture distribution in wood. The method of [5], configured according to Fig. 1, employed an instrument to measure the real and imaginary components of the impedance at 250 kHz. For an iterative inversion procedure to predict moisture distribution, the forward solution will need to be configured to predict the impedance between combinations of electrode segments which would then be compared with the measured values.

We explained above how an integral equation method conveys advantages for inverse methods, since little computational effort is required to provide a solution for each different configuration of the impressed field. In the method described by [5], guard electrodes were used, and hence we may make the approximation that the gaps between the electrode segments are arbitrarily narrow. In this case then, the electric field and current distribution remain constant, irrespective of which electrode segment is being measured, so that one forward calculation will suffice for each estimate of the wood impedance distribution in the inverse solution.

A further feature of this approach is that there is little computational overhead in providing values of impedance for many different measurement frequencies, and use of multiple frequencies is commonly used to extract a measure of product density. Hence we are keen to extend this work in the future to measurement of density distribution.

6. Conclusions

We have described a forward solution for calculating the impedance distribution in wood from its dielectric properties, and shown simulations of the electric field distribution in wood from the field of two parallel electrodes. The computational efficiency of the integral equation model has also been described and we forecast that this will have important industrial benefits. We have also predicted the displacement current in a PVC dielectric and provided good agreement with the measured value at 250 kHz. The next stage, is to apply the method to our earlier work which used a series model of impedance to provide tomographic reconstruction of the moisture distribution in wood.

Acknowledgement

This work was supported by the New Zealand Foundation for Research Science and Technology.

References

- [1]. F. Franks, Water, a comprehensive treatise, Vol. 1. The physics and physical chemistry of water, Ed. by J. B. Hasted, *Plenum Press*, London, 1972.
- [2]. S. O. Nelson, Electrical properties of agricultural products, a critical review, ASAE special publication SP-05-73, St Joseph, MI-ASAE, 1973.
- [3]. W. Leschnick and U. Schlemm, Measurement of the moisture and salt content of building materials, *3rd Workshop on Electromagnetic Wave Interaction with Water and Moist Substances*, USDA, Athens, Georgia, 1999.
- [4]. G. I. Torgovnikov, Dielectric properties of wood and wood-based materials, Ed. by T. E. Timel, *Springer Verlag*, Berlin, 1993.
- [5]. N. Sobue and M. Inagaki, *7th Conference on Electromagnetic Wave Interaction with Water and Moist Substances*, Hamamatsu, Japan, 2007.
- [6]. I. M. Woodhead, P. Riding, J. H. Christie and G. D. Buchan, Non-Invasive Measurement of Moisture Distribution, *Proceedings of the 2004 New Zealand National Conference on Non Destructive Testing*, Massey University, NZ, 2004.
- [7]. I. M. Woodhead, G. D. Buchan and D. Kulasiri. Pseudo-3-D Moment method for rapid calculation of electric field distribution in a low-loss inhomogeneous dielectric, *IEEE Transactions on Antennas and Propagation*, 49, 8, 2001, pp. 1117-1122.
- [8]. A. F. Kip, Fundamentals of Electricity and Magnetism, *McGraw-Hill*, 1962.
- [9]. R. F. Harrington, Field Computation by Moment Methods, *R E Kreiger*, 1968.

- [10].I. M. Woodhead, G. D. Buchan, I. G. Platt and J. H. Christie, Enhanced Integral Equation Modelling for Moisture Sensors, Sixth Conference on Electromagnetic Wave Interaction with Water and Moist Substances, *Weimar*, Germany, 2005, pp. 132-139.
 - [11].S. Ramo, J. R. Whinnery, and T. Van Duzer, Fields and Waves in Communication Electronics, *Wiley*, 1993.
 - [12].I. M. Woodhead, G. D. Buchan, I. G. Platt and J. H. Christie, 7th Conference on Electromagnetic Wave Interaction with Water and Moist Substances, *Hamamatsu*, Japan, 2007.
-

Guide for Contributors

Aims and Scope

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

Topics Covered

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

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

Submission of papers

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

Advertising Information

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

**e-Impact Factor 2007:
156.504**



Subscription 2008

*Sensors & Transducers Journal (ISSN 1726-5479)
for scientists and engineers who need to be
at cutting-edge of sensor and measuring
technologies and their applications.*

*Keep up-to-date with the latest, most significant
advances in all areas of sensors and transducers.*

**Take an advantage of IFSA membership
and save **40 %** of subscription cost.**

Subscribe online:

http://www.sensorsportal.com/HTML/DIGEST/Journal_Subscription_2008.htm