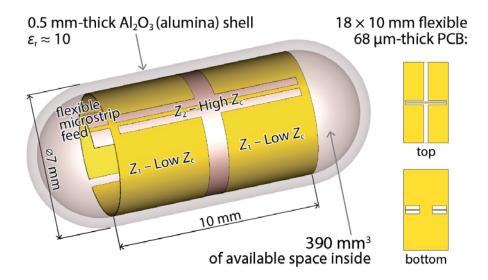
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Radio Science Bulletin Staff

Editor

W. R. Stone

Stoneware Limited 840 Armada Terrace San Diego, CA 92106, USA

Tel: +1-619 222 1915, Fax: +1-619 222 1606

E-mail: r.stone@ieee.org

Editor-in-Chief

Production Editor

P. Van Daele

URSI Secretariat Ghent University - INTEC Technologiepark - Zwijnaarde 15 B-9052 Gent BELGIUM

Tel: +32 9-264 33 20, Fax: +32 9-264 42 88

E-mail: Pet.VanDaele@UGent.be

I. Lievens

URSI Secretariat / Ghent University - INTEC Technologiepark - Zwijnaarde 15 B-9052 Gent, BELGIUM Tel: +32 9-264.33.20, Fax: +32 9-264.42.88

E-mail: ingeursi@ugent.be, info@ursi.org

Senior Associate Editors

A. Pellinen-Wannberg

Department of Physics Umea University BOX 812 SE-90187 Umea, SWEDEN

Tel: +46 90 786 74 92, Fax: +46 90 786 66 76 E-mail: asta.pellinen-wannberg@umu.se

O. Santolik

Institute of Atmospheric Physics Academy of Sciences of the Czech Republic Bocni II 1401, 141 31 Prague 4, CZECH REPUBLIC Tel: +420 267 103 083, Fax +420 272 762 528 E-mail os@ufa.cas.cz, santolik@gmail.com

Associate Editors, Commissions

Commission A

Nuno Borges Carvalho

Instituto de Telecomunicações
Universidade de Aveiro, Campus Universitario
3810-193 Aveiro, Portugal
Tele 251 224277000

Tel: +351 234377900, Fax: +351 234377901

E-mail: nbcarvalho@ua.pt

Tian Hong Loh

National Physical Laboratory Hampton Road Teddington TW11 0LW, United Kingdom Tel: +44 020 8943 6508

E-mail: tian.loh@npl.co.uk

Pedro Miguel Cruz

Rua Sao Sebastiao n34 Hab 33

4520-250 Santa Maria da Feira, Aveiro, PORTUGAL

Tel: +351 225898410

E-mail: pedro.cruz@controlar.pt

Nosherwan Shoaib

School of Electrical Engineering and Computer Science (SEECS) National University of Sciences and Technology (NUST) NUST Campus H-12, Islamabad, Pakistan

Tel: 051 90852561

E-mail: nosherwan.shoaib@seccs.edu.pk

Commission B

Andrea Michel

Department of Information Engineering Università di Pisa Pisa, Italy

E-mail: andrea.michel@iet.unipi.it

John Volakis

College of Engineering and Computing Florida International University 10555 W. Flagler Street, EC2477 Miami, FL 33174, USA

Tel: +1 305 348 2807 E-mail: jvolakis@fiu.edu

Commission C

Yves Louet

CS 47601, SUPELEC Avenue de Boulaie F-35576 Cesson-Sévigné, France

Tel: +33 2 99 84 45 34, Fax: +33 2 99 84 45 99

E-mail: yves.louet@supelec.fr

Commission D

Naoki Shinohara

RISH Kyoto University Uji 611-0011, Japan

Tel: +81 774 38 3807 Fax: +81 774 31 8463

E-mail: shino@rish.kyoto-u.ac.jp

Commission E

Virginie Deniau

IFSTTAR

20. rue Elisée Reclus BP 70317 F-59666 Villeneuve d'Ascq Cedex, France

Tel: +33 03 20438991

E-mail: virginie.deniau@ifsttar.fr

Commission F

Haonan Chen

Earth System Research lab, Physical Sciences Division NOAA

325 Broadway, Boulder, CO 80305, USA

Tel: +1 303 497 4616

E-mail: haonan.chen@noaa.gov

Tullio Tanzi

Télécom ParisTech - LabSoC, c/o EURECOM Campus SophiaTech Les Templiers 450 route des Chappes 06410 Biot, FRANCE Tel: +33 0 4 93008411, Fax: 33 0 493008200 E-mail: tullio.tanzi@telecom-paristech.fr

Commission G

Giorgiana De Franceschi

Dept. Arenonomy, Istituto Nazionale di Geofi sica e Vulcanology Via di Vigna, Murata 605 00 143 Roma, Italy

Tel: +39 06 51860307, Fax: +39 06 51860397 E-mail: giorgiana.defranceschi@ingv.it

Commission H

Jyrki Manninen

Sodankylä Geophysical Observatory Tähteläntie 62 FIN-99600 Sodanskylä, Finland

Tel: +358 400 151503, Fax +358 16 610248

E-mail: Jyrki.Manninen@oulo.fi

Commission J

Jacob W. Baars

Max Planck Institute for Radio Astronomy Auf dem Hügel 69 53121 Bonn, Germany Tel: +49 228 525303 E-mail: jacobbaars@arcor.de

Commission K

Kensuke Sasaki

Applied EM Research Institute NICT Koganei, Tokyo, Japan E-mail: k sasaki@nict.go.jp

Associate Editors, Columns

Book Reviews

G. Trichopoulos

Electrical, Computer & Energy Engineering ISTB4 555D Arizona State University 781 E Terrace Road, Tempe, AZ, 85287 USA

Tel: +1 (614) 364-2090 E-mail: gtrichop@asu.edu

Historical Papers

J. D. Mathews

Communications and Space Sciences Lab (CSSL) The Pennsylvania State University 323A, EE East University Park, PA 16802-2707, USA Tel: +1(814) 777-5875, Fax: +1 814 863 8457

E-mail: JDMathews@psu.edu

Et Cetera

T. Akgül

Dept. of Electronics and Communications Engineering Telecommunications Division Istanbul Technical University 80626 Maslak Istanbul, TURKEY Tel: +90 212 285 3605, Fax: +90 212 285 3565

E-mail: tayfunakgul@itu.edu.tr.

Women in Radio Science

A. Pellinen-Wannberg

Department of Physics and Swedish Institute of Space **Physics** Umeå University S-90187 Umeå, Sweden

Tel: +46 90 786 7492

E-mail: asta.pellinen-wannberg@umu.se

Ethically Speaking

R. L. Haupt

Colorado School of Mines **Brown Building 249** 1510 Illinois Street, Golden, CO 80401 USA Tel: +1 (303) 273 3721

E-mail: rhaupt@mines.edu

A. J. Shockley

E-mail: aj4317@gmail.com

Solution Box

Ö. Ergül

Department of Electrical and Electronics Engineering Middle East Technical University TR-06800, Ankara, Turkey E-mail: ozgur.ergul@eee.metu.edu.tr

Telecommunications Health & Safety

J. C. Lin

University of Illinois at Chicago 851 South Morgan Street, M/C 154 Chicago, IL 60607-7053 USA

Tel: +1 312 413 1052, Fax: +1 312 996 6465

E-mail: lin@uic.edu

Historical Column

G. Pelosi

Department of Information Engineering University of Florence Via di S. Marta, 3, 50139 Florence, Italy E-mail: giuseppe.pelosi@unifi.it

Early Career Representative Column

S. J. Wijnholds

Netherlands Institute for Radio Astronomy Oude Hoogeveensedijk 4 7991 PD Dwingeloo, The Netherlands E-mail: wijnholds@astron.nl

Education Column

Madhu Chandra

Microwave Engineering and Electromagnetic Theory Technische Universität Chemnitz Reichenhainerstrasse 70 09126 Germany

E-mail: madhu.chandra@etit.tu-chemnitz.de

URSI Officers and Secretariat

Current Officers triennium 2017-2020



President

M. Ando

Senior Executive Director
National Institute of Technology
701-2, Higashi Asakawa, Hachioji,
Tokyo 193-0834, Japan
Tel:+81-42-662-3123,
Fax: +81-42-662-3131
E-mail: ando@kosen-k.go.jp,
mando@antenna.ee.titech.ac.jp



Vice President

O. Santolik

Institute of Atmospheric Physics
Electrical Eng. Dept
Academy of Sciences of the Czech Republic
Bocni II, 1401
141 31 Prague 4, CZECH REPUBLIC
Tel: +420 267 103 083
Fax: 420 272 762 528

E-mail: os@ufa.cas.cz, santolik@gmail.com



Past President

P. S. Cannon

Gisbert Kapp Building
University of Birmingham
Edgbaston , Birmingham, B15 2TT,
UNITED KINGDOM
Tel: +44 (0) 7990 564772
Fax: +44 (0)121 414 4323
E-mail: p.cannon@bham.ac.uk



Vice President

A. Sihvola

Electronic Science Department
Aalto University
School of Electrical Engineering
PO Box 13000
FI-00076 AALTO
FINLAND
Tel: +358 50 5871286
E-mail: Ari.Sihvola@aalto.fi



Secretary General

P. Van Daele

URSI Secretariat
Ghent University - INTEC
Technologiepark - Zwijnaarde 15
B-9052 Gent
BELGIUM
Tel: +32 9-264 33 20
Fax: +32 9-264 42 88
E-mail: Pet.VanDaele@UGent.be



Vice President

P. L. E. Uslenghi

Dept. of ECE (MC 154)
University of Illinois at Chicago 851
S. Morgan Street
Chicago, IL 60607-7053
USA
Tel: +1 312 996-6059
Fax: +1 312 996 8664

Fax: +1 312 996 8664 E-mail: uslenghi@uic.edu



Vice President

W. Baan

Astron
Asserweg 45
9411 LP Beilen
THE NETHERLANDS
Tel: +31 521-595 773/100
Fax: +31 521-595 101
E-mail: baan@astron.nl

URSI Secretariat



Secretary General

P. Van Daele
URSI Secretariat
Ghent University - INTEC
Technologiepark - Zwijnaarde 15
B-9052 Gent
BELGIUM
Tel: +32 9-264 33 20
Fax: +32 9-264 42 88

E-mail: Pet.VanDaele@UGent.be



Assistant Secretary General AP-RASC

K. Kobayashi
Dept. of Electr and Commun. Eng,
Chuo University
1-13-27 Kasuga, Bunkyo-ku
Tokyo, 112-8551, JAPAN
Tel: +81 3 3817 1846/69
Fax: +81 3 3817 1847
E-mail: kazuya@tamacc.chuo-u.ac.jp



Assistant Secretary General

Stefan J. Wijnholds
Netherlands Institute for
Radio Astronomy
Oude Hoogeveensedijk 4
7991 PD Dwingeloo
The Netherlands
E-mail: wijnholds@astron.nl



Executive Secretary

I. Heleu
URSI Secretariat
Ghent University - INTEC
Technologiepark - Zwijnaarde 15
B-9052 Gent
BELGIUM
Tel. +32 9-264.33.20
Fax +32 9-264.42.88
E-mail info@ursi.org



Assistant Secretary General Publications & GASS

W. R. Stone
840 Armada Terrace
San Diego, CA 92106
USA
Tel: +1-619 222 1915
Fax: +1-619 222 1606
E-mail: r.stone@ieee.org



Administrative Secretary

I. Lievens
URSI Secretariat
Ghent University - INTEC
Technologiepark - Zwijnaarde 15
B-9052 Gent
BELGIUM
Tel: +32 9-264.33.20
Fax: +32 9-264.42.88
E-mail: ingeursi@ugent.be

Editor's Comments



W. Ross Stone Stoneware Limited 840 Armada Terrace San Diego, CA 92106, USA

Tel: +1-619 222 1915, Fax: +1-619 222 1606

E-mail: r.stone@ieee.org

Our Papers: Negative Group Delay, Refractivity Profiles, and In-Body Antennas

ur first two papers share a common theme: negative group delay. A circuit with negative group delay typically has the property that a time-limited signal (e.g., a pulse) centered at a frequency at which the negative group delay occurs will appear to exit the circuit before it enters the circuit. The first two papers in this issue examine the use of different topologies for realizing the negative group delay functionality.

The paper by B. Ravelo provides a basic overview of negative group delay RF circuits, including those covering the standard categories of filters: low-pass, bandpass, high-pass, and stop-band. The history of negative group delay circuits is reviewed, followed by an introduction to the basic topology and theory. The relationship to filter theory is explained. Methods for synthesizing, analyzing, and characterizing each of the four categories of negative group delay circuits are presented. Examples are given for each, using parallel and series R, L, and C components. Proof-of-concept designs and simulations are provided for the various cases.

The paper by Chung-Tse Michael Wu describes some of the latest developments in passive and active negative group delay circuits using distributed topologies with transmission-line elements. A survey that contrasts the lumped-element and transmission-line approaches to achieving negative group delay is first presented. Negative group delay circuits based on transversal and recursive filters are then described and analyzed. Both active and passive realizations are described. A FET-based distributed active negative group delay circuit is introduced. Simulations were used to validate the proposed design.

Numerical weather prediction models typically provide vertical refractivity profiles from altitudes of 5 m

to 10 m up to the stratosphere. Monin-Obukhov-Similarity-based turbulence models provide the refractivity profile in these first 5 m to 10 m above the sea's surface. However, a robust technique is essential for blending the profiles produced by these two techniques without producing nonphysical artifacts. The paper by Robert Marshall, Victor Wiss, Katherine Horgan, William Thornton, and Janet Stapleton presents such a technique. The technique differs from other approaches in two key ways that should make it more physically sound and more robust. Amulti-wavelength data-comparison process using the new technique did indicate improved blending.

Our last paper is by the winner of the "Prix Étudiant 2017" (2017 Student Paper Prize) of the French URSI Committee: Denys Nikolayev. He, Maxim Zhadobov, Pavel Karban, and Ronan Sauleau have provided us with a fascinating look at how the radiation performance of conformal antennas for miniature in-body devices can be improved. After a review of the problem of in-body devices and antennas in general, the authors look at the types of antennas that are used for in-body applications and their performance. The various factors that can be optimized to improve the in-body-to-out-of-body operating range are then considered. A method for synthesizing conformal inbody antennas is presented. A design example is presented, going through the whole synthesis, design, fabrication, and testing process. It was shown that the example design could operate at ranges of up to 14 m from various in-body sites.

Our Other Contributions

Stefan Wijnholds' Early Career Representatives Column Presents An Interview With The Recipient Of The 2017 Ursi Koga Gold Medal, Yue Li. His Perspectives On His Career To Date Should Be Of Interest Both To Those At An Early Stage In Their Careers, And To Those Who Work With Early-Career Radio Scientists.

Ethically Speaking, by Randy Haupt and Amy

Shockley, looks at how information can easily be deceptive. The illustration involves a story about coconuts. In reading it, I was reminded of some of the claims I've heard made by politicians – and, unfortunately, of some of the claims I've heard made by scientists and engineers trying to sell research proposals!

In his History Corner, Giuseppe Pelosi brings us a fascinating look at an interesting footnote to electromagnetics (a key part of which is literally contained in a footnote!). The column contains two separate papers dealing with connections between Michael Faraday and Italian physics. The first paper, by Stefano Selleri, examines the case of Francesco Zantedeschi, who claimed priority over Faraday's discovery of magnetic induction. The second paper, by Leonardo Possenti and Stefano Selleri, looks at Leopoldo Nobili, who developed the "astatic galvanometer" that Faraday used in demonstrating magnetic induction. As always, the carefully researched references and marvelous old figures make these most interesting reading.

Ali Farshkaran and Özgür Ergül bring us two problems in the latter's Solution Box column this time. Both involve periodic structures. The first structure is a metamaterial based on split-ring resonators. The second structure is a large array of RF antenna feeds. Both problems involve a large range of scale sizes, and both make use of the Equivalence-Principle Algorithm. Remember: a major intent of the Solution Box is to motivate input from our readers, in the form of either different (and hopefully, better) solutions to the same problems, or new and challenging problems in search of solutions.

In his Telecommunications Health and Safety column, James Lin recalls the interesting history of the microwave signals beamed at the US Embassy in Moscow in the middle to the latter part of the 20th century. His reexamination of what occurred then, in light of what we know now, brings a new perspective to the story.

Asta Pellinen Wannberg presents a Women in Radio Science column by Lee-Anne McKinnell. Dr. McKinnell began her career by modeling the ionosphere. She now is the Managing Director for Space Science within the South African National Space Agency (SANSA). Her story of how she got from that beginning to where she is now provides useful insight into how radio scientists can move from science to management and still make significant contributions to science.

AP-RASC is coming

The URSI Asia-Pacific Radio Science Conference (AP-RASC 2019) will be held March 9-15, 2019, in New Delhi, India. A call for papers appears in this issue. The submission deadline is October 1, 2018. I urge you to submit a paper and plan on attending this important conference.

Ross

On Low-Pass, High-Pass, Bandpass, and Stop-Band NGD RF Passive Circuits

B. Ravelo

Normandy University, UNIROUEN, ESIGELEC IRSEEM EA 4353
Technopole du Madrillet, Avenue Galilée
BP 10024
F-76801 Saint Etienne du Rouvray, France
E-mail: blaise.ravelo@yahoo.fr

Abstract

The negative group delay (NGD) function is one of the most intriguing phenomena that can be encountered in area of physics. Since the first experiments in the early 1980s, this abnormal phenomenon remains unfamiliar to conventional engineering. Based on physical, analytical, and experimental investigations, it was found that the NGD phenomenon corresponds to the advanced effect of a pulse signal at baseband frequency. This paper introduces the basic understanding of this extraordinary phenomenon. The RF and microwave-circuit theory dedicated to NGD passive circuits based on the S-parameter modeling is established. Two general types of lumped-element-based RF passive topologies, constituted of simple parallel and series mounted impedances, are explored. Low-pass, high-pass, bandpass, and stop-band elementary topologies of passive cells are treated and characterized. The low-pass NGD cells are first-order passive circuits consisting of RL-series mounted in parallel and RC-parallel networks mounted in series. The different steps of the circuit-parameter calculations as functions of the expected NGD level, insertion loss, and reflection coefficient are explained. To validate the theory, proofs-of-concept (POC) of NGD passive circuits were synthesized, designed, and simulated. As predicted in theory, the simulation results confirmed the feasibility of the low-pass, high-pass, bandpass, and stop-band NGD functions. The NGD circuits respected the basic criteria of RF and microwave circuits with reflection coefficients better than $-12 \, dB$. Despite the attenuation, the simulated low-pass NGD cell presented an NGD level of about -1 ns and a cutoff frequency equal to 46 MHz. The high-pass NGD cell presented a group-delay frequency response opposite to the low-pass NGD cell. The bandpass NGD cell exhibited an NGD level of about -2 ns at the center frequency of 0.5 GHz, and a bandwidth of about 92 MHz. Furthermore, the counterintuitive time-advance effect, induced by the NGD phenomenon, proven with various arbitrary-waveform baseband signals, was observed. A pulse advancement of about -1 ns was obtained with the considered low-pass passive cell.

1. Introduction

n the 1970s, an analytical investigation of the propagation of a Gaussian light pulse through an anomalous dispersion medium with negative refractive index was reported by Garrett and McCumber [1]. This theoretical result enabled understanding the negative group delay (NGD) effect in the time domain. After this theoretical conceptualization, the first experiments on NGD were performed in 1982 by Chu and Wong [2]. This experimental demonstration was based on the atomic-vapor medium, and showed the NGD phenomenon at optical wavelengths. However, several physicists remained skeptical about the existence of the NGD phenomenon. The NGD phenomenon was therefore assumed to typically be artifacts of numerical calculations, and not a real physical phenomenon. Consequently, this unfamiliar phenomenon was not sufficiently developed and less interesting to scientists, researchers, and engineers over the 1980s.

Despite this period of low interest, a new era of NGD functionality blew in with the 1990s with the unbelievable demonstrations with basic electronic circuits composed of familiar electronic components such as resistances, inductances, and capacitors. One decade after the first NGD demonstration by Chu and Wong, the first experiments with lumped electronic circuits was performed by the team of Chiao [3-6]. The NGD circuit topology was identified from an analogy between the atomic-vapor medium and the electronic-circuit's transfer function [3, 4]. Theoretical and experimental studies were then conducted with active optical systems [7-9] and electronic systems operating with audio signals [10-12] in order to illustrate the existence of the NGD phenomenon. During this period, one of the NGD effect's basic meanings was explained by electronic experiments considering pulse-shaped voltage signals with millisecond duration. It was visualized that the output pulse's leading and trailing edges occurred before the input pulse had completely penetrated into the NGD circuit. It was emphasized that this counterintuitive NGD phenomenon did not contradict the causality effect [5, 6, 10, 11]. However, at this stage, the complexity and operational speed limitations linked to the operational amplifiers did not motivate the electronic design engineers to exploit the NGD concept.

Some years later, the NGD phenomenon was synthesized with microwave and millimeter-wave circuits that were able to operate at higher frequencies [13-15]. In the same period, the NGD phenomenon was also generated with metamaterial microwave circuits, especially those based on periodic transmission-line structures [16-18]. Based on the microwave design and analyses, it was found that the NGD effect was generally generated with circuits that were typically lossy and resonate [13-24]. The NGD effect appeared around the resonance frequency. However, it was understood from time-domain experiments that this counterintuitive NGD effect was systematically accompanied with significant losses [18, 19]. This combined effect was inherently linked to the absorption around the resonance frequency. Because of the signification loss, there was little interest in the NGD concept during several decades.

To tackle this technical problem, microwave circuit topologies, based on the field-effect transistor (FET) and the low-noise amplifier (LNA), were proposed [25-28]. An analytical methodology enabling identification of simple NGD active microwave topologies was elaborated [26]. Several basic elementary NGD topologies susceptible to generating the NGD function were identified. A generalized NGD circuit theory was introduced. It was emphasized that the NGD function was similar to linear filter gain [29]. Low-pass, high-pass, bandpass, and stop-band NGD cells were identified. It was reported that the low- and high-pass NGD cells were typically first-order linear circuits.

An innovative RC-network-based high-pass NGD circuit was introduced in [30]. The bandpass and stop-band elementary cells were based on second-order resonating circuits. The NGD circuit's fundamental properties, such as the NGD level, the NGD cutoff frequencies, the NGD bandwidth, and the NGD figure-of-merit (FoM) were established and described. NGD circuit theory has been made widely available with the testing of several basic and elementary circuits. The feasibility of the theoretical concept has been validated by simulations and experiments. NGD effects have been simultaneously generated with the possibility of gain and loss compensation. Despite these developments in NGD circuit-design methodology, it was emphasized that the NGD effect does not allow any timeadvance configuration because of its inherent properties [31].

In addition to NGD design and synthesis, potential applications – notably, *RC*-interconnection propagation delay [32] cancellation – have been forecasted since the 2000s [33, 34]. The feasibility of this delay cancellation was later extended to signal recovery for signal-integrity enhancement, as suggested in [35-37]. Further potential

NGD applications for high-performance feed-forward amplifier design were also proposed [38].

Despite this trend of NGD theory becoming widely available, RF and electronic engineers are still not familiar with the NGD function. Further illustration is therefore needed for the NGD function to achieve further understanding in the academic and industrial points of view. In the present paper, we address a simple theoretical approach making it easy to understand the NGD function with lumped passive elementary cells. The aim of the paper is to make the NGD concept familiar to electricalengineering students, researchers, and those in industry. The present paper is also aimed at making the NGD concept and theory as familiar as possible to the non-specialist. In doing this – based on the analogy between NGD and filter theory [29] - the low-pass, high-pass, bandpass, and stopband elementary lumped RC cells are investigated. This microwave circuit theory is developed from particularly simple low-pass topologies of lumped-element components consisting of an RL series network and an RC parallel network. These act as first-order circuits that can be investigated in a manner similar to any familiar electrical function. A theoretical approach based on the S-parameter analysis is introduced in Section 2. The theory also presents the basic NGD properties and synthesis methodology for the basic NGD cells. By considering the familiar, known low-pass-to-bandpass circuit transformation in filter theory, bandpass NGD cells are also then investigated. The validity of the proposed NGD theory, simulations, and experimental results is presented and explored in Section 3. Both frequency- and time-domain analyses are deployed in order to show the NGD phenomena. Moreover, the ability to tune the NGD function level of the circuit parameters is tested for the deep understanding about the ability to control the NGD function with the lumped-circuit parameters. The conclusion of the paper is then presented in Section 4.

2. Generality of the Passive Topologies Under Study

The present section is focused on a simple way to design low-pass and bandpass NGD circuits, based on the familiar electronic components R, L, and C. After exploring the NGD effect's existence with two passive lumped-element-based topologies, we will investigate the S-parameter modeling methodology. The theoretical characterization of the active circuit obtained will then be described. At the end of each step, synthesis expressions enabling one to easily calculate the NGD circuit parameters as a function of the NGD specifications will be formulated.

2.1 Introduction to Basic Topology

The present subsection generally describes the elementary passive topologies of the circuit to be developed in this paper.

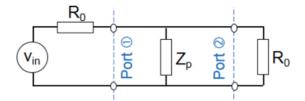


Figure 1. A shunt-impedance Z_p type passive topology.

Similar to all classical electronic and electrical circuits, the simplest and elementary topologies are based on the two-port circuit as a simple impedance that can be denoted Z. As pointed out in [25, 26, 29], we can start our investigation with a simple two-port circuit composed of a parallel impedance, Z_p , as depicted in Figure 1, or a series impedance, Z_s , as depicted in Figure 2. It should be underlined that in this paper, R_0 represents the reference impedance, equal to 50 Ω .

The present study is based on this two-port circuit *S*-parameter analysis. For the case of passive topologies, the associated *S* parameters can be defined by the symmetric relationship

$$[S] = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}. \tag{1}$$

2.2 S-Parameter Modeling

The present subsection describes the S-parameter modeling of the passive cells introduced in Figure 1 and Figure 2 of the previous subsections. The constituting element impedances, $Z_p(j\omega)$ and $Z_s(j\omega)$, are assumed to depend on the angular frequency, ω . After the determination of branch currents and applying the definition of the S parameters, we get the following expressions:

For the parallel-impedance-based cell:

$$\begin{bmatrix} S_{p}(j\omega) \end{bmatrix} = \begin{bmatrix} \frac{-R_{0}}{R_{0} + 2Z_{p}(j\omega)} & \frac{2Z_{p}(j\omega)}{R_{0} + 2Z_{p}(j\omega)} \\ \frac{2Z_{p}(j\omega)}{R_{0} + 2Z_{p}(j\omega)} & \frac{-R_{0}}{R_{0} + 2Z_{p}(j\omega)} \end{bmatrix}, (2)$$

For the series-impedance-based cell:

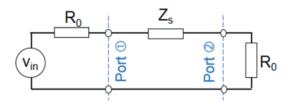


Figure 2. A series-impedance Z_s type passive topology.

$$\begin{bmatrix} S_s(j\omega) \end{bmatrix} = \begin{bmatrix} \frac{Z_s(j\omega)}{2R_0 + Z_s(j\omega)} & \frac{2R_0}{2R_0 + Z_s(j\omega)} \\ \frac{2R_0}{2R_0 + Z_s(j\omega)} & \frac{Z_s(j\omega)}{2R_0 + Z_s(j\omega)} \end{bmatrix}. (3)$$

It can be emphasized that the reflection and transmission coefficients of these passive circuits are linked by the relationship

$$S_{11}(j\omega) + S_{21}(j\omega) = 1. \tag{4}$$

This means that the circuit must generate significant insertion and reflection losses.

2.3 NGD Circuit Theory

Differently from the classical RF/microwave circuit theory, the unfamiliar NGD circuit theory is based on the sign of the group-delay analysis.

2.3.1 NGD Theoretical Analysis and Similarity to Filter Behavior

By denoting by $j\omega$ the circuit angular-frequency variable, according to circuit and system theory, it can be recalled that the group delay is defined by

$$\tau(\omega) = -\frac{\partial \varphi(\omega)}{\partial \omega}, \qquad (5)$$

with

$$\varphi(\omega) = \angle S_{21}(j\omega), \qquad (6)$$

Table 1. A comparison of the magnitude and group delay of NGD functions and conventional normal filters.

Characteristics	Normal Filter	NGD Function
Basic specifications	Transfer function gain	Transfer function group delay
G + MC	Root of the equation	Root of the equation $\tau(\omega_c) = 0$
Cutoff frequencies ω_c	$\left \left S_{21}(j\omega_c) \right = \left S_{21}(j\omega) \right _{\text{max}} / \sqrt{2} \right $	
Bandwidth	$\left \left S_{21}(j\omega_c) \right \ge \left S_{21}(j\omega) \right _{\max} / \sqrt{2} \right $	$\tau(\omega) \le 0$
Low-pass with bandwidth defined by		
$\omega \leq \omega_{c}$		
High-pass with bandwidth defined by		In the bandwidth, we have
$\omega \ge \omega_c$	In the bandwidth, we have	$\tau(\omega) \le 0$ and $ S_{21}(j\omega) $ should
Bandpass with bandwidth defined by	$\left \left S_{21}(j\omega_c) \right \ge \left S_{21}(j\omega) \right _{\max} / \sqrt{2} \right $	be as flat as possible.
$\omega_{c_1} \le \omega \le \omega_{c_2}$,	
Stop-band with bandwidth defined		
by $\omega \leq \omega_{c_1}$ and $\omega \geq \omega_{c_2}$		

being the transmission phase, expressed in radians. This last expression explains that our impedance cannot be a frequency-independent component, such as a simple resistance. In other words, to generate nonzero group delay, a reactive-element-based circuit is necessary.

It is worth noting that the group delay behaves similarly to the filter gain [29]. The NGD bandwidth corresponds to the frequency band where the group delay $\tau(\omega) < 0$. The cutoff angular frequency, ω_c , is analytically the root of the equation $\tau(\omega_c) = 0$. We can identify different types of group-delay cells. We have:

- A low-pass NGD function when the group delay is negative, $\tau(\omega) < 0$, in the lower frequency band, $\omega \le \omega_c$ or from $\omega \approx 0$ to the cutoff angular frequency, ω_c .
- A high-pass NGD when the group delay is negative, $\tau(\omega) < 0$, in the upper frequency band, $\omega \ge \omega_c$.
- A bandpass NGD when the group delay is negative, $\tau(\omega) < 0$, in the frequency band $\omega_{c_1} \le \omega \le \omega_{c_2}$ by supposing $\tau(\omega_{c_1}) = \tau(\omega_{c_2}) = 0$. In this case, the NGD central frequency, ω_0 , can be verified with

$$\tau(\omega_0) = \min[\tau(\omega)] < 0. \tag{7}$$

The NGD bandwidth can respectively be written as

$$\Delta \omega = \omega_{c_2} - \omega_{c_1} \,. \tag{8}$$

• A stop-band NGD when the group delay is negative, $\tau(\omega) < 0$, in the frequency band $\omega \le \omega_{c_1} \cup \omega_{c_2} \le \omega$ by supposing $\tau(\omega_{c_1}) = \tau(\omega_{c_2}) = 0$.

The performance of the passive NGD circuit can be evaluated with the figure-of-merit (FoM) defined by

$$FoM_{low-pass} = \left| S_{21} \left(\omega \approx 0 \right) \right| \tau \left(\omega \approx 0 \right) \omega_c \tag{9}$$

$$FoM_{band-pass} = \left| S_{21} \left(\omega \approx \omega_0 \right) \right| \tau \left(\omega = \omega_0 \right) \Delta \omega . \tag{10}$$

The better is the NGD circuit, the higher is the figure-ofmerit.

2.3.2 A Comparison Between NGD Functions and Normal Conventional Filters

Despite the previous definitions of the NGD function types, one may wonder or be confused about the NGD and classical-filter aspects. Table 1 provides a comparative illustration between NGD functions and conventional normal filters. Based on circuit theory, the conventional normal filter's bandwidths are defined where the transmission gain's magnitude satisfies the equation $\left|S_{21}(j\omega)\right| \geq \left|S_{21}(j\omega)\right|_{\max} / \sqrt{2}$. As previously described, the NGD functions are mainly based on the sign of the group delay.

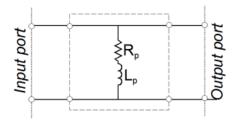


Figure 3. A low-pass NGD cell: *RL*-series shunt network.

2.3.3 Low-Pass NGD Passive Circuit Synthesis Method

Based on RF/microwave engineering, the main circuit parameters are basically the access matching and the insertion loss for passive circuits. Those parameters are still under consideration in the present study. However, in addition, we also deal with the group delay defined in Equation (5). For the low-pass NGD circuit, the NGD characterization described in this section is mainly obtained from the analytical expression of the S parameters and the group delay at very low frequencies, when $\omega \approx 0$. The synthesis method consists of the calculation of the NGD circuit's parameters as a function of the specified NGD level $\tau(\omega \approx 0) = \tau_0 < 0$, which is inversely linked to the NGD bandwidth; the insertion loss; and the reflection coefficients. In other words, the basic relations can be summarized in the following system:

$$\begin{cases}
|S_{11}(\omega \approx 0)| = s_{11} \\
|S_{21}(\omega \approx 0)| = s_{21} \\
|S_{22}(\omega \approx 0)| = s_{11}
\end{cases}$$

$$\tau(\omega \approx 0) = \tau_0$$
(11)

3. Shunt-Impedance-Type Elementary NGD Cells

The present section is focused on the NGD characterization of the family of shunt-impedance-type elementary NGD cell shown in Figure 1. Based on classical circuit theory, the simplest network configurations constituting the shunt impedance Z_p must be first-order circuits. This intuitive analysis leads us to consider RL and RC networks to build a low-pass NGD cell that will be analyzed in the present section.

3.1 Low-Pass Cell

The analytical identification performed in [26] stated that the only configuration of first-order or low-pass NGD

circuits associated with the parallel impedance configuration is an *RL*-series network:

$$Z_p(j\omega) = R_p + j\omega L_p. \tag{12}$$

The low-pass NGD elementary cell is depicted in Figure 3.

3.1.1 Frequency-Dependent *S* Parameters and Group Delay

For the shunt-impedance-based low-pass NGD cell, the *S* parameters can be rewritten as follows:

$$[S_{p}(j\omega)] = \begin{bmatrix} \frac{-R_{0}}{R_{0} + 2(R_{p} + j\omega L_{p})} & \frac{2(R_{p} + j\omega L_{p})}{R_{0} + 2(R_{p} + j\omega L_{p})} \\ \frac{2(R_{p} + j\omega L_{p})}{R_{0} + 2(R_{p} + j\omega L_{p})} & \frac{-R_{0}}{R_{0} + 2(R_{p} + j\omega L_{p})} \end{bmatrix}$$
(13)

From this we can determine the following reflection- and transmission-coefficient magnitudes:

$$\left|S_{p11}(j\omega)\right| = \left|\frac{-R_0}{R_0 + 2(R_p + j\omega L_p)}\right| \Rightarrow S_{p11}(\omega)$$

$$= S_{p22}(\omega) = \frac{2\sqrt{R_0^2}}{\sqrt{(R_0 + 2R_p)^2 + (L_p\omega)^2}}$$
(14)

$$\left|S_{p21}(j\omega)\right| = \left|\frac{2(R_p + j\omega L_p)}{R_0 + 2(R_p + j\omega L_p)}\right| \Rightarrow S_{p21}(\omega)$$

$$=S_{p12}\left(\omega\right)=\frac{2\sqrt{R_{p}^{2}+\left(L_{p}\omega\right)^{2}}}{\sqrt{\left(R_{0}+2R_{p}\right)^{2}+\left(L_{p}\omega\right)^{2}}}\,.$$

The associated transmission phase is given by

$$\varphi_p(\omega) = \arctan\left(\frac{L_p\omega}{R_p}\right) - \arctan\left(\frac{2L_p\omega}{R_0 + 2R_p}\right).$$
 (15)

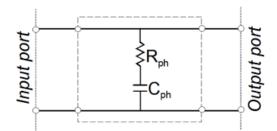


Figure 4. A high-pass NGD cell: RC-series shunt network family of the cell shown in Figure 3.

From the group delay defined in Equation (5), we have

$$\tau_{p}\left(\omega\right) = \frac{R_{0}L_{p}\left[2\left(L_{p}\omega\right)^{2} - R_{p}\left(R_{0} + 2R_{p}\right)\right]}{\left[\left(L_{p}\omega\right)^{2} + R_{p}^{2}\right]\left[\left(2L_{p}\omega\right)^{2} + \left(R_{0} + 2R_{p}\right)^{2}\right]}(16)$$

3.1.2 NGD Characterization

At very low frequencies, the S parameters of the parallel-impedance-based circuit become

$$[S_p(\omega \approx 0)] = \begin{bmatrix} \frac{-R_0}{R_0 + 2R_p} & \frac{2R_p}{R_0 + 2R_p} \\ \frac{2R_p}{R_0 + 2R_p} & \frac{-R_0}{R_0 + 2R_p} \end{bmatrix}.$$
 (17)

The associated group delay is given by

$$\tau_p\left(\omega \approx 0\right) = \frac{-R_0 L_p}{R_n(R_0 + 2R_n)}.$$
 (18)

It can be understood from the previous expression in Equation (18) that the passive cell introduced in Figure 3 behaves as a low-pass NGD circuit. In addition to the previous characteristics, one of the most important properties of the NGD cell is the NGD cutoff frequency, which can be denoted ω_{c_p} . It is the root of the equation $\tau_p(\omega_{c_p}) = 0$. The proposed shunt-impedance-based low-pass NGD cell cutoff frequency is given by

$$\omega_{c_p} = \frac{\sqrt{R_p \left(R_0 + 2R_p\right)}}{\sqrt{2}L_p} \,. \tag{19}$$

The NGD figure-of-merit is expressed as

$$FoM_{low-pass_{p}} = \frac{-R_{0}^{2}}{\left(R_{0} + 2R_{p}\right)\sqrt{2R_{p}\left(R_{0} + 2R_{p}\right)}}.(20)$$

It can be emphasized that the figure-of-merit is inversely proportional to the resistance R_p .

3.1.3 NGD Synthesis Method

Suppose we are given the desired insertion loss, a, the reflection coefficient, r, and the group delay, τ_0 <0. Analytically, the synthesis formulas are generated from Equation (18). After some calculations, we obtain the expressions for R_p and L_p associated with the shunt RL-series cell. The synthesis relations for this low-pass NGD cell are

$$\begin{cases} R_{p}(S_{11}) = R_{p}(S_{22}) = \frac{1-r}{2r}R_{0} \\ \text{or} \\ R_{p}(S_{12}) = R_{p}(S_{21}) = \frac{a}{2(1-a)}R_{0} \end{cases}$$
(21)

$$\begin{cases}
L_{p}(\tau_{0}) = -\left(1 + \frac{2R_{p}}{R_{0}}\right)R_{p}\tau_{0} \\
\text{or} \\
L_{p}(\omega_{c}) = \frac{\sqrt{R_{p}(R_{0} + 2R_{p})}}{\sqrt{2}\omega_{c}}
\end{cases} (22)$$

3.2 High-Pass NGD Elementary Cells

The high-pass NGD cell family of the circuit proposed in Figure 3 is depicted in Figure 4.

Similarly to filter theory, the high-pass NGD cells can be easily synthesized from the low-pass cells via the low-pass-to-high-pass transform. As illustrated in Figure 4, the constitute shunt impedance can be expressed as

$$Z_{ph}(j\omega) = R_{ph} + \frac{1}{j\omega C_{ph}}.$$
 (23)

The present subsection is focused on the NGD characteristics of the bandpass NGD cells associated with the previous cells.

3.2.1 High-Pass NGD Behavior

The *S* parameters of the series-impedance-based cell shown in Figure 4 become

$$\left[S_{ph}(j\omega)\right]$$

$$= \begin{bmatrix} \frac{j\omega R_{0}C_{ph}}{2 + j\omega C_{ph}(R_{0} + 2R_{ph})} & \frac{2(1 + 2j\omega R_{ph}C_{ph})}{2 + j\omega C_{ph}(R_{0} + 2R_{ph})} \\ \frac{2(1 + 2j\omega R_{ph}C_{ph})}{2 + j\omega C_{ph}(R_{0} + 2R_{ph})} & \frac{j\omega R_{0}C_{ph}}{2 + j\omega C_{ph}(R_{0} + 2R_{ph})} \end{bmatrix} (24)$$

Similar to the low-pass-to-high-pass filter transform, the resistance element is not changed: $R_{ph}=R_p$. The associated group delay is given by

$$\tau_{ph}\left(\omega \approx 0\right) = \frac{R_0 C_{ph}}{2} \,. \tag{25}$$

In addition to the previous characteristics, one of the most important properties of the NGD cell is the NGD cutoff frequency, which can be denoted ω_{c_h} . This is the root of the equation $\tau_{ph}\left(\omega_{c_h}\right)=0$. The proposed shunt-impedance-based high-pass NGD cell cutoff frequency is given by

$$\omega_{c_{ph}} = \frac{\sqrt{2}}{C_{ph}\sqrt{R_{p}(R_{0} + 2R_{p})}}$$
 (26)

Moreover, it is also found that for any integer n > 1, the group delay can be expressed as

$$\tau_{ph}\left(\omega=n\omega_{c_{ph}}\right)$$

$$= \frac{\left(1 - n^2\right) R_0 R_p C_{ph} \left(R_0 + 2 R_p\right)}{\left[R_0 + 2\left(1 + n^2\right) R_p\right] \left[n^2 R_0 + 2\left(1 + n^2\right) R_p\right]}. \tag{27}$$

It can be understood from the expressions in Equations (25), $\tau_{ph}\left(\omega\approx0\right)>0$, and (27), $\tau_{ph}\left(\omega=n\omega_{c_{ph}}\right)<0$, which generally means that $\tau_{ph}\left(\omega>\omega_{c_{ph}}\right)<0$. This means that the passive cell introduced in Figure 8 behaves as a highpass NGD circuit. The NGD figure-of-merit is expressed as $FoM_{high-pass_p}=FoM_{low-pass_p}$. It can be emphasized that the figure-of-merit is inversely proportional to the resistance R_p .

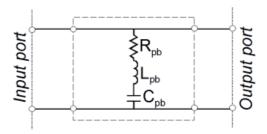


Figure 5. A bandpass NGD cell: *RLC*-series shunt network associated with the elementary cell shown in Figure 3.

3.2.2 Synthesis Method

For the high-pass NGD cell, the resistance parameter $R_{ph} = R_p$ can be synthesized with the relations in Equation (21). However, given the targeted positive group delay $\tau_0 > 0$, the capacitor C_{ph} can be extracted from the high-pass group delay expressed in Equation (25):

$$C_{ph} = \frac{2\tau_0}{R_0} \,. \tag{28}$$

This high-pass NGD cell capacitor can also be determined from the cutoff frequency expressed in Equation (26):

$$C_{ph} = \frac{\sqrt{2}}{\omega_{C_{nh}} \sqrt{R_p \left(R_0 + 2R_p\right)}}.$$
 (29)

3.3 Bandpass NGD Elementary Cells

Similarly to filter theory, the bandpass NGD cells can be easily synthesized from low-pass cells via the low-pass-to-band-pass transform. The present subsection is focused on the NGD characteristics of the bandpass NGD cells associated with the previous cells. In this case, to synthesize the associated bandpass NGD cell, we just need to replace the inductance L_p by an LC series network, as shown in Figure 5. Based on filter-circuit theory, during the low-pass-to-bandpass transform, the resistance element is not changed: $R_{pb} = R_p$.

3.3.1 Bandpass NGD Behavior

The proposed cell's resonance frequency, which is also the NGD central frequency, is defined by

$$\omega_0 = \frac{1}{\sqrt{L_{ss}C_s}} \ . \tag{30}$$

The associated S parameters at the center frequency are expressed as

$$[S_{pb}(\omega_0)] = [S_p(0)] = \begin{bmatrix} \frac{-R_0}{R_0 + 2R_p} & \frac{2R_p}{R_0 + 2R_p} \\ \frac{2R_p}{R_0 + 2R_p} & \frac{-R_0}{R_0 + 2R_p} \end{bmatrix}$$
(31)

It can be demonstrated that the associated group delay is

$$\tau_{pb}\left(\omega_{0}\right) = 2\tau_{p}\left(0\right) = \frac{-2R_{0}L_{pb}}{R_{p}\left(R_{0} + 2R_{p}\right)}.$$
 (32)

This group delay is always negative around the resonance frequency.

3.3.2 Bandpass NGD Characterization and Properties

The NGD center frequency of the passive cell shown in Figure 5 is equal to $\omega=\omega_0$. The NGD bandwidth is defined by

$$\Delta\omega_{c_{pb}} = 2\omega_{c_p} = \frac{\sqrt{2R_p\left(R_0 + 2R_p\right)}}{L_{pb}}.$$
 (33)

This means that the NGD cutoff frequencies are defined by

$$\omega_{c_{pb}} = \omega_0 \pm \omega_{c_p} = \frac{1}{\sqrt{L_{pb}C_{pb}}} \pm \frac{\sqrt{R_p(R_0 + 2R_p)}}{\sqrt{2}L_{pb}} \ (34)$$

The NGD figure-of-merit is expressed as

$$FoM_{band-pass_p} = 2FoM_{low-pass_p}$$
, (35)

which is inversely proportional to the resistance, R_p .

3.3.3 Synthesis Method

The bandpass NGD cell synthesis relationships can be inspired from the low-pass relationships defined in Equations (21) and (22). To achieve the same NGD level, the resistance can be obtained from the same relationship and half of the inductance $L_{ph} = L_p$, which must be considered based on the group delay defined in Equation (32). The associated capacitor can be calculated from the inductance and the expected NGD center angular frequency, which can be denoted ω_0 . We therefore have the capacitor-synthesis formula

$$C_{pb} = \frac{1}{\omega_0^2 L_{pb}} \,. \tag{36}$$

3.4 Stop-Band NGD Elementary Cells

Similarly to filter theory, the stop-band NGD cells can be easily synthesized from the low-pass cells via the low-pass-to-stop-band transform. Figure 6 represents the configuration of the stop-band cell associated with the circuit shown in Figure 3. Similarly to the low-pass-to-stop-band filter transform, the resistance element is not changed, $R_{ps} = R_p$. The present subsection is focused on the NGD characteristics of the bandpass NGD cells associated with the previous cells.

3.4.1 Stop-Band NGD Behavior, Characterization, and Properties

It can be demonstrated that the associated group delay is

$$\tau_{ps}\left(\omega_{0}\right) = R_{0}C_{ps}. \tag{37}$$

This group delay is always positive around the resonance frequency. The proposed shunt-impedance-based stop-band NGD cell cutoff frequencies are given by

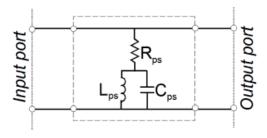


Figure 6. A stop-band NGD cell: R and LC-parallel series shunt network associated with the cell shown in Figure 3.

$$\omega_{c_{ps}} = \frac{1}{\sqrt{L_{ps}C_{ps}}} \pm \frac{\sqrt{2}}{C_{ps}\sqrt{R_{ps}(R_0 + 2R_{ps})}}.$$
 (38)

This means that the NGD bandwidths are

$$\begin{cases} \omega \leq \frac{1}{\sqrt{L_{ps}C_{ps}}} - \frac{\sqrt{2}}{C_{ps}\sqrt{R_{ps}\left(R_0 + 2R_{ps}\right)}} \\ \text{and} \\ \omega \leq \frac{1}{\sqrt{L_{ps}C_{ps}}} + \frac{\sqrt{2}}{C_{ps}\sqrt{R_{ps}\left(R_0 + 2R_{ps}\right)}} \end{cases}$$
(39)

For the case of a stop-band cell, the figure-of-merit cannot be defined.

3.4.3 Synthesis Method

The stop-pass NGD cell-synthesis relationships can be inspired from the combination of both low-pass and high-pass relationships. To obtain the attenuation, a, or the reflection coefficient, r, the resistance can be determined from the formula defined in Equation (21). For the given group delay, $\tau_0 > 0$, at the center angular frequency, which can be denoted ω_0 , the capacitor can be calculated with the relationship in Equation (28), $C_{ps} = C_{ph}$. The associated inductance can be calculated from the inductance and the expected NGD center angular frequency, which can be denoted ω_0 . We therefore have the inductance-synthesis formula

$$L_{ps} = \frac{1}{\omega_0^2 C_{ph}} \,. \tag{40}$$

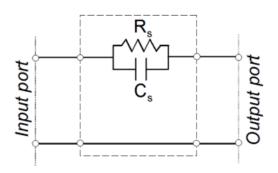


Figure 7. A low-pass NGD cell: RC-parallel series network.

4. Series Impedance-Type NGD Passive Cells

Similarly to the study performed in the previous section, the present section is focused on the NGD characterization of the family of series-impedance-type of elementary NGD topology shown in Figure 2. After checking different configurations, the first-order *RC*-parallel network constitutes the simplest cell to generate the lowpass NGD function.

4.1 Low-Pass NGD Elementary Cell

The analytical identification performed in [29] stated that the only configuration of first-order or low-pass NGD circuits associated with the series-impedance configuration is an *RC*-parallel network.

$$Z_s(j\omega) = \frac{R_s}{1 + j\omega R_s C_s}.$$
 (41)

Figure 7 represents the configuration of the elementary low-pass NGD cell.

4.1.1 Frequency-dependent *S* **Parameter and Group Delay**

The frequency-dependent S parameter of the proposed impedance-series-type cell can be expressed as

$$[S_s(j\omega)]$$

$$= \begin{bmatrix} \frac{R_s}{2R_0 + R_s + 2j\omega R_0 R_s C_s} & \frac{2R_0 (j\omega R_s C_s + 1)}{2R_0 + R_s + 2j\omega R_0 R_s C_s} \\ \frac{2R_0 (j\omega R_s C_s + 1)}{2R_0 + R_s + 2j\omega R_0 R_s C_s} & \frac{R_s}{2R_0 + R_s + 2j\omega R_0 R_s C_s} \end{bmatrix} (42)$$

From this we can determine the following reflectioncoefficient and insertion-loss magnitudes:

$$\left| S_{s_{22}} (j\omega) \right| = \left| S_{s_{11}} (j\omega) \right| = S_{s_{11}} (\omega)$$

$$= \frac{R_s}{\sqrt{(2R_0 + R_s)^2 + 4(\omega R_0 R_s C_s)^2}}$$
(43)

$$\left|S_{s_{12}}(j\omega)\right| = \left|S_{s_{21}}(j\omega)\right| = S_{s_{21}}(\omega)$$

$$= \frac{2R_0\sqrt{1 + (\omega R_s C_s)^2}}{\sqrt{(2R_0 + R_s)^2 + 4(\omega R_0 R_s C_s)^2}}.$$

The associated transmission phase is given by

$$\varphi_s(\omega) = \arctan(\omega R_s C_s) - \arctan\left(\frac{2\omega R_0 R_s C_s}{2R_0 + R_s}\right).$$
 (44)

From Equation (5), we have the group delay

$$\tau_{s}(\omega) = \frac{R_{s}^{2}C_{s}\left(2R_{0}R_{s}^{2}C_{s}^{2}\omega^{2} - 2R_{0} - R_{s}\right)}{\left(1 + R_{s}^{2}C_{s}^{2}\omega^{2}\right)\left[\left(2R_{0} + R_{s}\right)^{2} + 4R_{0}^{2}R_{s}^{2}C_{s}^{2}\omega^{2}\right]} (45)$$

4.1.2 NGD Characterization

At very low frequencies, the S parameters of the parallel-impedance-based circuit become

$$\left[S_{s}(\omega \approx 0)\right] = \begin{bmatrix} \frac{R_{s}}{2R_{0} + R_{s}} & \frac{2R_{0}}{2R_{0} + R_{s}} \\ \frac{2R_{0}}{2R_{0} + R_{s}} & \frac{R_{s}}{2R_{0} + R_{s}} \end{bmatrix}.$$
(46)

The associated group delay is given by

$$\tau_s\left(\omega \approx 0\right) = \frac{-R_s^2 C_s}{R_s + 2R_0}.$$
 (47)

It can be understood from the previous expression in Equation (47) that the passive cell introduced in Figure 3 behaves as a low-pass NGD circuit. In addition to the previous characteristics, one of the most important properties of the NGD cell is the NGD cutoff frequency, which can be denoted ω_{c_s} . It is the root of the equation $\tau_s(\omega_{c_s}) = 0$. The proposed shunt-impedance-based low-pass NGD-cell cutoff frequency is given by

$$\omega_{c_s} = \frac{\sqrt{1 + \frac{R_s}{2R_0}}}{R_s C_s} \,. \tag{48}$$

The NGD figure-of-merit is expressed as

$$FoM_{low-pass_s} = \frac{-R_s}{(2R_0 + R_s)\sqrt{R_s + 2R_0}}.$$
 (49)

In this case, it can be emphasized that the figure-of-merit is proportional to the resistance, R_p .

4.1.3 NGD Synthesis Method

The synthesis method consists of calculating R_s and C_s , which can be determined from the system of Equations (11) by considering the proposed seriesimpedance-type cell. The synthesis formulas are given by

$$\begin{cases} R_s(S_{11}) = R_s(S_{22}) = \frac{2r}{1-r}R_0 \\ \text{or} \\ R_s(S_{12}) = R_s(S_{21}) = \frac{1-a}{2a}R_0 \end{cases}, \tag{50}$$

$$\begin{cases} C_s \left(\tau_0\right) = -\frac{R_s + 2R_0}{R_s^2} \tau_0 \\ \text{or} \\ C_s \left(\omega_c\right) = \frac{\sqrt{1 + \frac{R_s}{2R_0}}}{R_s \omega_c} \end{cases}$$
 (51)

In the case of reflection-coefficient-based s_p resistance synthesis, the insertion loss is expressed as a function of r by the equation $S_{s_{21}}(\omega \approx 0) = r$. In the case of synthesis from the insertion loss, the reflection coefficient is expressed as a function of a by the equation $S_{s_{11}}(\omega \approx 0) = 1 - a$.

4.1.4 Equivalence Between the Parallel-and Series-Impedance Low-Pass NGD Cells

The equivalence between the two parallel- and series-impedance-based passive NGD topologies under study presents an electrical equivalence. By comparison of the transmission-parameter expressions, we have the equivalent relationship between the parallel and series resistances expressed as

$$R_p R_s = R_0^2 \,. (52)$$

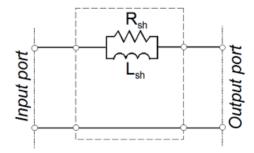


Figure 8. A high-pass NGD cell: *RL*-parallel series network associated with the low-pass cell shown in Figure 7.

In the same manner, the reactive-parameter equivalent relationships can be written as

$$\frac{L_p}{C_s} = R_0^2 (53)$$

4.2 High-Pass NGD Elementary Cells

The present subsection is focused on the NGD characteristics of the high-pass NGD cell associated with the circuit shown in Figure 7. The corresponding high-pass cell is depicted in Figure 8. The high-pass NGD cell is easily synthesized from the low-pass cell via the low-pass-to-high-pass transform. The resistance element is not changed: $R_{sh} = R_s$.

4.2.1 High-Pass NGD Behavior

The *S* parameters of the series-impedance-based cell shown in Figure 4 become

$$[S_{sh}(j\omega)] =$$

$$\begin{bmatrix} \frac{j\omega R_{s}L_{sh}}{2R_{0}R_{s}+j\omega L_{sh}\left(2R_{0}+R_{s}\right)} & \frac{2R_{0}\left(R_{s}+j\omega L_{sh}\right)}{2R_{0}R_{s}+j\omega L_{sh}\left(2R_{0}+R_{s}\right)} \\ \frac{2R_{0}\left(R_{s}+j\omega L_{sh}\right)}{2R_{0}R_{s}+j\omega L_{sh}\left(2R_{0}+R_{s}\right)} & \frac{j\omega R_{s}L_{sh}}{2R_{0}R_{s}+j\omega L_{sh}\left(2R_{0}+R_{s}\right)} \end{bmatrix} (54)$$

The associated group delay is given by

$$\tau_{sh}\left(\omega\approx0\right) = \frac{L_{sh}}{2R_0} \ . \tag{55}$$

The NGD cutoff frequency, $\omega_{c_{sh}}$, is given by

$$\omega_{c_{sh}} = \frac{R_s \sqrt{2R_0}}{L_{sh} \sqrt{2R_0 + R_s}}$$
 (56)

Moreover, it is also found that for any integer n > 1, the group delay can be expressed as

$$\tau_{sh}\left(\omega=n\omega_{c_{sh}}\right)=$$

$$\frac{\left(1-n^{2}\right)L_{sh}\left(2R_{0}+R_{s}\right)}{\left[2\left(1+n^{2}\right)R_{0}+R_{s}\right]\left[2\left(1+n^{2}\right)R_{0}+n^{2}R_{s}\right]}.$$
 (57)

It can be understood from Equation (55), $\tau_{sh}\left(\omega \approx 0\right) > 0$, and Equation (57), $\tau_{sh}\left(\omega = n\omega_{c_{sh}}\right) < 0$, which generally means that $\tau_{sh}\left(\omega > \omega_{c_{sh}}\right) < 0$. This means that the passive cell introduced in Figure 8 behaves as a high-pass NGD circuit.

The NGD figure-of-merit is expressed as

$$FoM_{high-pass_s} = FoM_{low-pass_s}, (58)$$

which is proportional to the resistance R_s .

4.2.2 Synthesis Method

The high-pass NGD resistance, $R_{sh} = R_s$, can be synthesized from Equation (50). Given the targeted positive group delay $\tau_0 > 0$, the inductance parameter can be synthesized from the group delay expressed in Equation (55), given by

$$L_{sh} = 2R_0\tau_0. (59)$$

The high-pass NGD cell inductance can also be alternatively determined from the high-pass cutoff frequency introduced in Equation (57):

$$L_{sh} = \frac{R_s \sqrt{2R_0}}{\omega_{c_{sh}} \sqrt{2R_0 + R_s}} \,. \tag{60}$$

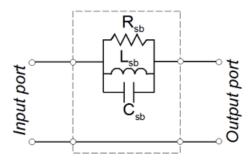


Figure 9. A bandpass NGD cell: *RLC*-parallel series network associated with the low-pass cell shown in Figure 7.

4.3 Bandpass NGD Elementary Cell

In this case, to synthesize the associated bandpass NGD cell we just need to replace the capacitor LC_s by an LC-parallel network, and we obtain the elementary cell shown in Figure 9. The resistance element is not changed, $R_{sb} = R_s$.

4.3.1 Bandpass NGD Behavior

The proposed cell's resonance frequency, which is also the NGD central frequency, is defined by

$$\omega_0 = \frac{1}{\sqrt{L_{sb}C_s}} \,. \tag{61}$$

The NGD bandpass behavior can be understood from the insertion-loss expression. The associated *S* parameters at the center frequency are then expressed as

$$[S_{sb}(\omega_0)] = [S_s(0)] = \begin{bmatrix} \frac{R_s}{2R_0 + R_s} & \frac{2R_0}{2R_0 + R_s} \\ \frac{2R_0}{2R_0 + R_s} & \frac{R_s}{2R_0 + R_s} \end{bmatrix}$$
(62)

The group delay is given by

$$\tau_{sb}(\omega_0) = 2\tau_s(0) = \frac{-4R_s^2 C_{sb}}{R_s + 2R_0}.$$
(63)

4.3.2 Bandpass NGD Characterization and Properties

The NGD center frequency of the passive cell shown in Figure 9 is equal to $\omega = \omega_0$. The NGD bandwidth is defined by

$$\Delta \omega_{c_{sb}} = 2\omega_{c_s} = \frac{\sqrt{1 + \frac{R_s}{2R_0}}}{R_s C_{sb}}.$$
 (64)

This means that the NGD cutoff frequencies are defined by

$$\omega_{c_{sb}} = \omega_0 \pm \omega_{c_s} = \frac{1}{\sqrt{L_{sb}C_{sb}}} \pm \frac{\sqrt{1 + \frac{R_s}{2R_0}}}{R_s C_{sb}}.$$
 (65)

This bandpass cell's NGD figure-of-merit is expressed as

$$FoM_{band-pass_s} = 2FoM_{low-pass_s},$$
 (66)

which is proportional to the resistance, R_s .

4.3.3 Synthesis Method

Similarly to the previous case of Subsection 3.3.3, the bandpass NGD cell resistance and capacitor parameters can be determined from the associated low-pass cell. The same equation allows determining the resistance. However, two times the low-pass NGD cell capacitor, $C_{sb} = 2C_s$, must be considered, based on the group delay defined in Equation (56). The associated inductance can be calculated from the inductance and the expected NGD center angular frequency, which can be denoted ω_0 . We therefore have the synthesis formula

$$L_{sb} = \frac{1}{\omega_0^2 C_{sb}} \,. \tag{67}$$

4.4 Stop-Band NGD Elementary Cells

Similarly to Subsection 3.4, the stop-band NGD cell can be easily synthesized from the low-pass cells via the

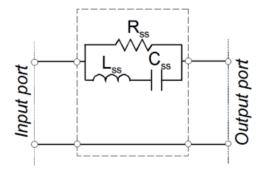


Figure 10. A stop-band NGD cell: *R* and *LC*-series parallel network associated with the low-pass cell shown in Figure 7.

low-pass-to-stop-band transform. Figure 10 represents the configuration of the impedance-series-type stop-band NGD cell. The resistance element is not changed: $R_{ss} = R_s$.

4.4.1 Stop-Band NGD Behavior

The proposed cell's resonance frequency is defined by

$$\omega_0 = \frac{1}{\sqrt{L_{ss}C_{ss}}} \,. \tag{68}$$

It can be demonstrated that the associated group delay is

$$\tau_{ss}\left(\omega_0\right) = \frac{L_{ss}}{2R_0} \,. \tag{69}$$

This group delay is always positive around the resonance frequency.

4.4.2 Stop-Band NGD Characterization and Properties

The proposed shunt-impedance-based stop-band NGD cell's cut-off frequencies are given by

$$\omega_{c_{ss}} = \frac{1}{\sqrt{L_{ss}C_{ss}}} \pm \frac{R_s\sqrt{2R_0}}{L_{ss}\sqrt{2R_0 + R_s}} \ . \tag{70}$$

This means that the NGD bandwidths are

$$\begin{cases} \omega \leq \frac{1}{\sqrt{L_{ss}C_{ss}}} - \frac{R_s\sqrt{2R_0}}{L_{ss}\sqrt{2R_0 + R_s}} \\ \text{and} \\ \omega \geq \frac{1}{\sqrt{L_{ss}C_{ss}}} + \frac{R_s\sqrt{2R_0}}{L_{ss}\sqrt{2R_0 + R_s}} \end{cases}$$
 (71)

For the case of the stop-band cell, the figure-of-merit cannot be defined.

4.4.3 Synthesis Method

By analogy with Section 3.4.3, the stop-pass NGD cell-synthesis relationships can be inspired by the combination of the low-pass and high-pass relationships. The resistance is the same relationship as for the low-pass cell defined in Equation (50). The inductance must be the same as for the high-pass cell defined in Equation (59) or Equation (60), $L_{ss} = L_{sh}$. The associated capacitor can be calculated from the inductance and the expected NGD center angular frequency, which can be denoted ω_0 . We therefore have the capacitor-synthesis formula

$$C_{ss} = \frac{1}{\omega_0^2 L_{sh}} \,. \tag{72}$$

To validate the overall NGD circuit theory, the design, simulation, and experiments for low-pass, high-pass, bandpass, and band-stop NGD cells built with lumped *R*, *L*, and *C* based elements are presented in the next section.

5. Validation Results

It can be understood from the previous theory that the NGD circuit under study can be assumed to behave like any familiar electronic circuit. The present section is focused on the simulation results of proof-of-concept NGD cells synthesized from the developed theory. The family of two previously explored topologies based on parallel and series impedances is explored. For each family, the low-pass NGD circuits were synthesized, designed, simulated, fabricated, and tested in order to achieve the following arbitrary specifications:

- NGD level $\tau_0 = -1 \text{ ns}$
- Reflection coefficient r = -12 dB.

The associated following circuits were then synthesized:

Table 2. Synthesized NGD circuit parameters.

Type Of NGD Cells	Low-Pass	High-Pass	Bandpass	Stop-Band
Resistance parameter	$R_p = 74.53_{\Omega}$ $R_s = 33.54_{\Omega}$			
Inductance parameter	$L_p = 2.97 \text{ nH}$	$L_{sh} = 100 \text{ nF}$	$L_{pb} = L_p$ $L_{sb} = 0.85 \text{nH}$	$L_{ps} = 2.53 \text{nH}$ $L_{ss} = L_{sh}$
Capacitor parameter	$C_s = 119 \text{pF}$	$C_{ph} = 40 \mathrm{pF}$	$C_{pb} = 0.34 \mathrm{pF}$ $C_{sb} = C_s$	$C_{ps} = C_{ph}$ $C_{sh} = 1.01 \text{ pF}$

- · High-pass NGD cell,
- Bandpass NGD cell aimed at operating at a center frequency of $f_0 = 0.5 \text{ GHz}$,
- Stop-band NGD cell with a center frequency $f_0 = 0.5$ GHz.

The proof-of-concept modeled computed results were compared with simulations run in the *ADS*® environment of the electronic circuit designer and simulator. The proposed *S*-parameter simulations were performed from dc to 1 GHz. The simulation results obtained will be explored in the next paragraphs.

5.1 NGD Cell Proof-of-Concept Syntheses and Designs

After the circuit synthesis from the arbitrary given NGD and specifications, the NGD circuit examples will be described. The NGD functionality can be understood from

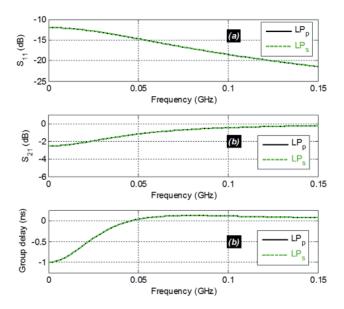


Figure 11. (a) The reflection and (b) transmission coefficients, and (c) group delay of the low-pass NGD circuits shown in Figure 3 and Figure 7.

the simulations. Table 2 summarizes the parameters of the low-pass, high-pass, bandpass, and stop-band NGD cells synthesized given the specifications $\tau_0 = -1$ ns and r = -12 dB

5.2 Frequency-Domain Results

S-parameter simulations of circuits parameterized as addressed in the first column of Table 2 were performed to illustrate the low-pass, high-pass, bandpass, and stop-band NGD functions.

5.2.1 Low-Pass NGD Results

Figures 11a and 11b respectively display the reflection and transmission coefficients of the low-pass NGD cells shown in Figure 3 and Figure 7 for the shunt- and seriesimpedance-based topologies. The shunt-impedance-based results are plotted with the solid line, and the seriesimpedance-based results are plotted with the dashed line. As illustrated by Figure 11c, these passive cells behaved as a low-pass NGD function with the same characteristics. The theoretical prediction and the simulations were in very good agreement, and they confirmed the low-pass NGD function with the proposed passive lumped cells. Both cells generated the same S-parameter results. They presented a low-pass NGD level $\tau(0) = -1$ ns and a cutoff frequency of about $f_c(NCD) = 46$ MHz. Over the NGD bandwidth, the insertion loss varied from -2.5 dB to -1.27 dB. In other words, the insertion-loss flatness was about 1.23 dB. The reflection coefficients were better than $-12 \, dB$.

5.2.2 High-Pass NGD Results

To simulate the high-pass cells, the parameters of the high-pass cells shown in Figure 4 (for the parallel-impedance-based cell) and in Figure 8 (for the series-impedance-based cell) addressed in the second column of Table 1 were considered. Figures 12a and 12(b) respectively display the reflection- and transmission-coefficient plots. Figure 12c depicts the associated group delays. As expected, both cells generated the same *S*-parameter results. In addition, they behaved as having an NGD high-pass

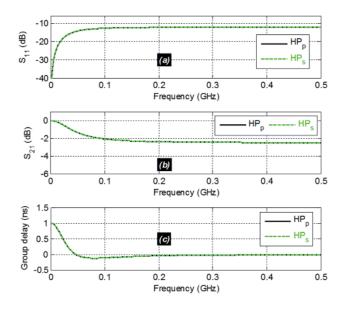


Figure 12. (a) The reflection and (b) transmission coefficients, and (c) the group delay of the high-pass NGD circuits shown in Figure 4 and Figure 8.

function. As theoretically predicted, the high-pass group delay, $\tau_{hp}(f) = -\tau_{lp}(f)$ was the opposite of the low-pass group-delay frequency response. It can be emphasized that the group delay was positive when $f < f_c$ and negative when $f > f_c$. A very good correlation between the theoretical concept of the high-pass NGD function and the simulations was obtained. As seen in Figure 12b, the insertion loss varied from $-2.38~\mathrm{dB}$ to $-1.25~\mathrm{dB}$ over the NGD bandwidth. The reflection coefficients were better than $-12~\mathrm{dB}$.

5.2.3 Bandpass NGD Results

To illustrate the feasibility of the bandpass NGD function, the parameters of the cells introduced in Figure 5 (for the parallel-impedance-based cell) and in Figure 9 (for the series-impedance-based cell) defined in the third column of Table 1 were considered. The simulated reflection and transmission parameters from 0.3 GHz to 0.7 GHz were respectively plotted in Figures 13a and 13b. Both cells presented similar S-parameter responses. More importantly, Figure 13c presents the group-delay frequency responses of the simulated circuits. As predicted in theory, the proposed lumped cells behaved with a bandpass NGD function. The cells generated NGD with level $\tau(f_0) = -2 \text{ ns}$ at the specified center frequency $f_0 = 0.5 \text{ GHz}$. The NGD bandwidth was about $\Delta f_{NGD} = 92 \text{ MHz}$. In the NGD bandwidth, the insertion loss varied from $-2.5 \, dB$ to -1.27dB. In other words, the insertion loss flatness was about 1.23 dB. The bandpass NGD cell reflection coefficients were better than $-12 \, dB$.

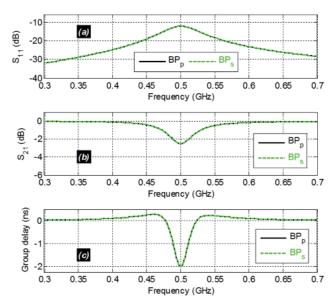


Figure 13. (a) The reflection and (b) transmission coefficients, and (c) the group delay of the bandpass NGD circuits shown in Figure 5 and Figure 9.

5.2.4 Stop-Band NGD Results

The stop-band NGD circuits shown in Figure 6 (for the parallel-impedance-based cell) and Figure 10 (for the series-impedance-based cell) were simulated with the parameters indicated in the last column of Table 1. The simulated reflection and transmission parameters are respectively displayed in Figures 14a and 14b. Both cells presented the same frequency responses. The group-delay responses are plotted in Figure 14c. As expected in theory, the circuit generated the NGD stop-band function. The stop-band NGD circuit group-delay frequency response $\tau_{sb}(f) = -\tau_{bp}(f)$ was the opposite of the bandpass NGD circuit's response. The group delay was positive in the frequency band centered at $f_0 = 0.5$ GHz with a bandwidth of about $\pm \Delta f_{NGD}/2 = 46$ MHz. As seen in Figure 14b, the insertion loss varied from -2.38 dB to -1.25 dB in the NGD bandwidth. The reflection coefficients are better than $-12 \, dB$.

5.3 Illustrative Time-Domain Results

In addition to this frequency-domain analysis introduced in the previous subsection, a time-domain investigation was also performed. The results reported in the present subsection are constrained only to the low-pass NGD cells. The proposed time-domain investigation was carried out with the ADS® transient analyses in the time parameters $t_{\min} = 0$ and $t_{\max} = 50$ ns with a time step of $\Delta t = 0.2$ ns. Figure 15 shows the configuration of the simulated circuits.

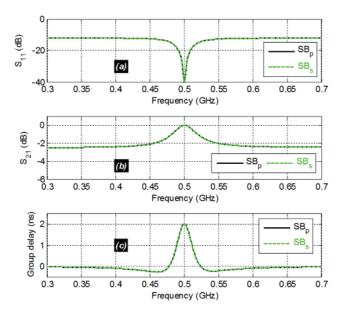


Figure 14. (a) The reflection and (b) transmission coefficients, and (c) the group delay of the stop-band NGD circuits shown in Figure 6 and Figure 10.

Three different input test voltages were attributed to v_{in} : v_1 (a Gaussian signal with a full width of about 40 ns), and arbitrary-waveform signals v_2 and v_3 . Figure 16 presents the plots of the comparisons of the transient input and output voltages generated by the parallel-impedanceand series-impedance-based low-pass NGD cells. The input signals were plotted in dotted lines. The shuntimpedance-based cell outputs were plotted with solid lines, and the series-impedance-based cell outputs were plotted with dashed lines. For the three different cases as seen in Figures 16a, 16a, and 16a, the output-voltage signals were significantly attenuated. However, it could be understood from the comparative plots of normalized voltages shown in Figures 16b, 16b, and 16b, that the time advances induced by the NGD phenomena were generated for the different waveform test signals.

The time advance could be assessed with the time shift between the minimum and maximum peaks of the input and output transient signals. This effect can be generated only for the baseband signal presenting a significant spectral frequency band belonging to the NGD bandwidth. Because of the non-flat nature of the group-delay responses shown in Figure 11b over the NGD bandwidth, the time advance could be evaluated from -1 ns to -0.4 ns as a function of the input signal time slope.

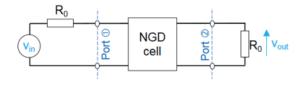


Figure 15. The configuration of the time-domain simulated circuits.

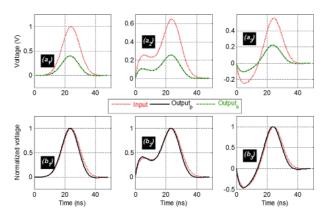


Figure 16. The time-domain simulation results for the low-pass NGD circuit shown in Figure 3 and Figure 7 for three different input signals: (a₁) v_1 , (a₂) v_2 , and (a₃) v_3 , and the associated normalized results: (b₁) v_1 (b₂) v_2 , and (b₃) v_3 .

6. Conclusion

A basic theory for understand the NGD function has been proposed. The fundamental knowledge enabling familiarization with NGD circuit design was described. More practically, a general RF circuit theory for passive NGD topologies was developed. Two types of topologies, based on the R, L, and C lumped-element parallel- and series-impedances, were investigated. For each topology, the S-parameter models were established, and the elementary low-pass NGD cell was identified. The NGD behavior, characterization, properties, and synthesis methods were then explained. The associated high-pass, bandpass, and stop-band cells were also investigated. The theoretical concepts were validated with proof-of-concept designs and simulations. Very good agreement between the theory and simulation results was found. As expected from the theory, the low-pass circuits generated NGD levels of about -1 ns over a bandwidth of about 46 MHz. The bandpass prototypes were synthesized to operate around a NGD center frequency of around 0.5 GHz. The high-pass NGD cell generated a group delay equal to the opposite of the low-pass cell. The bandpass NGD function was obtained with a NGD level of about $-2 \, \text{ns}$, centered at 0.5 GHz. Finally, transient simulations illustrated the time-advance effect caused by the NGD low-pass phenomenon.

7. Reference

- C. G. B. Garrett and D. E. McGumber "Propagation of a Gaussian Light Pulse Through an Anomalous Dispersion Medium," *Phys. Rev. A*, 1, 2, 1970, pp. 305-313.
- 2. S. Chu and S. Wong, "Linear Pulse Propagation in an Absorbing Medium," *Phys. Rev. Lett.*, **48**, 11, 1982, pp. 738-741.

- R. Y. Chiao, "Atomic Coherence Effects Which Produce Superluminal (But Causal) Propagation of Wavepackets," *Quantum Optics: Journal of the European Optical* Society Part B, 6, 4, 1994, pp. 359-369.
- R. Y. Chiao, E. L. Bolda, J. Bowie, J. Boyce, and M. W. Mitchell, "Superluminality and Amplifiers," *Prog. Crystal Growth Charact. Mat.*, 33, 1996, pp. 319-325.
- M. W. Mitchelll, and R. Y. Chiao, "Causality and Negative Group Delays in a Simple Bandpass Amplifier," *Am. J. Phys.*, 66, 14, 1998, pp. 14-19.
- 6. M. W. Mitchell, and R. Y. Chiao, "Negative Group Delay and 'Fronts' in a Causal System: An Experiment With Very Low Frequency Bandpass Amplifiers," *Phys. Lett. A*, 230, June 1997, pp. 133-138.
- L. J. Wang, A. Kuzmich and A. Dogariu, "Gain-Assisted Superluminal Light Propagation," *Nature*, 406, June 2000, pp. 277-279.
- A. Dogariu, A. Kuzmich, H. Cao and L. J. Wang, "Superluminal Light Pulse Propagation via Rephasing in a Transparent Anomalously Dispersive Medium," *Optics Express*, 8, 6, Mar. 2001, pp. 344-350.
- H. Cao, A. Dogariu, and L. J. Wang, "Negative Group Delay and Pulse Compression in Superluminal Pulse Propagation," *IEEE Journal of Selected Topics in Quantum Electronics*, 9, 1, February 2003, pp. 52-58.
- 10. M. Kitano, T. Nakanishi, K. Sugiyama, "Negative Group Delay and Superluminal Propagation: An Electronic Circuit Approach," *IEEE Journal of Selected Topics in Quantum Electronics*, 9, 1, 2003, pp. 43-51.
- 11. T. Nakanishi, K. Sugiyama, and M. Kitano, "Demonstration of Negative Group Delays in a Simple Electronic Circuit," *Am. J. Phys.*, **70**, 11, 2002, pp. 1117-1121.
- 12. J. N. Munday, and R. H. Henderson, "Superluminal Time Advance of a Complex Audio Signal," *Appl. Phys. Lett.*, **85**, July 2004, pp. 503-504.
- S. Lucyszyn, and I. D. Robertson, "Analog Reflection Topology Building Blocks for Adaptive Microwave Signal Processing Applications," *IEEE Trans. Microwave Theory Techn.*, 43, 3, 1995, pp. 601-611.
- S. Lucyszyn, I. D. Robertson and A.H. Aghvami, "Negative Group Delay Synthesizer," *Electronics Letters*, 29, 9, April 1993, pp. 798-800.
- C. D. Broomfield and J. K. A. Everard, "Broadband Negative Group Delay Networks for Compensation of Oscillators Using Feedforward Amplifiers," *Electronics Letters*, 36, 23, September 2000, pp. 1710-1711.

- 16. G. V. Eleftheriades, O. Siddiqui, and A. K. Iyer, "Transmission Line Models for Negative Refractive Index Media and Associated Implementations Without Excess Resonators," *IEEE Microwave Wireless Component Letters*, 13, 2, February 2003, pp. 51-53.
- 17. O. F. Siddiqui, M. Mojahedi and G. V. Eleftheriades, "Periodically Loaded Transmission Line With Effective Negative Refractive Index and Negative Group Velocity," *IEEE Trans. Antennas Propagat.*, **51**, 10, Oct. 2003, pp. 2619-2625.
- 18. O. F. Siddiqui, S. J. Erickson, G. V. Eleftheriades, M. Mojahedi, "Time-Domain Measurement of Negative Group Delay in Negative-Refractive-Index Transmission-Line Metamaterials," *IEEE Trans. Microwave Theory Techn.*, **52**, 5, May 2004, pp. 1449-1454.
- 19. N. S. Bukhman, and S. V. Bukhman, "On the Negative Delay Time of a Narrow-Band Signal as It Passes Through the Resonant Filter of Absorption," *Radiophysics and Quantum Electronics*, 47, 1, 2004, pp. 66-76.
- 20. S. S. Oh and L. Shafai, "Compensated Circuit with Characteristics of Lossless Double Negative Materials and Its Application to Array Antennas," *IET Microw. Antennas Propag.*, 1, 1, February 2007, pp. 29-38.
- 21. H. Choi, Y. Jeong, J. Lim, S. Y. Eom, Y. B. Jung, "A Novel Design for a Dual-Band Negative Group Delay Circuit," *IEEE Microwave Wireless Component Letters*, **21**, 1, January 2011, pp. 19-21.
- 22. G. Chaudhary and Y. Jeong, "Tunable Center Frequency Negative Group Delay Filter Using Coupling Matrix Approach," *IEEE Microwave Wireless Component Letters*, 27, 1, 2017, pp. 37-39.
- G. Liu, and J. Xu, "Compact Transmission-Type Negative Group Delay Circuit with Low Attenuation," *Electronics Letters*, 53, 7, March 2017, pp. 476-478.
- 24. W. Alomar and A. Mortazawi, "Method of Generating Negative Group Delay in Phase Arrays Without Using Lossy Circuits," *Proc. IEEE Int. Wireless Symp. (IWS)* 2013, Beijing, China, 14-18 April 2013, pp. 1-4.
- 25. B. Ravelo, "Investigation on Microwave Negative Group Delay Circuit," *Electromagnetics*, **31**, 8, November 2011, pp. 537-549.
- B. Ravelo, "Methodology of Elementary Negative Group Delay Active Topologies Identification," *IET Circuits Devices Syst. (CDS)*, 7, 3, May 2013, pp. 105-113.
- 27. C.-T. M. Wu and T. Itoh, "Maximally Flat Negative Group Delay Circuit: A Microwave Transversal Filter Approach," *IEEE Trans. on Microwave Theory and Techniques*, **62**, 6, June 2014, pp. 1330-1342.

- 28. B. Ravelo, "Demonstration of Negative Signal Delay with Short-Duration Transient Pulse," *Eur. Phys. J. Appl. Phys. (EPJAP)*, **55** (10103), 2011, pp. 1-8.
- B. Ravelo, "Similitude Between the NGD Function and Filter Gain Behaviours," *Int. J. Circ. Theor. Appl.*, 42, 10, October 2014, pp. 1016-1032
- B. Ravelo, "High-Pass Negative Group Delay RC-Network Impedance," *IEEE Transactions on Circuits* and Systems II: Express Briefs, 64, 9, September 2017, pp. 1052-1056.
- 31. M. Kandic and G. E. Bridges, "Asymptotic Limits of Negative Group Delay in Active Resonator-Based Distributed Circuits," *IEEE Transactions on Circuits and Systems I: Regular Papers*, **58**, 8, August 2011, pp. 1727-1735.
- 32. P. K. Chan and K. Karplus, "Computing Signal Delay in General RC Networks by Tree/Link Partitioning," *IEEE Trans. Computed Aided Design*, **8**, 9, August 1990, pp. 898-902.
- 33. R. Y. Chiao, "Faster Than Light Propagations, Negative Group Delays, and their Applications," *The Physics of Communication Proc. of the XXII Solvay Conference on Physics*, DOI 10.1142, November 2001, pp. 287-314.

- 34. D. Solli, R. Y. Chiao, and J. M. Hickmann, "Superluminal Effects and Negative Delays in Electronics, and their Applications," *Phys. Rev. E*, **66**, 5, November 2002, pp. 056601.1-056601.4.
- 35. B. Ravelo and A. K. Jastrzebski, "NGD Circuit Using a Microwave Amplifier for the Signal Integrity Improvement," Proc. of 2012 Asia-Pacific Symposium on Electromagnetic Compatibility (APEMC 2012), Singapore, 21-24 May 2012, pp. 1-4.
- B. Ravelo, "Recovery of Microwave-Digital Signal Integrity with NGD Circuits," *Photonics and Optoelectronics (P&O)*, 2, 1, January 2013, pp. 8-16.
- 37. B. Ravelo, S. Lalléchère, A. Thakur, A. Saini and P. Thakur, "Theory and circuit modelling of Baseband and Modulated Signal Delay Compensations with Low- and Band-Pass NGD Effects," *Int. J. Electron. Commun.* (AEÜ), 70, 9, September 2016, pp. 1122-1127.
- 38. H. Choi, Y. Jeong, C. D. Kim, and J. S. Kenney, "Efficiency Enhancement of Feedforward Amplifiers by Employing a Negative Group Delay Circuit," *IEEE Trans. Microw. Theory Tech.*, **58**, 5, May 2010, pp. 1116-1125.

Recent Developments in Distributed Negative-Group-Delay Circuits

Chung-Tse Michael Wu

Department of Electrical and Computer Engineering Rutgers University 94 Brett Road, Piscataway, New Jersey, USA E-mail: ctm.wu@rutgers.edu

Abstract

This paper reviews some of the latest developments in active and passive negative-group-delay (NGD) circuits based on distributed topology using transmission-line elements.

First, the concepts of microwave transversal- and recursive-filter-based negative-group-delay circuits are introduced. By using transversal and recursive-filter approaches, the desired amount of negative group delay can be synthesized with an increased bandwidth. The presented prototype, using a transversal-filter-based NGD circuit realized by a multi-section directional coupler, can achieve –1 ns group delay with a 500 MHz bandwidth at a center frequency of 1 GHz with an insertion loss of 20 db to 30 dB. Its active counterpart, realized by a distributed amplifier (DA), can achieve a –1 ns group delay with a 250 MHz bandwidth at 1 GHz and an insertion loss of around 8 dB. Both of these realizations have great input matching, with a reflection coefficient better than –25 dB.

Second, NGD circuits integrated with active transistors and transmission-line elements, such as short stubs, are discussed. The proof-of-concept prototype showed a -0.43 ns group delay with a 1.14 GHz bandwidth at a 5 GHz center frequency and an insertion loss of 2 dB. The fully distributed topology of these NGD circuits shows promising solutions to be utilized in next-generation microwave and millimeter-wave applications.

1. Introduction

The concept of negative group delay (NGD) has recently drawn a lot of attention in the microwave field, and has led to many practical applications. For instance, NGD has been utilized to enhance the efficiency of the feed-forward amplifier, to shorten delay lines, and to

realize broadband phase shifters and non-Foster elements [1-4]. Taking advantage of NGD circuits, it is possible to compensate for excessive positive group delays introduced by circuit components and electrical connections in electronic systems. The phenomenon of NGD might yield the output peak of a wave-packet preceding the input peak. This is due to the *RLC* time constants of the circuitry that affect different frequency components of the modulated signal in such a way that some emerge before others when examined in the time domain. The NGD phenomenon does not violate causality, since the initial transient pulse is still limited to the frontal velocity, which will never exceed the speed of light [5].

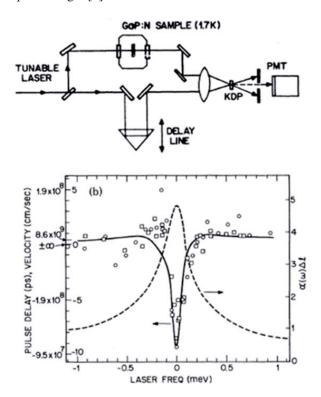


Figure 1. The NGD effect in the optical domain with GaP:N atomic [7].

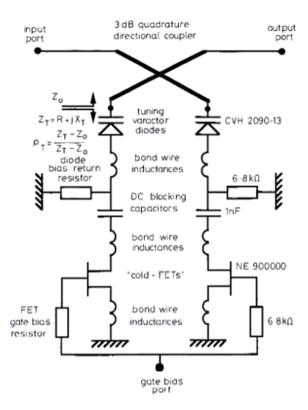


Figure 2. A lumped-element-based tunable NGD circuit [8].

Studies of the NGD phenomenon can be traced back to the 1970s, when analytical investigation and theoretical analysis of Gaussian light propagation in an NGD medium was first proposed [6]. Thereafter, in the 1980s, the first experimentation with the NGD effect was made in the optical domain with GaP:N atomic vapor, as shown in Figure 1 [7]. Later on, in the 1990s, theoretical and experimental investigations in the field of electronic and microwave engineering confirmed that certain passive circuit topologies can generate NGD phenomena [8, 9]. For low-frequency electronic circuits, the NGD phenomenon has been exhibited using simple low-pass and bandpass amplifiers [10-12]. On the other hand, in the microwave regime, because NGD occurs at the frequency band where the absorption or the attenuation is maximum [13], bandstop structures are conventionally used to realize NGD circuits (Figure 2). Based on either series or shunt *RLC* resonators, many active and passive NGD circuits have been proposed and demonstrated [14-18].

Nevertheless, the lumped-element approach may not be very suitable for NGD devices operating at a higher frequency range that goes beyond their self-resonances. In an effort to create a fully distributed topology of NGD circuits, transmission-line-based NGD circuits have recently been proposed and demonstrated to realize the desired negative group delay [19-24]. In this review article, recent developments of distributed-topology NGD circuits will be discussed. It will be shown that these distributed-topology-based methods are able to synthesize the prescribed amount of negative group delay that can be further utilized in electronic circuits.

2. Transversal- and Recursive-Filter-Based NGD Circuits

The first kind of distributed NGD circuits is based on microwave transversal and recursive filters, which can be viewed as a microwave equivalent of a finite-impulse-response (FIR) filter and an infinite-impulse-response (IIR) filter in the digital domain. Transmission lines in these structures are treated as delay elements to provide necessary time delay among the stages. By properly choosing the weighting/coupling coefficients along with the delay elements, the desired amount of NGD can be synthesized at the filters' output port.

2.1 Transversal-Filter-Based NGD Circuits

Figure 3 illustrates a general diagram of a continuous-time-transversal filter. It consists of delay lines (τ), weighting coefficients (b_N), and summing operators. The relationship between the input, x(t), and the output, y(t), in the time domain for a transversal filter with N weighting elements or N sections can be expressed as [25]

$$y(t) = \sum_{n=1}^{N} b_n x \left[t - \sum_{m=1}^{n} (\tau_{im} + \tau_{om}) \right].$$
 (1)

Its transfer function in the frequency domain can then be obtained by taking the Fourier transform. Furthermore, if we let $\tau_{im} = \tau_{om} = \tau_0$, it follows that the transfer function becomes

$$H(\omega) = \sum_{n=1}^{N} b_n e^{-j2n\omega\tau_0} .$$
(2)

By definition, the group delay of Equation (2) at $\omega = \omega_0$ can be written as follows:

$$\tau_g = -\frac{\partial \angle H(\omega)}{\partial \omega}\bigg|_{\omega = \omega_0}.$$
 (3)

From Equation (2), it can be observed that the phase response of the transfer function can be manipulated by altering the

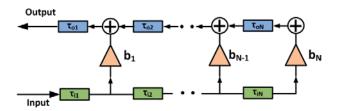


Figure 3. Aschematic diagram of a transversal filter [19].

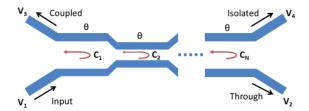


Figure 4. An N-section directional coupler [19].

tap coefficients (b_N). In fact, it has been analytically shown that in order for the group delay depicted in Equation (3) to have a maximally flat response, the tap coefficients have the following closed-form solution [19]:

$$b_{N-m} = \frac{\binom{N+\alpha-1}{m}\binom{\alpha-1-m}{N-m-1}}{2\binom{2N-3}{N-1}},$$
 (4)

where b_{N-m} refers to the tap coefficients shown in Figure 1, and the group delay, τ_g , of the transfer function, H, depicted in Equation (2) is equal to $(N-\alpha+1)\tau_0$. For a given stage N and negative group delay, which can be determined by the index α , the tap coefficients for a transversal filter exhibiting maximally flat negative group delay can therefore be readily obtained by Equation (4).

2.1.1 Passive Realization

A simple realization of a passive transversal filter in microwave regimes is to use a multi-section directional coupler, as shown in Figure 4. Assuming that the coupling is weak ($C_n \le -10 \text{ dB}$), and that each section is a quarter-wavelength long ($\theta = \pi/2$) at the center frequency, the total voltage transfer function of the coupled port of an N-section directional coupler can be expressed as [26]

$$\frac{V_3}{V_1} = \sum_{n=1}^{N} (jC_n \sin \theta) e^{-j(2n-1)\theta},$$
 (5)

where C_n is the coupling factor for the *n*th section of the directional coupler, and θ is the electrical length of the coupled lines. It is noted that Equation (5) has a mathematical form similar to Equation (2) by mapping θ to $\omega - \tau_0$.

Table 1. The coupling coefficients for an NGD circuit

	C_1	C_2	C ₃	C_4
N=2	0.3162	0.2372		
N=3	0.2372	0.3162	0.1107	
N=4	0.1757	0.3162	0.2012	0.0447

The coupling factors for different sections of directional couplers (N = 2,3,4) can be obtained from Equation (4), in which the desired group delay is set to be -1 ns. The maximum coefficients are then normalized to $-10 \, \text{dB}$ as depicted in Equation (6), which is 0.3162 on a linear scale. Table 1 summarizes these coefficients for directional couplers with various stages:

$$C_{N=2} = [0.3162, 0.2372],$$
 (6a)

$$C_{N=3} = [0.2372, 0.3162, 0.1107],$$
 (6b)

$$C_{N=4} = [0.1757, 0.3162, 0.2012, 0.0447].$$
 (6c)

Figure 5a plots the measured magnitude response of the NGD circuits using multi-section directional couplers. The magnitude of S_{31} decreases more, especially when more sections are used. This may be due to more loss introduced in the actual fabricated prototypes. Figure 5b plots the measured group delay of the fabricated prototypes using printed-circuit-board (PCB) technology with various numbers of stages for directional couplers. Overall, with

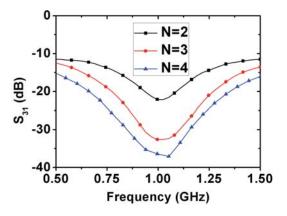


Figure 5a. The measured insertion loss for NGD circuits based on multi-section directional couplers [19].

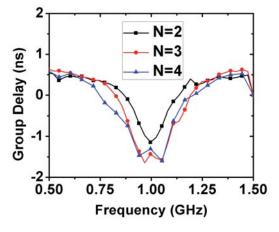
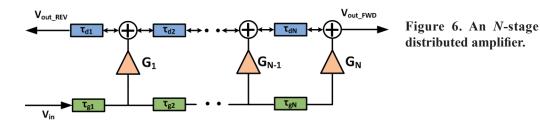


Figure 5b. The group delay for NGD circuits based on multi-section directional couplers [19].



more sections used in the directional couplers, the bandwidth of the NGD increases. Moreover, as mentioned above, a flat response of NGD can be achieved by using the proper coupling coefficients for each section of the directional coupler.

2.1.2 Active Realization

Although a multi-section directional coupler can provide a very simple way to realize the passive version of a microwave transversal filter, it suffers from tremendous loss in the NGD region, especially when the NGD-bandwidth product is large. This is because the out-of-band gain needs to be large in this case [27]. It turns out that distributed amplifiers (DAs) stand out as an excellent choice for providing amplification for the NGD circuits, as they are essentially one type of transversal filer in active fashion. Figure 6 illustrates the diagram of an N-stage distributed amplifier, in which G_k is the gain coefficient of the kth tap amplifier, and τ_{gk} and τ_{dk} indicate the time delay of the kth section of the gate line and drain line, respectively. Furthermore, if we choose $\tau_{gi} = \tau_{di} = \tau_0$, then the transfer functions of the forward and reverse port with respect to the input can be expressed as [20]

$$H_{FWD}(\omega) = \frac{V_{out_FWD}}{V_{in}} = \sum_{k=1}^{N} G_k e^{-j\omega(N\tau_0)} , \quad (7a)$$

$$H_{REV}(\omega) = \frac{V_{out_REV}}{V_{in}} = \sum_{k=1}^{N} G_k e^{-j\omega(2k\tau_0)}$$
. (7b)

One can immediately identify that the reverse transfer function, Equation (7b), also has the same mathematical form as Equation (2). It can further be observed that if the coefficients derived in Equation (4) are used for the gain coefficients G_k in Equation (7), an NGD response can be realized at the distributed amplifier's reverse port, while maintaining a flat gain at its forward port, since the G_k s sum up constructively as indicated in Equation (7a). It is worth mentioning that the distributed-amplifier-based NGD circuit can achieve unconditional stability as long as each stage is designed to be unconditionally stable, regardless of the number of stages.

As a proof-of-concept, a distributed amplifier, using commercial off-the-shelf discrete transistors (NEC

NE3210S01), was fabricated with PCB technology. As shown in Figure 7, the distributed amplifier contained two transistors with individual gate biases to form a two-stage NGD circuit. The electrical length between each stage was designed to be a quarter-wavelength at the center frequency of 1 GHz. Since the maximum transconductance (g_m) of the transistors we used was 0.075 S, the amounts of g_m in this two-stage distributed-amplifier-based transversal filter were (0.075 S, 0.05625 S).

Figure 8a shows the measured S parameters of the fabricated two-stage distributed amplifier. The forward gain showed a flat response of around 10 dB gain, whereas the reverse gain had a minimum of -7.8 dB at the center frequency of 1 GHz where NGD occurred. In addition, the return loss was greater than 30 dB, and the insertion loss was around 0.2 dB at the frequency of interest. The phase and group delays of the distributed amplifier are plotted in Figure 8b, indicating a great agreement between the ideal circuit simulation and measurement. The maximum group delay of the two-stage distributed amplifier was -1 ns at 1 GHz, and the NGD region was 0.9 GH to 1.1 GHz.

2.2 Recursive-Filter-Based NGD Circuits

In addition to transversal filters, microwave recursive filters can also be used to generate NGD of predetermined values in a desired frequency band by using only distributed components [22]. In this case, multi-stage quarter-wave transformers (QWT) are used to generate NGD of

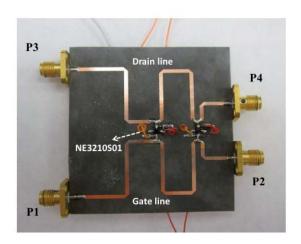


Figure 7. A prototype of a two-stage NGD circuit based on distributed amplifiers [19].

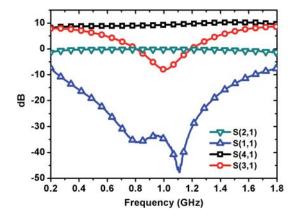


Figure 8a. The measured results of the magnitude for the two-stage NGD-distributed amplifier [19].

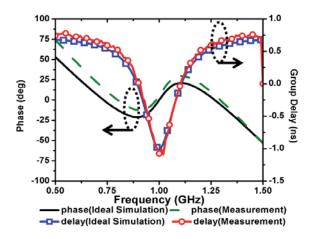


Figure 8b. The group delay and phase response for the two-stage NGD-distributed amplifier [19].

predetermined values, as shown in Figure 9. Essentially, a quarter-wave transformer behaves as a recursive filter, since the reflected waves will bounce back and forth among the impedance interfaces and form an infinite impulse response (IIR). The reflection coefficient, Γ , for the N-stage quarter-wave transformer can be written as

$$\Gamma = \frac{V_{in}^{-}}{V_{in}^{+}} = \frac{(A_n - D_n) + j(B_n - C_n)}{(A_n + D_n) + j(B_n + C_n)},$$
 (8)

where A_n, B_n, C_n , and D_n represent the transmissionmatrix parameters for the entire N-stage quarter-wave transformer circuit. The phase of the reflection coefficient is then expressed as

$$\angle\Gamma = \tan^{-1} \frac{\left(B_n - C_n\right)}{\left(A_n - D_n\right)} - \tan^{-1} \frac{\left(B_n + C_n\right)}{\left(A_n + D_n\right)}. \tag{9}$$

In order to obtain the prescribed maximally flat group delay, the characteristic impedances of each of the transmission

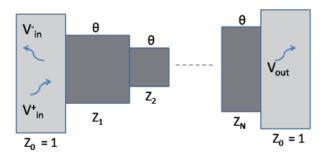


Figure 9. An *N*-stage quarter-wave transformer as a microwave recursive filter [22].

line $[Z_1, Z_2, Z_3, ..., Z_N]$ need to be obtained by solving the following equations:

$$\left| \Gamma \left(\theta = \frac{\pi}{2} \right) \right| = \Gamma_p \,, \tag{10a}$$

$$-\frac{\partial \angle \Gamma(\theta)}{\partial \theta}\Big|_{\theta = \frac{\pi}{2}} = \tau_{gp}, \qquad (10b)$$

$$-\frac{\partial^{2n-3} \angle \Gamma(\theta)}{\partial \theta} \Big|_{\theta = \frac{\pi}{2}} = 0, \qquad (10c)$$

where n=3,4,...,(N-1), Γ_p is the prescribed magnitude, and τ_{gp} is the prescribed NGD within a unit of the sampling period, T. In order to have the maximally flat response, all the higher-order derivatives shown in Equation (10c) are set to zero. Figure 10 shows the simulated results of three different NGDs at 1 GHz for a three-stage quarter-wave transformer using the normalized

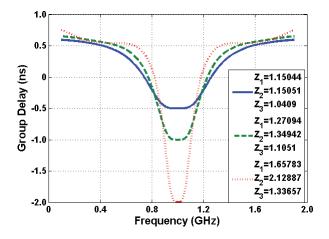


Figure 10. The simulated results for prescribed group delays of -0.5 ns, -1 ns, and -2 ns for a three-stage (N=3) quarter-wave transformer [22].

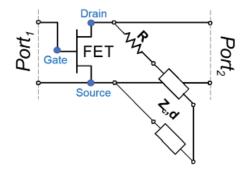


Figure 11. The topology of the NGD distributed active cell (NGDDAC) based on the FET.

characteristic impedances derived from Equations (10). It could be observed that the multi-stage quarter-wave transformer could exhibit NGD with maximally flat response about the center frequency. It was also noted that the bandwidth could be enhanced when more stages were cascaded.

3. FET-Based NGD Distributed Active Circuit with Resistive Short-Circuited Stub

Recently, it was introduced that another simpler active circuit, based on the association of a short-circuited stub, a series resistance, and an FET, was susceptible to exhibiting an NGD function [28, 29]. In contrast to the fully passive circuit proposed in [30, 31], we have the possibility of generating wideband NGD with amplification or positive gain. Unlike transversal-or recursive-filter types of NGD circuits that usually involve multiple stages of gain or coupling cells, this section presents a simple NGD active microwave circuit theory using one active transistor in connection with transmission-line structures.

3.1 Topological Concept

As previously mentioned, the proposed NGD distributed circuit uses an elementary FET. For the sake of analytical simplification, in this paper the FET is assumed to be composed of a voltage-controlled current source (VCCS) with a transconductance, g_m , and a drain-source resistance, R_{ds} .

3.1.1 FET-Based Distributed NGD Active Cell

Figure 11 represents the topology of the NGD distributed active cell (NGDDAC) under study in this section. It acts as a two-port microwave active circuit. The gate-source that constitutes the circuit's input port is assumed to be open but can be matched with a shunt

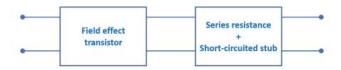


Figure 12. A block-diagram representation of the cell introduced in Figure 11.

resistance, depending on the targeted applications. The drain-source constituting the output is loaded by a parallel distributed load. The passive part of this circuit is composed of a resistance, R, in series with a short-circuited transmission line (TL) presenting a characteristic impedance, Z_c , and a physical length, d.

The S-parameter model of this active cell can be calculated from microwave circuit theory based on the four-port active block represented by the FET in cascade with another four-port passive block represented by the R-TL network. The global configuration of this topology is depicted in Figure 12.

Based on system theory, the total transfer matrix of the system proposed in Figure 12 can be written as

$$[M_{total}] = [M_{FET}] \times [M_{passive}]$$
 (11)

by denoting, as defined in [28, 29], $[M_{FET}]$ as the FET transfer matrix, and $[M_{passive}]$ as the transfer matrix of the passive-network part of the circuit shown in Figure 11.

The equivalent *S* parameters can be determined from the ABCD-to-*S* matrix conversion.

3.1.2. Description of the NGD Circuit Passive Part Constituted by the Distributed Short-Circuited Stub

The short-circuited stub constituting the NGD distributed active cell is assumed to be implemented in microstrip technology, as shown in Figure 13. The

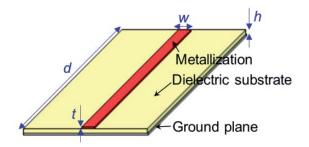


Figure 13. A microstrip-line structure and its physical parameters.

transmission line presents a physical length d, a metallization width w, and a thickness t, and is printed on a dielectric substrate with a height h. Its characteristic impedance is denoted Z_c . According to transmission-line theory, the periodic resonance frequencies are equal to

$$f_0(k) = \frac{kc}{2d\sqrt{\varepsilon_{reff}}} = \frac{\omega_0(k)}{2\pi},$$
 (12)

with $k = \{1, 2, 3, ...\}$ being an integer, and where c is the speed of light.

Moreover, the general expression of the stub input impedance is written as

$$Z_{in}(\omega) = jZ_c \tan\left(\frac{\omega d\sqrt{\varepsilon_{reff}}}{c}\right),$$
 (13)

where j is the complex number $\sqrt{-1}$, ω is the angular frequency, and ε_{reff} is the transmission line's effective permittivity. Based on the theory of Bahl and Trivedi [32], the transmission line's characteristic impedance is given by

$$Z_{c} = \frac{1}{2\pi} \sqrt{\frac{\mu_{0}}{\varepsilon_{reff} \varepsilon_{0}}} \log \left[\frac{h\psi\left(\frac{w}{h}\right)}{w} + \sqrt{1 + \frac{4h^{2}}{w^{2}}} \right]$$
(14)

with vacuum permittivity and permeability ε_0 and μ_0 . The real function $\psi(\bullet)$ is defined by

$$\psi(x) \approx 6 + (2\pi - 6) \exp\left(-\frac{13.155}{x^{0.7528}}\right).$$
 (15)

The log(•) function under consideration represents the decimal logarithm. These analytical expressions will serve as the initial step during the synthesis of the open-ended stud constituting the NGD distributed active cell.

3.1.3 Proposed NGD Distributed Circuit S Parameters and Synthesis Equations

Knowing the FET and the passive network ABCD matrices, the NGD distributed active cell equivalent matrix can be extracted with a matrix product. By denoting $Z_0 = 50 \Omega$ as the reference impedance, the proposed NGD cell topology presents output reflection and transmission coefficients given by

$$|S_{22}| = ||S_{21}| - Z_0 g_m| / (Z_0 g_m).$$
 (16)

At the NGD center radian frequency $\omega_0(k)$ previously introduced in Equation (2), the following transmission and output reflection parameters can then be determined from the ABCD-to-S matrix transform:

$$S_{21} \left[\omega_0(k) \right] = \frac{-2g_m R_{ds} Z_0 R}{R(R_{ds} + Z_0) + R_{ds} Z_0}, \tag{17}$$

$$S_{22} \left[\omega_0(k) \right] = \frac{R(R_{ds} - Z_0) - R_{ds} Z_0}{R(R_{ds} + Z_0) + R_{ds} Z_0}$$
(18)

The negative sign of the algebraic value of S_{21} is due to the systematic output-voltage inversion through the FET. It can be underscored that the cell presented in Figure 11 is not matched at its input, because S_{11} is naturally equal to -1. Such an issue can be easily solved by connecting an input shunt resistance between the FET's gate and the source. According to microwave circuit theory, the group delay can be analytically calculated by

$$\tau(\omega) = -\frac{\partial \angle S_{21}(\omega)}{\partial \omega} \,. \tag{19}$$

At the resonance frequencies $\omega = \omega_0(k)$, it can therefore be demonstrated that the group delay can be expressed as a function of the stub length by the relationship

$$\tau \left[\omega_0 \left(k \right) \right] = \frac{-dR_{ds} Z_0 Z_c}{vR \left\lceil RR_{ds} + Z_0 \left(R + R_{ds} \right) \right\rceil}, \qquad (20)$$

denoting the wave speed $v = c/\sqrt{\varepsilon_{reff}}$. The same group delay can also be expressed with the resonance frequency by the relationship

$$\tau \left[\omega_0 \left(k \right) \right] = \frac{-\pi R_{ds} Z_0 Z_c}{\omega_0 \left(1 \right) R \left[R R_{ds} + Z_0 \left(R + R_{ds} \right) \right]}. \quad (21)$$

It is noteworthy that this group delay is unconditionally negative for any parameters of the distributed cell.

Similar to filter theory, the proposed NGD cell-synthesis relationships can be established from the expected specifications: the NGD center-frequency resonance, $\omega = \omega_0$; the NGD level; the gain; and the matching level. Moreover, with the distributed configuration introduced in Figure 11, the group delay can be negative at very low

frequencies: $\omega_0(k=1)$. The following synthesis relation can thus be derived at base-band frequencies. The stub length can be obtained by inverting Equations (12) and (20). From the desired value of gain, $S_{21}(\omega_0)$, and NGD $\tau(\omega_0)$, the following synthesis relationships are established:

$$R = \frac{\left| S_{21}(\omega_0) \right| R_{ds} Z_0}{2g_m R_{ds} Z_0 - \left| S_{21}(\omega_0) \right| \left(Z_0 + R_{ds} \right)} , \qquad (22)$$

$$Z_{c} = \frac{-vR\tau(\omega_{0})\left[R_{ds}R + Z_{0}\left(R + R_{ds}\right)\right]}{dR_{ds}Z_{0}}.$$
 (23)

3.1.4 NGD Properties

First and foremost, it should be pointed out that the maximal transmission gain of the NGD distributed active circuit under study is defined as

$$S_{21max} = 2R_{ds}Z_0g_m/(R_{ds} + Z_0),$$
 (24)

which is obtained from Equation (22) by letting the denominator be greater than zero. The NGD function should present a cutoff frequency f_c . For the case of the topology introduced in Figure 1, the periodic NGD frequency band $\left[\omega_c(k),\omega_c(k+1)\right]$ can be defined by the equation

$$\tan\left[\frac{\pi\omega_{c}(k)}{2\omega_{0}(1)}-k\pi\right] = \frac{\sqrt{R\left[R\left(R_{ds}+Z_{0}\right)+R_{ds}R\right]}}{Z_{c}\sqrt{\left(R_{ds}+Z_{0}\right)}}.(25)$$

The NGD bandwidth is substantially given by

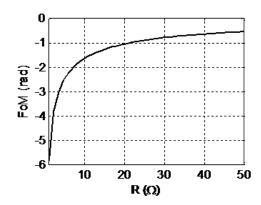
$$\Delta\omega_{NGD}\big|_{k=\{0,1,2,\ldots\}} = \omega_c(k+1) - \omega_c(k)$$
(26)

The figure-of-merit (FoM) associated with the proposed NGD distributed-active-cell topology is defined as

$$FoM_{NGD} \lceil \omega_0(k) \rceil = \Delta f \tau \lceil \omega_0(k) \rceil S_{21} \lceil \omega_0(k) \rceil$$
 (27)

As a function of the circuit parameters, this can be rewritten as

$$FoM_{NGD}\left[\omega_{0}\left(k\right)\right] = \frac{-d\sqrt{R_{ds}Z_{0}}Z_{c}\Delta\omega_{NGD}/(2\pi)}{\sqrt{2g_{m}R^{3}\left\lceil RR_{ds} + Z_{0}\left(R + R_{ds}\right)\right\rceil}}.(28)$$



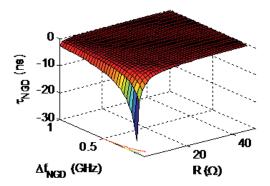


Figure 14. The NGD FoM as a function of R and Δf_{NGD} .

For further understanding of the meaning of the NGD figure-of-merit, a graphical illustration is proposed in Figure 14. It is noted that a higher absolute value of the FOM represents better performance of the NGD circuit. The figure presents the NGD's distributed active cell FoM as a function of R, and the level as a function of $(R=1\,\Omega\to 50\,\Omega,\,\Delta f_{NGD}=0.1\,\mathrm{GHz}\to 1\,\mathrm{GHz})$. This illustrative result was computed for the particular case of the FET EC-2612 ($g_m=98.14\,\mathrm{mS},\,R_{ds}=116.8\,\Omega$).

3.2 Application Example

As a proof of concept (POC), an NGD distributed active cell was synthesized with arbitrary specifications. This proof of concept was designed and simulated in the ADS schematic environment.

3.3 Proof of Concept NGDDAC Synthesis and Design

By applying the synthesis formulas defined in Section 2.3, the circuit parameters R and the short-circuited stub characteristic impedance and length were determined. By considering the desired values of gain, $S_{21\text{dB}}(0) = 0$ dB and $\tau(0) = -0.5$ ns, a stub having a quarter wavelength at a frequency of $f_0 = 5$ GHz in series with a resistance $R = 8 \Omega$ was synthesized and designed. This circuit integrated the bias and dc decoupling capacitors C = 1 pF. The schematic of the designed NGD distributed active cell proof of concept is depicted in Figure 15.

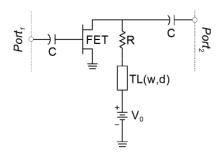


Figure 15. Schematic of the NGD distributed active cell proof of concept: $V_0 = 3$ V, C = 1 pF, w = 1.55 mm, d = 16.4 mm, $R = 8 \Omega$.

The FET used corresponded to the pHEMT EC-2612 parameters, which are characterized by a transcoductance of $g_m = 98.14$ mS and a drain-source resistance of $R_{ds} = 116.8 \,\Omega$. The stub was implemented with a microstrip transmission line printed on FR4 epoxy substrate having a relative permittivity of $\varepsilon_r = 4.4$, a loss tangent of $\tan(\delta) = 0.01$, and a thickness of h = 0.8 mm. The Cu conductor metallization thickness was $t = 35 \,\mu\text{m}$. The stub element, a with characteristic impedance of $Z_c = Z_0 = 50 \,\Omega$ was integrated in the NGD circuit.

In order to illustrate the possibility of the NGD level and cut-off frequency, an analytical estimation for $f < f_0/4$ using the approximation $Z_{in} = jZ_c \tan(x) \approx jZ_c x$ was investigated. A comparison between the NGD distributed active cell based on distributed and lumped elements was also performed and is displayed in Figure 16.

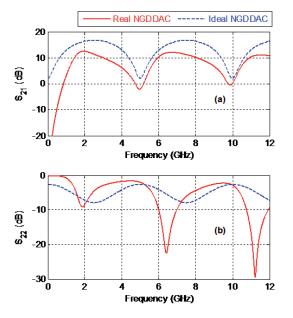


Figure 17. The simulated NGD-distributed active cell ideal and realistic (a) output return losses, and (b) transmission parameters.

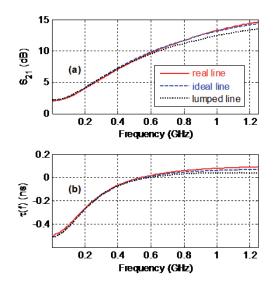


Figure 16. A comparison between the ideal transmission gain and the group delay of the proposed NGD distributed active circuit.

3.4 Validation Results

To check the feasibility of the NGD concept under study, S-parameter simulations of the ideal and realistic circuits were carried out from dc to 12 GHz. A good agreement was obtained between the behaviors of the transmission parameter and the group delay from the circuits built with the realistic and ideal NGD distributed active cell for the responses at very low frequencies, $f \approx 0$ Table 2 summarizes the NGD level, transmission gain, NGD bandwidth, and FoM around the optimal frequency, f_0 , using Equation (27). In addition, Table 3 calculates the FOM for the transversal-filter-based NGD circuits discussed in the previous section. It should be noted that the center frequencies (f_0) for Tables 2 and 3 were different, i.e., 5 GHz and 1 GHz, respectively. The two topologies should therefore be compared with each other after taking this factor into account.

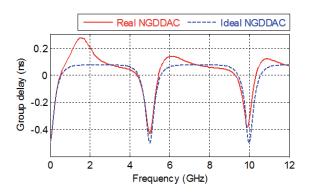


Figure 18. The simulated NGD distributed active cell ideal and realistic group delays.

Table 2. Ideal and realistic NGDDAC characteristics around $f_0 = 5$ GHz.

Parameters	Ideal Cir- cuit	Realistic Circuit	
$\tau(f_0)$	-0.5 ns	−0.43 ns	
$S_{21}(f_0)$	2.13 dB	−2 dB	
$\Delta f(f_0)$	1.11 GHz	1.14 GHz	
$FoM(f_0)$	-0.71	-0.39	

Furthermore, comparisons between the output return losses and the transmission parameters are displayed in Figure 17. The group-delay responses are shown in Figure 18. As expected, a 5 GHz periodical multi-band NGD aspect was observed. The main observed differences were due to the FET parasitic elements and the stub transmission-line losses.

Despite this occurrence of an NGD multi-band effect, it was noteworthy that a matching circuit was needed to improve the proposed NGD distributed active cell return losses. Lastly, similar to the resistive amplifier topology, this NGD circuit's noise factor depended on the FET's noise, and could be extracted from the Friss formula.

4. Conclusion

In this paper, some recent developments of NGD circuits – based on microwave transversal and recursive filters, as well as on active transistors loaded with transmission-line elements – were presented and discussed. Unlike the lumped-element approach that is usually limited to its self-resonance, by using the transmission-line-based elements, the fully distributed nature of these NGD circuits make them feasible for further operation at a higher frequency range, such as in the millimeter-wave regions.

5. Acknowledgment

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6. References

- 1.H. Choi, Y. Jeong, C. D. Kim, and J. S. Kenney, "Efficiency Enhancement of Feedforward Amplifiers by Employing a Negative Group Delay Circuit," *IEEE Trans. Microw. Theory Tech.*, **58**, 5, May 2010, pp. 1116-1125.
- 2. S. S. Oh and L. Shafai, "Compensated Circuit with Characteristics of Lossless Double Negative Materials and Its Application to Array Antennas," *Microw., Antennas Propag.*, 1, 1, February 2007, pp. 29-38.

Table 3. The FOM for transversal-filter-based NGD circuits around $f_0 = 1$ GHz.

Parameters	Passive	Active
$\tau(f_0)$	-1.5 ns	−1 ns
$S_{21}(f_0)$	−35 dB	-7.8 dB
$\Delta f(f_0)$	500 MHz	250 MHz
$Fom(f_0)$	-0.0133	-0.1018

- 3. H. Noto, K. Yamauchi, M. Nakayama, and Y. Isota, "Negative Group Delay Circuit for Feed-Forward Amplifier," IEEE Int. Microw. Symp. Dig., June 2007, pp. 1103-1106.
- T. Zhang, R. Xu, and C.-T. M. Wu. "Unconditionally Stable Non-Foster Element Using Active Transversal-Filter-Based Negative Group Delay Circuit." *IEEE Microwave and Wireless Components Letters*, 27, 10, 2017, pp. 921-923.
- L. Brillouin, Wave Propagation and Group Velocity, New York, Academic Press, 1960.
- 6. Garrett and D. E. McGumber, "Propagation of a Gaussian light pulse through an anomalous dispersion medium," *Phys. Rev. A*, **1**, 1970, pp. 305-313.
- S. Chu and S. Wong, "Linear Pulse Propagation in an Absorbing Medium," *Phys. Rev. Lett.*, 48, 1982, pp. 738-741.
- 8. S. Lucyszyn, I. D. Robertson and A. H. Aghvami, "Negative Group Delay Synthesizer," *Electron. Lett.*, **29**, 1993, pp. 798-800.
- S. Lucyszyn and I. D. Robertson, "Analog Reflection Topology Building Blocks for Adaptive Microwave Signal Processing Applications," *IEEE Trans. MTT*, 43, 3, March 1995, pp. 601-611.
- 10. M. W. Mitchell and R. Y. Chiao, "Negative Group Delay and 'Fronts' in a Causal System: An Experiment with Very Low Frequency Bandpass Amplifiers," *Physics Letters A*, **230**, June 1997, pp.133-138.
- 11. M. W. Mitchell and R. Y. Chiao, "Causality and Negative Group Delays in a Simple Bandpass Amplifier," *American Journal of Physics*, **66**, January, pp. 14-19, 1998.
- 12. M. Kitano, T. Nakanishi, and K. Sugiyama, "Negative Group Delay and Superluminal Propagation: An Electronic Circuit Approach," *IEEE Journal of Selected Topics in Quantum Electronics*, **9**, 1, January, pp. 43-51, 2003.

- 13. E. L. Bolda and R.Y. Chiao, "Two Theorems for the Group Velocity in Dispersive Media," *Physical Review A*, **48**, 5, November 1993, pp. 3890-3894.
- 14. B. Ravelo, A. Perennec, and M. Le Roy, "Synthesis of Broadband Negative Group Delay Active Circuits," IEEE International Microwave Symposium Digest, June 2007, pp. 2177-2180.
- 15. H. Choi, Y. Jeong, J. Lim, S. Y. Eom, Y. B. Jung, "A Novel Design for a Dual-Band Negative Group Delay Circuit," *IEEE Microwave Wireless Component Letters*, **21**, 1, January, 2011, pp. 19-21.
- S. Lucyszyn. I. D. Robertson, and A. H. Aghvami, "Negative Group Delay Synthesizer," *Electronics Letters*, 29, 9, April 1993, pp.798-800.
- 17. M. Kandic, and G. E. Bridges, "Asymptotic Limits of Negative Group Delay in Active Resonator-Based Distributed Circuits," *IEEE Transactions on Circuits and Systems I: Regular Papers*, **58**, 8, August 2011, pp. 1727-1735.
- 18. O. Siddiqui, M. Mojahedi, and G. Eleftheriades, "Periodically Loaded Transmission Line with Effective Negative Refractive Index and Negative Group Velocity," *IEEE Transactions on Microwave Theory and Techniques*, **52**, 5, May 2004, pp. 1449-1454.
- 19. C.-T. M. Wu and T. Itoh, "Maximally Flat Negative Group Delay Circuit: A Microwave Transversal Filter Approach," *IEEE Trans. on Microwave Theory and Techniques*, **62**, 6, June 2014, pp.1330-1342.
- 20. C.-T. M. Wu, S. Gharavi, B. Daneshrad and T. Itoh, "A Dual-Purpose Reconfigurable Negative Group Delay Circuit Based on Distributed Amplifiers," *IEEE Microwave and Wireless Components Letters*, November 2013, pp. 593-595.
- 21. C.-T. M. Wu, S. Gharavi, and T. Itoh, "Negative Group Delay Circuit Based on a Multisection Asymmetrical Directional Coupler," Asia-Pacific Microwave Conference 2013, Seoul, Korea, November 2013.
- 22. M. A. Ali and C.-T. M. Wu, "Negative Group Delay Circuit Based on Microwave Recursive Filters," *International Journal of Microwave Science and Technology*, 2015.

- 23. G. Chaudhary and Y. Jeong, "Negative Group Delay Phenomenon Analysis in Power Divider: Coupling Matrix Approach," IEEE Transactions on Components, Packaging and Manufacturing Technology, 7, 9, September 2017, pp. 1543-1551.
- 24. T. Zhang, R. Xu, and C.-T. Michael Wu, "Voltage-Insensitive Negative Group Delay Circuit Based on a Stepped-Impedance Distributed Amplifier," *IEEE Microwave and Wireless Components Letters*, 2017.
- 25. A. Borjak, P. P. Monteiro, J. J. O'Reilly, and I. Darwazeh, "High Speed Generalized Distributed-Amplifier-Based Transversal-Filter Topology for Optical Communication Systems," *IEEE Transactions on Microwave Theory and Techniques*, **45**, 8, August 1997, pp.1453-1457.
- 26. D. M. Pozar, *Microwave Engineering, Fourth Edition*, Toronto, John Wiley & Sons, 2011.
- 27. M. Kandic and G. E. Bridges, "Limits of Negative Group Delay Phenomenon in Linear Causal Media," *Progress in Electromagnetics Research*, **134**, 2013, pp. 227-246.
- 28. B. Ravelo, "Distributed NGD Active Circuit for RF-Microwave Communication," *International Journal of Electronics and Communications (AEÜ)/Int. J. Electron. Commun.*, **68**, 4, April 2014, pp. 282-290.
- B. Ravelo, Theory and Design of Analogue and Numerical Elementary NGD Circuits: Theoretical Characterization of Analogue and Numerical Elementary NGD Circuits, Germany, LAP Lambert Academic Publishing, GmbHm Etomsa, Sarrebruck Co. KG eds., 2012, p. 344.
- 30. B. Ravelo, "Negative Group-Delay Phenomenon Analysis with Distributed Parallel Interconnect Line," *IEEE Transactions on Electromagnetic Compatibility*, **58**, 2, April 2016, pp. 573-580.
- 31. B. Ravelo, "Theory on Coupled Line Coupler-Based Negative Group Delay Microwave Circuit," *IEEE Transactions on Microwave Theory and Techniques*, **64**, 11, November 2016, pp. 3604-3611.
- I. J. Bahl and D. K. Trivedi, "A Designer's Guide to Microstrip Line," *Microwaves*, May 1977. using directional couplers.

A Zero-Order-Closure Turbulent Flux-Conservation Technique for Blending Refractivity Profiles in the Marine Atmospheric Boundary Layer

Robert E. Marshall¹, Victor R. Wiss², Katherine L. Horgan², William D. Thornton², and Janet K. Stapleton²

¹Mount Pleasant Meteorology Woodford, Virginia, USA Tel: +1 (804) 867-7203 E-mail: mpmet@sprynet.com

²Naval Surface Warfare Center Dahlgren Division Dahlgren, Virginia, USA

Abstract

Recent advances in mesoscale numerical weather prediction (NWP) models have supported four-dimensional (4D) radio-frequency (RF) propagation modeling in challenging heterogeneous refractive marine environments. Numerical weather prediction models typically provide a vertical profile of refractivity every 1 km to 3 km horizontally in the domain of interest for each hour in a 48-hour forecast. Due to surface roughness and turbulence constraints, these profiles extend from the stratosphere to within 5 m to 10 m of the sea's surface. Because of strong evaporation at the sea's surface, significant impacts on RF system performance can be induced by refractivity gradients in the first 10 m above sea level (ASL). Historically, the lower-layer refractivity profiles have been calculated using Monin-Obukhov-Similarity- (MOS) based turbulence models. This dualmodel approach requires a robust technique for blending on the order of 10³ profiles per forecast hour without creating non-physical refractivity artifacts. This paper describes a zero-order-closure turbulent-flux technique for blending numerical weather prediction and Monin-Obukhov Similarity refractivity profiles, and presents the results of a multi-wavelength data-comparison process.

1. Introduction

Refraction of RF energy in the atmosphere is determined by the vertical structure of refractivity (N). Atmospheric pressure, atmospheric temperature, and partial pressure due to water vapor contribute to N [1, 2]. This relationship is given by

$$N = (n-1)10^6 \tag{1}$$

$$=\frac{77.6}{T}\left(p+\frac{4810e}{T}\right),$$

where n is the refractive index, T[K] is the atmospheric temperature, p[hPa] is the total atmospheric pressure, and e[hPa] is the partial pressure due to water vapor. N(z) is the vertical profile of N for height z above the surface of the Earth.

The modified refractivity, M, removes the effects of the Earth's curvature from propagation calculations, allowing the use of Cartesian instead of cylindrical coordinates [3]. The vertical profile of M as a function of the height above the Earth's surface is given by

$$M(z) = N(z) + \frac{10^6 z}{a} \tag{2}$$

$$= N(z) + 0.157z,$$

where z [m] is the height above the surface, and a [m] is the mean radius of the Earth (6.378×10^6 m). The vertical gradient of M(z) determines the refractive regime of the marine atmospheric boundary layer (MABL).

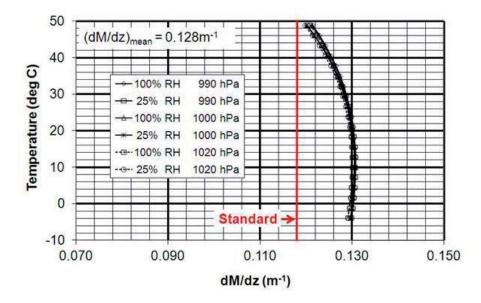


Figure 1. The vertical gradient of modified refractivity in a well-mixed marine atmospheric boundary layer.

The vertical thermodynamic structure of the marine atmospheric boundary layer is traditionally described in terms of potential temperature (θ) and water-vapor mixing ratio (w), since these are conserved variables of an air parcel if it experiences only adiabatic transformation with no net heat transfer as it moves in turbulent eddies throughout the marine atmospheric boundary layer [4]. The blending technique described in this paper is unique, since it is performed on θ , w, and p. The potential temperature in terms of T in Equation (1) is given by

$$\theta = T \left(\frac{p_0}{p} \right)^{\frac{R}{c_p}} . \tag{3}$$

The reference pressure, p_0 , is 1000 hPa. The gas constant for dry air, R, has the value $2.87 \times 10^2~\mathrm{Jkg}^{-1}\mathrm{K}^{-1}$. The specific heat of dry air at constant pressure, c_p , is $1.00467 \times 10^3~\mathrm{Jkg}^{-1}\mathrm{K}^{-1}$.

The water-vapor mixing ratio (w) is given by

$$w = \frac{0.622e}{p - e} \approx \frac{0.622e}{p} \,. \tag{4}$$

Inserting Equations (1), (3), and (4) into Equation (2) yields

$$M = \left[\frac{77.6}{\dot{e}\left(\frac{p}{1000}\right)^{0.286}}\right] \left[P + \frac{4810\frac{wp}{0.622}}{\theta\left(\frac{p}{1000}\right)^{0.286}}\right] + 0.157z \quad (5)$$

The vertical gradient of Equation (5) is given by

$$\frac{dM}{dz} = \frac{dp}{dz} \left(\frac{1.336 \times 10^7 w}{\theta^2 p^{0.572}} + \frac{399.54}{\theta p^{0.286}} \right)$$

$$-\frac{d\theta}{dz} \left(\frac{6.212 \times 10^7 wp^{0.428}}{\theta^3} + \frac{559.6 p^{0.714}}{\theta^2} \right)$$

$$+0.157 \text{ m}^{-1}$$
. (6)

The marine atmospheric boundary layer is often well mixed, due to mechanical and convective turbulence [5]. In a well-mixed layer, θ and w are conserved, and thus

$$\frac{d\theta}{dz} = \frac{dw}{dz} = 0$$
.

The vertical gradient of M for a well-mixed layer is reduced to

$$\frac{dM}{dz} = \frac{dp}{dz} \left(\frac{1.336 \times 10^7 w}{\theta^2 p^{0.572}} + \frac{3.995 \times 10^2}{\theta p^{0.286}} \right) + 0.157 \quad (7)$$

Figure 1 is a plot of Equation (7) for the ranges of relative humidity, atmospheric pressure, and temperature expected in the marine atmospheric boundary layer. Notice that a well-mixed marine atmospheric boundary layer produces a modified refractivity gradient slightly greater than standard.

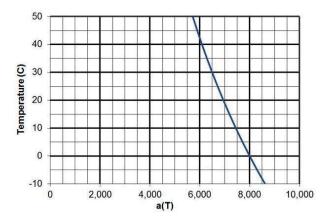


Figure 2. a(t) from Equation (8) at a pressure of 10^3 hPa.

The mean of the 360 values of the vertical gradient of M in Figure 1 is 0.128 m^{-1} . This allows for an instructive description of the vertical gradient of M more related to classic atmospheric-boundary-layer thermodynamic structure. Analysis of a wide range of global marine atmospheric-boundary-layer refractivity structures by the Naval Surface Warfare Center, Dahlgren Division, over the last ten years led to the observation that the vertical gradient of w is typically two to six times more influential on the vertical gradient of M than is the vertical gradient of θ . The radio-frequency engineer is highly knowledgeable about the influence of the dependent variable (M) in Equation (7)on RF system performance. The atmospheric-boundarylayer meteorologist is equally knowledgeable regarding the independent variables (θ, w) in Equation (8) and how they relate to classic marine atmospheric-boundarylayer thermodynamic structure. This equation has been successfully employed to exchange valuable knowledge between these two supporting disciplines. The blending technique presented in this paper occurs with $\theta(z)$ and w(z) that leads to a calculation of M(z).

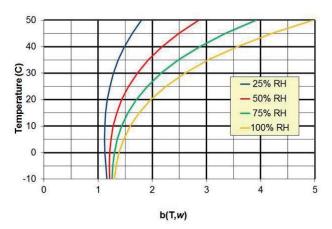


Figure 3. b(T,w) as a function of relative humidity (%RH) and temperature from Equation (8) at a pressure of 10^3 hPa.

$$\frac{\partial M}{\partial z} \approx 0.128 + a(\theta) \frac{\partial w}{\partial z} - b(\theta, w) \frac{\partial \theta}{\partial z}.$$
 (8)

From Equation (6), it can be seen that a(T) is weakly dependent on pressure and inversely proportional to the square of potential temperature. Figure 2 is a plot of a(T) for a typical marine atmospheric boundary layer atmospheric pressure of 10^3 hPa for a range of expected temperatures in the marine atmospheric boundary layer. Figure 3 represents b(T, w) over a range of relative humidity and temperature typical in the marine atmospheric boundary layer for an atmospheric pressure of 10^3 hPa.

In recent years, mesoscale numerical weather prediction (NWP) models have been investigated and employed for the purpose of providing prognostic location and time-specific refractivity fields [6-8]. Vertical profiles on horizontally spaced grids of the independent variables in Equation (1) support calculation of vertical profiles of M on the same structured grid. Vertical thermodynamic profiles are on discrete levels at each horizontal grid point. Due to roughness length and turbulence modeling requirements, these numerical weather prediction models can only provide data to within 5 m to 10 m of the sea's surface. With the atmosphere at the sea's surface near saturation, the rapid decrease in water vapor with height leads to refractivity structure with significant engineering impacts in this nearsurface region, where numerical weather prediction models provide no thermodynamic profile data. Monin-Obukhov-Similarity (MOS) models have traditionally been employed to predict refractivity in the lowest layer, known as the atmospheric surface layer [9].

The complete vertical profile of M is thus created by blending two different types of models in a manner that does not produce non-physical gradients in M. The mesoscale numerical weather prediction model solves the prognostic equations based on Newton's second law of motion, the equations of state for an ideal gas, the first law of thermodynamics, conservation of mass, and conservation of moisture. The numerical weather prediction model predicts vertical profiles of wind speed, pressure, temperature, moisture, and modified refractivity at discrete vertical levels on a horizontal grid from the surface layer to the stratosphere, and produces vertical profiles every 1 km to 3 km every hour for a 48-hour forecast. The Monin-Obukhov Similarity model assumes that the atmospheric flow is horizontally homogeneous and quasi-stationary; that the turbulent fluxes of momentum, heat, and moisture are constant with height; that molecular exchanges are insignificant compared to turbulent exchanges; that rotational effects can be ignored; and that the influence of surface roughness, boundary-layer height, and geostrophic winds are fully accounted for by the ratio of the surface drag to the air density [10]. The Monin-Obukhov Similarity model parameterizes vertical thermodynamics leading to continuous profiles. For refractivity-profile predictions, the surface-layer model is

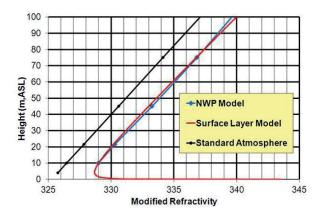


Figure 4. Modified refractivity examples represented by a Monin-Obukhov Similarity surface-layer model in red, and a numerical weather prediction model in blue. The marked data points for the blue numerical weather prediction model curve indicate vertical resolution. The black curve represents a standard atmosphere.

historically referred to as an evaporation-duct model. The problem is demonstrated in Figure 4.

The Monin-Obukhov Similarity surface-layer model in Figure 4 is driven by the wind speed, temperature, and water-vapor content predicted by the numerical weather prediction model at 10 m above sea level in the example in Figure 4. The remaining Monin-Obukhov Similarity surface-layer model input is the sea-surface temperature provided by the numerical weather prediction model at each numerical weather prediction model horizontal grid point. The dilemma, as posed in Figure 4, is to determine at what height to abandon the Monin-Obukhov Similarity surface-layer model and to transfer to the numerical weather prediction model. This must not only be accomplished without producing unrealistic vertical profiles of M, but it must be robustly performed for as many as 56,000 profiles associated with a 48-hour numerical weather prediction forecast.

2. A Zero-Order-Closure Turbulent Flux-Conservation Blending Technique

The use of numerical weather prediction modeling to predict RF system performance is becoming an internationally employed technology. As a result, multiple organizations have developed techniques for blending Monin-Obukhov Similarity and numerical weather prediction refractivity profiles. Prior to the use of numerical weather prediction models, blending techniques were designed for a more limited number of measured profiles of M, where an analyst in the loop was practical.

The Johns Hopkins University Applied Physics Laboratory, Direction general de l'armement (DGA, France), and the Naval Post Graduate School have developed blending techniques for modified refractivity profiles [11-13]. The Defence Science Technology Organisation determines the height of the surface layer in a refractivity-profile-assimilation model by assuming that the wind speed and friction velocity, as well as the potential temperature and temperature scale, are positively correlated at each analysis height [14]

The blending technique described in this paper differs from the techniques described above in two fundamental ways. First, the center of the blending layer is defined as the predicted height of the surface or constant-flux layer. Above this height, the validity of the surface-layer model becomes suspect. Secondly, the blending occurs in thermodynamic space (θ , w, and p), and the resulting blended M curve is calculated from the blended thermodynamic data. Our thinking is that since refractivity is a derived engineering variable, based on the thermodynamic vertical profiles found in natural atmospheric boundary-layer structures, blending is best accomplished at the thermodynamic level. Implicit in this thinking, compared to other models, is that we do not have to assume that ducting always occurs in the surface layer.

The height of the surface layer is defined by the height at which the turbulent fluxes vary by a mathematically tolerable level, commonly taken as 10% [15]. The height of the surface layer is determined by calculating the momentum, heat, and moisture flux at each numerical weather prediction model level, beginning at the lowest, using the Monin-Obukhov Similarity model output driven by the numerical weather prediction at that height. The Monin-Obukhov Similarity accepts sea-surface temperature, and temperature, humidity, and wind speed at each discrete numerical weather prediction height. It is assumed that the air at the surface is saturated, and the wind speed is zero. It is then determined at what increasing numerical weather prediction model height these turbulent fluxes first vary by more than 10% from the surface value, thereby testing one of the major assumptions of the Monin-Obukhov Similarity surface-layer model: that turbulent fluxes are constant with height [10]. Monin-Obukhov Similarity is a zero-order turbulence closure scheme where all resulting equations are fully parameterized [16]. Higher-order closure schemes that employ prognostic equations could be considered, but this Monin-Obukhov Similarity flux-profile approach appears to provide a suitable surface-layer height, leading to a robust engineering product. Two assumptions are made in this determination. It is assumed that the first numerical weather prediction model level is in the surface layer. It is also assumed that the fluxes vary linearly between discrete numerical weather prediction model levels.

The momentum flux is defined as the covariance of the turbulent components of the horizontal and vertical wind speeds:

$$\overline{uw} = \text{vertical momentum flux } = u_*^2,$$
 (9)

$$u_* \equiv \text{friction velocity} = Uk / \lceil \ln(z/z_0) - \psi_m \rceil,$$
 (10)

where

 $U \equiv$ mean wind speed at each NWP model height $k \equiv$ von Karmon constant ≈ 0.4 $z \equiv$ height of each NWP model layer $z_0 \equiv$ roughness depth $\psi_m \equiv$ similarity function for momentum.

The heat flux is defined as the covariance of the turbulent components of potential temperature and vertical wind speed.

$$\overline{\theta w} = \text{vertical heat flux} = \theta_* u_*,$$
 (11)

 $\theta_* \equiv \text{turbulent heat scale}$

$$= (\Theta - \Theta_s) k / \lceil \ln(z/z_0) - \psi_\theta \rceil, \tag{12}$$

where

 Θ = mean potential temperature at each NWP model height

 $\Theta_s \equiv$ mean potential temperature at the surface $\psi_\theta \equiv$ similarity function for heat

$$\Theta = T \left(\frac{p_0}{p} \right)^{\frac{R}{C_p}}$$

$$p_0 = 10^3 hPa$$

 $p \equiv$ mean pressure at each NWP vertical level $R \equiv$ gas constant for dray air $2.87 \times 10^2 \text{ Jkg}^{-1} \text{K}^{-1}$ $C_p \equiv$ specific heat of dry air at constant pressure $= 1.00467 \times 10^3 \text{ Jkg}^{-1} \text{K}^{-1}$.

The moisture flux is defined as the covariance of the turbulent components of specific humidity and vertical wind speed.

$$\overline{qw} \equiv \text{vertical moisture flux} = q_* u_*,$$
 (13)

 $q_* \equiv \text{turbulent moisture scale}$

$$= (Q - Q_s) k / \left[\ln(z/z_0) - \psi_q \right], \tag{14}$$

where

Q = mean specific humidity at each NWP model height

 $Q_s =$ mean specific humidity at the surface $\psi_a =$ similarity function for humidity

$$Q = \frac{0.622e}{p - e} = \frac{w}{w + 1}$$

The similarity functions are empirical functions of the ratio of the height in the surface layer (z) to the Monin-Obukhov length (L). L is defined as the height in the surface layer where turbulent kinetic energy (TKE) produced by wind shear is equal to turbulent kinetic energy produced by buoyancy [10]. Using Equations (10), (12), and (14), the turbulent fluxes of momentum, heat, and moisture are calculated at each numerical weather prediction model vertical level, beginning at the lowest.

$$\overline{uw} = u_*^2 = \left\{ Uk / \left[\ln \left(z / z_0 \right) - \psi_m \right] \right\}^2,$$
 (15)

$$\overline{\theta w} = \theta_* u_* \left[\frac{\left(\Theta - \Theta_S\right) k}{\ln\left(z/z_0\right) - \psi_\theta} \right] \left[\frac{Uk}{\ln\left(z/z_0\right) - \psi_m} \right], \quad (16)$$

$$\overline{qw} = q_* u_* \left[\frac{(Q - Q_s)k}{\ln(z/z_0) - \psi_q} \right] \left[\frac{Uk}{\ln(z/z_0) - \psi_m} \right]. \quad (17)$$

The first height higher than the first numerical weather prediction model level that corresponds to a 10% change from the nearest surface value for any of the three fluxes is considered to be the point where the Monin-Obukhov Similarity surface-layer profile is gracefully abandoned for the numerical weather prediction profile. The surface-layer model employed in this work was the Navy Atmospheric Vertical Surface Layer Model (NAVSLaM) [17] version 1.0, and the numerical weather prediction model was the Coupled Ocean Atmosphere/Mesoscale Prediction System (COAMPS®) [18]. NAVSLaM was run at 0.25 m vertical resolution. COAMPS® was typically run with a 10 m vertical resolution in the surface layer and a 3 km horizontal resolution. The similarity functions used to calculate the turbulent fluxes at each numerical weather prediction height were those employed by NAVSLaM. L used to evaluate the similarity functions was also provided by NAVSLaM. Fluxes were calculated beginning at the lowest COAMPS® level, and progressing to subsequent higher levels until the fluxes departed from the lowest-level values by 10%.

The technique assumes the surface-layer height is the height at which the COAMPS® derived fluxes vary by 10% from the NAVSLaM (N) fluxes calculated for the constant-flux layer. As an example, examine moisture flux:

$$0.9 \ge \frac{q_C^* u_C^*}{q_N^* u_N^*} \ge 1.1 ,$$

 $q_C^* \equiv$ The required turbulent moisture scale at each COAMPS height to provide the specific humidity at that height

 $u_C^* \equiv$ The required turbulent momentum scale at each COAMPS height to provide the wind speed at that height

 $q_N^* \equiv$ The constant flux layer turbulent moisture scale calculated by NAVSLaM

 $u_N^* \equiv$ The constant flux-layer turbulent momentum scale calculated by NAVSLaM

$$q_N^* = \frac{\left(Q_{z,N} - Q_{0,N}\right)k}{\ln\left(\frac{z}{z_0}\right) - \Psi_{\mathbf{q}}}$$

$$u_N^* = \frac{\left(U_{z,N} - U_0\right)k}{\ln\left(\frac{z}{z_0}\right) - \psi_m} = \frac{U_{z,N}k}{\ln\left(\frac{z}{z_0}\right) - \psi_m}$$

$$q_C^* = \frac{\left(Q_{z,C} - Q_{0,C}\right)k}{\ln\left(\frac{z}{z_0}\right) - \psi_q}$$

$$u_C^* = \frac{\left(U_{z,C} - U_0\right)k}{\ln\left(\frac{z}{z_0}\right) - \psi_m} = \frac{U_{z,C}k}{\ln\left(\frac{z}{z_0}\right) - \psi_m}$$

$$\frac{q_C^*}{q_N^*} = \frac{(Q_{z,C} - Q_{0,C})}{(Q_{z,N} - Q_{0,N})}$$

$$\frac{u_C^*}{u_N^*} = \frac{U_{z,C}}{U_{z,N}}$$

$$0.9 \ge \frac{q_C^* u_C^*}{q_N^* u_N^*} \ge 1.1$$

$$=0.9 \ge \frac{\left(Q_{z,C} - Q_{0,C}\right)}{\left(Q_{z,N} - Q_{0,N}\right)} \frac{U_{z,C}}{U_{z,N}} \ge 1.1 \tag{18}$$

Similarly, it can be shown for momentum flux and temperature flux, respectively,

$$0.9 \ge \frac{u_C^* u_C^*}{u_N^* u_N^*} \ge 1.1$$

$$=0.9 \ge \left(\frac{Uz,C}{Uz,N}\right)^{2} \ge 1.1 \tag{19}$$

$$0.9 \ge \frac{\theta_C^* u_C^*}{\theta_N^* u_N^*} \ge 1.1$$

$$=0.9 \ge \frac{\left(\Theta_{z,C} - \Theta_{0,C}\right)}{\left(\Theta_{z,N} - \Theta_{0,N}\right)} \frac{U_{z,C}}{U_{z,N}} \ge 1.1.$$
 (20)

It thus can be seen from Equations (18) to (20) that the determination of the surface-layer height is in fact calculated by the excursions of the COAMPS® bulk variables from the NAVSLaM bulk variables with height, and these do not depend on the form of the similarity functions.

2.1 Turbulent Flux Calculations

Example heat, momentum, and moisture turbulent flux calculations using Equations (15) to (17) and COAMPS® data are displayed in Figure 5 (COAMPS® is a registered trademark of the Naval Research Laboratory). The COAMPS® data points at 10 m, 22 m, 35 m, and 75 m are indicated. Because all of the required NAVSLaM input parameters were not available from COAMPS® at the surface, it was assumed that the lowest COAMPS® level was in the constant-flux layer, and the turbulent flux at that level was representative of the surface value. Flux values were assumed to vary linearly between discrete COAMPS® levels. The gold vertical bars were the $\pm 10\%$ excursion values. The heat flux varied by 10% from the lowest value at 14.8 m, the momentum flux varied by 10% at 18.2 m, and the moisture flux varied by 10% at 30.9 m. The height of the surface laver for this case was thus assumed to be 14.8 m, as predicted by the heat-flux profile. This height was then defined as the center of the blending zone.

2.2 Blending Zone

Analogous to molecular mean free path, Prandtl [19] proposed a turbulent mixing length over which a parcel of air will maintain identity before mixing with the surrounding fluid. In this blending technique, the Prandtl mixing length

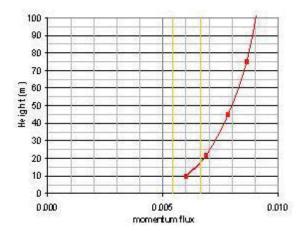


Figure 5a. The momentum flux in Nm^{-2} , calculated from the COAMPS® data depicted in Figure 4 and used in Equation (12). The gold vertical bars indicate the $\pm 10\%$ excursion from the nearest surface value.

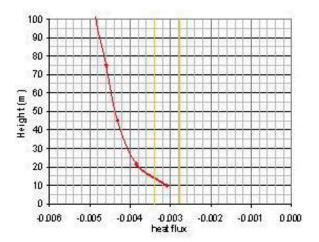


Figure 5b. The heat flux in Wm^{-2} , calculated from the COAMPS® data depicted in Figure 4 and used in Equation (13). The gold vertical bars indicate the $\pm 10\%$ excursion from the nearest surface value.

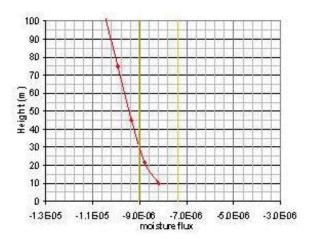


Figure 5c. The moisture flux in kgsm⁻², calculated from the COAMPS® data depicted in Figure 4 and used in Equation (14). The gold vertical bars indicate the $\pm 10\%$ excursion from the nearest surface value.

defines the depth of the blending zone, and is centered at the blending point determined by the flux-excursion method described in the previous section. There are many parameterizations available in the literature for the Prandtl mixing length. The formulation for the Prandtl mixing length chosen for this blending technique was developed by the European Centre for Medium Range Weather Forecasting (ECMWF) [20], and is displayed in Equation (21):

$$\frac{1}{k_m} = \frac{1}{k z_S} + \frac{1}{s},\tag{21}$$

 $l_m \equiv \text{Prandtl mixing length}$ k = 0.4 $z_s \equiv \text{surface-layer height}$ $\lambda = 150 \text{ m}.$

For the surface-layer height of 14.8 m in this example, the resulting Prandtl mixing length from Equation (18) was 5.7 m. The resulting blending zone was from 11.9 m to 17.6 m. A $\ln^2(z)$ weighting function was employed every 0.25 m across the blending zone to create a smooth blend of the slopes of the NAVSLaM thermodynamic variables and the slopes of the COAMPS® thermodynamic variables. Linear interpolation was employed between discrete COAMPS® levels. The 0.25 m resolution was chosen as a conservative value for the purpose of resolving evaporation duct heights to within 1.0 m. A $\ln^2(z)$ function was chosen instead of a linear function to minimize the impact of the blend, and to allow the Monin-Obukhov Similarity and numerical weather prediction model data to provide the solution. The weighting function is shown for the current example in Figure 6.

The smoothed thermodynamic slope curves were

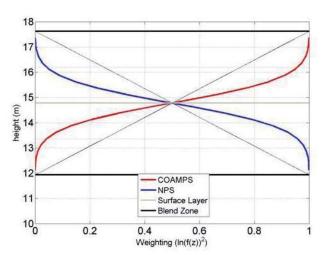


Figure 6. The weighting function for the numerical weather prediction and Monin-Obukhov Similarity models for a surface-layer height of 14.8 m and a blending length of 2.8 m.

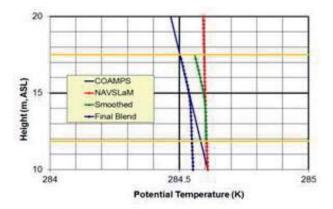


Figure 7a. The blending results for the potential temperature. The horizontal gold lines delineate the blending zone.

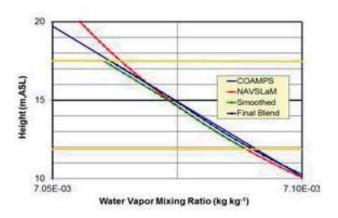


Figure 7b. The blending results for the water-vapor mixing ratio. The horizontal gold lines delineate the blending zone.

vertically integrated to produce vertical profiles of potential temperature and water-vapor mixing ratio. Because the Monin-Obukhov Similarity model and the numerical weather prediction model intercepted at the bulk parameter input level of 10 m, the blending of the

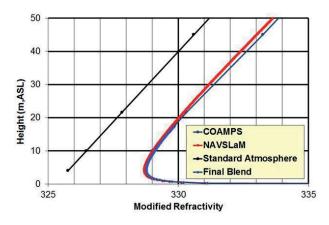


Figure 8. The final blending results for the modified refractivity.

thermodynamic curves had to be completed by sliding the blended curves toward the COAMPS® curves so that they matched at the top of the blending layer. This procedure did not affect the vertical gradient of refractivity or the resulting RF propagation. Atmospheric-pressure blending was accomplished in the same manner. This smoothing and blending technique for the current example is shown in Figure 7.

The final blended values of θ and w were converted to T and e through Equations (3) and (4), respectively. The resulting final blended profile of M was calculated from Equation (2). The results for the current example are displayed in Figure 8.

2.3 Data Comparison

The Wallops 2000 Microwave Propagation Measurements Experiment [21] provided a multiwavelength two-dimensional measured propagation data set for comparison with the blending technique described in the previous sections. Figure 9 delineates a 40 km path off Wallops Island, Virginia, USA where S-, C-, and X-band propagation measurements were made between 1512 UTC and 1605 UTC on April 28, 2000. The multi-wavelength propagation measurements were made from 0 m to 10 m above sea level along this 40 km path. A 3-km-horizontalresolution COAMPS® grid for 1600 UTC was included the 40 km path. The COAMPS® data were processed by a Barnes objective analysis scheme [22, 23] to produce a meteorological profile along the bearing every 2 km. The blending technique described in the previous sections was applied to each of these 21 profiles. The location of the Naval Postgraduate School meteorological flux buoy is also indicated in Figure 9 [21]. Bulk meteorological parameters from this instrument were used to calculate a single surface-layer refractivity curve to be used with each



Figure 9. The propagation measurement bearing off Wallops Island, Virginia, USA, between 1512 UTC and 1605 UTC on April 28, 2000. The NPS flux meteorological buoy was located along the bearing approximately 13 km offshore.

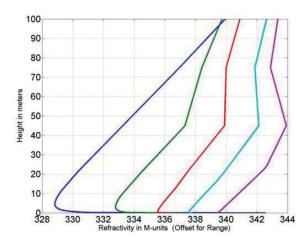


Figure 10. Blended modified refractivity profiles at 0 km, 10 km, 20 km, 30 km, and 40km along the bearing in Figure 9.

helicopter sounding collected along the 40 km path [21].

Figure 10 displays the thinned (for clarity) resulting range-dependent modified refractivity profiles at 0 km, 10 km, 20 km, 30 km, and 40 km, respectively from left to right along the path in Figure 9. The profile at 0 km was that described in the development of the blending technique in the previous sections. Notice the decrease in evaporation

duct height in the offshore direction.

Comparisons of the measured S-band one-way propagation factor from 1512 UTC to 1605 UTC with the COAMPS®/NAVSLaM blend one-way propagationfactor prediction are provided in Figure 11. Propagation measurements were made from 0 m to 10 m above sea level along the 40 km path using the Microwave Propagation Measurement System (MPMS) [21]. The propagation modeling was performed by employing the 21 blended profiles along the bearing in Figure 9 with the tropospheric electromagnetic parabolic equation routine (TEMPER) [24]. TEMPER is a parabolic-wave-equation RF propagation model developed at the Johns Hopkins University-Applied Physics Laboratory that considers sea surfaces as well as terrain. At this wavelength, the first multipath null was not observed in this 10-m-deep layer. The difference graphic represents measurement minus model.

A similar analysis for the C-band measurements between 1512 UTC and 1605 UTC on April 28, 2000, is demonstrated in Figure 12. Notice that at this shorter wavelength, the first multipath null is observable in the top left corner. The X-band analysis is provided in Figure 13. Due to the even shorter wavelength, the multipath nulls were more prominent in this 10 m deep layer of one-way

Table 1. S-band comparison statistics.

	Refractivity Source	50 th Percentile Absolute Error (dB)	90th Percentile Absolute Error (dB)	
All Dates and Times	COAMPS®	0.8	2.4	
All Dates and Times	Helicopter	1.3	3.4	

Table 2. C-band Comparison Statistics.

	Refractivity Source	50 th Percentile Absolute Error (dB)	90 th Percentile Absolute Error (dB)	
All Dates and Times	COAMPS®	1.2	3.1	
All Dates and Times	Helicopter	1.8	4.7	

Table 3. X-band Comparison Statistics.

	Refractivity Source	50 th Percentile Absolute Error (dB)	90 th Percentile Absolute Error (dB)	
All Dates and Times	COAMPS®	1.2	5.3	
All Dates and Times	Helicopter	2.2	6.8	

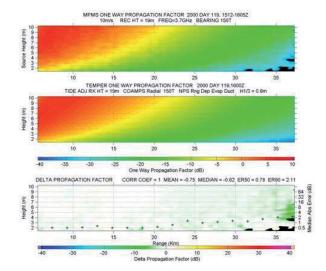


Figure 11. The S-band (3.7 GHz) propagation-factor measurements (upper graphic), the COAMPS®/NPS blend propagation-factor predictions (middle graphic), and the differences (lower graphic), plotted in range and height. The 50th percentile error was 0.8 dB, and the 90th percentile error was 2.1 dB.

propagation factor.

It is important to note that the measurement data was taken over nearly an hour as the transmitter boat sailed along the path in Figure 9. The marine atmospheric boundary layer and the resulting refractivity field were constantly slightly adjusting to the temperature and water vapor in the air flowing over the sea's surface during this period. This data comparison assumed that the propagation factor measured remained constant over this range during the period of collection. It could also be seen that as the multipath nulls showed in the close-range X-band data, the mean absolute error was increased.

A total of six two-dimensional propagation measurements made over three days were used for comparison with similar results. Tables 1 to 3 summarize the 50th and 90th percentile error results for the S, C, and X bands, respectively. They include not only the performance statistics for the COAMPS®/NPS blend, but also the performance statistics for predictions based on rangedependent meteorological soundings made by the Johns Hopkins University Applied Physics Laboratory helicopter [21]. In the case of a COAMPS®/NAVSLaM blend, it is a single COAMPS® model forecast hour. In the case of the helicopter, it is the period over which the meteorological helicopter sampled the vertical structure of the marine atmospheric boundary layer along the MPMS measurement bearing. In some cases, there were multiple helicopter runs for one MPMS propagation measurement. As is standard test and evaluation practice, the fully blended helicopter soundings were composed of helicopter measurements and a surface-layer model. NAVSLaM was driven by bulk inputs from the NPS buoy located approximately 13 km offshore, as in Figure 9. The blending technique was similar to those in the Multi-source Assimilation and Refractivity

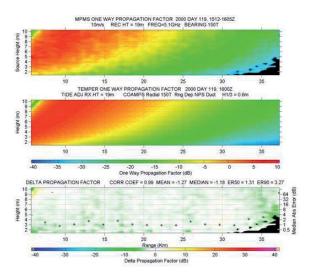


Figure 12. The C-band (5.1 GHz) propagation-factor measurements (upper graphic), the COAMPS®/NPS blend propagation-factor predictions (middle graphic), and the differences (lower graphic), plotted in range and height. The 50th percentile error was 1.3 dB, and the 90th percentile error was 3.3 dB.

Interpolator (MARI) [11]. The same evaporation duct defined by data from the NPS buoy was blended with each range-dependent helicopter sounding.

It could be observed from Figures 11 to 13 and Tables 1 to 3 that the blending technique described in this paper produced relatively lower errors compared to measurements. In the median, over all the data-comparison events, the range-dependent COAMPS®/NAVSLaM blend surface-layer refractivity profiles produced slightly better

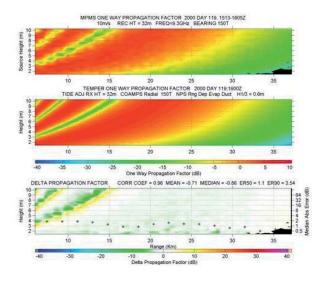


Figure 13. The X-band (9.3 GHz) propagation-factor measurements (upper graphic), the COAMPS®/NPS blend propagation-factor predictions (middle graphic), and the differences (lower graphic), plotted in range and height. The 50th percentile error was 1.1 dB, and the 90th percentile error was 3.5 dB.

results than the constant-evaporation-duct height profiles produced by blending the same surface-layer profile with each helicopter profile. It can also be seen that the measured minus modeled errors tended to increase with decreasing wavelength as the multipath nulls became more prominent.

3. Conclusions

A zero-order-closure turbulent flux-conservation technique for blending refractivity profiles from Monin-Obukhov Similarity and numerical weather prediction models has been described and compared with six twodimensional multi-wavelength data sets. The technique is unique in that it determines the approximate depth of the surface layer at each numerical weather prediction grid point, and thereby defines the legitimate vertical domain for the surface-layer model at each numerical weather prediction grid point. Blending is accomplished over one Prandtl mixing length with the conserved thermodynamic variables. The blended thermodynamic variable curves are then employed to calculate the final blended modified refractivity profile at each numerical weather prediction grid point. The multi-wavelength data-comparison results indicated that the range-dependent COAMPS®/NAVSLaM surface-layer refractivity profiles in the median over all comparison data showed slight improvement relative to constant evaporation duct heights blended with rangedependent measured soundings.

4. Acknowledgement

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5. References

- B. R. Bean and E. J. Dutton, *Radio Meteorology*, New York, Dover Publications, 1968, p. 435.
- D. E. Kerr, *Propagation of Short Radio Waves*, London, UK, Peter Peregrinus Ltd., 1987, pp. 191-192.
- 3. H. A. Hsu, *Coastal Meteorology*, San Diego, CA, Academic Press, Inc., 1988, pp. 206-207.
- 4. J. M. Wallace and P. V. Hobbs, *Atmospheric Science: An Introductory Survey*, San Diego, CA, Academic Press, 1977, pp. 68-76.
- R. B. Stull, An Introduction to Boundary Layer Meteorology, Dordrecht, The Netherlands, Kluwer Academic Publishers, 1988, pp. 10-11.
- 6. T. Haack, C. Wang, S. Garrett, A. Glazier, J. Mailhot and R. Marshall, "A Mesoscale Model Inter-Comparison of

- Boundary Layer Refractivity and Atmospheric Ducting," *Journal of Applied Meteorology and Climatology*, **49**, 12, December 2010, pp. 2437-2457.
- 7. C. Wang, D. Wilson, T Haack, P Clark, H. Lean, R. Marshall, "Effects of Initial and Boundary Conditions of Mesoscale Models on Atmospheric Refractivity," *Journal of Applied Meteorology and Climatology*, **51**, 1, January 2012, pp. 115-132.
- 8. R. E. Marshall, W. D. Thornton, G. H. Lefurjah and T. S. Casey, "Modeling and Simulation of Notional Future Radar in Non-Standard Propagation Environments Facilitated by Mesoscale Numerical Weather Prediction Modeling," *Naval Engineers Journal*, **120**, 4, December 2008, pp. 55-66.
- 9. J. C. Wyngaard, and O. R. Cote, "The Budgets of Turbulent Kinetic Energy and Temperature Variance in the Atmospheric Surface Layer," *Journal of the Atmospheric Sciences*, **28**, 2, March 1971, pp.190-201.
- 10. S. P. Arya, *Introduction to Micrometeorology*, San Diego, CA, Academic Press, 2001, pp. 213-223.
- A. K. Kochhar, "Multiple-Source Assimilation and Refractivity Interpolator (MARI)," USNC/URSI National Radio Science Meeting, Albuquerque, NM, July 9-14, 2006.
- 12. J. Claverie, E. Mandine and Y. Hurtaud, "PREDEM: un nouvel outil de simulation pour la prédiction des performances des systèmes radars," ECPS Conference, Brest, France, March 15-18, 2005.
- 13. P. Frederickson, "An Evaluation of the Use of Mesoscale Numerical Weather Prediction Model Data with Electromagnetic Propagation Tactical Decision Aids," USNC/URSI National Radio Science Meeting, Boulder, CO, January 5-8, 2011.
- 14. D. M. Phillips and C. P. Baker, "Refractivity Profile Assimilation Model the Atmospheric Boundary Layer," Defence Science and Technology Organisation, Rep. DSTRO-RR-0148, Salisbury, South Australia, July 1999.
- 15. G. S. Poulos and S. P. Burns, "An Evaluation of Bulk Ri-Based Surface Layer Flux Formulas for Stable and Very Stable Conditions with Intermittent Turbulence," *Journal of the Atmospheric Sciences*, **60**, 20, October 15, 2003, pp. 2523-2537.
- 16. M. Z. Jacobson, *Fundamentals of Atmospheric Modeling*, Cambridge, UK, Cambridge University Press, 2005, p. 237.
- 17. P. A. Frederickson, K. L. Davidson, and A. K. Goroch, "Operational Bulk Evaporation Duct Model for MO-RIAH, Ver.1.2," Naval Postgraduate School, Rep. NPS/

- MR-2000-002, Monterey, CA, 2000.
- 18. R. M. Hodur, X. Hong, J. D. Doyle, J. Pullen, J. Cummings, P. Martin, and M. A. Rennick, "The Coupled Ocean Atmosphere Prediction System (COAMPS)," *Oceanography*, 15, 1, 2002, pp. 88-99.
- 19. L. Prandtl, "Bericht ueber Untersuchungen zur ausgebileten Turbulenz," *ZAMM*, **3**, 1925, pp 136-139.
- 20. P. White et al., "Part IV: Physical Processes," in *EC-MWF IFS documentation CY25R1*, European Centre for Medium-Range Weather Forecasting, Reading, United Kingdom, 2003.
- 21. J. Stapleton, D. Shanklin, V. Wiss, T. Nguyen, and E. Burgess, "Radar Propagation Modeling Assessment Using Measured Refractivity and Directly Sensed Propagation Ground Truth," Naval Surface Warfare Center Dahlgren Division, Rep. NSWCDD/TR-01/132, Dahlgren, VA, 2001.
- 22. S. L. Barnes, "A Technique for Maximizing Details in Numerical Weather Map Analysis," *Journal of Applied Meteorology and Climatology*, **3**, 4, August 1964, pp. 396-409.
- 23. S. L. Barnes, "Mesoscale Objective Map Analysis Using Weighted Time-Series Observations," *Technical Memorandum ERL NSSL*, **62**, 1973, p. 60.
- 24. G. D. Dockery, R. S. Awadallah, D. E. Freund, J. Z. Gehman and M. H. Newkirk, "An Overview of Recent Advances for the TEMPER Radar Propagation Model," Proceedings of the IEEE Radar Conference, April 2007, pp. 896-905.

Introducing the Authors



Robert E. Marshall received a BS and MS in Electrical Engineering from Virginia Tech in 1971 and 1973, respectively. He taught radio-frequency engineering at Virginia Tech from 1973-1983 while investigating satellitepath attenuation and depolarization due to precipitation as a member of the Satellite Communications Group. He earned a PhD in Atmospheric Science from North Carolina State University in 1995, specializing in radar and atmospheric-boundary-layer meteorology. Dr. Marshall is a retired senior scientist at the Naval Surface Warfare Center in Dahlgren,

Virginia, where he performed research in RF propagation and numerical weather prediction. He is currently the US National Committee for the International Union of Radio Science representative to the American Meteorological Society.



Victor R. Wiss received his BS in Electrical Engineering with emphasis in Physical Phenomena from Tennessee Technological University in 1984. He has worked in the research, development, testing, and evaluation of radar systems for the Naval Surface Warfare Center, Dahlgren Division, for 25 years. For the last 15 years, he has served as Lead Engineer for radio-frequency propagation and meteorological measurements.



Katherine L. Horgan received a BS in Meteorology from North Carolina State University in 2006. She is currently working on her MS in Atmospheric Science from Texas Tech University. Katherine is a scientist at the Naval Surface Warfare Center in Dahlgren, Virginia, where she performs research in meteorology and RF propagation.



William D. Thornton received a BS in Chemistry from Athens College, AL, in 1974. Mr. Thornton worked with AAW Fire Control Radar Systems for 30 years at Naval Surface Warfare Center in Dahlgren, VA. For the past 12 years he has worked in the fields of estimating radar-propagation performance in littoral clutter environments.



Janet K. Stapleton graduated with honors from Tennessee Technological University in 1985 with a bachelor's degree in Electrical Engineering. Upon graduation, she joined the Naval Surface Warfare Center in Dahlgren, VA. Throughout her career, she has supported a variety of Navy research and development programs. Many of these endeavors were related to low-altitude propagation of radio-frequency (RF) signals. The culmination of Mrs. Stapleton's work in RF propagation came with the Office of Naval Research project responsible for the measured data used in this report, where Mrs. Stapleton served as the Principal Investigator. Mrs. Stapleton is currently on staff in the Radar Development Branch of the Electromagnetic and Sensors Systems Department at the Naval Surface Warfare Center, Dahlgren Division. Mrs. Stapleton has been a member of USNC/URSI Commission F on Wave Propagation and Remote Sensing since 1996.

Conformal Antennas for Miniature In-Body Devices: The Quest to Improve Radiation Performance

Denys Nikolayev^{1,2}, Maxim Zhadobov¹, Pavel Karban², and Ronan Sauleau¹

Institute of Electronics and Telecommunications of Rennes (IETR – UMR CNRS 6164)

University of Rennes 1, France

E-mails: d@deniq.com

maxim.zhadobov@univ-rennes1.fr

ronan.sauleau@univ-rennes1.fr

²Regional Innovation Centre for Electrical Engineering (RICE), University of West Bohemia, Czechia karban@kte.zcu.cz

Abstract

In-body devices for wireless biotelemetry and neural interfacing could empower many breakthroughs in medicine and clinical research. Despite significant progress in antenna design, improving the radiation performance of miniature in-body devices remains a major challenge because, for the time being, they are able to operate at distances of only up to a few meters. Here, we start by presenting a comprehensive review of existing antenna solutions and operating-range extension methods. We then describe the design and operation of a miniature capsule-conformal microstrip antenna with improved radiation efficiency. We demonstrate that with the proposed methodology, the operating range of deep-body (> 5 cm) devices could reach 10 m to 15 m. This would allow monitoring physiological parameters unaffecting mobility and the quality of life of a user, as well as increasing the energy efficiency of the in-body device.

1. Introduction

Body-implanted electronics came into existence when the first pacemaker was invented in the 1950s [1]. This healthcare innovation exposed the potential and revealed vast opportunities in the field of implantable electronic devices, enabling new ways of diagnostics and treatment, while maintaining a patient's mobility. In particular, Richard

Feynman exposed the future of body-implanted electronics in his lecture "There's Plenty of Room at the Bottom" [2]. The first practical realizations of in-body capsule-shaped devices (in-body-capsules), equipped with sensing and transmitting capabilities, appeared in 1957 in *Nature*, in a note from Zworykin and Farrar [3], and a letter from Mackay and Jacobson [4]. Farrar also reported the wireless capsule that senses gastrointestinal motility by means of pressure variation; it operated at frequencies around 1 MHz [5]. Similar devices were reported in the 1960s and 1970s [6-8], all operating in the near field: well below 10 MHz. This substantially limited both the operating range and the throughput of the system [9].

In the 2000s, progress in microelectromechanical systems and microfluidics, along with further miniaturization of electronics and biosensors, empowered a new generation of body-implanted devices. These created numerous applications in medicine, clinical research, wellness, and defense [10-13]. Modern implantable, ingestible and injectable (in-body) devices for biomedical telemetry [14] can continuously monitor and yield physiological parameters (for instance, endoscopic imagery [15], intracorporeal temperature [16], pressure [17], pH [18], glucose levels [19], and so on), while maintaining mobility and improving the quality of life of a patient. Apart from telemetering various diagnostic data, in-body devices can perform the following functions: brain-machine interfacing [20], defibrillation, deep-brain and heart stimulation [21], drug delivery [22], and hyperthermia [23].



Figure 1a. The manufactured prototype of a conformal microstrip antenna by Mahe et al. [63] (©2012 Yann Mahe et al.).

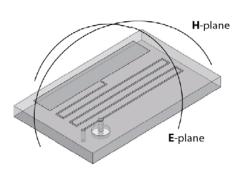


Figure 1b. The design for the antenna shown in Figure 1a (©2012 Yann Mahe et al.).

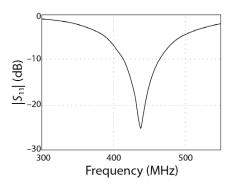


Figure 1c. The simulated reflection coefficient for the antennas shown in Figure 1a (©2012 Yann Mahe et al.).

A modern in-body device typically consists of (1) a biomedical application circuit to acquire physiological data or to provide treatment, (2) a microcontroller to process the data and to give instructions to the device's circuitry, (3) a wireless link containing an antenna, and (4) a power source. The device uses a wireless link to transmit biotelemetry data or to receive operational and treatment instructions [24]. A power source can be a button cell or a miniature wireless powering/recharging circuit [25].

Despite several power-efficient alternatives (e.g., a human-body communication method [26]), far- and midfield (the region where the wavelength is comparable to the distance between an implant and the transmitter [27]) transmissions in the VHF to SHF bands (as defined by the ITU) yield the longest operating range and highest data transfer rates for in-body devices [28].

An antenna operating in the VHF to SHF forms a coupled system of accelerating charges with biological tissues. This system (Tx) radiates to surrounding free space due to non-conserved current and charge in the localized region surrounding the antenna [29]. The antenna's radiation is therefore inseparable from this system, and the operating range is thus the distance from the surface of the body to the antenna of the external equipment (Rx). Assuming the invariable environment (including the fixed position of the in-body device) and given the external receiver properties (antenna gain, receiver sensitivity, and noise level), the operating range depends on the realized gain of the in-body antenna (a function of the reflection coefficient, directivity, and the radiation efficiency) and the input power. In this study, we consider the in-body device to be operating at the maximum authorized input power within the safety limits, and the radiation being omnidirectional. We therefore focus on ways of improving the radiation efficiency and matching stability.

2. In-Body Antenna Types and Performance

Several VHF to SHF antenna designs have been proposed in recent years [30]. The first to appear were standard wire antennas, adjusted to operate in lossy body tissues. For instance, Kwak et al. proposed a helical antenna [31], and Lee et al. reported spiral antennas [32, 33]. Although having satisfactory radiation characteristics (gain G = -26.2 dBi in [34] implying a radiation efficiency $\eta < 0.1\%$), wire antennas cannot be cheaply and easily mass produced, and their impedance performance depends strongly on the electromagnetic (EM) properties of surrounding tissues. Printing the antenna on a substrate allows integrating it easily with device circuitry, and partially decoupling the antenna from the surrounding tissues. Planar printed antennas can thus achieve better robustness than wire antennas. Merli et al. proposed a dual-band (MedRadio 403 MHz and ISM 2.45 GHz bands) multilayer spiral antenna [35] that was fully shielded from the circuitry. Liu et al. reported a wideband 2.45 GHz circularly-polarized multilayer antenna [36]. Dissanayake et al. exploited the effects of dialectic loading for miniaturization and impedance-matching purposes, and designed an ultrawideband (UWB) substrate-integrated slot antenna [37]. Despite having generally better impedance stability than the wire antennas (the radiation efficiency remained $\eta < 0.1\%$), the planar printed antennas are bulky and occupy significant volume (from about 15% to 40%) inside in-body capsules. For this reason, the antenna designs on rigid substrates are used less and less for capsule applications, but remain widely employed for planar devices [38-40].

Conformal designs possess all the advantages of antennas on rigid PCBs, but occupy negligibly small space inside a device (typically less than 5%, Figure 1a). In addition, their electrical size can be larger as they can cover nearly all the surface of the capsule. Various types

of conformal designs have been reported. Izdebski et al. designed a meandered dipole antenna conforming to the interior surface of a capsule [41]. The antenna operated at 1.4 GHz with a fractional bandwidth at $|S_{11}| = -10$ dB (hereafter referred to as the "bandwidth" or BW) of about 10%, and a gain G = -26 dBi when simulated in the small intestine of the truncated Ansoft human-body model. However, in [42] Rajagopalan et al. used the same antenna to perform link-budget calculations, and reported G = -32 dBi. The antenna was sensitive to the surrounding tissue's electromagnetic properties, as well as requiring retuning when circuitry was present. Xu et al. proposed another dipole antenna operating at 403 MHz with an enhanced bandwidth of 36% [43]. However, the gain (G = -37 dBi) was significantly reduced compared to the previous antenna. Bao et al. recently developed a tri-band inverted-F antenna [44] with gains of G = -30, 25, 23 dBi for 403 MHz, 915 MHz, and 2.45 GHz, respectively, when simulated inside the stomach of the torso model Gustav (CST Microwave Studio [45]).

Much attention has been focused on loop antennas, because – in theory – they may provide higher in-body efficiencies than dipoles and monopoles, due to their predominantly magnetic near field. It allows that the near-field coupling is less to non-magnetic biological tissue (relative magnetic permeability $\mu_r \approx 1$) [46]. However, in practice a magnetic in-body antenna close to the ideal antenna has yet to be proposed, and the radiation efficiency of loop antennas has stayed comparable to counterparts. Nevertheless, some remarkable designs in terms of efficiency-to-bandwidth ratio have been reported. Alrawashdeh et al. designed a range of loop antennas for various applications: from the antennas for knee implants [47, 48] to the multi-band complementary split-ringresonator-loaded antenna with unprecedented impedance bandwidth [49]. Yun et al. developed the meander-loop antenna conforming to the outer surface of the capsule, thus maximizing the antenna's electrical size [50]. The 434 MHz loop antenna designed by Suzan et al. [51] further improved this approach by extending down to the half-spherical extremity of the capsule. The authors achieved G = -28dBi when simulated in an 80 mm × Ø180 mm cylindrical phantom with muscle-equivalent EM properties (hereafter, all tissue EM properties are as reported by Gabriel et al. [52-54]).

The main drawbacks of conformal loop antennas are their sensitivity to the capsule circuitry in terms of both impedance and radiation efficiency, and their lack of robustness against the variation of the EM properties of surrounding tissues. For instance, the resonance frequency of the antenna may shift from 403 MHz in muscle to 4 GHz in air [55]. This requires designing antennas with extremely large bandwidths to compensate for the detuning. That means that the antenna losses must increase, and thus the radiation efficiency has to be sacrificed [56-59]. Bao et al. proposed a workaround to increase the robustness to the

environment by designing a wideband slot-loop antenna [60]. It operated around $f_0 = 2.45$ GHz with a bandwidth of 114% and a G = -22 dBi when simulated in a cuboid (60 mm × 60 mm × 70 mm) muscle-equivalent phantom.

Another type of conformal in-body antenna is the microstrip antenna. These antennas are intrinsically more robust, both to the varying EM properties of surrounding tissues (as f_{res} is defined mostly by the substrate geometry and its dielectric properties [61]), and to the device circuitry (as the antenna contains the ground plane). On the other hand, microstrip antennas usually have much narrower bandwidths [62] compared to the above-mentioned types of antennas, especially considering that substrates should be as thin as possible to minimize the volume occupied by the antenna. Finding a proper miniaturization technique is also a challenge. Cheng et al. used a complementary split-ring resonator (CSRR) to load a 2.45 GHz $\lambda/2$ patch antenna, reducing its length to 10.5 mm. The substrate was 254 µm thick. No data were given on the antenna's radiation performance in-body. Mahe et al. employed a $\lambda/4$ steppedimpedance resonator along with meandering to miniaturize a 434 MHz antenna (Figure 1) [63] (a 400 MHz version was reported in [64]). The substrate was 50 µm thick. The gain was $G = -33 \, \text{dBi}$ and the bandwidth was $\approx 10\%$ when simulated in a Ø200 mm cylindrical phantom with $\varepsilon_r = 49.6$, $\sigma = 0.51 \text{ Sm}^{-1}$. Finally, Psathas et al. proposed a microstrip meandered antenna operating at 402 MHz [65]. The bandwidth was comparable to the previous antenna ($\approx 10\%$), with the gain reaching G = -30 dBi when simulated in a homogeneous 100 mm³ cubic phantom with muscle-equivalent EM properties. The miniaturization employed a shorting pin and meandering techniques, which permitted obtaining dual-band characteristics as well (such as, for instance, in [38]).

Despite significant progress in antenna design, improving the operating range of miniature in-body devices remains a major challenge (for the time being, they are able to operate only up to a few meters). Among the main issues to face are low radiation efficiencies ($\eta < 0.1\%$) and antenna-impedance detuning due to strong coupling to lossy and dispersive biological tissues.

3. Extending Operating Range

The radiation efficiency is constrained by attenuation and reflection losses in tissues [10], as well as by the required miniaturization of antennas, which imposes fundamental limits on the maximum achievable radiation efficiency [66]. The antenna detunes, since its impedance strongly depends on the electromagnetic properties of biological tissues that vary both in terms of permittivity and conductivity [53]. Ingestible antennas are more susceptible to impedance detuning than implantable antennas, as they must operate in a dynamically changing gastrointestinal (GI) tract.

3.1 Choosing Optimal Operating Frequency

The maximum achievable radiation efficiency, η , of an ideal in-body antenna depends on the operating frequency [10]. The optimal frequency range depends on how deep the antenna is in the body, what tissues surround it, and how electrically large the antenna is. Poon et al. [67] showed that the optimal wireless powering of an in-body device by a small current loop can be achieved by operating at GHz frequencies (mid-field region). A number of studies suggest that an optimal frequency exists as well for the energy transfer in the far field from a body to surrounding free space [68-70]. Considering the dispersive properties of body tissues, attenuation and reflection losses, and the efficiencyto-bandwidth limitations of electrically small antennas [58], the optimal frequency range for deep-body implantation (d > 3 cm) was found to be in the 10^8 Hz to 10^9 Hz range [68, 69]. The most-suitable unlicensed frequency bands for deep-body applications (e.g. ingestible) are therefore the MedRadio (Medical Device Radiocommunications Service) (401 MHz to 406 MHz, 413 MHz to 419 MHz, 426 MHz to 432 MHz, 438 MHz to 444 MHz, 451 MHz to 457 MHz) [71], ISM (Industrial, Scientific and Medical Service) (433 MHz to 434.8 MHz) [72], and WMTS (Wireless Medical Telemetry Service) 611 MHz [73]. As for the shallow implantation (e.g., subcutaneous), the closer the antenna is to the skin, the less the signal attenuates within the tissue. Higher frequencies are Therefore preferable. The most-efficient bands for subcutaneous applications would be then the ISM 915 MHz, WMTS 1.4 GHz, ISM 2.45 GHz, and up to the ISM 5.8 GHz.

3.2 Improving Radiation Efficiency

Considering that the operating frequency, f_0 , is close to optimal, the radiation efficiency is still constrained by the attenuation and reflection losses in tissues. In addition, the required miniaturization of antennas operating below $\approx 1 \, \text{GHz}$ imposes fundamental limits on the achievable radiation efficiency for electrically small antennas [66].

At least two approaches are currently under development [74]: 1) magnetic antennas (e.g., loops) and 2) dielectrically loaded microstrip antennas. Each has its advantages and drawbacks. A magnetic-type antenna couples less to tissues due to the magnetic component dominating in its near field [46]. As stated above, loop antennas give good radiation performance. However, a spatial variation of tissue EM properties affects the antenna's impedance, and thus can deteriorate matching. Typically, to compensate for the antenna's detuning, an extended bandwidth, BW, is preferred. However, this limits the maximum-achievable radiation efficiency for a given antenna size, as $BW \propto ka/\eta$ [58]. Bao et al. recently demonstrated a potential workaround of this problem by designing a robust multi-band loop-slot antenna [60].

Another technique is dielectric loading: this increases the robustness of antennas [28, 37], which allows reducing the necessary bandwidth and increasing the electrical size, ka. Merli et al. [75] and Skrivervik [76] studied the effect of implantable device encapsulation on radiation efficiency, and found that it improves with increasing permittivity of encapsulation. Increased radiation efficiency was achieved in [28, 40] by loading microstrip antennas with a thin ceramic superstrate (<1 mm). A high-permittivity filling of the device—ideally, matched with the tissue's permittivity—helps to further increase η [59]. In this way, a dielectrically loaded microstrip antenna can potentially outperform loop antennas in both robustness and radiation performance.

3.3 On-Body Matching Layers and Repeaters

Merli et al. studied the effects of on-body matching layers that improve power transmission from a body [75]. An ideal matching layer (71 mm thick) can increase the power transmission up to 8 dB. Realistic materials (fiber, neoprene, and silicon have been studied) with reasonable thicknesses (up to 20 mm) can provide up to 2 dB improvement.

Kiourti et al. proposed a dual-band on-body repeater antenna [38]. The antenna received a low-power MedRadio signal (401 MH to 406 MHz) from an in-body implant, and retransmitted it using the 2.45 GHz ISM band. This approach reduced the required implant power by a factor of 100 to achieve the same range without the repeater antenna.

4. Towards Conformal Antennas with Enhanced Radiation Performance

The aforementioned approaches allow one to substantially improve the operating range of in-body devices. Depending on the receiver antenna's sensitivity and link-budget evaluation, a range of 10 m to 15 m is foreseeable in the near future for deep-body-implanted devices ($d \approx 5 \, \mathrm{cm}$) [59]. Along with an on-body repeater, this range can be further extended.

Here, we demonstrate the improved radiation efficiency of a 434 MHz conformal microstrip antenna and a method of achieving it. An antenna fitting within a 17 mm × Ø7 mm is suitable for a wide range of in-body capsule applications. Its ultra-miniature dimensions, enhanced robustness, and efficiency (compared to counterparts) allow one to employ it for both implantable and ingestible applications (such as, e.g., BodyCAP e-Celsius – intracorporeal temperature telemetry capsule [77]).

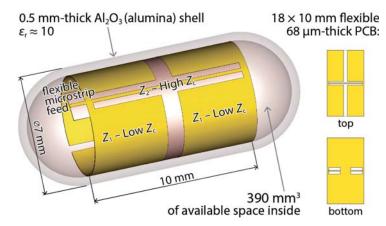


Figure 2. A conformal microstrip in-body antenna inside a 17 mm \times \emptyset 7 mm biocompatible capsule.

4.1 Antenna Miniaturization and Synthesis

Fitting a 434 MHz antenna ($\lambda/2 \approx 34$ cm) within the 17 mm× \varnothing 7 mm capsule (Figure 2) required miniaturization. A stepped-impedance resonator (SIR) technique [78] showed good performance in terms of miniaturization of microstrip in-body antennas [28, 63]. We used a $\lambda/2$ stepped-impedance resonator with two impedance steps – low Z-to-high Z and high Z-to-low Z – in order to reduce the antenna's size and to match the antenna's input impedance to $Z_{ANT} = 50~\Omega$.

A $\lambda/2$ stepped-impedance resonator antenna could be synthesized using the transmission-line impedance equation [79, p. 59] for the three-section transmission line with identical first and third elements (Figure 3a):

$$Z_1 \left[Z_1 \tan(\beta_2 l_2) + 2Z_2 \tan(\beta_1 l_1) \right]$$

$$-Z_2^2 \tan^2(\beta_1 l_1) \tan(\beta_2 l_2) = 0, \qquad (1)$$

where Z_n is the characteristic impedance of each section $[\Omega]$, β_n is the phase constant (rad/m), and l_n is the section length [m], with n=1,2. The phase constant, β_n , is defined as

$$\beta_n = \frac{2\pi}{c} f_{res} \sqrt{\varepsilon_{r_n}^{eff}} , \quad n = 1, 2 , \qquad (2)$$

where $c \approx 3 \times 10^8 \text{ ms}^{-1}$ is the speed of light in vacuum and $\varepsilon_{r_n}^{eff}$ is the effective relative permittivity of the transmission-line environment. The effective relative permittivity, $\varepsilon_{r_n}^{eff}$, is defined as the relative permittivity of a homogeneous medium that equivalently replaces the heterogeneous medium [79, p. 148].

Equation (1) relates the high Z_1 and low Z_2 line geometries and EM properties of the environment to a resonant frequency f_{res} (when $\mathrm{Im}(Z_{ANT}) = 0$).

The characteristic impedance of a generic TEM transmission line with negligible losses is given by

$$Z_c = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \approx \sqrt{\frac{L}{C}},$$
 (3)

where L is the specific (i.e., per unit length) inductance (Hm^{-1}) and C is the specific capacitance (Fm^{-1}). C and L may be represented through the phase velocity, v_p [80, p. 457]:

$$v_p = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{\mu^{eff} \varepsilon^{eff}}}, \tag{4}$$

$$\sqrt{L} = \frac{1}{v_p \sqrt{C}} = \sqrt{\frac{\mu^{eff} \varepsilon^{eff}}{C}} \; .$$

Substituting Equation (4) into Equation (3) gives the following expression for the characteristic impedance:

$$Z_c = \frac{\sqrt{\mu_r^{eff} \varepsilon_r^{eff}}}{cC} \,. \tag{5}$$

As neither the capsule environment nor the biological tissues exhibit ferromagnetic properties, we can assume that $\mu_{r_n}^{eff} = 1$. One can therefore evaluate the specific capacitance, C, as

$$C = \frac{2W_e}{V^2},\tag{6}$$

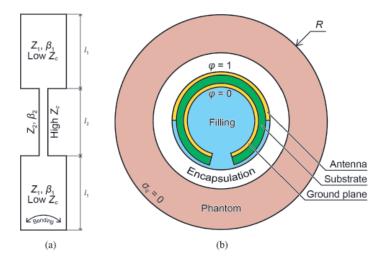


Figure 3. The theoretical model of the antenna: (a) an *H*-type half-wave microstrip stepped impedance resonator, (b) the two-dimensional cross section (not to scale) of the folded antenna inside a capsule within a circular phantom of radius *R*.

where W_e is the total electrical energy stored in the system [J], and V stands for the electrical potential difference [V].

The closed-form solution of Equation (6) is possible only for the simple cases. A numerical solution is required for the given geometry cross section (Figure 3b). The governing partial differential equation (PDE) can be written as $-\nabla \cdot (\delta \nabla \varphi) = \rho$, where ϕ is the sought-for electrostatic potential, and ρ is the charge density. The boundary conditions were defined as the following (Figure 3b): $\phi = 1$ on the cross-section perimeter of the antenna, $\phi = 0$ on the ground plane, and the zero-charge (Neumann) condition was imposed on the outer boundaries of the studied domain as $e\partial \varphi/\partial n_0 = 0$. The study domain of radius e0 circumscribed the cross section of the structure (Figure 3b). The radius e1 had to be large enough (e2 cm in our case) in order to accurately estimate the specific capacitance, e3.

We used the in-house software Agros2D [81] to analyze the formulated problem with the fully hp-adaptive finite-element electrostatic formulation of Equation (6). The automatic hp-adaptivity was set up to maintain the relative error $\Delta C/C \le 1\%$. Curvilinear elements were used to accurately represent the circular geometry of the model (Figure 3b).

With this synthesis methodology, the following was necessary to make the most of the design in terms of the radiation efficiency:

- 1. maximizing the electrical size of the antenna, *ka*, by using the entire cylindrical surface of the capsule;
- 2. further increasing *ka* by loading the antenna with high permittivity and low loss materials;
- 3. avoiding meandering the high Z_1 section, therefore preventing the oppositely flowing currents and improving polarization purity;
- 4. decoupling the antenna from tissues (the results in a narrower bandwidth, as $BW \propto ka/\eta$);

5. averting the impedance detuning due to the varying EM properties of tissues by using a high-permittivity superstrate of a sufficient thickness (determined during optimization routine).

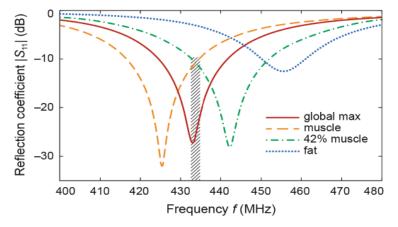
Increasing the substrate thickness of an in-body microstrip antenna results in a higher radiation efficiency, as well [82]. However, the antenna on a thicker substrate occupies more volume inside the capsule. It therefore requires finding a tradeoff between the size and the efficiency. In this study, we used a 50-µm-thick substrate.

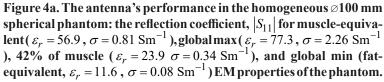
4.2 Materials

The conformal antenna was designed for the 50- μ m Rogers ULTRALAM® 3850HT substrate (liquid crystal polymer, $\varepsilon_r = 2.9$, $\tan \delta = 0.022$ at 434 MHz). The plating thickness was 9 μ m. The capsule shell (acts as the antenna superstrate) was made of Al₂O₃ (alumina, $\varepsilon_r = 10$, $\tan \delta = 10^{-4}$ at 434 MHz) that was biocompatible, inexpensive, and widely available. The shell was 0.5-mm thick, the outer capsule diameter was $\varnothing 7$ mm (Figure 2). The capsule with was filled with pure water ($\varepsilon_r = 78.4$ $\tan \delta = 0.022$ at 434 MHz) to further enhance the dielectric loading of the antenna. However, for the industrial implementation, solid high-permittivity (and low-loss) materials may be preferred: for instance, a ceramic-powder-loaded polymer [83] or epoxy [84].

5. Numerical Design and Optimization

We used CST *Microwave Studio*® 2016 [45] to model and optimize the antenna. At first, a planar antenna approximation was solved and fine-tuned (in terms of impedance) using the CST time-domain solver (finite integration technique), then validated using the frequency-domain solver (Finite-Element Method (FEM)). Both methods used an automatic adaptive-mesh refinement with





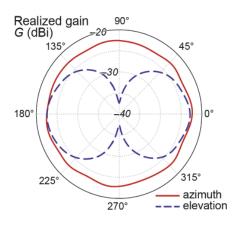


Figure 4b. The antenna's performance in the homogeneous Ø100 mm spherical phantom: the simulated radiation pattern for muscle-equivalent EM properties of the phantom.

 $\Delta[|S_{11}(f_{res})|]$ < 1% error tolerance for three consecutive iterations as a convergence criterion. The time-domain models used hardware acceleration (two NVIDIA Tesla K20c GPUs) that significantly reduced the simulation time and, therefore, the fine-tuning routine. The optimized parameters of the planar antenna initialized the conformal antenna analysis and the tuning in a spherical phantom using the FEM solver. The automatic adaptive-mesh refinement settings were set as for the time-domain solver.

The final (conformal) antenna was analyzed and fine-tuned centered inside a $\varnothing 100$ mm spherical homogeneous phantom (as in [59]) with EM properties varying from fat (global min, $\varepsilon_r = 11.6$, $\sigma = 0.08~{\rm Sm}^{-1}$) to global max ($\varepsilon_r = 77.3$, $\sigma = 2.26~{\rm Sm}^{-1}$) in order to assess the robustness (both tissue EM properties at 434 MHz according to Gabriel et al. [52-54]). A spherical phantom allows accurate estimation of the radiation performance of antennas with undefined position in a body (such as, e.g., an ingestible) as the spherical shape keeps the intrinsic radiation pattern of the antenna. Cuboid and cylindrical shapes may mislead regarding the antenna's performance in terms of directivity.

However, this method does not provide an accurate estimate of the antenna's radiation performance for realistic in-body scenarios. For this purpose, we used an anatomically realistic phantom, "Nelly," implemented in CST *Microwave Studio*® (optimized for a tetrahedral mesh).

5.1 Antenna Performance

To maximize the robustness, we tuned the antenna to resonate below the mid-ISM band, so that $|S_{11}| = -10$ dB at 434.79 MHz (the upper bound of the 434 MHz mid-ISM band, Figure 4a) in the phantom with global max EM properties ($\varepsilon_r = 77.3$, $\sigma = 2.26$ Sm⁻¹). The

antenna remained well matched (i.e., $|S_{11}| < -10 \, \mathrm{dB}$) for up to 42% of muscle EM properties ($\varepsilon_r = 23.9$, $\sigma = 0.34 \, \mathrm{Sm}^{-1}$, Figure 4a). This range ($\varepsilon_r \in [23.9, 77.3]$ $\sigma \in [0.34, 2.26] \, \mathrm{Sm}^{-1}$) covered the majority of biological tissues except fat and bones [52-54]. In fat, the antenna matching was $|S_{11}| = -3.2 \, \mathrm{dB}$ at f_0 ; however, $f_{res} = 456 \, \mathrm{MHz}$. Therefore, $|S_{11}| < -10 \, \mathrm{dB}$ in fat (as well as in bones) could be achieved using a matching circuit. The bandwidth was 17 MHz, which was substantially narrower than that of the counterparts, indicating better decoupling of the antenna from lossy tissues. In addition, this bandwidth was sufficient for robust operation of the antenna with 50 Ω feeds in the majority of biological tissues.

Figure 4b shows the radiation pattern of the antenna at 434 MHz inside the $\emptyset 100$ mm spherical phantom with muscle-equivalent EM properties. The radiation pattern was dipole-like, which was consistent with the electrically small antenna fundamental limitations on directivity. The realized gain was $G = -22.4\,\mathrm{dBi}$, and the radiation efficiency reached $\eta = 0.4\%$. The radiation performance of the antenna in realistic phantoms (implantation in fat, stomach, colon, and head have been studied), its robustness to circuitry, and the link-budget evaluations were given in [59]. The antenna transmitted for up to 14 m for all studied implantation sites (except in fat, where in the worst case – the direction of the radiation minimum, $\min[G]$ – the signal-to-noise ratio, SNR, > 0 held up to 7 m).

6. Experimental Characterization

Despite the existence of reliable methods for impedance measurements, the radiation characterization of both electrically and physically small antennas remains challenging. The antenna under test (AuT) couples strongly to a feeding cable that leads to impaired measured data [85]. Currents induced on the cable affect

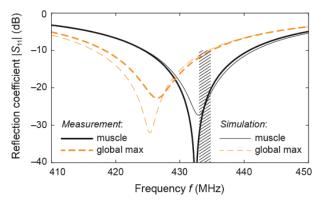


Figure 5a. The antenna's experimental reflection coefficient, $|S_{11}|$, in liquid phantoms with muscle-equivalent, global max, and average GI EM properties.

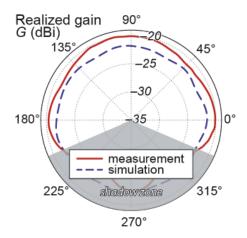


Figure 5c. The experimental far-field characterization: the measured co-polarized radiation pattern of the antenna under test contained in a ∞100 mm sphere filled with muscle-equivalent liquid phantom.

both the radiation pattern and the matching, confounding the antenna's radiation with the radiation from the cable. Different approaches allow minimizing this effect: baluns [86], differential-feeding techniques [51], electro-optical converters [87], or measurements using a monostatic scattering characterization of an antenna [88]. For in-body antennas, the problem is more complicated since in addition to these sources of error, the antenna has to be measured in a lossy phantom.

6.1 Prototype Manufacturing and Phantoms

We used the laser ablation technique (LPKF ProtoLaser S) to prototype the antenna on a 50- μ m Rogers ULTRALAM® 3850HT substrate (Figure 11a) with 9- μ m thick copper. The printed antenna was next bent to conform inside a 17 mm × \varnothing 7 mm alumina tube. This was then soldered to a 100 mm 50 Ω coaxial feed terminated

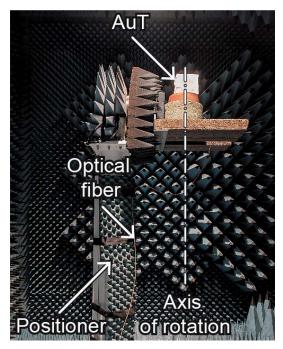


Figure 5b. The experimental far-field characterization: the antenna under test in a phantom mounted on the positioner and fed using an optical fiber.

by an SMA connector. Finally, the capsule was filled with de-ionized water and sealed at both ends. To insulate (with air) the cable from the phantoms, we fitted a $\varnothing 10$ mm polyamide tube around the cable, and between the capsule and the SMA connector.

We prepared two liquid phantoms with muscle-equivalent and global-max EM properties to experimentally validate the antenna's performance in terms of impedance, robustness, and radiation. We used a water-sucrose-NaCl recipe to achieve the target EM properties; the concentrations were given in [59]. The EM properties of the phantoms were verified using the SPEAG DAK kit with the DAK-12 probe [89].

6.2 Impedance Characterization

We used an Agilent PNA-X vector network analyzer to measure the antenna's impedance. The reference plane was set at the SMA connector. The cable's effect on the impedance was de-embedded using CST's *Design Studio*. Figure 5a shows the measured reflection coefficients for two liquid phantoms. The experimental results agreed well with the simulations. More-precise manufacturing methods (for instance, photolithography) could further improve the agreement.

6.3 Radiation Performance

To evaluate the radiation performance using the farfield direct-illumination technique (Figure 5b), we used a

Table 1. The designs, capsule sizes, operating frequencies, and radiation performance
in the given phantom of conformal capsule antennas as reported in the literature.

Ref.	Туре	Size [mm]	f ₀ [MHz]	G_{f_0} [d $f Bi$]	Phantom: Tissue, Shape, Size [mm]
This	Microstrip	17 × Ø7	434	-22	Muscle, sphere, ∅100
[63]	Microstrip	17 × Ø7	434	-33	$\varepsilon_r = 49.6$ $\sigma = 0.51, \text{ cyl.}, \emptyset 200$
[65]	Microstrip	24 × Ø10	402	-30	Muscle, cube, 100 ³
[41]	Dipole	26 × Ø11	1400	-26	Muscle, cuboid, $350^2 \times 200$
[43]	Dipole	24 × Ø11	402	-37	Skin, cube, 180 ³
[44]	IFA	25 × Ø11	402	-30	Stomach, anatomical
[49]	Loop	25 × Ø10	402	-25	Mus., ellip. cyl., 180 × 100 × 50
[60]	Slot-loop	25 × Ø10	402	-22	Muscle, cuboid, $60^2 \times 70$

Ø100 mm spherical glass container filled with a muscle-equivalent liquid phantom. The antenna under test was centered inside of the container. An electro-optical converter (enprobe LFA-3 [90]) fed the AuT so that an optical fiber replaced the RF cable inside an anechoic chamber, thus minimizing the main source of signal impairment. The estimation of the realized gain used the gain-substitution technique, employing a reference antenna of known gain (ETS-Lindgren Model 3164-06 [91], 300 MHz to 6 GHz).

Figure 5c shows the antenna's far field. The maximum realized gain was about -20 dBi for co-polarization, and -33 dBi for cross-polarization (X-pol). The far-field pattern was consistent with the simulated pattern except for the backward radiation, which was distorted due to the shadowing effect of the tower positioner (Figure 5b).

7. Conclusion

Enhancing the operating range of biotelemetry devices up to 10 m to 15 m would allow monitoring physiological parameters without affecting the mobility and quality of life of a user. In addition, power-efficient wireless neural interfaces could empower many breakthroughs in medicine and clinical research. Substantial improvement of the range or power efficiency is achievable by combining the approaches reviewed with the radiation-efficiency enhancement of body-implanted antennas.

In particular, conformal microstrip designs showed enhanced radiation performance for in-body applications. As demonstrated by the design, a thin microstrip antenna on a 50 μ m-thick substrate, conforming to a miniature 17 mm \times \varnothing 7 mm capsule, could operate up to 14 m from various in-body sites. The miniature dimensions of the antenna, and its enhanced robustness and efficiency (compared to counterparts, Table 1) would allow one to employ it for both implantable and ingestible applications.

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9. References

- 1. W. Greatbatch and C. F. Holmes, "History of Implantable Devices," *IEEE Engineering in Medicine and Biology Magazine*, **10**, 3, September 1991, pp. 38-41.
- 2. R. P. Feynman, "There's Plenty of Room at the Bottom," *Engineering and Science*, **23**, 5, February 1960, pp. 22-36.
- 3. V. K. Zworykin and J. T. Farrar, "A 'Radio Pill," *Nature*, **179**, 4566, 1957, p. 898.
- 4. R. S. Mackay and B. Jacobson, "Endoradiosonde," *Nature*, **179**, 4572, June 1957, pp. 1239-1240.
- 5. J. T. Farrar, V. K. Zworykin, and J. Baum, "Pressure-Sensitive Telemetering Capsule for Study of Gastrointestinal Motility," *Science*, **126**, 3280, November 1957, pp. 975-976.
- 6. J. O. Sines, "Permanent Implants for Heart Rate and Body Temperature Recording in the Rat," *AMA Archives of General Psychiatry*, **2**, 2, February 1960, pp. 182-183.
- 7. M. Herbert, "Pill-Type Swallowable Transmitter," US3144017 A, August 11, 1964.

- 8. B. W. Watson, S. J. Meldrum, H. C. Riddle, R. L. Brown, and G. E. Sladen, "pH Profile of Gut as Measured by Radiotelemetry Capsule," *British Medical Journal*, **2**, 5805, April 1972, pp. 104-106.
- 9. E. Y. Chow, M. M. Morris, and P. P. Irazoqui, "Implantable RF Medical Devices: The Benefits of High-Speed Communication and Much Greater Communication Distances in Biomedical Applications," *IEEE Microwave Magazine*, **14**, 4, June 2013, pp. 64-73.
- D. Nikolayev, M. Zhadobov, R. Sauleau, and P. Karban, "Antennas for Ingestible Capsule Telemetry," in Advances in Body-Centric Wireless Communication: Applications and State-of-the-Art, London, UK, IET, 2016, pp. 143-186.
- 11. K. S. Nikita, *Handbook of Biomedical Telemetry*, Hoboken, NJ, John Wiley & Sons, 2014.
- 12. R. Bashirullah, "Wireless Implants," *IEEE Microwave Magazine*, **11**, 7, December 2010, pp. 14-23.
- 13. M. R. Basar, F. Malek, K. M. Juni, M. S. Idris, and M. I. M. Saleh, "Ingestible Wireless Capsule Technology: A Review of Development and Future Indication," *International Journal of Antennas and Propagation*, 2012, December 2012, p. e807165.
- 14. A. Kiourti and K. S. Nikita, "A Review of In-Body Biotelemetry Devices: Implantables, Ingestibles, and Injectables," *IEEE Transactions on Biomedical Engi*neering, 64, 7, July 2017, pp. 1422-1430.
- G. Iddan, G. Meron, A. Glukhovsky, and P. Swain, "Wireless Capsule Endoscopy," *Nature*, 405, 6785, May 2000, pp. 417-417.
- 16. K. Yamasue, H. Hagiwara, O. Tochikubo, C. Sugimoto, and R. Kohno, "Measurement of Core Body Temperature by an Ingestible Capsule Sensor and Evaluation of its Wireless Communication Performance," *Advanced Biomedical Engineering*, 1, 2012, pp. 9-15.
- 17. E. Y. Chow, A. L. Chlebowski, S. Chakraborty, W. J. Chappell, and P. P. Irazoqui, "Fully Wireless Implantable Cardiovascular Pressure Monitor Integrated With a Medical Stent," *IEEE Transactions on Biomedical Engineering*, 57, 6, June 2010, pp. 1487-1496.
- Given Imaging, "Bravo pH," available: http://www. givenimaging.com/en-int/Innovative-Solutions/Reflux-Monitoring/Bravo-pH/.
- 19. M. C. Shults, R. K. Rhodes, S. J. Updike, B. J. Gilligan, and W. N. Reining, "A Telemetry-Instrumentation System for Monitoring Multiple Subcutaneously Implanted Glucose Sensors," *IEEE Transactions on Biomedical Engineering*, 41, 10, October 1994, pp. 937-942.

- L. Song and Y. Rahmat-Samii, "An End-to-end Implanted Brain-Machine Interface Antenna System Performance Characterizations and Development," *IEEE Transactions on Antennas and Propagation*, 65, 7, July 2017, pp. 3399-3408.
- 21. S. Y. Lee, Y. C. Su, and C. J. Cheng, "A Near-field Telemetry Device with Close-loop Endocardial Stimulation for a Pacemaker," 2010 International Symposium on Next Generation Electronics, 2010, pp. 1-4.
- 22. F. Munoz, G. Alici, and W. Li, "A Review of Drug Delivery Systems for Capsule Endoscopy," *Advanced Drug Delivery Reviews*, **71**, 2013, pp. 77-85.
- G. Baronzio, G. Parmar, M. Ballerini, A. Szasz, M. Baronzio, and V. Cassutti, "A Brief Overview of Hyperthermia in Cancer Treatment," *Journal of Integrative Oncology*, 3, 1, 2014, pp. 1-10.
- 24. M. R. Yuce and T. Dissanayake, "Easy-to-swallow Wireless Telemetry," *IEEE Microwave Magazine*, **13**, 6, September 2012, pp. 90-101.
- 25. A. Yakovlev, S. Kim, and A. Poon, "Implantable Biomedical Devices: Wireless Powering and Communication," *IEEE Communications Magazine*, **50**, 4, April 2012, pp. 152-159.
- 26. C. H. Hyoung et al., "Human Body Communication System and Method," US20100274083 A1, October 28, 2010.
- 27. J. S. Ho, S. Kim, and A. S. Y. Poon, "Midfield Wireless Powering for Implantable Systems," *Proceedings of the IEEE*, **101**, 6, June 2013, pp. 1369-1378.
- 28. D. Nikolayev, M. Zhadobov, P. Karban, and R. Sauleau, "Increasing the Radiation Efficiency and Matching Stability of In-body Capsule Antennas," 10th European Conference on Antennas and Propagation (EuCAP 2016), Davos, Switzerland, 2016.
- 29. D. Sinha and G. A. J. Amaratunga, "Electromagnetic Radiation Under Explicit Symmetry Breaking," *Physical Review Letters*, **114**, 14, p. 147701, Apr. 2015.
- 30. A. Kiourti and K. S. Nikita, "Recent Advances in Implantable Antennas for Medical Telemetry," *IEEE Antennas and Propagation Magazine*, **54**, 6, December 2012, pp. 190-199.
- 31. S.-I. Kwak, K. Chang, and Y.-J. Yoon, "The Helical Antenna for the Capsule Endoscope," 2005 IEEE Antennas and Propagation Society International Symposium, Washington, DC, 2005, **2B**, pp. 804-807.
- 32. S.-H. Lee et al., "A Wideband Spiral Antenna for Ingestible Capsule Endoscope Systems: Experimental

- Results in a Human Phantom and a Pig," *IEEE Transactions on Biomedical Engineering*, **58**, 6, June 2011, pp. 1734-1741.
- 33. S.-H. Lee, K. Chang, K. J. Kim, and Y.-J. Yoon, "A Conical Spiral Antenna for Wideband Capsule Endoscope System," IEEE Antennas and Propagation Society International Symposium, 2008, San Diego, CA, 2008, pp. 1-4.
- 34. J. Faerber and M. P. Y. Desmulliez, "Conformal Meander Shaped Antenna for Biotelemetry in Endoscopic Capsules," 2015 Loughborough Antennas Propagation Conference (LAPC), 2015, pp. 1
- 35. F. Merli, L. Bolomey, J. Zurcher, G. Corradini, E. Meurville, and A. K. Skrivervik, "Design, Realization and Measurements of a Miniature Antenna for Implantable Wireless Communication Systems," *IEEE Transactions on Antennas and Propagation*, 59, 10, October 2011, pp. 3544-3555.
- 36. C. Liu, Y.-X. Guo, and S. Xiao, "Circularly Polarized Helical Antenna for ISM-Band Ingestible Capsule Endoscope Systems," *IEEE Transactions on Antennas and Propagation*, 62, 12, December 2014, pp. 6027-6039.
- 37. T. Dissanayake, K. P. Esselle, and M. R. Yuce, "Dielectric Loaded Impedance Matching for Wideband Implanted Antennas," *IEEE Transactions on Microwave Theory* and Techniques, 57, 10, October 2009, pp. 2480-2487.
- 38. A. Kiourti, J. R. Costa, C. A. Fernandes, and K. S. Nikita, "A Broadband Implantable and a Dual-Band On-body Repeater Antenna: Design and Transmission Performance," *IEEE Transactions on Antennas and Propagation*, 62, 6, June 2014, pp. 2899-2908.
- 39. T. Karacolak, A. Z. Hood, and E. Topsakal, "Design of a Dual-band Implantable Antenna and Development of Skin Mimicking Gels for Continuous Glucose Monitoring," *IEEE Transactions on Microwave Theory and Techniques*, 56, 4, April 2008, pp. 1001-1008.
- 40. A. Kiourti and K. S. Nikita, "Miniature Scalp-implantable Antennas for Telemetry in the MICS and ISM Bands: Design Safety Considerations and Link Budget Analysis," *IEEE Transactions on Antennas and Propagation*, 60, 8, August 2012, pp. 3568-3575.
- 41. P. M. Izdebski, H. Rajagopalan, and Y. Rahmat-Samii, "Conformal Ingestible Capsule Antenna: a Novel Chandelier Meandered Design," *IEEE Transactions on Anten*nas and Propagation, 57, 4, April 2009, pp. 900-909.
- 42. H. Rajagopalan and Y. Rahmat-Samii, "Wireless Medical Telemetry Characterization for Ingestible Capsule Antenna Designs," *IEEE Antennas and Wireless Propagation Letters*, 11, 2012, pp. 1679-1682.

- 43. L.-J. Xu, Y.-X. Guo, and W. Wu, "Bandwidth Enhancement of an Implantable Antenna," *IEEE Antennas and Wireless Propagation Letters*, **14**, 2015, pp. 1510-1513.
- 44. Z. Bao, Y. X. Guo, and R. Mittra, "Single-Layer Dual-/ Tri-Band Inverted-F Antennas for Conformal Capsule Type of Applications," *IEEE Transactions on Antennas* and Propagation, **PP**, 99, 2017, pp. 1-1.
- 45. Computer Simulation Technology AG, "CST Microwave Studio," available: https://www.cst.com/Products/CSTMWS, [accessed August 6, 2016].
- 46. D. P. Chrissoulidis and J. M. Laheurte, "Radiation from an Encapsulated Hertz Dipole Implanted in a Human Torso Model," *IEEE Transactions on Antennas and Propagation*, 64, 12, December 2016, pp. 4984-4992.
- 47. R. Alrawashdeh, Y. Huang, and A. A. B. Sajak, "A Flexible Loop Antenna for Biomedical Bone Implants," The 8th European Conference on Antennas and Propagation (EuCAP2014), Hague, Netherlands, 2014, pp. 999-1002.
- 48. R. Alrawashdeh, Y. Huang, and P. Cao, "A Flexible Loop Antenna for Total Knee Replacement Implants in the MedRadio Band," Antennas and Propagation Conference (LAPC), 2013 Loughborough, 2013, pp. 225-228.
- 49. R. S. Alrawashdeh, Y. Huang, M. Kod, and A. A. B. Sajak, "ABroadband Flexible Implantable Loop Antenna with Complementary Split Ring Resonators," *IEEE Antennas and Wireless Propagation Letters*, **14**, 2015, pp. 1506-1509.
- 50. S. Yun, K. Kim, and S. Nam, "Outer-Wall Loop Antenna for Ultrawideband Capsule Endoscope System," *IEEE Antennas and Wireless Propagation Letters*, 9, 2010, pp. 1135-1138.
- 51. M. M. Suzan, K. Haneda, C. Icheln, A. Khatun, and K. Takizawa, "An Ultrawideband Conformal Loop Antenna for Ingestible Capsule Endoscope System," 10th European Conference on Antennas and Propagation (EuCAP 2016), Davos, Switzerland, 2016, pp. 1-5.
- 52. C. Gabriel, S. Gabriel, and E. Corthout, "The Dielectric Properties of Biological Tissues: I. Literature Survey," *Physics in Medicine and Biology*, 41, November 1996, pp. 2231-2249.
- 53. S. Gabriel, R. W. Lau, and C. Gabriel, "The Dielectric Properties of Biological Tissues: II. Measurements in the Frequency Range 10 Hz to 20 GHz," *Physics in Medicine and Biology*, 41, November 1996, pp. 2251-2269.
- 54. S. Gabriel, R. W. Lau, and C. Gabriel, "The Dielectric Properties of Biological Tissues: III. Parametric Models for the Dielectric Spectrum of Tissues," *Physics in Medicine and Biology*, 41, November 1996, pp. 2271-2293.

- 55. R. Alrawashdeh, Y. Huang, and P. Cao, "A Conformal U-shaped Loop Antenna for Biomedical Applications," 7th European Conference on Antennas and Propagation (EuCAP2013), Gothenburg, Sweden, 2013, pp. 157-160.
- 56. A. Karlsson, "Physical Limitations of Antennas in a Lossy Medium," *IEEE Transactions on Antennas and Propagation*, **52**, 8, August 2004, pp. 2027-2033.
- 57. J. S. McLean, "A Re-examination of the Fundamental Limits on the Radiation Q of Electrically Small Antennas," *IEEE Transactions on Antennas and Propagation*, 44, 5, May 1996, pp. 672-676.
- 58. S. R. Best, "Bandwidth and the Lower Bound on Q for Small Wideband Antennas," IEEE Antennas and Propagation Society International Symposium 2006, Albuquerque, NM USA, 2006, pp. 647-650.
- 59. D. Nikolayev, M. Zhadobov, L. Le Coq, P. Karban, and R. Sauleau, "Robust Ultra-miniature Capsule Antenna for Ingestible and Implantable Applications," *IEEE Transactions on Antennas and Propagation*, 65, 11, November 2017, pp. 6107-6119.
- 60. Z. Bao, Y. X. Guo, and R. Mittra, "An Ultra-Wideband Conformal Capsule Antenna with Stable Impedance Matching," *IEEE Transactions on Antennas and Propagation*, 65, 10, October 2017, pp. 5086-5094.
- 61. D. Nikolayev, M. Zhadobov, R. Sauleau, P.-A. Chapon, E. Blond, and P. Karban, "Decreasing SAR and Enhancing Transmission of an In-body Biotelemetry Capsule by Reducing the Near-field Coupling with Surrounding Tissues," BioEM 2015, Monterey, CA, 2015, pp. 465-468.
- R. Garg, P. Bhartia, I. Bahl, and A. Ittipiboon, *Microstrip Antenna Design Handbook*, Norwood, MA, Artech House, 2001.
- 63. Y. Mahe, A. Chousseaud, M. Brunet, and B. Froppier, "New Flexible Medical Compact Antenna: Design and Analysis," *International Journal of Antennas and Propagation*, **2012**, May 2012.
- 64. Y. Mahe, A. Chousseaud, and M. Brunet, "New Design of an Ultra Compact Printed-Circuit Antenna," *Micro*wave and Optical Technology Letters, 54, 8, 2012, pp. 1783-1785.
- 65. K. A. Psathas, A. Kiourti, and K. S. Nikita, "A Novel Conformal Antenna for Ingestible Capsule Endoscopy in the MedRadio Band," 34th Progress in Electromagnetics Research Symposium (PIERS 2013), Stockholm, Sweden, 2013.
- J. Volakis, C.-C. Chen, and K. Fujimoto, Small Antennas: Miniaturization Techniques & Applications, New York, McGraw Hill Professional, 2010.

- 67. A. S. Y. Poon, S. O'Driscoll, and T. H. Meng, "Optimal Frequency for Wireless Power Transmission into Dispersive Tissue," *IEEE Transactions on Antennas and Propagation*, **58**, 5, May 2010, pp. 1739-1750.
- 68. L. Xu, M. Q.-H. Meng, H. Ren, and Y. Chan, "Radiation Characteristics of Ingestible Wireless Devices in Human Intestine Following Radio Frequency Exposure at 430, 800, 1200, and 2400 MHz," *IEEE Transactions on Antennas and Propagation*, 57, 8, August 2009, pp. 2418-2428.
- 69. L. C. Chirwa, P. A. Hammond, S. Roy, and D. R. S. Cumming, "Electromagnetic Radiation from Ingested Sources in the Human Intestine Between 150 MHz and 1.2 GHz," *IEEE Transactions on Biomedical Engineering*, **50**, 4, April 2003, pp. 484-492.
- 70. A. K. Skrivervik, M. Bosiljevac, and Z. Sipus, "Propagation Considerations for Implantable Antennas," 11th European Conference on Antennas and Propagation (EuCAP 2017), Paris, France, 2017.
- 71. "Medical Device Radiocommunications Service (MedRadio)," Federal Communications Commission (FCC), available: https://www.fcc.gov/medical-device-radiocommunications-service-medradio, [accessed October 16, 2017].
- 72. "ITU Radio Regulations (article 5), footnotes 5.138, 5.150, and 5.280," International Telecommunication Union (ITU), available: http://www.itu.int/net/ITU-R/terrestrial/faq/index.html#g013. [accessed: October 16, 2017].
- 73. "Wireless Medical Telemetry Service (WMTS)," Federal Communications Commission (FCC), available: https://www.fcc.gov/wireless/bureau-divisions/broadband-division/wireless-medical-telemetry-service-wmts, [accessed: October 16, 2017].
- 74. D. Nikolayev, M. Zhadobov, P. Karban, and R. Sauleau, "Long-range Antenna Systems for In-Body Biotelemetry: Design Methodology and Characterization Approach," EMBEC & NBC 2017, Tampere, Finland: Springer, Singapore, 2017, pp. 233-236.
- 75. F. Merli, B. Fuchs, J. R. Mosig, and A. K. Skrivervik, "The Effect of Insulating Layers on the Performance of Implanted Antennas," *IEEE Transactions on Antennas and Propagation*, **59**, 1, January 2011, pp. 21-31.
- 76. A. K. Skrivervik, "Implantable Antennas: The Challenge of Efficiency," 7th European Conference on Antennas and Propagation (EuCAP 2013), Gothenburg, Sweden, 2013, pp. 3627-3631.
- 77. BodyCap Medical, "e-Celsius," available: http://www.bodycap-medical.com/.

- 78. M. Sagawa, M. Makimoto, and S. Yamashita, "Geometrical Structures and Fundamental Characteristics of Microwave Stepped-impedance Resonators," *IEEE Transactions on Microwave Theory and Techniques*, 45, 7, July 1997, pp. 1078-1085.
- D. M. Pozar, *Microwave Engineering, Fourth Edition*, Hoboken, NJ, Wiley, 2012.
- 80. C. A. Balanis, *Antenna Theory: Analysis and Design, Third Edition*, Hoboken, NJ, John Wiley & Sons, 2005.
- D. Nikolayev, Z. Kubík, P. Karban, and J. Skála, "Impedance Analysis of Transmission Line Cells for EMC Applications using Agros2D," *Applied Mathematics and Computation*, 289, 2016, pp. 381-387.
- D. Nikolayev, "Miniature Antennas for Biomedical Applications," PhD Dissertation, University of Rennes 1, Rennes, France, 2017.
- 83. S. Koulouridis, G. Kiziltas, Y. Zhou, D. J. Hansford, and J. L. Volakis, "Polymer-Ceramic Composites for Microwave Applications: Fabrication and Performance Assessment," *IEEE Transactions on Microwave Theory* and Techniques, 54, 12, December 2006, pp. 4202-4208.
- 84. S. Lee, J. G. Hyun, H. Kim, and K. W. Paik, "A study on Dielectric Constants of Epoxy/SrTiO3 Composite for Embedded Capacitor Films (ECFs)," *IEEE Transactions on Advanced Packaging*, **30**, 3, August 2007, pp. 428-433.

- 85. L. Huitema, C. Delaveaud, and R. D'Errico, "Impedance and Radiation Measurement Methodology for Ultra miniature Antennas," *IEEE Transactions on Antennas and Propagation*, **62**, 7, July 2014, pp. 3463-3473.
- 86. S. Pivnenko, J. Zhang, A. Khatun, T. Laitinen, and J. Carlsson, "Characterization of Small Antennas for Hearing Aids by Several Measurement Techniques," Proceedings of the Fourth European Conference on Antennas and Propagation, Barcelona, Spain, 2010, pp. 1-5.
- 87. T. H. Loh, D. Cheadle, and L. Rosenfeld, "Radiation Pattern Measurement of a Low-profile Wearable Antenna Using an Optical Fibre and a Solid Anthropomorphic Phantom," *Electronics*, **3**, 3, August 2014, pp. 462-473.
- 88. W. Wiesbeck and E. Heidrich, "Wide-band Multiport Antenna Characterization by Polarimetric RCS Measurements," *IEEE Transactions on Antennas and Propagation*, **46**, 3, March 1998, pp. 341-350.
- 89. Schmid & Partner Engineering AG, "Dielectric Assessment Kit," available: http://www.speag.com/products/dak/dielectric-measurements/, [accessed: August 6, 2016].
- enprobe GmbH, "LFA-3 Analog Fiber Optic Link," available: http://www.enprobe.de/products_FO-Links. htm, [accessed: July 2, 2016].
- 91. ETS-Lindgren, "3164-06 Open Boundary Quad-ridged Horn," available: http://www.ets-lindgren.com/3164-06, [accessed: July 14, 2016].

In Memoriam: Jean Van Bladel

It is a privilege for me to pay tribute to Jean Van Bladel, my predecessor as Secretary General, who had a lasting impact on URSI, on science, the scientific community and engineering education and students for over more than half a century.

When in 1968 Professor Jean Van Bladel asked me whether I would join him as an assistant and PhD student, I could not imagine that this would turn out to be a defining moment in my professional life. Having worked closely with Jean Van Bladel at the university, in the framework of the International Union of Radio Science (URSI), and also in the Royal Belgian Academy of Science and Arts,

I am very well aware that it is completely impossible to enumerate here all his achievements and awards. So allow me to limit myself to highlight the main points.

After working as an associate professor and full professor at Washington University, St. Louis and the University of Wisconsin, Madison in the USA, Jean Van Bladel returned to Belgium to found, as a full professor, the Laboratory of Electromagnetism and Acoustics at Ghent university. Until his retirement in 1987 he was the driving force behind the growth and the scientific successes of his department. In addition, between 1976 and 1978, Jean Van Bladel served as Dean of the Faculty of Applied Science of the University and, from 1981 until his retirement as professor emeritus in 1987, he was a member of the University Board.

In 1984 Jean Van Bladel was elected as Secretary General of URSI, the International Union of Radioscience. During 10 years until I succeeded him in 1994 he devoted significant time and energy to the reorganization and revitalization of URSI. In recognition of his tireless efforts and tactful diplomacy in tricky international situations he was awarded the title of Honorary President of this International Union of Radioscience.

In 1984 he was elected a member of the Royal Belgian Academy of Science and Arts. Among his contributions to



the Academy let me just mention that from 1990 on he served as the delegate of the Belgian Academies to ICSU, the International Council for Science, and in 1995 he was elected president of the Royal Belgian Academy.

Over his distinguished scientific career Jean Van Bladel received many prestigious awards such as Heinrich Hertz Medal and the Antennas and Propagation Society's 1997 Distinguished Achievement Award from the IEEE, an Honorary Doctor's Degree from the University of Liège and both in 1978 and 1984 he was awarded the Francqui Chair at the Free University of Brussels. A complete list of his noteworthy

professional service and other honors and awards is too lengthy to delineate here, but let me simply say that it is truly impressive by all international standards.

However I have to mention the vast and outstanding contributions of Jean Van Bladel to science in general and to electromagnetic theory and applications in particular. His books and numerous papers in scientific journals have been important resources to researchers and teachers alike, and they will stand the test of time. Over a long and distinguished career, which lasted for over 60 years, he has exhibited a rare depth of understanding and originality and he, therefore, commands the respect of everyone in the electromagnetics community. Through his scientific contributions and the gratitude of the many students and scientists he advised, helped and inspired his memory will live on for many years to come.

For me personally Jean Van Bladel was a teacher and a mentor who I admired very much. He was in the true, profound sense of the word a gentleman, a man of integrity, a man of culture, gentle and trustworthy, a man for whom duty and honor were all important.

Professor Paul Lagasse Honorary President of URSI

In Memoriam: Karl Rawer

t is with sadness that we report the passing of Prof. Karl Rawer at his home in March, Germany, two days before his 105th birthday. He died peaceful during his afternoon nap, with the book that he was reading on his lap. Prof. Rawer was one of the pioneers of the exploration of the ionosphere from the ground and from space, and in the understanding ofradiowavepropagation in the ionospheric medium. He leaves a



rich legacy and a large body of work in ionospheric and atmospheric physics, including his book, *Die Ionosphäre*, published in 1952 and translated into many languages. He received many honors. He was the Director of the Frauenhofer Institute for Space Research in Freiburg, Germany, and the project scientist of the first German-US Aeronomy Satellites, AEROS-A and AEROS-B.

Karl Rawer was born on April 19, 1913, in Neunkirchen, Germany. He studied mathematics and physics under Gustav Mie and Gustav Dötsch in Freiburg, and under Arnold Sommerfeld and Jonathan Zenneck in München. In his dissertation in 1939, he used hyperbolic and Epstein functions to solve, for the first time, the problem of radiowave propagation in a stratified medium. From there on, he was hooked on ionospheric research. During World War II, he was charged with developing ionospheric predictions in support of HF communications, working with Johannes Plendl and Walter Dieminger. After the war, he was invited to establish an ionospheric-prediction service in what was then Germany's "French Zone." He developed close ties with his French counterparts, and was the first German after the war to be invited to lecture at the Sorbonne University (prof. associé 1958-1960, and prof. d'échange 1961-1964). After first working under the auspices of the French Service Prévision lonosphérique de la Marine (SPIM), Rawer in 1956 established the "Ionosphäreninstitut" in Breisach, Germany, and served as its director from 1956 to 1969. This institute gained international reputation in the field of ionospheric radio wave propagation and forecasting; the development of ionosondes in cooperation with research organizations in the USA and France; and joint measuring campaigns in

Italy, Greece, Norway, and Africa. Throughout his career, Prof. Rawer was a strong proponent of international science cooperation, recognizing its potential to build bridges after the terrible war years and to foster peace. The International Geophysical Year (IGY) 1957/58 was the perfect opportunity. Representing Germany, he participated in many of the activities. Together with Roy Piggott in the UK, he published the

Handbookfor the Scaling of Ionograms, a precious reference book that is a must at every ionosonde station worldwide. In 1966, Rawer was elected Vice Chair of Commission G of the International Union of Radio Science (URSI), and served as Vice Chair and then Chair until 1972. At the 2017 URSI GASS in Montreal, the first Karl Rawer Gold Medal was awarded, a medal in honor of the work and life of Prof. Karl Rawer.

A new chapter in Prof. Rawer's scientific career began with the first successful launch of the newly developed French "Veronique" rocket from Hammaguir (Algeria) in the Sahara Desert in 1954. With scientific payloads developed under his leadership, ionospheric conditions were observed in situ along the rocket's trajectory, showing for the first time the steep increase in electron density in the D-region. Many more launches followed, and with his expertise in instrument development and mission management, Rawer played a key role in the German involvement in the beginnings of space exploration. When the Committee on Space Research (COSPAR) was founded in 1958 for the promotion of scientific research at an international level, Rawer actively participated. In 1964, he became the Chair of the German National Committee of COSPAR. He vigorously exploited the opportunity that COSPAR offered to establish long-lasting relationships between scientists from West and East across the cold-war borders, but also with researchers in India and in hitherto neglected countries in the Far East and Africa. With a focus on his new area of interest, Rawer, in cooperation with the Fraunhofer Society, founded the Institute für Physikalische Weltraumforschung (IPW) in Freiburg, and served as its director from 1969 to 1979. Under Rawer's leadership, the IPW became a focal point of space exploration in Germany. It was responsible for Germany's second and third satellites, the AEROnomy Satellites AEROS-A and AEROS-B, which were launched in 1972 and 1974, respectively. The EUV spectrometer, impedance probe, and retarding potential analyzer for these missions were developed and tested in-house. Together with the US Atmosphere Explorer C, D, E satellites, the AEROS-A and -B satellites were some of the first to provide a global view of the ionosphere and upper atmosphere, and led to a much improved understanding of the processes that shape this region of geospace.

Data from the AEROS satellites, together with measurements from the worldwide network of ionosondes, were the foundation for the International Reference Ionosphere (IRI), a project that Prof. Rawer initiated under the auspices of COSPAR and URSI. He chaired the IRI Working Group from 1968 to 1976, and continued his active involvement into the mid-1990s. Under his guidance and leadership, the IRI project took off on a path that has led it to become the recognized international standard for the ionosphere that it is today. As participants of the bi-annual IRI Workshops, we will always remember Rawer's scientific rigor and endurance that kept us on our seats and engaged in spirited discussions until late in the day, and his joy and happiness during the social events with a good glass of wine and dancing late into the evening. The Final Discussion session at the end of the workshop was his trademark, with setting out of goals for improvements of the model and finding volunteers to accomplish these tasks.

Since 1955, Prof. Rawer had been affiliated with the Albert-Ludwigs-Universität of Freiburg, lecturing and advising graduate and doctoral students. Even when extremely busy with his many national and international science projects, he always had an open door and ear for his students, and mentored their careers long past their final exams. His research activities in ionospheric modeling continued after his retirement, with support from the German Research Foundation (DFG) and ESA's European Satellite Operations Center (ESOC). In 1993, he published the book *Wave Propagation in the Ionosphere*.

Rawer's greatest love and pride (and maybe one of the secrets of his longevity) was his large family, with three sons, four daughters, 19 grandchildren, and 31 greatgrandchildren.

On the occasion of Prof. Rawer's 100th birthday, Bodo Reinisch delivered a laudation on Prof. Rawer's life and accomplishments at the German URSI National Committee meeting: *Adv. Radio Sci.*, **12**, 2014, pp. 221-223 (www.adv-radio-sci.net/12/221/2014/).

Bodo Reinisch Lowell Digisonde International E-mail: bodo.reinisch@digisonde.com

> Dieter Bilitza George Mason University E-mail: dbilitza@gmu.edu

In Memoriam: Thomas J. (Tom) Brazil

homas (Tom) Brazil died suddenly on Friday, April 13, 2018. He was Professor Emeritus of Electronic Engineering, University College Dublin (UCD), and the current President of the IEEE Microwave Theory and Techniques Society (IEEE-MTTS). He was a Member of the Royal Irish Academy (RIA) from 2004, serving as its Secretary (2009-2013) and also as Chair of a number of the Academy Committees, including the All-Ireland URSI Committee and the RIA's Communications and Radio Science Committee from 2000 to 2008. He



represented Ireland on the URSI Council and as Ireland's Commission D (Electronics and Photonics) Member for very many years. His copious energy, drive and comprehensive insights also led him to contribute to, and be consulted on, science policy both in Ireland and at a European Union (EU) level. He served on a variety of national and international scientific and engineering committees and review bodies, especially in relation to formulating of the EU billion-euro research programs.

Tom retired as Professor of Electronic Engineering at UCD last September, where his reputation as teacher, mentor, and representative was second to none. He was elected by his fellow academics to the Governing Body of UCD for three five-year terms. He also served as a Member of the Senate of the National University of Ireland (NUI).

His humble demeanor belied the tremendous respect in which he was held by his students, the academic fraternity nationally and internationally, and in particular, the global microwave and millimeter-wave research and academic community, especially the IEEE MTT-S and the European Microwave Association (EUMA). He spent four years as an IEEE Worldwide Distinguished Lecturer in Microwave CAD 1999-2003. He was Chair of a number of major international IEEE conferences in microwave engineering, such as the European Microwave Conference in the UK in 2006, and the European Microwave (EUMW) Integrated Circuits Conference held in London in 2016. In fact, only the week before he died, he was working closely with his EuMW 2018 colleagues at a TPC meeting in Madrid (April 6-8, 2018), where he chaired the Subcommittee on Device Modeling topics. Both IEEE MTT-S and EUMA/ EUMW will be marking his passing in special ways in the coming months.

Thomas Joseph Brazil was born on September 4, 1952, on the Mall in Birr Co. Offaly in Ireland. Birr is renowned as the home of the Earls of Rosse: in Birr Castle, a great Parsons engineering family, especially of steam-engine fame. However, more than steam engines were invented there. Of interest to URSI astronomers is that William Parsons, Third Earl of Rosse, built the "Leviathan of Parsonstown." This was a historic reflecting telescope of 72 in (1.8 m) aperture. It was the largest telescope in the world from 1845 until the construction of the 100 in (2.5 m) Hooker Telescope in 1917. More recently, as is

also well known to URSI astronomers, in 2017, the new LOFAR radio-telescope station IE613, known in Ireland as the I-LOFAR telescope, was constructed and switched on. This westernmost station in the LOFAR network adds considerably to the LOFAR baseline. In 2018, it observed for the first time a billion-year-old red-dwarf flare star called CN Leo, almost 75 trillion kilometers away. Tom was a member of the founding committee of this I-LOFAR telescope, and thoroughly enjoyed his home-to-roots visits to Birr Castle for I-LOFAR planning meetings.

Tom was the eldest of four children of Elizabeth and Walter Brazil, who was then Area Manager in the Irish train and bus semi-state company. In 1960, the family relocated to Dublin. Tom was a stellar student in his local De La Salle Christian Brothers School. From his school days right through life, he was renowned for his wonderful wit and ability – when the serious talking was over and done with – to draw out the funny side of everything. His daughter Lia's favorite story of his childhood was of his constant interest in how things worked, often manifest in very practical ways – including taking the back off the precious family television, and disassembling his sister's dolls on Boxing Day.

After his father died in 1969, Tom worked closely with his mother to ensure his siblings, Marian, Bernice, and Walter, got the love and practical support they needed to flourish.

Tom topped his Electrical Engineering graduation class in UCD in 1973 – first place, first-class honors at the age of 20,—and was in the first cohort of engineering students to do a PhD in UCD. He did so under the direction of the then newly appointed first UCD Professor of Electronic

Engineering, Prof. John O. (Seán) Scanlan. His topic was circuit and solid-state modeling and analysis of the then novel Impact Avalanche Transit Time (IMPATT) devices. He subsidized his meager postgraduate scholarship each year by giving crash courses in numerical analysis to engineering students. This also gave him his first taste for teaching, which became a love of his life. Together with another postgrad student, they would cover the full year's course, including past-examination questions and solutions, in a continuous 12-hour lecturing stint over a day and one-half to a class of 180 students a few weeks before the exam. After graduating in 1977, he took an engineering position as a Research Scientist in Plessey Research (Caswell) in Northampton, UK, working on microwave subsystem development.

In 1979, he moved into his first academic position at the University of Birmingham. This marked the formal beginning of Tom's emergence as a great educator. He had a very strong instinct to share his knowledge and wisdom, and really was a brilliant teacher. His stint in the University of Birmingham was short, as he returned to Dublin to take up a lectureship in electronic engineering in his alma mater, UCD's Electrical Engineering Department, in January 1980. There, with the close collaboration of Prof. Seán Scanlan, he founded the RF and Microwave Research Group. That group thrives to this day, and has a strong international reputation for fundamental and applied research into radio transmitters and receivers. In particular, Tom and his group made notable research contributions in the field of microwave and millimeter-wave nonlinear high-power amplifiers, and in nonlinearity impairment linearization-mitigating concepts and technology. The fruits of his work today already impact across all radio communications infrastructures, from mobile phones and phone masts to Galileo satellite transmitters. The group also produced some dozens of research graduates, PhDs, and Masters in Engineering, and of course a deep track record of research-journal publications, especially in the IEEE Transactions on Microwave Theory and Techniques. Those of his graduates who stayed in Ireland helped seed a very advanced technology industry here, the envy of many highly developed economies.

While Tom was very modest about his achievements, on his passing, the renowned microwave engineering academic, industrialist, and entrepreneur, Prof. David Rhodes CBE, FRS, FR Eng, said "[he was] one of the brightest and most intelligent microwave engineers of our time."

Tom succeeded Seán Scanlan in the Chair of Electronic Engineering in 2003, and became Head of the School of Electrical and Electronic Engineering for 14 years. He was proactive in charting a steady course for the school through the choppy waters of rapid and radical change, all the while unwavering in his maintenance of sound academic principles. Not for him were the short-lived academic fashions of the day, or allowing these to ever dilute solid comprehensive engineering-education foundations. Hundreds of UCD graduates have reaped the rewards of this excellent engineering formation in their professional lives, and gone on to contribute to Ireland's immense economic and industrial growth, development, and success.

A sense of care and of duty pervaded his life, from his PhD students to the secondary-school students participating in the annual Irish National Young Scientists Competition, whose projects he loved judging. Nurturing and mentoring intelligence and curiosity, especially in young people, was the cornerstone of his professional life. He believed that good academics help others succeed and go beyond themselves, and he surely did that. He had this generous approach through his life, being available to others and unstintingly giving of himself. In fact, he always worked with his office door open, so that anybody, staff or student, could consult him at any time. Because of the open door, all became aware that when on the phone he would lean back in his chair and put his feet up on his desk. He always enjoyed the wry comments from his colleagues over coffee breaks to which this gave rise. His spirit of service came naturally to him. Even as an undergraduate engineering student himself, he was always ready to help his fellow students. In particular, he was the "go-to" man for anyone who missed a lecture. He had an incredible writing hand, both in neatness and speed, and had the reputation for taking the tidiest, most structured, and most comprehensive lecture notes of all. Even his lecturers sought him out to get the note versions of their own lectures, with the intention of converting their lectures into course textbooks.

Among his peer international community of engineers, he was renowned not only as a leading thinker and a driver of research, but also as someone who readily sought to treat you as a friend. He was that all-rounder combination of teacher and mentor, scientific researcher, contributor to society nationally and internationally, and friend. Most of all, he was a family man: a kind, gentle, and wonderful person, loving husband to Eileen and devoted father to Lia, David, and Tom Junior. He was a gentleman and a scholar. May he rest in peace. As prayed in Ireland's native language: "ar dheis láimh Dé go raibh a h-anam uasail" (May his gentle soul be at God's right hand).

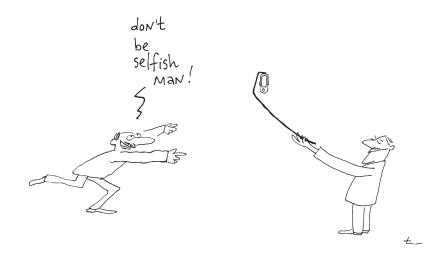
Máirtín O'Droma E-mail: Mairtin.ODroma@ul.ie

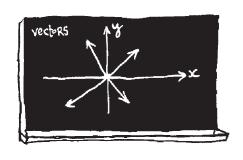
Et Cetera



Tayfun Akgül Istanbul Technical University Dept. of Electronics and Communications Engineering Telecommunications Division 80626 Maslak Istanbul, Turkey Tel: +90 212 285 3605; Fax: +90 212 285 3565

E-mail: tayfunakgul@itu.edu.tr.







t -- + 8055

Historical Papers



Giuseppe Pelosi
Department of Information Engineering
University of Florence
Via di S. Marta, 3, 50139 Florence, Italy
E-mail: giuseppe.pelosi@unifi.it

Foreword

On September 13, 2017, Sir John Meurig Thomas held a lecture in Florence [1]. Thomas, now retired, held the Chair of Chemistry at the Royal Institution, which was created for Michael Faraday. Thomas is renowned for his excellent book Michael Faraday and the Royal Institution: The Genius of Man and Place (Institute of Physics Publishing, 1991). The book was translated in 2006 in Italian as Michael Faraday La storia romantica di un genio (Firenze University Press) by Luigi Dei, now Rector of the University of Florence, and has been released to the public domain on the occasion of this lecture of September 13 (Figure 1).

In the book, it is recalled that from February 21, 1814, to April 7, 1814, Sir Humphry Davy [Penzance, UK, December 17, 1778 - Geneva, CH, May 29, 1829] on the occasion of his continental tour (Figure 2), took Faraday to Florence, where they visited the local museum and saw Galileo's first telescope (Figure 2). In Florence, Davy conducted experiments on the combustion of diamond in oxygen, using the Great Duke great burning glass. As

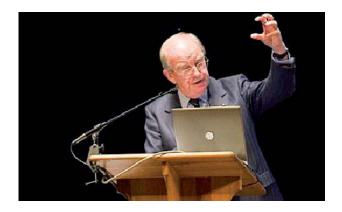


Figure 1. Sir John Meurig Thomas, giving his lecture in Florence in September 2017.

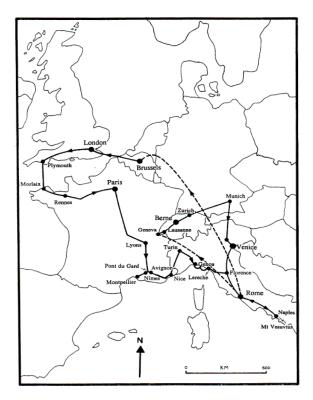


Figure 2a. The continental tour of Davy and Faraday (1813-1815).

Faraday remembered, "After several attempts Sir H. Davy observed the diamond to burn visibly, and when removed from the focus it was found to be in a state of active and rapid combustion. The diamond glowed brilliantly with a scarlet light inclining to purple, and when placed in the dark continued to burn for about four minutes. As Faraday observed, it was "a phenomenon never observed before." In a letter to his mother, he added "Florence, too, was not destitute of its attractions for me, and in the Accademy del Cimento and the Museum attached to it is contained an inexhaustible fund of entertainment and improvement."



Figure 2b. The monumental "Galileo Tribune" (decorated in 1841) at the "Specola" Museum of Florence, where the Scientific Assemblies in Florence used to take place.

I hence sought for further investigations on later connections between Michael Faraday and Italy, and Florence, in particular. In the following, two short papers are published. The first paper is on a minor figure in Italian physics who claimed priority over Faraday's discovery of magnetic induction: Francesco Zantedeschi. The second paper is on the most preeminent physicist in Italy at the time, and the greatest instrumentation builder, Leopoldo Nobili. He was closely connected with Faraday, again concerning magnetic induction, since it was thanks to his "astatic galvanometer" that Faraday managed to prove the phenomenon of magnetic induction.

Reference

1. http://www.fupress.com/contenuti/the-character-legacy-and-genius-of-michael-faraday---lecture-by-sir-thomas-meurig/740

Faraday-Neuman-Lenz Law of Induction or Zantedeschi-Neuman-Lenz Law of Induction?

Stefano Selleri

DINFO – University of Florence via di S. Marta 3, 50139, Florence, Italy E-mail: stefano.selleri@unifi.it

recent, extremely nice and entertaining book [1] (Figure 1a) cited Francesco Zantedeschi [Dolcè, Verona, Italy, August 18, 1797 – Padua, Italy, March 29, 1873] (Figure 1b) as a precursor of Michael Faraday [Southwark, London, UK, September 22 1791 – Hampton Court, Middlesex, UK, August 25, 1867] in discovering the law of magnetic induction in 1829, two years before Faraday himself. This is information that was reported elsewhere [2, 3], as well as on the Internet, most notably on Wikipedia [4]. However, other texts were more cautious [5, 6] or completely avoided citing Zantedeschi [7].

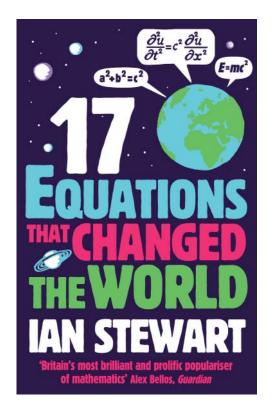


Figure 1a. The cover of the book by Ian Stewart.

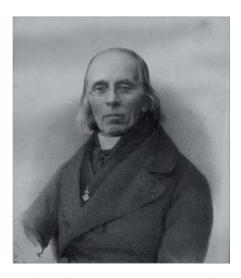


Figure 1b. Fancesco Zantedeschi.

It interesting to understand what Zantedeschi really did, and why he is credited. Information was sought in the original papers, which are mostly in Italian and hence of difficult access to our international community.

In 1820, Hans Christian Ørsted [Rudkøbing, Benmark, August 14, 1777 – Copenhagen, Denmark, March 9, 1851] discovered that an electric current could deviate the magnetic needle of a compass. This was a landmark in the study of electricity and magnetism, since it proved a connection between the two. Once the magnetic effects of a current were established, the electric effects of a magnet were highly expected.

In 1929, an obscure Italian Abbot, Francesco Zantedeschi, published a short communication [8] on the chemical effects of magnets. As a *post scriptum*, he added the few lines reported in Figure 2, where he claimed to have obtained such electric effects. He then published a French version of the same communication [9].

PS. Aggiuago in forma di appendice all'esperienza 1.ª e 2.ª della 1.ª parte un altro fatto da me osservato più

402 VARIETA'.

volte in questo mese, il quale non dovrà almeno riuscire discaro, perchè tende quale anello ad unire i diversi fatti elettro-magnetici colla loro sorgente. Ho preso una calamita fatta a ferro di cavallo del peso circa di una libbra francese, che potea sostenere un peso di circa 4 a 5 libbre, ed attorno a ciascun polo ho avvolto strettamente un filo sottilissimo di rame in modo che, collocata la calamita ad una distanza di 15 a 16 piedi parigini, potea sperimentare sulle estremità separate di detti fili. Ora preso un moltiplicatore a due calamite, ho ai capi del filo del medesimo (che è di rame circondato di seta) attaccate due piastrine di rame ben lucide, colle quali, mediante due verghe di legno per non alterare la temperatura, congiunu i fili che abbiam detto essere in comunicazione coi poli della calamita, ho veduto che l'ago magnetico sviasi dalla naturale sua posizione declinando verso l'oriente il polo al disopra del quale entra l'azione magnetica del polo nord, e verso l'occidente, se questa entra al disotto di esso, non altrimenti di quello che avviene coll'elettrico ordinario. La declinazione era da 8º a 10°. Mi pare che questo fenomeno non si possa ascrivere alla facoltà elettromotrice, perchè il rame trovasi fra due forze eguali e contrarie. E dato anche, come ho esperimentato nei liquidi, che le correnti elettriche, qualunque sia la loro direzione, non sviinsi, come la luce e il calorico raggiante, non dovrebbe il moltiplicatore dare alcun segno, come è chiaro. Pare dunque che tale effetto debba ascriversi al magnetico, e però che il polo nord equivalga al polo zinco d'un apparato voltiano. Io spero che altri esperimentando con moltiplicatori più delicati, come col siderescopio di Lebaillif, potra otteuere effetti maggiori che udirò quando che sia con placere. .

Pavia, 27 marzo 1829.

Figure 2a. The post scriptum in [8] where Zantedeschi wrote about his experiment on the electric effects of a magnet.

Zantedeschi wound coils of copper wire around the poles of a magnet. He then connected these wires with a galvanometer (a two-needle multiplier, as Nobili's astatic galvanometer with a multiplication coil was called at that time), and affirmed seeing a deviation in the magnetic needle (Figure 3). From both texts [8, 9] we can understand that the magnet had tight windings of copper, and that the wires forming the coils extended far from the magnet, so that their free ends were 15 to 16 French feet (about 5 m) from the magnet itself. It was quite unlikely that such an experiment would have led to the described effect. We know now that the electric effect is bound to a variation of the magnetic-induction flux in a coil. Zantedeschi's tightly wound coils were not a possible source of such a variation, and the transient nature of the phenomenon was not described at all by Zantedeschi. It is anyway important to stress that something was longed for and awaited. We therefore can think that Zantedeschi might have genuinely believed to have seen an effect. Indeed, Michael Faraday himself had already made some early experiments [10], which failed due to the low sensitivity of his galvanometer.

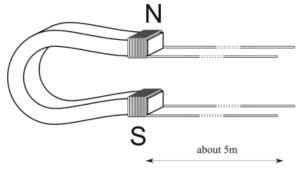
In 1931, Faraday set up a more-refined experiment. He understood that the magnetic field generated by a coil

P.S. I add as an appendix to experiences n. 1 and 2 of part 1 another phenomenon I observed several times this month, which should not sound unlikely, because a, as a ring, it unite various electro-magnetic facts with its source. I took a horseshoe magnet, of about 1 French pound of weight, strong so as to lift a weight of about 4 or 5 pounds, and around each pole I tightly winded a very thin copper wire so that, with the magnet 15 to 16 French foot away, I could experiment with the open ended of these wires. Now, taken a two needle galvanometer, I connected to the its wires (which are in copper wrapped in silk) two shiny copper plates, which I moved with wooden sticks, not to alter their temperature, and connected them with the wires which we said winded around the magnet. I saw the galvanometer needle move from its rest position, going east the point of the needle above which the action of the north pole of the magnet enters, going west if the action enters from below, analogously as for ordinary electricity. The deviation was from 8° to 10°. I believe that this phenomenon cannot be due to electromotive force, since the copper is placed between two opposite, equal, forces. Furthermore, as I noticed in liquids, electrical currents, notwithstanding their direction, do not deviate, as it happens for light and caloric rays, the galvanometer should give no sign, as it is clear. It hence looks like that such a phenomenon is to be ascribed to magnetism, such that north pole is equivalent to the zinc pole of a voltaic pile. I hope that further experiments, with more sensible galvanometers, as Lebaillif galvanometer, could show larger effects, of which I will hear news with delight. Pavia, March 27, 1829

Figure 2b. A translation by the author of the post scriptum in Figure 2a.

of currents does indeed induce a current in a close but electrically disconnected coil, but only at the transients, that is, when the current in the primary coil passes from zero to a steady-state value and – still extremely important – an opposite current is generated when the primary coil excitation ends. The details of the communication of this discovery are interesting. Other researchers, among whom was Leopoldo Nobili, duplicated these experiments very early, and much excitation ran in the Italian journals on priority. In particular, Giuseppe Gazzeri [Florence, Italy, November 9, 1771 – Florence, Italy, June 22, 1847], in the pages of the Antologia Fiorentina [11], explicitly cited Zantedeschi's 1829 work [8] in a note, saying:

Concerning preliminary studies, we warn the reader that prof. Zantedeschi published in March 1829 (*Biblioteca Italiana* vol. 53, p. 393) a result by him obtained winding a coil around the poles of a magnet, connecting the wires to a galvanometer. His result was the deviation of the needle by 8°-10°. Apparently, it seems the discovery by Faraday, but it cannot be, because in his set-up the currents discovered by Faraday cannot exist [11, p. 174 footnote].



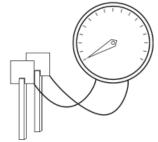


Figure 3. Zantedeschi's experiment, according to his description in [8].

Of course, this enraged Zantedeschi, who bitterly replied on the same *Antologia* pages [11], stating that,

What is the difference between the Englishman [Faraday] experiments and mine? I coiled the wire on the magnet, while he moved the coils toward the magnet. On anything else and on the <u>fundamental fact</u> [emphasis by Zantedeschi] I see no differences [11, p. 232].

He then claims that the *post scriptum* was too short to explain every detail of his experiment, that he placed and removed an iron bar to the magnet as Nobili did [13, p. 233], and that the effect was transient. Zantedeschi continued claiming for a long time [14] with even more strong words against Faraday:

When it is said that I connected the coils to a galvanometer "in the usual way" it is unjust. Who, before me, imagined to connect a galvanometer to a coil? Faraday two years later did, and did not mention me. I formally invite Mr. Faraday to break his silence and disrobe himself of the vest of an usurper which he wore up to now on this topic. I wrote letters to him, which never got reply [14, p. 11].

Indeed, Faraday in the end, cites Zantedeschi positively! Zantedeschi, among the other things, experimented with flames, observing a deviation in the flame when a magnet was present. He explained the phenomenon by a diamagnetic effect of hot gasses, and published his observations in an Italian gazette [15]. Faraday had previously affirmed that gasses had no magnetic properties at all. Once Faraday knew about Zantedeschi's results, he experimented again and found that indeed they had magnetic properties [16]. Faraday fully acknowledged Zantedeschi, and added a partial English translation of [15] to his paper.

Yet it is somewhat ironical that, again, Zantedeschi was not the discoverer of the phenomenon he was studying. Another Italian priest, Michele Alberto Bancalari [Chiavari, Genoa, February 20, 1805 – Genoa, August 10, 1864] made the first observation on flame deviations and reported it to the Italian Scientific Assembly in Venice in 1847. No written record by Bancalari stands, only verbal accounts of the sessions [17], which Zantedeschi attended. Yet both Zantedeschi and Faraday correctly cite him.

References

- 1. Ian Stewart, Seventeen Equations That Changed the World, London, Profile Books, 2013, Chapter 11.
- G. Romano, "On Frame-Invariance in Electrodynamics," arXiv:1209.5960v2, 2012.
- 3. A. Ohry, "Michael Faraday (1971-1867) Science, Medicine, Literature and His Disability," *Progress in Health Sciences*, **1**, 2011, pp 204-207.
- 4. https://en.wikipedia.org/wiki/Francesco_Zantedeschi (read on 06/09/2017).
- A. Pazienti, "Commemorazione del Professore, Cav. Ab. Francesco Zantedeschi (1797-1873) [Obituary of Professor, Knight, Abbot, Francesco Zantedeschi (1797-1873)]" Read at the Royal Venetian Institute June 22, 1873, Venice, Grimaldo & C., 1873.
- 6. M. Tinazzi, "Francesco Zantedeschi: Manoscritti e Lettere Veronesi [Francesco Zantedeschi, Manuscripts and Letters from Verona]," Atti del XVIII Congresso nazionale di storia della fisica e dell'astronomia, Como, Centro Volta, Villa Olmo, May 15-16, 1998.
- E. Bellone "Michael Faraday," in P. Rossi (ed.), Storia della Scienza Moderna e Contemporanea, Vol. II, Turin, UTET, 1988, pp. 485-502.
- 8. F. Zantedeschi, "Nota sopra l'azione della calamita e di alcuni fenomeni chimici [Note on magnet's action and on some chemical phenomena],"*Biblioteca Italiana*, 53, 1929, pp 398-402.
- 9. F. Zantedeschi, "Des modifications qu'éprouve un aimant soumis à l'influence de quelques actions chimiques [On the modifications which a magnet undergoes under the influence of some chemical actions], Bibliothèque Universelle des Sciences, Belles-Lettres et Arts, XLIII, 1830, pp. 27-29.
- 10. M. Faraday, "Electro-Magnetic Current," *The Quarterly Journal of Science, Literature and the Arts,* XIX, 1825, p. 338.

- 11. G. Gazzeri, "Sulla priorità delle ultime scoperte elettromagnetiche, in risposta ad alcuni articoli della Litterary Gazette di Londra [On the priority of the latest discovery in electromagnetism, in response to some articles of the Litteray Gazette of London]," Antologia, giornale di Scienze Lettere e Arti, XLV, March 1832, pp. 173-176.
- 12. F. Zantedeschi, "Reclamo [Complaint]," *Antologia, giornale di Scienze Lettere e Arti,* **XLVI**, June 1832, pp. 232-233.
- 13. F. Zantedeschi, "Lettera al Direttore dell'Antologia [Letter to the Director of the Antologia]," *Antologia, giornale di Scienze Lettere e Arti*, **XLVII**, September 1832, pp. 167.
- 14. F. Zantedeschi, "Risposta all'accuse date sulla priorità di alcune scoperte dal Sig. Profess. Majocchi al Profess.

- Zantedeschi [Reply to the accusations on the priority of some discoveries issued by Prof. Majocchi against Prof. Zantedeschi, Tip. Tremeschin, Vicenza, Italy, 1843.
- 15. F. Zantedeschi, "Dei movimenti che presenta la fiamma sottoposta all'influenza elettro-magnetica [On the movements of a flame subject to electro-magnetic influence]," *Gazzetta Piemontese*, October 12, 1847.
- 16. M. Faraday, "On the Diamagnetic conditions of Flame and Gases," *Philosophical Magazine*, 31, December 1847, pp. 401-421.
- 17. Diario del Nono Congresso Scientifico Italiano [Verbal account of the ninth Italian Scientific Conference], Venice (IT), September 14-27, 1847, verbal account of the days 21 and 22 September, p. 53 and p. 62.

Leopoldo Nobili: His Galvanometer and His Connections to the Faraday-Neuman-Lenz Law of Induction

Leonardo Possenti and Stefano Selleri

DINFO – University of Florence via di S. Marta 3, 50139, Florence, Italy E-mails: stefano.selleri@unifi.it, leonardo.Possenti@unifi.it

The discovery of the phenomenon of magnetic induction, nor the Faraday-Neumann-Lenz law of induction, was something much expected, after Hans Christian Ørsted [Rudkøbing, Benmark, August 14, 1777 - Copenaghen, Denmark, March 9, 1851] discovered that electric currents had an effect on a magnetic needle. Many researchers, among whom the most notable was Michael Faraday [Southwark, London, UK, September 22, 1791 - Hampton Court, Middlesex, UK, August 25, 1867], actively sought such a phenomenon, yet the instrumentation then available was exceedingly crude [1]. For an electric phenomenon to be apparent, a spark should be observed for voltage, or a current strong enough for visible effects. Some more-sensitive device able to detect feeble currents was necessary. Indeed, Ørsted's discovery made possible the development of such an instrument: the galvanometer. In that same 1820, Johann Schweigger [Erlangen, Germany, April 8, 1779 – Halle, Germany, September 6, 1857] build a first galvanometer by winding a coil of wire around a magnetic needle free to rotate. This was later enhanced by "multiplying" the effect of the current by using several coils of wire.



Figure 1a. Leopoldo Nobili.

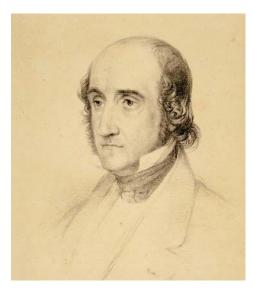


Figure 1b. Vincenzo Antinori.

However, it was only with the refinement of such instruments by Leopoldo Nobili [Trassilico, Lucca, Italy, July 5, 1784 – Florence, Italy, August 22, 1835] (Figure 1) that the reliable detection of feeble currents was feasible. Nobili, a preeminent Italian physicist and top scientific instrument maker in Europe, used two oppositely oriented needles on the same suspending wire, and a coil in the shape of a figure eight (1825). The double needle was insensitive to the strong, static, Earth's magnetic field, hence greatly increasing the sensitivity of the instrument [2] (Figure 2). He named his device the *astatic* galvanometer.

In the same period, in 1824 exactly, François Arago [Estagel, Perpignan, France, February 26, 1786 – Paris, France, October 2, 1853] found that a rotating magnetic needle was slowed down by the presence of nonmagnetic metals close to it [3, 4]. He also observed that a rotating copper disk caused a suspended magnet over and close to it to rotate if free, or else was slowed down by the presence of the magnet if this latter was fixed. However, this phenomenon remained inexplicable, and was not immediately connected to electricity (Figure 3, from [5], p. 38).

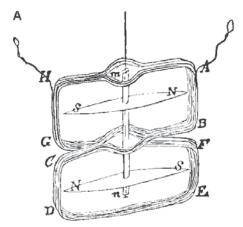


Figure 2a. The layout of the astatic galvanometer, from Nobili's original paper [2].

Eventually, in 1831, Faraday set up an experiment in which Nobili's a static galvanometer showed a transient current in a coil when another coil connected to a generator, or a permanent magnet, was moved close to or away from it.

The point now is that Faraday devised his experiment in 1831, and read the results on November 24, 1831, at the Royal Society. However, he was quite slow in publishing a paper: a short note appeared only in April 1832 [6]. On the other hand, the news of his highly expected, successful induction experiment spawned at light speed through Europe. The experiment was described by Faraday himself to Jean Nicolas Pierre Hachette [Mézières, Ardennes, France, May 6, 1769 – Paris, France, January 16, 1834], who read a communication in French to the Académie des Sciences in Paris on December 26, 1831. Such a French communication, published in the journal Le Temps [7], reached Florence, where it was read by Vincenzo Antinori [Florence, Italy, 1792 – Florence, Italy, 1865] (Figure 1) and Leopoldo Nobili, who immediately duplicated the experiment and produced a paper.



Figure 2b. One of the original astatic galvanometers, built by L. Nobili in 1826 and preserved at the "Museo Galileo," the museum of the History of Science, in Florence, which owns several of Nobili's devices.

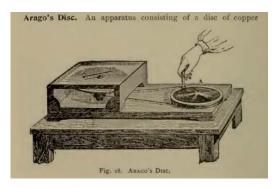


Figure 3a. Arago's disk, from [5].

In Antinori and Nobili's paper, the authors fully acknowledged Faraday's priority. They regretted that Faraday had not yet published his results, and thanked Hachette for having spread the news [8]. Such a paper was dated January 3, 1832, but appeared in an issue of a Journal dated November 1831 (vol. XLIV). Nobili and Antinori quickly wrote a second paper on the subject [9], dedicated to the currents induced on a rotating disk in a magnetic field, hence solving the problem of the rotation observed by Arago [3, 4].

The problem is that Antinori and Nobili's paper was the only item available in the open literature for a few months. As was common practice in that period, it was submitted in French, German, and even English, to the *Philosophical Magazine*, in an annotated translation performed by Faraday himself [10]. It was thus the only well-organized paper on the subject up to Faraday's paper [11], where Faraday himself summarized these events. The priority issue, never claimed by Antinori and Nobili, was nicely settled.



Figure 3b. The first page of the book *Essai sur la Philosophie des Sciences* by A. Ampére (1834), with a friendly dedication of the author to Leopoldo Nobili [private collection, courtesy of Fausto Barbagli, Natural History Museum, University of Florence].

Yet in the Literary Gazette there appeared a series of columns publicizing Faraday's discovery [12], and later announcing [13] that Faraday intended to explain the Arago rotation phenomenon on the basis of this new discovery. This in turn upset Giuseppe Gazzeri [Florence, Italy, November 9, 1771 – Florence, Italy, June 22, 1847], a renowned chemist, who attacked the *Literary Gazette* and its journalists (not Faraday!) from the pages of the Antologia Fiorentina [14]. Faraday replied in a letter to the Literary Gazette, and a discussion on the Arago phenomenon arose. The notes by Faraday in [10] mainly point to his previous work, and say that "I am criticizing Sig. Nobili and Antinori for not understanding my views. It was impossible that I could put forth in a brief letter, matter which, though I have condensed it as much as possible, still occupies seventy quarto pages of the Philosophical Transaction." It was true: Nobili and Antinori only had available [7], not [11]. As a result, a misunderstanding was highly possible.

Nobili and Antinori replied, stating that their interpretation was analogous to that made by Ampére of Arago's discoveries [15]. Ampére was the most renowned physicist at the time, and Nobili was Italy's greatest physicist. Faraday bitterly replied, and a long discussion started. This was quite unusual for Faraday, usually extremely polite with other physicists. A possible explanation is that Faraday was worried that Nobili and Ampére, two of the greatest physicists and friends (Figure 3), were interpreting the induction phenomenon he discovered in terms of actions at a distance, whereas Faraday was figuring those lines of force that would have later opened the road to Maxwell. Faraday could have been afraid that a mathematical theory of induction in terms of actions at a distance could be produced, whereas he, self-taught experimenter, could never come up with one. He might then have thought of indirectly attacking Ampére through Nobili [17].

Surprisingly enough, Nobili, close to the end of his life, denied any claim of explaining induction via action at a distance, and espoused Faraday's concepts [18]. However, he claimed that he had developed a similar yet less refined concept earlier, too [19].

References

- 1. M. Faraday, "Electro-Magnetic Current," *The Quarterly Journal of Science, Literature and the Arts*, **XIX**, 1825, p. 338.
- 2. C. L. Nobili, "Ueber einen neuen Galvanometer," *Journal für Chemie und Physik*, **XXXXV**, 1 825, pp. 249-256.
- 3. F. Arago, "On Rotation Magnetism." Proces verbal, Academy of Sciences, 22 November 1824, in *F. Arago Meteorological Essays*, London, Longman, Brown, Green and Logmans, 1855.
- 4. F. Arago, "Séance du lundi 7 mars," *Annales de Chimie et de Physique*, **XXVIII**, 1825, pp. 325-326.

- T. O'Conor Sloane, *The Standard Electrical Dictionary*, Second Edition, New York, Norman W. Henley & Co., 1897.
- No author, "Proceedings at the Friday-Evening Meetings of the Royal Institution of Great Britain," *Philosophical Magazine*, 11, April 1832, pp. 299-301.
- 7. No author, Le Temps, 28 December 1831.
- L. Nobili, V. Antinori, "Sopra la forza elettromotrice del magnetismo [On the magnetic electromotive force]," Antologia, giornale di Scienze Lettere e Arti, XLIV, November 1831, pp. 149-161.
- L. Nobili, V. Antinori, "Nuove esperienze elettromagnetiche e Teoria Fisica del magnetismo di rotazione [New electromagnetic experiments, and Physical Theory of rotational magnetic field]," Antologia, giornale di Scienze Lettere e Arti, XLV, January 1832, pp. 107-122.
- 10. M. Faraday (translation and notes), "On the Electro-motive Force of Magnetism. By Signori Nobili and Antinori; (from the Antologia, No. 131): with notes by Michael Faraday," *Philosophical Magazine*, 11, June 1832, pp. 401-413.
- 11. M. Faraday, "Experimental Researches in Electricity," Philosophical Transactions of the Royal Society of London, 122, 1832, pp. 125-162.
- 12. No author, Literary Gazette, N, 788, February 25, 1832, p. 119.
- 13. No author, *Literary Gazette*, N, 791, March 17, 1832, p. 169.
- 14. G. Gazzeri, "Sulla priorità delle ultime scoperte elettro-magnetiche, in risposta ad alcuni articoli della Litterary Gazette di Londra [On the priority of the latest discovery in electromagnetism, in response to some articles of the Litteray Gazette of London]," *Antologia, giornale di Scienze Lettere e Arti*, XLV, March 1832, pp. 173-176.
- 15. L. Nobili, V. Antinori, "Sopra vari punti di Magneto-elettricismo," *Antologia, giornale di Scienze Lettere e Arti*, **XLVI**, June 1832, pp. 142-143.
- 16. J.C: Maxwell, "On Faraday's Lines of Force," *Transactions of the Cambridge Philosophical Society,* X, part I, 1955, pp. 155-229.
- 17. S. Sbrighi, "La controversia Nobili-Faraday sull'induzione elettromagnetica," in G. Tarozzi [ed.] *Leopoldo Nobili e la cultura scientifica del suo tempo*, Bologna, Nuova Alfa Ed., 1985, pp. 69-95.
- L. Nobili "Teoria fisica delle Induzioni Elettrodinamiche," in *Memorie ed Osservazioni Edite ed Inedite del Cavalier Leopoldo Nobili*, Vol. 1, Firenze, David Passigei & Co., 1834, pp. 257-279.
- L. Nobili, Questioni sul Magnetismo, Modena, Eredi Soliani, 1824.

Ethically Speaking



Randy L. Haupt
Colorado School of Mines
Brown Building 249
1510 Illinois Street, Golden,
CO 80401 USA

Tel: +1 (303) 273 3721 E-mail: rhaupt@mines.edu

Amy J. Shockley

E-mail: aj4317@gmail.com



A Coconut Deception

Randy L. Haupt and Amy J. Shockley

Sue (wife/mother of the authors of this article) was strolling along a beach in Mexico when she got hit in the head by a coconut. Did you know that coconuts actually severely injure people, and may even cause death when they hit someone on the head? If you want to find the odds of dying from a falling coconut and search the Web for "death by coconut," you will find that a brewery just released a new beer called Death by Coconut. We suggest instead searching for "how many people die from coconuts." The predominant number that appears is 150 deaths/year due to a coconut falling on someone's head. Wow!

Where did that number come from? Club Direct (British travel insurance) managing director Brent Escott said that "Coconuts kill around 150 people worldwide each year, which makes them about ten times more dangerous than sharks" [1]. He got his number by extrapolating from the data published in a medical study [2]. One Web page estimates that "6 out of every one million people get bonked by a coconut" [3]. They arrived at that number by first estimating the number of coconuts on trees from the number of coconuts harvested in a year, then used the number of people on Earth and the land area where coconuts live. Assuming that 1% of the people die from getting hit by a coconut, then they estimated that 400 people die each year. These numbers should make you think twice before napping under a palm tree.

So, what happened to poor Sue? If you knew the following facts, you would be concerned: "Mature coconut

palms may have a height of 24 up to 35 meters and an unhusked coconut may weigh 1 to 4 kg, meaning that blows to the head of a force exceeding 1 metric ton are possible" [2]. Fortunately, the tree that Sue meandered under was a rather small palm. In what is probably the most fortunate part of this situation, her head bumped into the coconut: the coconut never fell from the tree. While startling to head-butt a coconut when walking on the beach, not paying attention, physical injury was thus minimal.

Our coconut story was very misleading. We did not lie, but we did purposely deceive you. The coconut was not on a tall tree, and it did not fall. The statistics we cited from the references were also bogus. In reality, it is difficult to find an instance of one person ever dying from a coconut that fell from a tree. The deaths per year that are frequently cited are based on faulty assumptions, and not real data.

To deceive is to instill a belief in someone that is not actually true. Deception is quite prevalent in today's society, whether driven by true malicious intent, as a mistake, or as a practical joke. The ethical line in deception is intent. If the deceiver is acting with the intent to gain an unjust benefit or cause harm to another, they are acting unethically. Identifying ill-intended deception can be difficult, and requires building upon the skills required to be less gullible. In addition to those skills, you should use your inner compass to gauge if a scenario "feels right." Include information that you know about the individual, and their morals and past actions. Asking probing questions can help identify a

deception as well as if it is driven by poor intentions (often times, deceit is driven by peoples' inability to say "I don't know"). Don't hesitate to consult others in order to get varying opinions and views of the situation.

Just because a "fact" is quoted in many different places and by reputable people doesn't make it true. Vladimir Lenin said, "A lie told often enough becomes the truth."

References

- 1. M. Perkins, *Surviving Paradise*, London, Quidnunc Press, 2006; https://books.google.com.
- 2. P. Barss, "Injuries Due to Falling Coconuts," *J. Trauma*, **24**, 11, November 1984, pp. 990-991.
- 3. http://diaryofnumbers.blogspot.com/2010/11/death-by-coconut.html

Maxwell Newsletters Available

The spring and summer 2018 *James Clerk Maxwell Newsletters* of the Clerk Maxwell Foundation are available at www.clerkmaxwellfoundation.org. Among other items, the spring issue contains an article on the discovery of gravitational waves. The summer issue surveys the use of light as a replacement for radio frequencies in Wi-Fi and microcellular communication situations.





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Solution Box



Özgür Ergül
Department of Electrical and Electronics Engineering
Middle East Technical University
TR-06800, Ankara, Turkey
E-mail: ozgur.ergul@eee.metu.edu.tr

SOLBOX-09, SOLBOX-10

Ali Farshkaran and Özgür Ergül

Department of Electrical and Electronics Engineering
Middle East Technical University
TR-06800, Ankara, Turkey
E-mails: ali.farshkaran@metu.edu.tr, ozergul@metu.edu.tr

1. Introduction

Deriodicity is a major property of many structures in electromagnetic applications, such as antenna arrays [1], frequency-selective surfaces, metamaterials [2], and photonic crystals [3]. Array elements (unit cells, antennas, etc.) are periodically arranged in order to enhance the response of a single element or to gain new capabilities due to interactions between them. Naturally, electromagnetic simulations of periodic structures have a long history in the literature. This is still an active area as the structures become more complicated and require more sophisticated (accurate, efficient, stable) tools for precise analysis. When the structure is infinitely large, and particularly when the periodicity is sub-wavelength, there are excellent tools based on Fourier series and finite-difference models, e.g., see [4] and [5]. Similarly, when the elements can be represented pointwise with or without interactions, there are analytical (e.g., using array factor) and semi-analytical (e.g., using lumped elements and/or transmission-line models) techniques. On the other hand, challenges arise when each element is a complex electromagnetic problem itself while it needs to interact with other complex elements. In addition, if the finiteness is an important geometric parameter of a periodic structure, its full-wave models may lead to large-scale problems that can be difficult to solve numerically. In such cases, it is tempting to substitute high-order mathematical

models for the elements [6], specifically by isolating their inner dynamics to derive the required equivalence [7] within the decomposed models. A well-known method in this path is called the Equivalence-Principle Algorithm (EPA), which has been used and improved (e.g., hybridized with or used in other methods) by numerous researchers [7-11].

In this issue, two different electromagnetic problems involving periodic arrangements are presented (SOLBOX-09 and SOLBOX-10). In SOLBOX-09, a microwave metamaterial involving 3 × 9 × 9 split-ring resonators (SRRs) is considered. Resonances of SRRs make the problem challenging at certain frequencies. A larger structure is considered in SOLBOX-10, where an array of 20 × 20 radio-frequency antennas needs to be analyzed. The antenna design — namely, a cage-dipole antenna—involves thin lines and very small gaps. For both problems, solutions using an EPA implementation are also presented and compared with brute-force solutions via the Method of Moments (MoM) and the Multilevel Fast Multipole Algorithm (MLFMA).

The contributors are confident that different numerical solutions and analysis methods, probably leading to faster and/or more accurate solutions, can be found. We are looking for alternative solutions to these problems (SOLBOX-09 and SOLBOX-10), as well as to previous problems

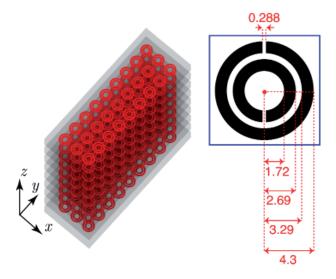


Figure 1. An array of $3 \times 9 \times 9$ SRRs that are arranged periodically. The SRR geometry is the same as that in [12], which was used to construct a composite metamaterial structure. Equivalence boxes that were used in the NEPA-MLFMA solutions are also shown.

(SOLBOX-01 to SOLBOX-08) that can be found in the earlier issues of this column. Please consider submitting your contributions to Ozgur Ergul (ozergul@metu.edu.tr).

2. Problems

2.1 Problem SOLBOX-09

(by Ali Farshkaran and Ö. Ergül)

Figure 1 depicts a $3 \times 9 \times 9$ array of SRRs that are arranged periodically in free space. The periodicities in the x, y, and z directions are 10.508 mm, 10.508 mm, and 18 mm, respectively. The dimensions for a single SRR are shown in detail. This geometry was previously used in [12] to construct a composite metamaterial. The surfaces are assumed to have zero thickness, while they are modeled

as perfect electric conductors. The array is excited by a y-directed Hertzian dipole located at x = 48 mm, if the center of the array is at the origin. It is desired to find the response of the structure (e.g., far-zone scattering, near-zone field distributions, induced current density, etc.) in a range of frequencies from 4.5 GHz to 6.5 GHz. The SRRs are expected to resonate at around 5.25 GHz to 5.5 GHz, at which frequencies the numerical solutions are expected to be challenging.

2.2 Problem SOLBOX-10

(by Ali Farshkaran and Ö. Ergül)

Figure 2 depicts an array of 20×20 cage-dipole antennas located in free space. The antenna geometry with $3.2~\rm cm \times 6.8~cm$ size is the same as that in [13], which was optimized and designed for radio-frequency-identification (RFID) applications. The surfaces are assumed to be perfectly conducting with zero thickness. The antennas are arranged periodically on the x-y plane, with 8 cm and 13 cm center-to-center distances in the x and y directions, respectively. The overall size of the structure is hence $1.552~\rm m \times 2.538~m$. The array is illuminated by a plane wave propagating in the z direction with the electric field polarized in the x direction. The frequency is set to $2.0~\rm GHz$, making the array larger than $10\lambda \times 17\lambda$, where λ is the operating wavelength. It is desired to find the scattered fields in the far zone.

3. Solution to Problem SOLBOX-09

3.1 Solution Summary

Solver type (e.g., noncommercial, commercial): Noncommercial research-based code developed at CEMMETU, Ankara, Turkey

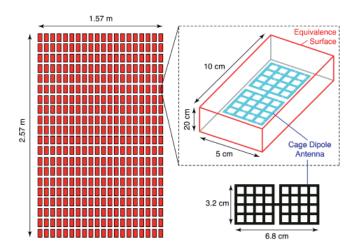
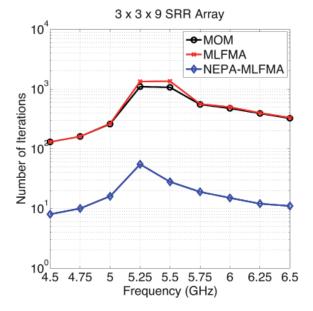


Figure 2. An array of 20 × 20 cagedipole antennas. The antenna geometry, which was designed for RFID applications, was taken from [13]. Equivalence boxes that were used in the NEPA-MLFMA solution are also shown.



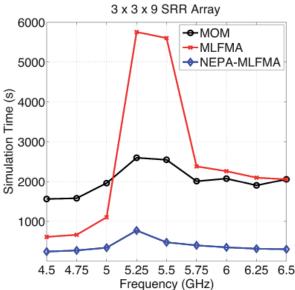


Figure 3. Three different solutions of SOLBOX-09 by using NEPA-MLFMA, in addition to conventional implementations of MoM and MLFMA. The number of GMRES iterations and the solution time (in seconds) are plotted with respect to frequency.

Solution core algorithm or method: Frequency-domain Equivalence-Principle Algorithm (EPA) accelerated with the Multilevel Fast Multipole Algorithm (MLFMA)

Programming language or environment (if applicable): *MATLAB* + *MEX*

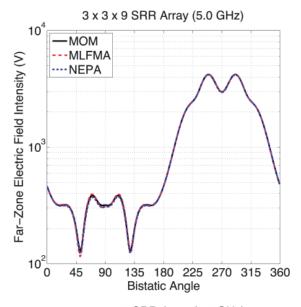
Computer properties and used resources: 2.5 GHz Intel Xeon E5-2680v3 processors (using single core)

Total time required to produce the results shown (categories: <1 sec, <10 sec, <1 min, <10 min, <1 hour, <10 hours, <1 day, <10 days, >10 days):

< 1 hour for 9 frequencies

3.2 Short Description of the Numerical Solutions

The problem SOLBOX-09, involving a 3 × 9 × 9 array of SRRs, was solved by using a *MATLAB* implementation that was based on the hybridization of EPA [8] and MLFMA [14] in the frequency domain. Solutions were performed at nine discrete frequencies, i.e., with 250 MHz intervals from 4.5 GHz to 6.5 GHz. The EPA implementation used the formulation in [8] with N-type projections of fields via the Gram matrices, while the surface-to-surface translations were accelerated via the MLFMA. The overall implementation was hence called NEPA-MLFMA. The electric-field integral equation



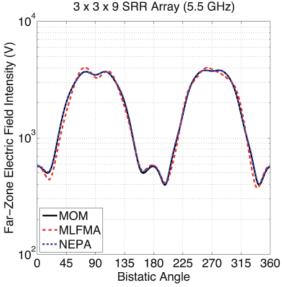


Figure 4. Three different solutions of SOLBOX-09 by using NEPA-MLFMA, in addition to conventional implementations of MoM and MLFMA. The far-zone electric field intensity is plotted with respect to the bistatic angle on the *z-x* plane at 5.0 GHz and 5.5 GHz.

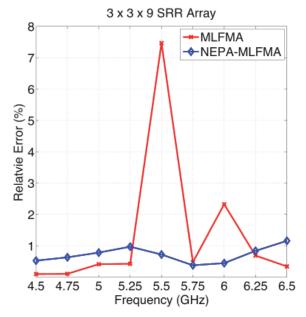


Figure 5. The relative error in two different solutions of SOLBOX-09 using a conventional MLFMA and NEPA-MLFMA. The relative error was plotted with respect to frequency from 4.5 GHz to 6.5 GHz. The error was calculated by considering scattered electric field intensity on the *z-x* plane and using MoM results as references.

(EFIE) was used to formulate the scattering problems. Each SRR was discretized by using 1 mm triangles, on which Rao-Wilton-Glisson (RWG) functions [15] were defined to expand the induced current density. Employing 73 unknowns per SRR, a total of 17,739 RWG functions were used for the overall array. For the solutions with NEPA-MLFMA, nine equivalence surfaces (rectangular boxes) were defined, each enclosing a layer of 3 × 9 SRRs, as also depicted in Figure 1. The size of each equivalence surface was 40 mm × 105 mm × 12 mm, i.e., the distance between the surfaces of the neighboring equivalence boxes was 18 mm - 12 mm = 6 mm. The equivalence surfaces were also discretized by using the RWG functions. Using 1356 RWG functions per equivalence surface, 2 × 12,204 unknowns were used to expand equivalent electric and magnetic currents. For comparisons, solutions were also performed by using a conventional MoM and a standard MLFMA [16]. All iterative solutions were performed by using the generalized minimal residual (GMRES) algorithm without preconditioning. The threshold of an iterative convergence was set to 0.0001. Finally, all electromagnetic interactions in MoM, MLFMA, and NEPA-MLFMA were computed with a maximum 1% relative error.

3.3 Results

Figure 3 presents the number of GMRES iterations and the solution time at nine different frequencies from 5.5 GHz to 6.5 GHz. It could be observed in the top plot

that the iteration counts increased drastically at 5.25 GHz and 5.5 GHz for all solutions, i.e., using MoM, MLFMA, and NEPA-MLFMA. At the same time, NEPA-MLFMA dramatically reduced the number of iterations in comparison to MoM and MLFMA at all frequencies. It was remarkable that the discrepancy between MoM and MLFMA (specifically at 5.25 GHz and 5.5 GHz) was due to the illconditioning, which made the iterative solution extremely sensitive to errors in matrix-vector multiplications. At these frequencies, MLFMA was even slower than MoM due to larger numbers of iterations. As depicted in the bottom plot of Figure 3, NEPA-MLFMA significantly reduced the solution time, especially at 5.25 GHz and 5.5 GHz, in comparison to MoM and MLFMA. At 5.25 GHz, the speedup provided by NEPA-MLFMA was 3.36, and 7.45 with respect to MoM and MLFMA.

Figure 4 presents the scattered electric field intensity in the far zone at 5.0 GHz and 5.5 GHz. The amplitude of the field was plotted with respect to bistatic angle from 0° to 360° on the z-x plane. We observed that at both 5.0 GHz and 5.5 GHz, the MoM and NEPA-MLFMA solutions were consistent with each other. As shown in the top plot, MLFMA also provided consistent results at 5.0 GHz. However, at 5.5 GHz (bottom plot of Figure 4), the scattering values obtained by using MLFMA visibly deviated from those obtained with MoM and NEPA-MLFMA. This was again caused by ill-conditioning and accumulation of errors during iterative solutions when MLFMA was used for matrix-vector multiplications. Finally, Figure 5 provides an overall plot for the relative errors in MLFMA and NEPA-MLFMA solutions with respect to MoM solutions. It could be observed that the error was mostly below 1% for NEPA-MLFMA, while it reached more than 7% for MLFMA. It appeared that MLFMA solutions must be accelerated via strong preconditioners as practiced in [17], not only to improve the efficiency but also to avoid excessive errors at critical frequencies.

4. Solution to Problem SOLBOX-10

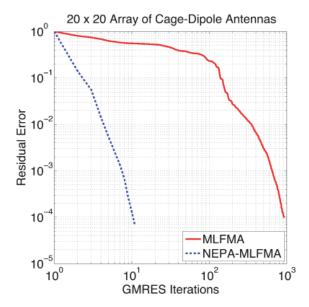
4.1 Solution Summary

Solver type (e.g., noncommercial, commercial): Noncommercial research-based code developed at CEMMETU, Ankara, Turkey

Solution core algorithm or method: Frequency-domain Equivalence-Principle Algorithm (EPA) accelerated with the Multilevel Fast Multipole Algorithm (MLFMA)

Programming language or environment (if applicable): *MATLAB* + *MEX*

Computer properties and used resources: 2.5 GHz Intel Xeon E5-2680v3 processors (using single core)



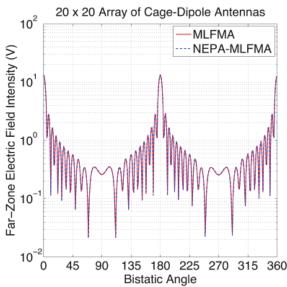


Figure 6. Two solutions of SOLBOX-10 using a conventional MLFMA and NEPA-MLFMA. In addition to convergence histories of iterative solutions, the electric field intensity in the far-zone is shown with respect to the bistatic angle on the *z-y* plane.

Total time required to produce the results shown (categories: <1 sec, <10 sec, <1 min, <10 min, <1 hour, <10 hours, <1 day, <10 days, >10 days): <1 hour

4.2 Short Description of the Numerical Solutions

In order to solve the problem SOLBOX-10, the NEPA-MLFMA implementation described in Section 3.2 was used. For the solution at the given frequency of 2.0 GHz, each cage-dipole antenna was discretized with 521 RWG functions defined on triangulated surfaces. This made a total of $400 \times 521 = 208,400$ unknowns for expanding the electric current density on the antenna surfaces. For

employing EPA, each antenna was symmetrically located in a 5 cm × 10 cm × 2 cm equivalence surface, as also depicted in Figure 2. Considering the distances between the antennas (8 cm and 13 cm in the x and y directions), the surface-to-surface distance between the equivalence surfaces was 3 cm in both x and y directions. The equivalence surfaces were also discretized with the RWG functions. In comparison to the discretization of the antennas, a coarser mesh was used, leading to 186 RWG functions per equivalence surface and a total of 2 × 74,400 unknowns to expand the equivalent electric and magnetic currents. For comparisons, a standard MLFMA implementation was also used, where the discretized antenna array was directly solved without employing EPA. For both NEPA-MLFMA and MLFMA solutions, the antennas were formulated with EFIE. All electromagnetic interactions were computed with a maximum 1% error. Iterative solutions were performed by using the GMRES algorithm without preconditioning.

4.3 Results

Figure 6 presents the results of simulations performed by using MLFMA and NEPA-MLFMA. In the top plot, the residual error was plotted with respect to GMRES iterations. The advantage of NEPA-MLFMA was clearly visible as improved convergence rate and reduced number of iterations from 917 to only 11. In the bottom plot of Figure 6, the scattered electric field intensity in the far-zone was plotted with respect to bistatic angle on the *z-x* plane. The NEPA-MLFMA and MLFMA solutions were very consistent, verifying the accuracy of solutions.

4. References

- 1. C. A. Balanis, Antenna Theory: Analysis and Design, New York, Wiley, 2005.
- C. Caloz and T. Itoh, Electromagnetic Metamaterials: Transmission Line Theory and Microwave Applications: The Engineering Approach, New York, Wiley, 2006.
- J. D. Joannopoulos, S. G. Johnson, J. N. Winn, and R. D. Meade, Photonic Crystals, Molding the Flow of Light, Princeton, Princeton University Press, 2008.
- P. Harms, R. Mittra, and W. Ko, "Implementation of the Periodic Boundary Condition in the Finite-Difference Time-Domain Algorithm for FSS Structures," IEEE Trans. Antennas Propagat., 42, 9, September 1994, pp. 1317-1324.
- 5. L. Li, "Use of Fourier Series in the Analysis of Discontinuous Periodic Structures," J. Opt. Soc. Am. A, 13, 9, September 1996, pp. 1870-1876.
- F. Vipiana, G. Vecchi, and P. Pirinoli, "A Multiresolution System of Rao-Wilton-Glisson Functions," IEEE

- Trans. Antennas Propagat., 55, 3, March 2007, 924-930.
- M.-K. Li and W. C. Chew, "Multiscale Simulation of Complex Structures Using Equivalence Principle Algorithm with High-Order Field Point Sampling Scheme," IEEE Trans. Antennas Propagat., 56, 8, August 2008, pp. 2389-2397.
- P. Ylä-Oijala and M. Taskinen, "Electromagnetic Scattering by Large and Complex Structures with Surface Equivalence Principle Algorithm," Waves in Random and Complex Media, 19, 1, February 2009, pp. 105-125.
- H. Shao, J. Hu, W. Lu, H. Guo, and Z. Nie, "Analyzing Large-Scale Arrays Using Tangential Equivalence Principle Algorithm with Characteristic Basis Functions," IEEE Proc., 101, 2, February 2013, pp. 414-422.
- 10. K. Zhang, J. Ouyang, and F. Yang, "Solving the Radiation Problem of Large-Scale Antenna Array by the Accelerated Periodic Equivalence Principle Algorithm," IEEE Antennas Wireless Propag. Lett., 13, June 2014, pp. 1195-1198.
- 11. D. M. Solis, F. Obelleiro, and J. M. Taboada, "Surface Integral Equation-Domain Decomposition Scheme for Solving Multiscale Nanoparticle Assemblies with Repetitions," IEEE Photonics J., 8, 5, October 2016.

- 12. H. İbili, B. Karaosmanoğlu, and Ö. Ergül, "Demonstration of Negative Refractive Index with Low-Cost Inkjet-Printed Microwave Metamaterials," Microw. Opt. Technol. Lett., 60, 1, January 2018, pp. 187-191.
- 13. F. Mutlu, C. Önol, B. Karaosmanoğlu, and Ö. Ergül, "Inkjet-Printed Cage-Dipole Antennas for Radio-Frequency Applications," IET Microwaves, Antennas & Propagation, 11, 14, November 2017, pp. 2016-2020.
- 14. W. C. Chew, J.-M. Jin, E. Michielssen, and J. Song, Fast and Efficient Algorithms in Computational Electromagnetics, Norwood, MA, Artech House, 2001.
- S. M. Rao, D. R. Wilton, and A. W. Glisson, "Electromagnetic Scattering by Surfaces of Arbitrary Shape," IEEE Trans. Antennas Propagat., 30, 3, May 1982, pp. 409-418.
- 16. Ö. Ergül and L. Gürel, The Multilevel Fast Multipole Algorithm (MLFMA) for Solving Large-Scale Computational Electromagnetics Problems, New York, Wiley-IEEE, 2014.
- 17. L. Gürel, Ö. Ergül, A. Ünal, and T. Malas, "Fast and Accurate Analysis of Large Metamaterial Structures Using the Multilevel Fast Multipole Algorithm," Prog. Electromagn. Res., 95, 2009, pp. 179-198.

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Telecommunications Health and Safety



James C. Lin
University of Illinois at Chicago
851 South Morgan Street, M/C 154
Chicago, IL 60607-7053 USA
E-mail: lin@uic.edu

The Moscow Embassy Microwave Signal

ately, there has been a great deal of scientific, public, and media attention about the health and safety of prolonged human exposure to radio-frequency (RF) radiation, especially with regard to cancer. The situation has been acerbated, in part, by dissemination of a report from a US government-sponsored experimental study [1, 2]. Indeed, release of the laboratory-rat cancer result was deemed as something of a public-health obligation by the reporting government entity: the National Institute of Environmental Health Sciences/National Toxicology Program [3].

The recent interest in this topic prompted me to recall an event that occurred in the mid 1970s, when the biological and health effects of RF and microwave radiation were brought to the fore by revelation of two US ambassadors to Moscow dying of cancer, and the then-ambassador Walter Stoessel threatening to resign in 1976, because of widespread staff concerns regarding potential health implications of an unusual microwave signal the Soviets were directing at the US Embassy in Moscow [4]. (Stoessel died of leukemia in 1986. He was 66 years old [5].)

Available reports suggest that since the 1960s, it had been known that the Soviets were targeting the upper floors of the central wing of the embassy in Moscow with low-level microwave radiation from nearby buildings, first from one, and then two sites [4, 6]. Indeed, it actually may have begun as soon as embassy staff had moved into the complex on Tchaikovsky Boulevard back in 1953, and persisted through at least 1988.

The levels of microwave exposure went up and down over the years. The direction and intensity of the 0.5 GHz to 10 GHz microwave signal changed in 1975 from 0.5 mW/m² for nine hours per day to 0.1 to 1.5 mW/m² for 18 hours per day, but it was always directed toward or aimed at the upper floors of the embassy. Only background levels were detected elsewhere in the embassy complex.

It is noteworthy that these levels were actually below what was considered as safe for human exposure in the US at the time. As a matter of fact, between 1966 and 1982, the American National Standards Institute (ANSI) guideline for safe human exposure to microwave radiation was 100 W/m^2 . Essentially, the same standard was adopted by the US Occupational Safety and Health Administration (OSHA). In contrast, the Soviets' standards were 1 mW/m^2 and 10 mW/m^2 for general public and occupational exposures, respectively [7]. The Soviet standards were derived from observations made in laboratory experiments using small animals, and surveys of people occupationally exposed to microwave radiation.

The existence of the microwave signal had been kept secret for years. This was because at the time, no one knew exactly why the Soviets were doing it, or that there might be any health consequences (a point I will get back to later).

Conjectures on intent and purpose abounded; the reasons why the Soviets did it remained a mystery. Speculations ranged from the Soviets' attempt to disable or interrupt communication signals from American electronic listening devices, to energizing electronic snooping gadgets

that may have been implanted in the building prior to American occupancy, to influencing the psychological states or brainwashing embassy staff.

At the time, Soviet publications and scientific understanding concerning microwave interaction with animal behavior and neurophysiology, including the central nervous system, were replete with accounts of direct effects of low-level microwave exposure on animals and humans [8, 9]. There was also broad interest in clinical and hygienic or public-health findings, especially under occupational conditions. Most of the reported hygienic effects were of the nature of subjective complaints, commencing two to five years after the start of work involving microwave radiation. Specific categories included "asthenic syndrome," characterized by depression, fatigue, headache, irritability, loss of appetite, and memory. Another category, "autonomic syndrome," featured fainting spells, heart enlargement, and pulse and pressure liability. The third group, "diencephalic syndrome," was represented by digestive abnormality, insomnia, and sexual dysfunction.

This episode harkens back to 1952, when American diplomatic security personnel discovered a tiny electronic eavesdropping device in the American Ambassador's Moscow office [10]. It was concealed inside a carved Great Seal of the US given by the Soviets to the US Ambassador to Moscow in 1945. The Ambassador proudly hung it in the embassy. It was a passive RF transponder-type sensor: a predecessor of current-day RFID sensor technology, activated by RF energy launched from an external source, which allowed Soviet agents to eavesdrop on secret conversations for seven years before detection. From that point on, the embassy was under periodic surveillance for electronic signals. There thus was a distinct reason for the discovery of the microwave signal at the embassy complex on Tchaikovsky Boulevard back in 1953.

In any case, according to reports, when Ambassador Stoessel learned about the microwave signal, he threatened to resign unless the embassy community was informed. As a result, existence of the microwave signal was finally made public in a press conference called by the Ambassador in 1976. Still, the embassy community felt betrayed about being kept in the dark for so long [6].

It is conceivable that more of the embassy community were anxious about the effect the microwave signal might be having on their health, especially since the US Congress enacted the Radiation Control for Health and Safety Act in 1968 [11]. The deliberations had highlighted a general lack of current scientific knowledge on biological effects and health implications of both ionizing and non-ionizing radiation exposure, and unveiled the considerable amount of unnecessary radiation that people were exposed to each year, including microwaves.

The US Congress had declared then that the public's health and safety must be protected from the dangers of radiation from electronic products. *The act* authorized the

federal government to set *radiation* standards, monitor compliance, and undertake research. It directed the US Department of Health, Education and Welfare to establish and carry out an electronic product radiation control program designed to protect the public's health and safety from radiation emitted by electronic products, including microwaves.

An immediate benefit of Stoessel's press conference was the installation of metallic screens on the embassy's outer windows to provide a substantial degree of shielding against microwave penetration through windows into the building [5]. The nominal screening efficiencies were about 1,000 to 100,000, depending on such factors as mesh size and type of materials.

Furthermore, while apparently unknown to the embassy staff, other activities were already underway. The US government had initiated a research program, code named "Operation Pandora," at the Walter Reed Army Institute of Research. Herb Pollack, a physician, Joseph Sharp, a behavioral psychologist, and Mark Grove, a microwave electronics engineer, were principals [10]. The program subjected trained Rhesus monkeys to microwave exposures, mimicking characteristics gathered by monitors at the Moscow embassy. Microwave-induced interruption in the monkey's performance for food was studied in a classic operant-conditioning experimental protocol. The study was terminated in 1969. Reported findings included some microwave irradiation associated "aberrant behavior." However, agreement on an unambiguous consensus for behavioral psychological changes was not reached among project personnel.

Apparently, soon after the highly publicized press conference where existence of the Moscow Embassy microwave signal was finally made public in 1976, a two-year epidemiological research was initiated by the US Department of State at Johns Hopkins University, near Washington DC [12-14]. The study involved 1,827 employees and 3,000 dependents at the Moscow Embassy, and 2,561 employees and 5,000 dependents at comparable other US Foreign Service posts in the Soviet bloc as a control population, namely, Belgrade, Budapest, Leningrad, Prague, Sophia, Warsaw, and Zagreb, during the period from 1953 to 1975. The control or comparison group was chosen to match the study group in selection criteria and environmental factors such as climate, diet, disease, and general social milieu, except that the postings were not subjected to microwave irradiation.

The purpose was to assess any differences in morbidity and mortality between the Moscow and comparison groups. Extensive efforts were devoted to identify and trace the populations. Information on illness, conditions, or symptoms was gathered and validated. Death certificates were used to ascertain mortality. Standardized mortality ratios and morbidity indices for various groups were developed for the study. At completion of the study in

1978, the investigators' conclusion was that the Moscow and comparison groups did not significantly differ in overall and specific mortality, and no compelling evidence was observed to implicate the Moscow microwave signal in any adverse health effect. Nevertheless, investigators had noted that the study population was relatively young, and it might have been too early to detect long-term health and mortality outcomes.

The most perplexing question remains: what was the Soviets' purpose in microwaving the Moscow embassy?

At a later point, there was an indication that the Soviets had suggested it was a jamming signal calculated to thwart US electronic spying devices. This is a plausible but simplistic rationalization; however, the signal strengths were rather weak for jamming maneuvers.

One possibility is that the Soviets were using microwaves to activate numerous snooping devices they had implanted in the building prior to American occupancy. This obviously was an expected scenario, given the success of the bug concealed in the carved Great Seal, especially for the reason that electronic fabrication capability had advanced by leaps and bounds since 1945. However, ever since discovery of the Great Seal bug, surveillance for electronic signals had become routine at the embassy complex.

Another intriguing proposition was that the Soviets were bouncing the microwave signal off the embassy's window glass in an attempt to eavesdrop on conversations taking place inside the office. The theory was as follows: conversation-generated sound waves would set the glass window pane into tiny vibrations, which does happen, in principle. Reflection of the microwave signal impinging on the window pane would be modulated by the vibrations in amplitude and phase, which might then be electronically demodulated to reproduce conversations taking place inside the office. While feasible, there are technological challenges in converting the faint electronic signals to voice, although it is not impossible. At best, the reflected microwave intensity would be down about 90% while also being in a potentially noisy electronic operating environment. Nevertheless, given the demonstrated sophistication of the Great Seal bug from an earlier period, it could be well within the Soviets' capability.

Finally, it might have been a designed exploitation of the Soviet understanding of how prolonged exposure to low-level microwaves affects the mental state of exposed subjects. If that was the intent, the Moscow microwave signal indeed may have accomplished its intended purpose, in part. The embassy staff clearly showed anxiety after learning about the existence of the microwave signal. They were concerned about potential health effects the microwave signal might be having on them or their children. It became somewhat of a morale problem for a time.

References

- 1. J. C. Lin, "Potential Game Changer for Mobile Phone Radio Frequency Radiation Carcinogenesis," *URSI Radio Science Bulletin*, No. 358, 2016, pp. 120-122.
- 2. J.C. Lin, "The NIEHS/NTP Study to Evaluate the Toxic and Carcinogenic Potential of Mobile Phone RF Radiation," *URSI Radio Science Bulletin*, No. 359, 2016, pp. 48-50.
- 3. M. Wyde, M. Cesta, C. Blystone, S. Elmore, P. Foster, M. Hooth, G. Kissling, D. Malarkey, R. Sills, M. Stout, N. Walker, K. Witt, M. Wolfe, J. Bucher, "Report of Partial findings from the National Toxicology Program Carcinogenesis Studies of Cell Phone Radiofrequency Radiation in HSD: Sprague Dawley rats (Whole Body Exposure)," bioRxiv, doi: http://dx.doi.org/10.1101/055699, May 26, 2016.
- 4. P. Brodeur, "Microwave I," *The New Yorker*, December 13, 1976, pp. 50-110, and "Microwave II," December 20, 1976, pp. 43-83.
- 5. New York Times, "Walter J. Stoessel Jr. Dies at 66; A Former Ambassador to Moscow," *New York Times*, December 11, 1986.
- C. Sibilla, "Microwaving Embassy Moscow, Moments in U.S. Diplomatic History," Association for Diplomatic Studies and Training http://adst.org/2013/09/microwaving-embassy-moscow/and http://adst.org/2013/09/ microwaving-embassy-moscow-another-perspective/ accessed July 20, 2017.
- S. M. Michaelson and J. C. Lin, Biological Effects and Health Implications of Radiofrequency Radiation, New York, Plenum, 1987, Chapter 20
- 8. I. R. Petrov (ed.), *Influence of Microwave on the Organisms of Man and Animals*, Washington DC, NASA, 1972.
- 9. J. C. Lin, "Early Contributions to Electromagnetic Fields in Living Systems" J. C. Lin (ed.), *Advances in Electromagnetic Fields in Living Systems*, New York, Plenum, 1994, pp. 1-25.
- 10. Congressional Record, May 16, 1972. https://www.cia.gov/library/readingroom/.../CIA-RDP80-01601R000300340036-6.pdf, accessed on July 20, 2017.
- 11. Public Law 90-602, 90th Congress, H.R. 10790, October 18, 1968: An Act, to Amend the Public Health Service Act to Provide for the Protection of the Public Health from Radiation Emissions from Electronic Products, Washington, DC, 1968.

- 12. U.S. Senate, Microwave Irradiation of the U.S. Embassy in Moscow, Committee on Commerce, Science, and Transportation, U.S. Government Printing Office, April (43-949), Washington, DC 1979.
- 13. C. Silverman, "Epidemiologic Studies of Microwave Effects," *Proceedings of the IEEE*, **68**, 1, 1980, pp. 78-84.
- 14. S. M. Michaelson and J. C. Lin, *Biological Effects and Health Implications of Radiofrequency Radiation*, New York, Plenum, 1987, Chapter 19.

Women in Radio Science



Asta Pellinen-Wannberg Umeå University, Department of Physics and Swedish Institute of Space Physics S-90187 Umeå, Sweden Tel: +46 90 786 7492

E-mail: asta.pellinen-wannberg@umu.se

From Science to Management

Lee-Anne McKinnell

South African National Space Agency PO Box 32 Hermanus, 7200, South Africa E-mail: Imckinnell@sansa.org.za

y career path in radio science seemed to start mostly by accident. However, I was probably programmed from birth to where I eventually found myself. I had always intended to be an engineer, and was brought up with electronics as the natural field to be in. When it came time to select a university, I chose a field that combined science and engineering, ending up at Rhodes University in Grahamstown, South Africa, doing an undergraduate degree in Physics and Electronics.

The Physics Department at Rhodes had a strong radio science interest, with an active ionospheric physics group. By the time I was in my honors year, I had

already started to engage in those activities. I received my PhD in Space Physics from Rhodes University in 2003 for a thesis entitled, "The Development of a Neural Network Based Ionospheric Model for the Bottomside Electron Density Profile Over Grahamstown, South Africa." The thesis work cemented the role that I would play in the radio-science arena over the next decade, in the areas of ionospheric physics and space weather.



After my PhD, I completed a postdoctoral year as a research fellow in the Graz University of Technology in Austria. This was an amazing experience, and made me a strong believer in the value of postdoctoral fellowships. My postdoctoral project was on the use of neural networks for modeling the lower ionosphere (D layer), utilizing incoherent-scatter-radar data and rocketbased measurements. One of the most amazing experiences for me was assisting on a Norwegian project and visiting the EISCAT radar. It was my first and only experience of the Northern Lights, and the power of science in general and space weather in particular has been with me ever since.

After returning to South Africa, I was offered a joint appointment as a Researcher with Rhodes University and the Hermanus Magnetic Observatory (HMO). The HMO was a national facility of the National Research Foundation (NRF). It was a dream job, as I had the best of both worlds: academic life focusing on research that I loved and aspired to do, and student development. I am extremely passionate

about student development, and had an active group of students and postdoc fellows from all over Africa working with me on various aspects of ionospheric modeling. I also became integrated into the URSI community, having been the recipient of an URSI Young Scientist Award twice (1996 and 1999), and regularly attending the URSI General Assemblies. I have attended every URSI General Assembly between 1996 and 2017 (a total of eight in a row). I am also very involved in the National URSI Committee of South Africa, first as the representative for Commission G, and in recent years as the Chair of the Committee.

Through my research interests, I also became a contributor and member of the International Reference Ionosphere (IRI) Working group, which is a joint working group of URSI and COSPAR. Several model developments that my group worked on where incorporated into the IRI, and I was Chair of the group for four years, from 2010 to 2014.

During the period between 2004 and 2010, I sat on a number of international committees and published extensively. I received a B3 rating from the South African NRF, which indicated international recognition for my research. Over the years, I like to believe that I contributed to the space-research focus in South Africa, bringing the concept of a space-weather capability to the country as well as developing capability in this scarce skills area.

My research focus was also in assisting with the development of capability within Africa through active collaborations with Nigeria, Zambia, and Kenya. I also supervised a number of students from different countries within Africa. A major project for me was in June 2009, when I co-chaired the Local Organizing Committee for the International Heliophysical Year (IHY)-Africa 2009 Workshop, held in Livingstone, Zambia. This workshop aimed to promote an awareness of Space Science in Africa, and assist African space scientists to develop international contacts in the field.

In 2009, I was fortunate to receive three awards, including the African Union Regional Women Scientist Award for Basic Science, Technology and Innovation in the Southern African Region, and a Department of Trade and Industry (DTI) 2009 Technology award in the Advanced High Technology Category for the industry linked project "Ionospheric Model: Phase 5."

In 2007, I started to move towards management of science. In 2010, I was asked to lead the HMO through a migration process to the newly established South African

National Space Agency (SANSA). SANSA became operational on April 1, 2011, and I accepted the position of Managing Director for the Space Science program (essentially the new version of the HMO). Rhodes University offered me a Visiting Research Professorship that allowed me to continue supervising students, even though I had moved permanently to SANSA.

Eventually, after struggling to balance both research and management, I realized that I needed to be either a good researcher or a good director, but that there was no way I could be good at both. A key aspect was the opportunity to make a difference. So, in 2013, I registered for an MBA with the Business School Netherlands. This was a wonderful learning experience for me, coming from a science background. I graduated with my MBA in September 2015. During the past decade I have led a number of successful research, science-advancement and infrastructure-funding proposals, and I have tried to mentor and nurture talent within the fascinating world of radio science and space. I miss the pure-research side of things. However, I take strength in the fact that I am able to influence focus and policy that will allow many young researchers in South Africa to grow the country's knowledge economy.

Currently, I am the Managing Director for Space Science within the South African National Space Agency (SANSA). The position involves providing both strategic direction and operational oversight to the space science program and facility located in Hermanus, South Africa. In South Africa, space science is defined as the area between the sun and the Earth and everything in between, referred to as the near-Earth space environment, as well as the impact of solar activity on Earth systems. The space-science program is responsible for research, infrastructure, and products related to the near-Earth space environment, and so, although I am not undertaking research myself these days, I am still able to influence and direct focus areas in space science for the organization and nationally. One of the leading focus areas for the next few years will be the "operationalizing" of space-weather models to provide robust reliable prediction and forecast products to various sectors. SANSA has embraced this move, and is currently putting things in place to ensure an operationalized environment for its space-weather center. This will involve moving our focus to a more regional focus, and steering our research towards the eventual operational requirements. Both the area of space weather as well as the directing of research for the African continent have always been passions of mine, and I look forward to playing a significant role in these areas in the future.







INTERNATIONAL SYMPOSIUM ON ELECTROMAGNETIC THEORY (EMTS 2019)

May 27-31, 2019, San Diego, CA, USA

First Call For Papers

The International Symposium on Electromagnetic Theory (EMTS 2019) will be held May 27-31, 2019, in San Diego, CA, USA. It is organized by Commission B (Fields and Waves) of the International Union of Radio Science (URSI), and is financially cosponsored by the United States National Committee for URSI (USNC-URSI) and the IEEE Antennas and Propagation Society (IEEE AP-S). EMTS 2019 is the 23rd event in the triennial series of international EMT symposia, which has a long history since 1953. Its scope covers all areas of electromagnetic theory and its applications. It is the major scientific event of Commission B, along with the URSI General Assembly and Scientific Symposium, Atlantic Radio Science Conference (AT-RASC), and Asia Pacific Radio Science Conference (AP-RASC). The venue is the hotel Westin San Diego, which is minutes from downtown activities including the San Diego Zoo, Balboa Park and its numerous museums, and the Gaslamp district for dining and nightlife. San Diego is the eighth largest city in USA, and is often referred to as "America's Finest City." Known for its great hotels, beautiful weather, pristine beaches, friendly people, and a plethora of entertainment, San Diego is a favorite destination for visitors across the globe. The San Diego airport is conveniently close to our symposium venue, so transportation to the conference will be quick and easy.

Welcome to San Diego in May 2019! The conference will offer plenary talks by distinguished speakers, regular oral and poster sessions, and a one-day school for young scientists (May 27), focusing on a topic in electromagnetics. A number of Young Scientist Awards will be offered, covering the registration fee and accommodation during the conference. In addition, business meetings, receptions, and a conference banquet will be organized. EMTS 2019 will focus on electromagnetic fields and their applications. Contributions on any aspect of the scope of Commission B are solicited. Some suggested topics are listed below. Special-session topics will be listed later on the Web site. All submissions (two to four pages in IEEE two-column format) will be reviewed by the Commission B Technical Advisory Board. Accepted and presented papers may be submitted to IEEE Xplore.

Important dates

- Paper submission site opens: July 15, 2018
- Deadline for paper submission: October 22, 2018
- Notification of acceptance: January 10, 2019
- Early-bird and author registration ends: March 30, 2019

Contact: Technical Program: Kazuya Kobayashi <kazuya@tamacc.chuo-u.ac.jp> Local Organizing Committee: Sembiam Rengarajan <srengarajan@csun.edu>

Suggested Topics

1. Electromagnetic theory

- Analytical and semi-analytical methods
- Mathematical modeling
- Canonical problems
- Scattering and diffraction
- Inverse scattering and imaging

2. Computational methods

- Integral equation methods
- Partial differential equation methods
- High-frequency and hybrid methods
- Fast solvers and high-order methods
- Time-domain techniques
- Computational algorithms

3. Materials and wave-material interaction

- Metamaterials and metasurfaces
- Plasmonics and nanoelectromagnetics
- Electromagnetic bandgaps and other periodic structures

- Optical devices
- EMC and EMI
- · Bioelectromagnetics

4. Antennas and propagation

- Antenna theory
- Antenna measurements
- Multi-band and wideband antennas
- Antenna arrays and MIMOs
- Wireless communication systemsGuided waves and structures
- Random media and rough surfaces
- Millimeter wave/5G propagation
- Millimeter-wave antennas
- MIMO for 5G communication

5. Other topics

- History of electromagnetics
- Education in electromagnetics

www.emts2019.org

Early Career Representative Column



Stefan J. Wijnholds
Netherlands Institute for Radio Astronomy
Oude Hoogeveensedijk 4
7991 PD Dwingeloo, The Netherlands
E-mail: wijnholds@astron.nl

Associate Editor's Introduction

At the triennial occasion of the General Assembly and Scientific Symposium (GASS), URSI acknowledges scientific achievements in the field of radio science by awarding outstanding individuals with a number of URSI awards. Two of those awards are "early career" awards, meaning that they are awarded to a young scientist not more than 35 years old on September 30 of the year preceding the URSI GASS. These early career awards are the Issac Koga Gold Medal and the Santimay Basu Prize.

The Santimay Basu Prize is awarded to a young scientist who has made an outstanding contribution to research that furthers the understanding of radiowave propagation in random media and its application for the benefit of society. The award takes into account the excellence of the research, the merit of the candidate in achieving his or her results, and the efforts required to accomplish the research. At the

2017 URSIGASS in Montreal, the Santimay Basu Prize was presented to Dr. Jamesina Simpson with the citation, "For advancing three-dimensional finite-difference time-domain (FDTD) solutions of electromagnetic wave propagation within the global Earth-ionosphere waveguide applied to space weather, remote-sensing, and very-low-frequency propagation."

The Issac Koga Gold Medal is awarded to a young scientist who has made an outstanding contribution to any of the branches of science covered by the Commissions of URSI. The award is for career achievements of the candidate, with evidence of significant contributions within the most recent six-year period. At the 2017 URSI GASS in Montreal, the Issac Koga Gold Medal was presented (Figure 1) to Dr. Yue Li with the citation, "For contributions to the development of electromagnetic metamaterial circuits and antenna designs in mobile communication systems." It is a great pleasure to put Dr. Li in the spotlight in an interview in this column.

Interview with Yue Li: Winner of the 2017 URSI Issac Koga Gold Medal

hat was your educational background?

Although I did not get a good grade in the college entrance examination, I was quite fortunate to be the last student (with the lowest grade) enrolled by Zhejiang University, a famous Chinese University in the field of engineering. To prove I was not the worst student, I worked hard in the university and won the qualification of Tsinghua University as a graduate student in 2007. Tsinghua University is the best university in China, and it is a big challenge to graduate. I joined the microwave group

of Prof. Zhenghe Feng, who became my PhD supervisor. There, my major was microwave antenna design. After I finished the PhD degree in 2012, I stayed in the same group and started the new topic of metamaterials and circuit design. In December 2013, I joined the group of Prof. Nader Engheta at the University of Pennsylvania, in pursuit of new techniques of fields and waves with a wide range of optics such as metamaterials and nanophotonics. In January 2016, I returned to Tsinghua University as an Assistant Professor.

How would you describe your career so far?

With challenges, but interesting and meaningful. The experiences at the University of Pennsylvania and Tsinghua University had taught me how to think about science and technology, how to develop new concepts, and how to apply them in practical engineering. The curiosity of science always pushes me to learn new topics. There are challenges, but your passions will help you to overcome these hurdles. Being an Assistant Professor in Tsinghua University is an interesting career, and you will not easily predict what you will do in the next five years. You are always learning new things and creating new things.

How did you become interested in your current research field?

My current research field is technologies in electromagnetics, including antennas, circuits, and metamaterials. The amazing physics behind this applied science made me become interested in this field. You should imagine that by engineering different metallic or dielectric structures, we can control and tame the electromagnetic fields and waves. For example, you can design an antenna to totally radiate in one direction, rather than omni-directionally, or you can tune the scattering light at will just using a layer of metal. Such counterintuitive phenomena fascinate me in pursuit of the technologies in electromagnetics.

What motivates you in your field of study?

The difference between pursuing novelties in theory and engineering. For an engineering department, we may focus more on how to put a new technique into practical usage, such as solving new problems, application to new environments, or designing new structures. But for theoretical innovation, a new concept or a new phenomenon is more important, with strict theoretical analysis, numerical simulations, and ideal experiments. The motivation for my research is to overcome this difference, to develop new theory and apply it in practical systems or devices. Challenges are always there, but this is my goal, creating new concepts from theory to engineering.

Which challenges have you faced during your career?

In the field of electromagnetics, the topics are quite wide and you need to learn a lot of new concepts. For instance, you need to learn techniques from dc to RF, and from microwaves to optics. You also need to learn fabrication processes and measurements. Learning new things always comes with challenges, but if you are passionate about it, it is quite interesting.

What is the current "hot field to study" in your area, and what do you think it will be in the future?

In my opinion, the circuit concepts inspired by metamaterials form a promising topic in the field of electronics and optics. As we know, integrated-circuit techniques change our daily life as we use such lumped circuits in electronic devices, such as computers, mobile phones, and so on. However, existing circuit techniques only operate up to a few gigahertz, i.e., microwave range, which limits the signal-processing rate and wireless-data-transfer speed. If we can achieve the integrated-circuit idea in the optical domain, we may easily design a supercomputer with the dimensions of a cell phone, and we may transfer an HD movie in just one second. However, the materials hindered the development of such great circuits in the optical domain, as we no longer have metal or less-dispersive dielectrics in the optical domain. Even though nature did not provide the materials we need, we can artificially design materials with such properties, and this is the motivation for the topic of metamaterials. Based on the concept and advanced design of metamaterials, we may translate the techniques from the microwave range to the optical range, leading to the development of new technologies and theories. Among them, the lumped-circuit design is the most significant in the optical domain, not only to design components and devices at sub-wavelength scale, but to increase the rates of signal processing and data transfer. Wireless communication will come to a new generation.

What fascinates you most in your current position?

The new ideas in science and technology, the smart students, and the creative colleagues. The most fascinating moment is the feasibility of a new idea, which is successfully published in a paper or adopted in engineering projects.

Which achievements earned you the Issac Koga Gold Medal?

I think there were three contributions for the Koga Gold Medal.

First, there was the idea of lumped circuitry inside a waveguide, also named "waveguide metatronics." Based on this idea, we can design lumped circuits using waveguide metamaterials in different ranges, such as the microwave domain, the terahertz domain, and the optical domain, breaking the limitations of material selections.

Second, the development of photonic doping, which transplants the doping idea from the microscopic scale to the macroscopic scale. We can easily control the magnetic properties of an epsilon-near-zero medium by tuning the parameters of an inserted dielectric rod, such as the diameter and permittivity. This is also a new paradigm of metamaterials without using periodic structures.

Third, for the contribution to mobile antenna design. In this topic, advanced techniques of multiple-domain cooperation (such as the spatial, time, and frequency domains) are used to design multiple antennas within a small volume, with the merits of high isolation, small dimensions, and omnidirectional radiation. Such ideas can be adopted in the design of mobile-phone antennas, base-station antennas, and access-point antennas.

Which opportunities/persons have been instrumental for your career so far?

There are three persons with a significant impact on my career. The first two I met in my graduate-student pursuits in the microwave group of the Department of Electronic Engineering at Tsinghua University. I met my supervisor, Prof. Zhenghe Feng, and my co-supervisor, Prof. Zhijun Zhang. They brought me into the antenna world. They were experienced professors in microwave techniques, and taught me how to find and solve problems in practical projects. By accumulating experience in engineering, I can find new problems from the engineering point of view. The third person I met during my days in Prof. Nader Engheta's group in the University of Pennsylvania. Prof. Engheta is a scientific giant in the field of metamaterials and nanophotonics. He taught me how to theoretically solve a problem and helped me to think theoretically. These three great professors taught me not only in science and technologies, but also how to be a good person. They started my career of academic life.

What do you hope to achieve in the coming years?

First, as a professor, I hope to successfully teach. In my class of antennas and metamaterials, I hope more students will become interested in such areas, and I can help them to do research on these topics.

Second, I hope my research will have good progress. We have lots of interesting ideas, but need to prove them theoretically and experimentally. I hope my group members will have more great achievements in the fields of antennas and metamaterial-inspired circuits.

What advice would you give to students or early-career researchers?

I am also an early-career researcher. I am glad to share some experience with other early-career researchers, and also with students. At the beginning, everything is tough, and we need to be optimistic, even though the reality is different. We may have to face more failures than successes. We need to maintain our passion. The joy of discovery in science and technology comes from passion. Even though you choose a "cold" area, passion will lead you to excellent research and great achievements. Please believe your passion, which will be leading you to get your goals.

A Short Biography of Yue Li

Yue Li received his BS in Telecommunication Engineering from Zhejiang University, Zhejiang, China, in 2007, and his PhD in Electronic Engineering from Tsinghua University, Beijing, China, in 2012. He is currently an Associate Professor in the Department of Electronic Engineering at Tsinghua University. In June 2012, he was a Postdoctoral Fellow in the Department of Electronic Engineering, Tsinghua University. In December 2013, he was a research scholar in the Department of Electrical and Systems Engineering, University of Pennsylvania. He was also a visiting scholar at the Institute for Infocomm Research (I2R), A*STAR, Singapore, in 2010, and at the Hawaii Center of Advanced Communication (HCAC), University of Hawaii at Manoa, Honolulu, HI, USA, in 2012. Since January 2016, he has been with Tsinghua University.

He has authored and coauthored over 80 journal papers and 30 international conference papers, and holds 15 granted Chinese patents. His current research interests include metamaterials, plasmonics, electromagnetics, nanocircuits, mobile and handset antennas, MIMO and diversity antennas, and millimeter-wave antennas and arrays. He was the recipient of the Issac Koga Gold Medal at the URSI General Assembly and Scientific Symposium in 2017; the Second Prize of Science and Technology Award of China Institute of Communications in 2017; the Best Student Paper Award (Third Prize) from APCAP 2017; the Young Scientist Award from URSI AP-RASC 2016; the Young Scientist Award from EMTS 2016; the Best Student Paper Award form ICMMT 2016; the Best Paper Award form ISAPE 2016; the Young Scientist Award from URSI GASS in 2014; the Outstanding Doctoral Dissertation of Beijing Municipality in 2013; and the Principal Scholarship of Tsinghua University in 2011. He serves as an Associate Editor of the IEEE Transactions on Antennas and Propagation and the IEEE Antennas and Wireless Propagation Letters.



Figure 1. The Issac Koga Gold Medal being presented to Dr. Yue Li (r) by Prof. Kazuya Kobayashi during the opening ceremony of the 2017 URSI GASS in Montreal, Canada.

Report on IEEE RADIO 2017

Prof. Weng Cho Chew, IEEE Antennas and Propagation Society (AP-S) President Elect 2018, officially opened the fifth edition of the 2017 IEEE Radio and Antenna Days of the Indian Ocean (IEEE RADIO 2017) international conference (Figure 1). This was held at the Protea Hotel by Marriott Cape Sea Point, Cape Town, South Africa, from September 25-28, 2017. The conference was organized by the Radio Society (Mauritius), and financially sponsored by IEEE AP-S. IEEE RADIO 2017 was technically cosponsored by the Union Radio Scientifique Internationale (URSI) and IEEE Region 8.

The local organizing committee consisted of researchers from CentraleSupélec, France; Université de La Réunion; University of Mauritius; and Square Kilometre Array (SKA) Africa. We were grateful to SKA Africa, Newton Fund, Development in Africa for Radio Astronomy (DARA), Mobile & Wireless Forum (MWF), and Computer Simulation Technology (CST) for providing financial sponsorship for the conference.

IEEE RADIO 2017 gathered participants from over twenty different countries, coming from all five continents. The conference featured twelve regular sessions, covering diverse topics such as radio astronomy, antenna design, wave propagation and scattering, couplers, waveguides and

resonators, wireless communication systems, devices and circuits, computational electromagnetics, and biological effects and medical applications of electromagnetic fields. A first workshop was dedicated to the important SKA project, and a second workshop addressed the technical and financial implications of counterfeit devices. Several internationally recognized scientists delivered invited talks during the conference.

In line with the previous editions, the oral presentations of young scientists and students were evaluated by a jury. A cash prize of 300 Euros and a shield were awarded to the Best Young Scientist less than 36 years old. Moreover, three cash prizes of 300 Euros, 200 Euros, and 100 Euros as well as shields were awarded to the first, second, and third best student papers, respectively.

The next edition of the RADIO international conference will be held on the beautiful island of Mauritius in 2018.

Vikass Monebhurrun General Chair, IEEE RADIO 2017 E-mail: vikass.monebhurrun@centralesupelec.fr



 $Figure 1. \ The opening ceremony of IEEE \, RADIO \, 2017 \, on \, Monday, September \, 25, 2017.$

USNC-URSI Student Paper Winners

The US National Committee of URSI held its annual National Radio Science Meeting January 3-6, 2018, in Boulder, Colorado. The winners of the Student Paper Contest at the meeting were as follows:

First Prize: Yahya Mohtashami (Figure 1)

"A Balun-Free Hybrid Helix/Monopole Antenna for

Microwave Ablation"

University of Wisconsin, Madison

Prize amount: \$1000

Second Prize: Daisong Zhang (Figure 2)

"A Novel Flexible Electro-Textile 3T MRI RF Coil Array for Stroke Prevention: Design, Characterization and

Prototyping"

University of California, Los Angeles

Prize amount: \$750



Figure 2. Daisong Zhang (c) won the Second Prize in the USNC-URSI Student Paper Contest.

Third Prize: Wenyang Li (Figure 3)

"Comparison Redundant and Sky Model Based Interferometric Calibration: A First Look with Phase II

of the MWA" Brown University Prize amount: \$500



Figure 1. Yahya Mohtashami (c), winner of the First Prize in the USNC-URSI National Radio Science Meeting Student Paper Contest is shown with USNC-URSI Chair Sembiam Rengarajan (l) and Erdem Topsakal (r), Chair of the Student Paper Contest.



Figure 3. Wenyang Li (c) won the Third Prize in the USNC-URSI Student Paper Contest.



ISAPE 2018

The 12th International Symposium on Antennas, Propagation and EM Theory December 3 - 6, 2018, Hangzhou, China www.meeting.org/isape2018

ISAPE, a serial symposium on antennas, propagation, and EM theory, always offers an active forum for exchanging creative ideas and experiences on the latest developments and designs in the areas of antennas, propagation, and electromagnetic theory for professors, researchers, engineers, and excellent students all over the world. The 12th International Symposium on Antennas, Propagation and EM Theory, ISAPE 2018, will be held in Hangzhou, China. All prospective papers in the areas of antennas, propagation, electromagnetic theory, computational electromagnetics, and EMC are welcome. All accepted papers will be indexed by the INSPEC database and EI Compendex. Paper submission deadline: September 1, 2018

SUGGESTED TOPICS

A. Antennas & Related Topics

- A1. Microstrip & Printed Antennas
- A2. Active & Integrated Antennas
- A3. Array Antennas, Phased Arrays and Feeding Circuits
- A4. Small Antennas
- A5. Adaptive & Smart Antennas
- A6. Multi-Band/Wideband Antennas
- A7. Wire & Slot Antennas
- A8. Aperture Antennas & Feeds
- A9. Millimeter Wave & Sub-Millimeter Wave Antennas
- A10. Optical Technology in Antennas
- A11. Antennas in Mobile Communication
- A12. Antenna Measurements
- A13. FSS, Polarizers & Radomes
- A14. Reconfigurable Antennas & Arrays
- A15. Reflector/Lens Antennas & Feeds
- A16. Others

B. Propagation & Related Topics

- B1. Mobile & Indoor Propagations
- B2. Mobile Channel Characterization & Modeling
- B3. Millimeter & Optical Wave Propagation
- B4. Earth-Space & Terrestrial Propagation
- B5. Radio Meteorology
- B6. Remote Sensing
- B7. SAR Polarimetry & Interferometry
- **B8.** Tunnel Propagation
- B9. Propagation in Ionized and Non-Ionized Media
- B10. Radio Astronomy
- B11. Ionospheric Modification
- B12. Tropospheric, Stratospheric and Ionospheric Sounding
- B13. Incoherent Scatter Radar & Observations
- B14. Others

C. EM Theory & Related Topics

C1. Bioelectromagetics

- C2. EM Fields in Complex Media
- C3. Geo-Electromagnetics
- C4. Theoretical Electromagnetics & Analytical Methods
- C5. Transient EM fields
- C6. High-Frequency Techniques
- C7. Nonlinear electromagnetics
- C8. Random Media & Rough Surfaces
- C9. Waveguiding Structures
- C10. Time-Domain Techniques
- C11. Inverse Problems & Imaging
- C12. Scattering, Diffraction, & RCS
- C13. Metamaterials & Electromagnetic Bandgap Structures
- C14. Measurement Techniques
- C15. Nano-Electromagnetics
- C16. Seismo-Electromagnetics
- C17. Others

D. Computational Electromagnetics

- D1. Integral Equation Methods
- D2. Differential Equation Methods
- D3. Hybrid Techniques
- D4. Optimization Techniques for CEM
- D5. Asymptotic & High-Frequency Techniques
- D6. Low-Frequency Electromagnetics
- D7. Computational Bioelectromagnetics
- D8. Pre- & Post-Processing
- D9. Nondestructive Techniques
- D10. NEC Modeling & Analysis
- D11. FEKO Modeling & Analysis
- D12. CST Modeling & Analysis
- D13. MEFiSTo Modeling & Analysis
- D14. Object-Oriented Computational Electromagnetics
- D15. Transmission-Line Theory
- D16. Others

E. Electromagnetic Compatibility & Related Topics

- E1. Probe & Sensor
- E2. Absorbing Materials
- E3. Test Chambers
- E4. EMC Test & Measurement
- E5. Coupling & Crosstalk

- E6. EMC Standards
- E7. EM Environment
- E8 Automotive EMC
- E9. EM Bioeffects
- E10. EMC in Communications
- E11. EMC in Power Engineering
- E12. Lightning, ESD & EMP
- E13. EMC in Computer & PCBs
- E14. Shielding, Filtering & Grounding
- E15. EMC in Microelectronics
- E16. Immunity & Susceptibility
- E17. Spectrum Management
- E18. EMI Prediction Analysis & Reduction Technique
- E19. EMC Education
- E20. Others

F. Others

- F1. High-Power Microwave Applications
- F2. UWB & Impulse Applications
- F3. Ubiquitous Network Systems
- F4. Satellite Communication Systems
- F5. Radio Technologies for Intelligent Transport Systems
- F6. Subsurface Sensing
- F7. MEMS-NEMS & MMIC
- F8. Passive & Active Circuits
- F9. Power Amplifiers, Linearization, &
- Active Components
- F10. Millimeter Wave & Sub-
 - Millimeter Wave Components, Circuits & Systems
- F11. Signal Processing for
 - Communications
- F12. Advanced Process, Packaging & Integration Technologies
- F13. 3D RF Technology
- F14. Electromagnetic Materials
- F15. Electromagnetic Environment Effects (E3)
- F16. Earthquake Precursors & Monitoring

F17. THz Technology

Sponsor: Chinese Institute of Electronics (CIE). Cosponsors: CIE Radio Propagation Society, CIE Antenna Society Local Organizer: Hangzhou Dianzi University. Working Language: English. Paper Submission: See the conference Web site:

www. meetingcn.org/isape2018

URSI Conference Calendar

March 2018

Gi4DM 2018

Kyrenia, Turkish Republic of Northern Cyprus, 14-18 March 2018

Contact: K2 Conference and Event Management Kosuyolu Mh. Ali Nazime Sk. No: 45 Kosuyolu 34718 Kadikoy / Istanbul Phone: +90 (216) 428 95 51 - Fax: +90 (216) 428 95 91 E-mail: gi4dm@k2-events.com, http://www.gi4dm2018.org

8th VERSIM Workshop

Apatity, Russia, 19-23 March 2018

Contact: Dr. Andrei Demekhov <u>andrei@appl.sci-nnov.ru</u> <u>http://www.iugg.org/IAGA/iaga_ursi/versim/</u>

Geolocation and navigation in space and time

The URSI-France 2018 Workshop *Paris, France, 28-29 March 2018* Contact: http://ursi-france.org/

May 2018

Baltic URSI Symposium (part of Microwave Week 2018)

Poznan, Poland, 14-16 May 2018

Contact: Prof. Dr. Andrzej Napieralski, Baltic URSI Symposium 2018 Chairman & Dr Przemysław Sękalski, http://mrw2018.org/ursi2018/national-ursi-2018-topics/

AT-RASC 2018

Second URSI Atlantic Radio Science Conference

Gran Canaria, Spain, 28 May – 1 June 2018 Contact: Prof. Peter Van Daele, URSI Secretariat, Ghent University – INTEC, Technologiepark-Zwijnaarde 15, B-9052 Gent, Belgium, Fax: +32 9-264 4288, E-mail address: E-mail: peter.vandaele@intec.ugent.be, http://

www.at-rasc.com

July 2018

COSPAR 2018

42nd Scientific Assembly of the Committee on Space Research (COSPAR) and Associated Events

Pasadena, CA, USA, 14 - 22 July 2018

Contact: COSPAR Secretariat (cospar@cosparhq.cnes.fr) http://www.cospar-assembly.org

August 2018

Metamaterials 2018

12th International Congress on Artificial Materials for Novel Wave Phenomena

Espoo, Finland, 27-30 August 2018

Contact: http://congress2018.metamorphose-vi.org/

October 2018

COMPENG

2018 IEEE Workshop on Complexity in Engineering

Florence, Italy, 10-12 October 2018

Contact: compeng2018@ino.cnr.it, http://compeng2018.iceesezioneitalia.it/

RADIO 2018

IEEE Radio and Antenna Days of the Indian Ocean 2018

Mauritius,15-18 October 2018

Contact: http://www.radiosociety.org/radio2018/

ISAP 2018

2018 International Symposium on Antennas and Propagation

Busan, Korea, 23-26 October 2018 Contact: http://isap2018.org/

November 2018

APMC

Asia-Pacific Microwave Conference 2018

Kyoto, Japan, 6-9 November 2018 Contact: http://www.apmc2018.org/

LAPC 2018

Loughborough Antennas and Propagation Conference

Loughborough, United Kingdom, 12-13 November 2018 Contact: Poppy Seamarks, Tel: +44 (0)1438 767 304, Fax: +44 (0)1438 765 659, Email: lapc@theiet.org

https://events.theiet.org/lapc/

March 2019

C&RS "Smarter World"

18th Research Colloquium on Radio Science and Communications for a Smarter World

Dublin, Ireland, 8-9 March 2019

Contact: Dr. C. Brennan (Organising Cttee Chair) http://www.ursi2016.org/content/meetings/mc/Ireland-

2017-CRS Smarter World CFP.pdf

AP-RASC 2019

2019 URSI Asia-Pacific Radio Science Conference

New Delhi, India, 9-15 March 2019

Contact: Prof. Amitava Sen Gupta, E-mail: sengupto53@

yahoo.com

May 2019

EMTS 2019

2019 URSI Commission B International Symposium on Electromagnetic Theory

San Diego, CA, USA, 27-31 May 2019

Contact: Prof. Sembiam R. Rengarajan, California State University, Northridge, CA, USA, Fax +1 818 677 7062,

E-mail: srengarajan@csun.edu

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- ABD-ALHAMEED, Dr. R.A., School of Electrical Engineering & Computer Science, University of Bradford, Chesham B3.13, B3.19B, West Yorkshire BD7 1DP, UNITED KINGDOM, Tel. +44 (0) 1274 232323/4033, E-mail R.A.A.Abd@Bradford.ac.uk (110)
- ADIMULA, Prof. I.A., Physics Department, University of Ilorin, Ilorin, NIGERIA, Tel. 234 802 629 2655, E-mail iaadimula@hotmail.com (113)
- AGUILERA, Mr. R., Centro de Estudios Espaciales, Universidad de Chile, Casilla 411-3, SANTIAGO 3, CHILE, Tel. +562-5568382, Fax +562-8441003 (108)
- AIKIO, Dr. A., Dept. of Physical Sciences, University of Oulu, PO Box 3000, FI-90014 OULU, FINLAND, Tel. +358 8 5531 363, Fax +358 8 5531 287, E-mail Anita. Aikio@oulu.fi (109)
- AJEWOLE, Prof. O., Department of Physics, Federal University of Technology, Pmb 704, 340001 Akure, NIGERIA, Tel. 234 803 455 0871, E-mail oludare. ajewole@futa.edu.ng, oludareajewole61@yahoo.com (108)
- AKGÜL, Dr. T., Dept. of Electronics and Communications Engineering, Telecommunications Division, Istanbul Technical University, 80626 Maslak Istanbul, TURKEY, Tel. +90 212 285 3605, Fax +90 212 285 3565, E-mail tayfunakgul@itu.edu.tr. (114)
- AKSUN, Prof. I., College of Engineering, Koc University, Rumelifeneri Yolu, 34450 Sarıyer Istanbul ,TURKEY, Tel. +90 212 338 1539, Fax +90 212 338 1548, E-mail iaksun@ku.edu.tr (106)
- AL-BADRANI, Mr. M., Director, Directorate of International Cooperation, KACST, P.O Box 6086, RIYADH 11442, SAUDI ARABIA, Tel. +966 1 481 3384, Fax +966 1 481 3441, E-mail int_coop@kacst. edu.sa, mbadrani@kacst.edu.sa (113)
- AL-RAJEHI, Dr. A., Astronomy and Geophysics Research Institute, King Abdulaziz City for Science & Technology, P. O. Box 6086, RIYADH 11442, SAUDI ARABIA, Tel. +966 1 481 3535, Fax +966 1 481 3526, E-mail arrajehi@kacst.edu.sa (106, 108, 109, 110)
- ALENCAR, Prof. M.S. de, Centro de Ciencias e Tecnologia, Departamento de Engenharia Eletrica, Universidade Federal de Campina Grande, Av. Aprigio Veloso 882, Bodocongo, 58109-970 Campina Grande, BP, BRASIL, Tel. + 55 83 3310 1122, E-mail malencar@iecom.org. br (107)
- ALENCAR, Prof. Luiz, Pontificia Universidade Catolica do Rio de Janeiro, Centro Técnico-Cientifico, Centro de Estudos em Telecommunicações, CETUC-PUC/Rio, Rua Marquês de S. Vicente 225, Gavea, 22453-900 Rio de Janeiro, BRAZIL, Tel. +55 21 31141618, E-mail smello@cetuc.puc-rio.be (106)
- ALOMAINY, Dr. A., Engineering Building, Queen Mary, University of London, Mile End Road, London E1

- 4NS,UNITED KINGDOM, Tel. +44 020 7882 3324, E-mail a.alomainy@gmul.ac.uk (106)
- ALSUSA, Dr. E., School of Electrical & Electronic Engineering, University of Manchester, Oxford Road, Manchester M13 9PL, UNITED KINGDOM, E-mail E.Alsusa@manchester.ac.uk (107)
- ALTADILL, Mr. D., Observatorio del Ebro, Crta. Observatori, No. 8, E 43520 Roquetes, Spain, E-mail david_altadill@obsebre.es, daltadill@obsebre.es (112)
- ALTAN, Prof. O., ITU Civil Engineerin, Faculty Division of Photogrammetry 3,,4469 Maslak Istanbul, TURKEY, E-mail oaltan@itu.edu.tr (112)
- ALTINTAS, Prof. A., Dept. of Electr. & Electronics Eng., Bilkent University, Faculty of Engineering, , 06533 Bilkent ANKARA, TURKEY, Tel. +90 312 290 1489, Fax +90 312 266 4192, E-mail altintas@ee.bilkent.edu. tr, info@ursi.org.tr (113)
- ALVAREZ, Prof. H., Departamento de Astronomia, Universidad de Chile, Casilla 36-D, SANTIAGO 16, CHILE, Tel. +56 2-229 4002, Fax +56 2-229 4101, E-mail halvarez@das.uchile.cl (110)
- AMBROSINI, Dr. R., Institute of Radioastronomy, INAF, Via Gobetti 101, 40129 BOLOGNA, ITALY, E-mail r.ambrosini@ira.inaf.it (110)
- AMBROZIAK, Dr. S.J., Department of Radio CommunicationSystem and Networks, Gdansk University of Technology, 11/12 Narutowicza Street, 80-233 Gdansk, POLAND, Tel. 48516470737, Fax 48583472232, E-mail sj_ambroziak@eti.pg.gda.pl (112)
- AMMANN, Dr. M., School of Electronic & Communications Engineering, Dublin Institute of Technology, Kevin Street, DUBLIN 8, IRELAND, Tel. +353 1 4024905, Fax +353 1 4024690, E-mail max.ammann@dit.ie (109,110)
- ANANTHAKRISHNAN, Prof. S., Electronic Science Department, Pune University, Ganeshkhind, PUNE 411007, INDIA, Tel. +91 20 2569 9841, Fax +91 20 65214552, E-mail subra.anan@gmail.com (105,108)
- ANDERS, Prof. J., Institute of Microelectronics, University of Ulm, Albert-Einstein-Allee 43, 89081 Ulm, GERMANY, E-mail jens.anders@uni-ulm.de (107)
- ANDERSEN, Prof. J. Bach, Aalborg University, Inst. of Electronic Systems, Center for Personal Communication, Niels Jernes Vej 12, DK-9220 AALBORG EAST, DENMARK, Tel. +4598314213, E-mail jba@es.aau.dk (110)
- ANDO, M., Prof., Senior Executive Director, National Institute of Technology, 701-2, Higashi Asakawa, Hachioji, Tokyo 193-0834, Japan, Tel:+81-42-662-3123, Fax: +81-42-662-3131 E-mail: ando@kosen-k.go.jp, mando@antenna.ee.titech.ac.jp (105,114)

- ANG, Prof., R; L-K, Singapore University of Technology and Design, Block 3 Level 5, Room 01, 8 Somapah Road, Singapore 487372, SINGAPORE, Tel. +65 6499-4558, E-mail ricky ang@sutd.edu.sg (109)
- ANGELSEN, Prof. B.A.J., Department of Circulation and Medical Imaging, NTNU, N-7487 TRONDHEIM, NORWAY, Tel. +4791 320934, E-mail bjorn.angelsen@ntnu.no (110)
- ARIKAN, Dr. F., Faculty of Engineering, Haceteppe University, Beytepe, Ankara, TURKEY, Tel. +312 297 7095, Fax +312 299 2125, E-mail arikan@hacettepe. edu.tr (109)
- ARMSTRONG, Dr. T.R., Measurement Standards laboratory, Industrial Research Limited, P.O. Box 31-310, Lower Hutt, NEW ZEALAND, Tel. +64 4 931 3199, Fax +64 4 931 3194, E-mail t.armstrong@irl. cri.nz (106)
- ARNAUT, Prof. L.R., School of Electronic Engineering and Computer Science, Queen Mary University of London, Mile End Road, E14FZ London, UNITED KINGDOM, Tel. +44 20 78826125, E-mail luk.arnaut@googlemail.com, l.arnaut@qmul.ac.uk (111)
- AROGUNJO, Prof. A.M., Department of Physics, Federal University of Technology, Akure, NIGERIA, Tel. 234 703 655 5992, E-mail arogmuyi@yahoo.com (110)
- ARTHABER, Dr. H., Institute of Electrodynamics, Microwave and Circuit Engineering, Vienna University of Technology, Gusshausstrasse 25/354, 1040 Vienna, AUSTRIA, Tel. +43 1 58801 35 420, Fax +43 1 58801 935 420, E-mail holger.arthaber@tuwien.ac.at (106)
- ASGHARI, Assoc. Prof. H., Electrical Engineering and Computer Science, Seaver College of Science and Engineering, Doolan Hall 205, Los Angeles, CA, USA, E-mail masghari@lmu.edu (107)
- ASSIS, Prof M.S., Rua Coelho Neto, 17 Ap.301, Laranjeiras, 22231-110 Rio de Janeiro, Brazil, Tel. +55 21 255 29487, E-mail msassis@openlink.com.br (108)
- ASTIN, Dr. I., Department of Electronic and Electrical Engineering, University of Bath, Room 2 East 4.2, Claverton Down, Bath BA27AY, UNITED KINGDOM, E-mail I.Astin@bath.ac.uk (108)
- ATALAR, Prof. E., Aysel Sabuncu Brain Research Center, Bilkent University, Bilkent, Ankara 06800, TURKEY, Tel. 0090 312 290 3272, E-mail ergin@ee.bilkent.edu. tr (110)
- ATTIA, Prof. A., Electronic Research Institute, Dokki, Giza, EGYPT, E-mail _attiya@eri.sci.eg (108)
- AZANA, Prof. J., Énergie Matériaux Télécommunications Research Centre, , 800, De La Gauchetière Ouest Bureau 6900, Montréal (Québec) H5A 1K6, CANADA, E-mail azana@emt.inrs.ca (107)
- AZI, Dr. S.O., University of Benin, Benin City, NIGERIA, Tel. 234 803 239 5000, E-mail soazi1@yahoo.co.uk (107)
- BAAN, Prof. W.A., ASTRON, Asserweg 45, 9411 LP Beilen ,NETHERLANDS, Tel. +31 521-595 773/100, Fax +31 521-595 101, E-mail baan@astron. nl (105,111,114)

- BAARS, Dr J.W.M., mm-astronomy, Max Planck Institute for Radio Astronomy, Auf dem Hügel 69, 53121 Bonn, Germany, Tel. +49-228-525303, E-mail jacobbaars@arcor.de (114)
- BÄCKSTRÖM, Dr. M., Saab AB, SE-58188 LINKÖPING, SWEDEN, Tel. +46 734 18 15 12, Fax +46 13 18 55 20, E-mail mats.backstrom@saabgroup.com (111)
- BAE, Dr. S-H, Deputy Director (Principal Research Officer), 29 Wonhyoro 41 gil, Yongsangu, Seoul, 140-848, South Korea, Tel. +82 2 710 6527, Fax +82 2 710 6449, E-mail joseph@msip.go.kr (109)
- BAGGALEY, Prof. W.J., Department of Physics and Astronomy, University of Canterbury, Private Bag, CHRISTCHURCH 1, NEW ZEALAND, Tel. +64 3-364-2558, Fax +64 3-364-2469, E-mail jack. baggaley@canterbury.ac.nz (109)
- BAMFORD, Dr. R.A., Department of Physics, University of Oxford, Parks Road, Oxford OX1 3PU, UNITED KINGDOM, Tel. +44 1235 446517, E-mail ruth. bamford@physics.ox.ac.uk (109)
- BATISTA, Dr. I.S., INPE Instituto Nacional de Pesquisas Espaciais, , Av. dos Astronautas 1758, Jd. da Granja, 12227-010 Sao José dos Campos, SP, BRAZIL, Tel. +55 12 39456000 (109)
- BENCZE, Prof. P., Geof. Kut. Labor, MTA (Hungarian Academy of Sciences), Csatkai E. u. 6, H-9400 SOPRON, HUNGARY, Tel. +36 99-314291, Fax +36 99-313267 (109)
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- BEUNZA, Eng. O.M., Cnel. Ramon L. Falcon 1535, 3rd floor, Apt. A, C1407GND BUENOS AIRES, ARGENTINA, Tel. +541-772-1471, Fax +5411 4776 0410, E-mail postmast@caerce.edu.ar (108)
- BILITZA, Dr. D., Space Weather Laboratory, George Mason University, 4400 University Drive, Fairfax VA 22030-444, USA, Tel. +1 301 286-0190, Fax +1 301 286-1771, E-mail dieter.bilitza-1@nasa.gov, dbilitza@gmu.edu (112)
- BITTENCOURT, Dr. J.A., INPE Instituto Nacional de Pesquisas Espaciais, Av. dos Astronautas 1758, Jd. da Granja, 12227-010 Sao José dos Camos, S.P,BRAZIL, Tel. +55 12-39456000, E-mail jabittencourt@hotmail. com (109)
- BLANC, Dr. E., Analyse Surveillance Environnement, Commissariat Energie Atomique, P.O. Box 12, 91680 BRUYERES LE CHATEL, FRANCE, Tel. +33 169 26 49 96, Fax +33 169 26 71 30, E-mail elisabeth.blanc@cea.fr (109)
- BLUMBERG, Prof. Dan G., Ben-Gurion University of the Negev, P.O.B. 653, Beer-Sheva 84105, ISRAEL, Tel. +972-8-6472009, E-mail Blumberg@bgu.ac.il (108)
- BOCK, Dr D., Assistant Director Operations, CSIRO Astronomy and Space Science, Australia telescope National Facility, PO Box 76, EPPING, NSW 1710, AUSTRALIA, Tel. +61 2 9372 4276, Fax +61 457 552 777, E-mail Douglas.Bock@csiro.au (110)

- BOGENFELD, Dr. E., Deutsche Telekom AG, T-Labs (Research & Development), Wireless Technologies & Networks, Deutsche-Telekom-Allee 7, D-64295 DARMSTADT, GERMANY, Tel. +49 (0)6151 58 35834, Fax +49 (0)391 580216 938, E-mail eckard. bogenfeld@telekom.de (113)
- BOLAS, Prof. T.E., LCDR, DITIC, Rua do Arsenal, 1149-001 LISBOA, PORTUGAL, Tel. +351 9177 44 784, E-mail ludovico.bolas@marinha.pt (109)
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- BORTNIK, Dr J., 201 Warwick Lane, Leonia, New Jersey 07605, USA, Tel. (626) 354-0480, Fax (310) 206-5219, E-mail jbortnik@gmail.com (112)
- BÖSCH, Prof. W., Institut für Hochfrequenztechnik, Graz University of Technology, Inffeldgasse 12, 8010 Graz, AUSTRIA, Tel. +43 316 873 3300, E-mail wbosch@ tugraz.at (107)
- BOSKA, Dr. J., Institute of Atmospheric Physics, Academy of Sciences of Czech Republic, Bocni II-1401, PRAGUE 4 141 31, CZECH REPUBLIC, Tel. +420 272 016 065, Fax +420 272 762 528, E-mail boska@ufa.cas.cz (109)
- BRADLEY, Prof. R. F., Technology Center, National Radio Astronomy Observatory, 1180 Boxwood Estate Road, VA 22903 Charlottesville, USA, Tel. +1 434-296-0291, Fax +1 434-296-0324, E-mail rbradley@ nrao.edu (110,111)
- BRAZIL, Prof. T., School of Electrical & Electronic Engineering, University College Dublin, Room 237, Engineering Building, DUBLIN 4, IRELAND, Tel. +353 1 716 1929, Fax +353 1 283 0921, E-mail Tom. Brazil@ucd.ie (107)
- BREINBJERG, Prof. O., Department of Electrical Engineering, Technical University of Denmark, Ørsteds Plads, Building 348, DK-2800 Kgs. LYNGBY, DENMARK, Tel. +45 4525 3814, Fax +45 4588 1634, E-mail ob@elektro.dtu.dk (106,113)
- BREKKE, Prof. A., Institute for Physics and Technology, University of Tromso, N-9037 TROMSO, NORWAY, Tel.+4777645167, E-mail asgeir.brekke@uit.no (109)
- BRENNAN, Dr. C., School of Electronic Engineering, Dublin City University, DUBLIN 9, IRELAND, Tel. +35317007649, E-mail BrennanC@eeng.dcu.ie (108)
- BRYNILDSEN, Ms. N., Institute of Theoretical Astrophysics, P.O. Box 1029 Blindern, N-0315 OSLO, NORWAY, Tel. +47 22 856502, Fax +47 22 856505, E-mail nilsbr@astro.uio.no ()
- BUI, Dr., E-mail buivp@ihpc.a-star.edu.sg (106)
- BULLETT, Dr. T., Cires, Noaa/ngdc, University of Colorado, 325 Broadway E/GC2, Boulder, CO 80305, USA, Tel. 303-497-4788, E-mail Terry.Bullett@noaa. gov (111)
- CALLEGARO, Dr. L., INRIM, Strada delle Cacce 91, 10135 Torino, ITALY, Tel. 011 391 94 35, E-mail l.callegaro@inrim.it (106)

- CANNON, Prof. P.S., Gisbert Kapp Building, University of Birmingham, Edgbaston, Birmingham B15 2TT, UNITED KINGDOM, Tel. +44 (0)168 4540026, Fax +44 (0)121 414 4323, E-mail p.cannon@bham.ac.uk, president@ursi.org (105, 114)
- CAO, Dr., Space Science Institute, Beihang University, 37, Xueyuan Road, Haidian District, 100191 Beijing, China, Tel. 86.10.62582644, Fax 86.10.82338856, E-mail jbcao@buaa.edu.cn (109)
- CAPSALIS, Prof. C., Division of Information Transmission Systems and Material Technology, School of Electr. and Comp. Engineering, National Technical University of Athens, Iroon Polytechniou 9, GR-15773 ATHENS, GREECE, Tel. +30 210 772 3517, Fax +30 210 772 2281, E-mail ccaps@central.ntua.gr (108)
- CAPSONI, Prof. C., Dept. Elettronica, Informazione e Bioingegneria (DEIB), Politecnico di Milano, Via Ponzia, 34/5, 20133 MILAN, ITALY, Tel. 02 23993572, E-mail capsoni@elet.polimi.it (108)
- CARLSSON, Dr. J., Provinn AB, P.O. Box 2220, SE-403 14 Göteborg, SWEDEN, Tel. +46 736 55 20 48, E-mail jan.carlsson@provinn.se (106)
- CARLSSON, Dr. O., Wrap International, Tanneforsgatan 8, SE-582 24 Linköping,SWEDEN, E-mail olov. carlsson@wrap.se (108)
- CAROBBI, Prof. C., Dip. Ingegneria dell'Informazione, University of Florence, Via Santa Marta 3, Florence, ITALY, Tel. 0552758501, E-mail carlo.carobbi@unifi. it (113)
- CARVALHO, Prof., Instituto de Telecomunicacoes, Universidade de Aveiro, Campus Universitario, 3810-193 Aveiro, PORTUGAL, Tel. +351 234377900, Fax +351 234377901, E-mail nbcarvalho@ua.pt, nbcarvalho@av.it.pt (106,114)
- CERDEIRA, Dr. R.P., ESA-ESTEC, TEC-EEP, Postbus 299, 2200 AG NOORDWIJK, NETHERLANDS, Tel. +31 71 565 8658, E-mail roberto.prieto.cerdeira@esa. int (109)
- CHANDRA, Prof. Dr. M., Chairholder for Microwave Engineering and Photonics, Chemnitz University of Technology, Reichenhainer Strasse 70, D-09126 CHEMNITZ, GERMANY, Tel. +49 (0)371 531 33168, Fax +49 (0)371 531 8 33168, E-mail madhu. chandra@etit.tu-chemnitz.de, mahdu.chandra@gmx. de (108,111)
- CHANDRASEKAR, Prof. V., Engineering B117, Colorado State University, Fort Collins, Colorado 80523, USA, Tel. +1 970 491 7981, Fax +1 970 491 2249, E-mail chandra@engr.colostate.edu, chandra.ve@gmail.com (108)
- CHANG, Prof. D-C, , Oriental institute of Technology, 58,Sec.2,Sihchuan Rd.,Pan-Chiao City, Taipei County 22061,TAIWAN, E-mail dcchang@mail.oit.edu.tw (106)
- CHANG, Prof H-C, Department of Electrical Engineering, National Taiwan University, Room 513, Taipei 106-17, Taiwan, Tel. +886-2-23635251 ext., Fax +886 2 23637363, E-mail hungchun@ntu.edu.tw (106)

- CHAU, Dr. Jorge L., Jicamarca Radio Observatory, Instituto Geofisico del Peru, Apartado 13-0207, LIMA 13, PERU, Tel. +51 1-3172313, Fax +51 1-4344563, E-mail chau2iap@gmail.com (109)
- CHÁVEZ MUÑOZ, Ing. D., Departamento de Ingenieria, Universidad Católica del Perú, Grupo de Telecomunicaciones Rurales, Av.Universitaria 1801, San Miguel, LIMA 32, PERU, Tel. +51-1-626-2452, Fax +51-1-626-2116, E-mail dehavez@puep.edu.pe (107)
- CHEN, Prof. K-S, Center for Space and Remote Sensing Research, National Central University, No. 300, Jung-da Road, Jhongli City, TAOYUAN 320, CHINA (SRS), Tel. +886-3-4227151 ext7617, Fax +886-3-4273586, E-mail chenks@radi.ac.cn (108)
- CHERPAK, Prof. N.T., A. Usikov Institute of Radiophysics and Electronics, NASU, 12, ac. Proskura Str., KHARKOV 61085, UKRAINE, Tel. +380 57 7203363, Fax +380 57 3152105, E-mail cherpak@ire.kharkov. ua (108)
- CHINEKE, Dr. T.C., Department of Physics and Industrial Physics, Imo State University, Owerri, Imo State, NIGERIA, Tel. 234 803 722 9905, E-mail chidiezie@yahoo.com (106)
- CHOI, Prof. J., Department of Electronics Convergence Engineering, Kwangwoon University, Wolgae-dong, Npwon-gu, Seoul, 139-703, SOUTH KOREA, Tel. +82 2 940 5298, Fax +82 2 916 9270, E-mail jinchoi@ kw.ac.kr (109)
- CHRISSOULIDIS, Prof. D.P., Division of Telecommunications, Dept. of Electrical and Computer Eng., Aristotle University of Thessaloniki, P.O. Box 1562, GR- 54124 THESSALONIKI, GREECE, Tel. +30 231 099 6334, Fax +30 231 099 6334, E-mail dpchriss@eng.auth.gr (108)
- CHU, Prof. Y-H, Secretary General Office, National Central University, No. 300, Jungda Road, CHUNG-LI, TAOYUAN 320, CHINA (SRS), Tel. +886 3-4227151 ext. 57010, Fax +886 3-4254842, E-mail yhchu@jupiter. ss.ncu.edu.tw (109)
- CHUKWUMA, Dr. V.U., Department of Physics, Olabisi Onabanjo University, P.O. Box 351, Ago Iwoye, NIGERIA, Tel. 234 805 507 5270, E-mail uzodinmachukwuma@gmail.com (106)
- CHUN, Prof. J., Department of Electrical Engineering, Korea Advanced Institute of Science & Technology, 291 Daehak-ro, Yusong-gu, Daejeon 305-701, SOUTH KOREA, Tel., Fax 042 350 8057, E-mail chun@kaist. ac.kr (107)
- CLARK, Prof. A.R., School of Electrical and Information Eng., University of Witwatersrand, Room CM4-236, 3050 WITS, SOUTH AFRICA, Tel. +27 11 717 7223, Fax +27 11 403 1929, E-mail alanrobertclark@gmail. com (106)
- CLEMENTE, Dr. Pais, Director Serviço Otorrinolaringologia, Faculdade De Medicina Do Porto, Hospital De São João porto, Porto, Portugal, Tel. +351217212201, E-mail pais.clemente@gmail. com (110)

- CLERICI, Dr. M., School of Engineering, University of Glasgow, Rankine Building, Oakfield Avenue, R624, Glasgow G12 8QQ, UNITED KINGDOM, E-mail Matteo.Clerici@glasgow.ac.uk (107)
- CLETTE, Dr. F., Observatoire Royal de Belgique, 3, avenue Circulaire, B-1180 Bruxelles, Belgium, Tel. (322) 373-0233, Fax (322) 374-9822, E-mail frederic. clette@oma.be (110)
- CLILVERD, Dr. M.A., British Antarctic Survey, High Cross, Madingley Road, CAMBRIDGE, CB3 0ET, UNITED KINGDOM, Tel. +44 1223 221541, Fax +44 1223 221226, E-mail macl@bas.ac.uk (112)
- COHEN, Dr. L., Radar Division, Naval Research Laboratory, 4555 Overlook Ave. S.W., Washington, DC 20375, USA, Tel. +1 202 404 7726, E-mail Lawrence. Cohen@nrl.navy.mil (108)
- COFFEY, Ms. M., Programme Manager, Royal Irish Academy, 19 Dawson Street, Dublin D02 HH58,IRELAND, E-mail M.Coffey@ria.ie (113)
- CUPIDO, Prof. L., IPFN Aveiro, Instituto de Telecomunicações Polo de Aveiro, Campus Universitario de Santiago, P- 3810-193 AVEIRO, PORTUGAL, Tel. +351 23 437 02 00, E-mail cupido@ua.pt (110)
- D'INZEO, Prof. G., DIET, University of Rome "La Sapienza", Via Eudossiana, 18, I-00184 ROME, ITALY, Tel. +39 06 4458 5853, Fax +39 06 4742 647, E-mail dinzeo@die.uniroma1.it (110)
- DANILOV, Prof. V.V., Radiophysical Department, T. Shevchenko Kiev National University, 2 Glushkova avenue, Building 5, KIEV 03127, UKRAINE, Tel. +380 44 5260551, E-mail danilov@univ.kiev.ua (107)
- DANKLMAYER, Dr. A., Millimetre Wave Radar And High Frequency Sensors, Fraunhofer FHR, Neuenahrer Str. 20, 53343 Wachtberg, Germany, Tel. +49 228 9435 350, E-mail Andreas. Danklmayer@fhr.fraunhofer.de (111)
- DATTA-BARUA, Dr., ASTRA, 12703 Spectrum Drive, San Antonio, TX, 78249, USA, Tel. (210) 877-9150, Fax (210) 877-9150, E-mail sdattabarua@gmail.com (109)
- DE ARRUDA MELLO, Prof. D.A., FEEC DECOM, Universidade Estadual de Campinas (UNICAMP), AV. Albert Einstein 400 Room 322, 13083-852 Campinas SP, BRAZIL, Tel. +55 19 3521 3808, E-mail darli@decom.fee.unicamp.br (107)
- DE FRANCESCHI, Dr. G., Dept. Aeronomy, Istituto Nazionale di Geofisica e Vulcanologia, Via di Vigna Murata 605, 00 143 Roma,ITALY, Tel. +39 (06) 51860307, Fax +39 (06) 51860397, E-mail giorgiana. defranceschi@ingv.it (109)
- DEHOLLAIN, Dr. C., EPFL, STI, IMM, LEG, ELB-Ecublens, Station 11, CH-1015 LAUSANNE, SWITZERLAND, Tel. +41 21 693 69 71, Fax +41 21 693 36 40, E-mail catherine.dehollain@epfl.ch (107)
- DEMEKHOV, Dr. Andrei G., Institute of Applied Physics, Russian Academy Of Sciences, 46, Ulyanov St., 603950 Nizhny Novgorod, Russia, Tel. +78314364279, Fax 78314160616, E-mail andrei@appl.sci-nnov.ru (109)

- DEMIR, Assoc. Prof. S., Department of Electrical and Electronics Engineering, Faculty of Engineering, Middle East Technical University, Balgat, Ankara 06531, TURKEY, Tel. +90 312 210 2354, Fax +90 312 210 2304, E-mail simsek@metu.edu.tr (108)
- DENIAU, Prof. D., IFSTTAR, 20 rue elisée reclus, 59650 villeneuve d'ascq, FRANCE, Tel. 320438991, E-mail virginie.deniau@ifsttar.fr (108)
- DOHERTY, Prof. P., Co-Director/Research Scientist, Institute for Scientific Research, Boston College, 140 Commonwealth Avenue, CHESTNUT HILL, MA 02467-3862, USA, Tel. +1 617 552 8767, Fax +1 617 552 2818, E-mail Patricia. Doherty@bc.edu (109,111)
- DOMINGUEZ, Eng. N.A., CORCA, , Avenida del Liberta dor 327, 1638 VICENTE LOPEZ, B.A., ARGENTINA, Tel. +54 1-772-1471, Fax +54 11 4776 0410, E-mail postmast@caerce.edu.ar (113)
- DONG, Mr. Q-S, China Research Institute of Radio Wave Propagation, Beijing Research Center, PO Box 6301, 102206 BEIJING, CHINA (CIE), Tel. +863733712001, Fax, E-mail qsdong22s@sina.com (108)
- DUARTE CRUZ, Dr. P.M., Instituto de Telecomunicacoes, Campus Universitario de Santiago, Aveiro 3810-193, PORTUGAL, E-mail pedrocruz82@gmail.com, pedro. cruz@controlar.pt (106,114)
- EHSAN, Dr. N., Code 555, Bldg. 19, Rm. N1, NASA Goddard Space Flight Center, 8800 Greenbelt Rd., Greenbelt, MD, 20771, USA, Tel. +1 301-286-8406, E-mail negar.ehsan@nasa.gov (107)
- EL HENNAWY, Prof. H.S., Faculty of Engineering, Ain Shams University, 77A El Nasr Rd, Nasr City, Cairo, EGYPT, Tel. +202 2682 1800, Fax +202 2685 0617, E-mail hadia.elhennawy@gmail.com, helhennawy@ieee.org (106)
- EL-BADAWY, Prof. H., National Telecommunication Institute, 5 Mahmoud Elmiligy Street, Elhay Elsades, NASR CITY, CAIRO,EGYPT, E-mail Heshamelbadawy@mcit.gov.eg (113)
- EL-HADIDI, Prof. DR. M., Faculty of Engineering, Cairo University, Giza, EGYPT, E-mail hadidi@eun.eg (110)
- EL-KHAMY, Prof. S.E., Dept. of Electrical Engineering, Alexandria University Faculty of Engineering, Abou-Keer Street, ALEXANDRIA 21544, EGYPT, Tel. +2010-1497360, Fax +203 5971853, E-mail elkhamy@ieee.org, said.elkhamy@gmail.com (107)
- ELLENBOGEN, Dr. T., Department of Physical Electronics, School of Electrical Engineering, Tel Aviv University, room 505, Software Engineering Building, TEL AVIV, ISRAEL, Tel. 972-3-640-7372, E-mail tellenbogen@ tauex.tau.ac.il (107)
- ELMIKATY, Prof. DR. H.A., Faculty of Engineering, Mansoura University, , Mansoura, Dakahlia, EGYPT, E-mail h.elmikati@gmail.com (110)
- ELVIDGE, Dr. Sean, Poynting Institute, Gisbert Kapp Building, University of Birmingham, Pritchatt's Road, Edgbaston, Birmingham, B15 2TT, UNITED KINGDOM,Tel.+441214142747,Fax+441214144291, E-mail s.elvidge@bham.ac.uk (109)

- ERGUL, Assoc. Prof. O., Middle East Technical University, Department of Electrical and Electronics Eng., TURKEY, Tel. 905336353612, E-mail ozgur.ergul@eee.metu.edu.tr (114)
- FALLOWS, Dr. R., LOFAR Telescope Scientist Company, ASTRON, DWINGELOO, NETHERLANDS (112)
- FALODUN, Dr. S.E., Department of Physics, Federal University of Technology, AKURE, NIGERIA, Tel. 234 803 353 4973, E-mail sefalodun@futa.edu.ng, besfal@yahoo.com (107)
- FARKAS, Prof. P., Lermontovova 19, 811 05 Bratislava, SLOVAKIA, Tel. +421-2-60 29 18 44, Fax +421-2-68 27 96 01, E-mail farkas@ut.fei.stuba.sk, p.farkas@ieee.org (107)
- FEICK, Dr. R., Depto. de Electronica, Universidad Técnica Federido Santa Maria, Casillo 110 V, VALPARAISO, CHILE, Tel. +56 32-626 364 ext. 209, Fax +56 32-665 010, E-mail rodolfo.feick@usm.cl (107)
- FEJES, Prof I., Moricz zs. u. 16/A, SOLYMAR 2083, HUNGARY, Tel. +36 27 374 980, Fax +36 27 374 982, E-mail fejes@gpsnet.hu (110)
- FERENCZ, Prof. Cs., ELTE Department of Geophysics, Space Research Group, Pazmany Peter setany 1/A, H-1117 BUDAPEST, HUNGARY, Tel. +36 1 209 0555/6652, Fax +36 1 372 2927, E-mail spacerg@sas. elte.hu, csaba@sas.elte.hu (109)
- FICHTE, Dr. Ing. L.O., Ellerhoop 1, D-22885 Barsbuettel, GERMANY, Tel. +49 40 6541 2460, Fax +49 40 6541 2282, E-mail lars-ole.fichte@hsu.hh.de, fichte@ieee. org (110)
- FIGUEIROA, Prof. H.E.H., Department of Microwaves and Optics (DECOM), FEEC, University of Campinas (UNICAMP), Av. Albert Einstein 400 Room 316, 13083 852 Campinas SP, BRAZIL, Tel. +55 19 3521 3735, E-mail hugoehf@gmail.com, hugo@decom.fee. unicamp.br (113)
- FISER, Assoc. Prof. O., Institute of Atmospheric Physics, Academy of Sciences of the Czech Republic, Bocní II 1401, PRAGUE 4 141 31, CZECH REPUBLIC, Tel. +420 272 016 038, Fax +420 272 763 745, E-mail ondrej@ufa.cas.cz (113)
- FOERSTER, Dr., GFZ German Research Centre for Geosciences, Section 2.3 (Earth's Magnetic Field), Helmholtz Centre Potsdam, Telegrafenberg, D-14473 Potsdam, Germany, Tel. +49 (0) 331 288 1776, Fax +49 (0) 331 288 1235, E-mail mfo@gfz-potsdam.de (109)
- FOPPIANO, Dr. A.J., Departamento de Geofísica, Universidad de Concepción, Casilla 160-C, Correo 3, CONCEPCION, CHILE, Tel. +56-41-2203083 o 2204136, E-mail foppiano@udec.cl (109)
- FORSSELL, Prof. B., Department of Electronics and Telecommunications, NTNU O.S., Bragstads plass 2, N-7491 TRONDHEIM, NORWAY, E-mail borje. forssell@iet.ntnu.no (107)
- FRANCHOIS, Prof. A.I., Information Technology (INTEC), Ghent University, Sint Pietersnieuwstraat 41, B-9000 GHENT, BELGIUM, Tel. +32 9 264 89 37, Fax +32 9 264 99 69, E-mail Ann.Franchois@ugent.be (110)

- FRIEDRICH, Dr. M., Communications and Wave Propagation, Technical University Graz, Inffeldgasse 12,8010 GRAZ, AUSTRIA, Tel. +43 316 873 7441, Fax +43 316 463 697, E-mail Martin. Friedrich@tugraz. at (109)
- FROLLO, Prof. I., Institute of Measurement Science, Slovak Academy of Sciences, Dubravska Cesta 9, BRATISLAVA 841 04, SLOVAKIA, Tel. +421 2-591 04 422, Fax +421 2-5477 5943, E-mail frollo@savba. sk (110)
- FRØYSTEIN, Dr. H.A., Justervesenet, Festveien 99, N-2007 Kjeller, NORWAY, Tel. +47 64 848484, Fax +47 64 848485, E-mail haf@justervesenet.no (106)
- FUJISAWA, Dr K., Yamaguchi University, Yoshida 1677-1, Yamaguchi-city, Yamaguchi 753-8511, Japan, Tel. +81-83-933-5973, Fax +81-83-933-5973, E-mail kenta@ yamaguchi-u.ac.jp (110)
- FULLER-ROWELL, Dr T., Cooperative Institute for Research in Environmental Sciences, Univ. of Colorado, NOAA Space Weather Prediction Center, 325 Broadway, Boulder, CO 80305-3328, USA, Tel. +1 303-497-5764, Fax+1 303-497-3645, E-mail tim.fuller-rowell@noaa. gov (114)
- FUSCO, Prof. V.F., ECIT Institute, The Queen's University of Belfast, Northern Ireland Science Park, Queens Road, Queen's Island, BELFAST BT3 9DT, NORTHERN IRELAND, Tel. +44 28 9097 1700, Fax +44 28 9097 1702, E-mail michelle.mccusker@ecit.qub.ac.uk (106)
- GAGLIARDINI, Dr. D.A., Julian Alvarez 1218, 1414 BUENOS AIRES, ARGENTINA, Tel. +541-772-1471, Fax +54 11 4776 0410, E-mail postmast@caerce.edu. ar (108)
- GALKIN, Mr. I., University of Massachusetts Lowell, 600 Suffolk Str, 01862 Lowell, MA,USA, Tel. 978-934-4912, Fax, E-mail Ivan. Galkin@borealis-designs.com, ivan_galkin@uml.edu (111)
- GALLEGO PUJOL, Dr. J.D., Observatorio Astronomico Nacional, Apdo 1143, ALCALA DE HENARES, 28800 MADRID, SPAIN, Tel. +34 91 885 5060, Fax +34 91 885 5062, E-mail gallego@oan.es (108)
- GALOPEAU, Prof. P., LATMOS, Quartier des garennes, 11 boulevard d'Alembert, F-78280 GUYANCOURT,FRANCE, Tel. +33 1 80 28 50 67, E-mail patrick.galopeau@latmos.ipsl.fr (109)
- GAO, Dr. Xian Ke, Institute of High Performance Computing, 1 Fusionopolis Way, #16-16 Connexis, Singapore 138632,SINGAPORE, E-mail gaoxk@ ihpc.a-star.edu.sg (107)
- GAO, Dr., S., SINGAPORE, E-mail gaosp@ihpc.a-star. edu.sg (108)
- GARAVAGLIA, Prof. M., Departamento De Física, Centro De Investigaciones Opticas, Camino Centenario Y 506, Gonnet, CC31897 La Plata, Argentina, Tel. ++ 54 221 471 4341, Fax ++ 54 221 471 4341, E-mail garavagliam@ciop.unlp.edu.ar (107)
- GARBINI, Ing. A., CORCA, Avenida del Liberta dor 327, 1638 VICENTE LOPEZ, B.A., ARGENTINA, Tel. +54 11 4772 1471, Fax +54 11 4776 0410, E-mail postmast@caerce.edu.ar (113)

- GARDNER, Dr. R.L., 6152 Manchester Park Circle, ALEXANDRIA, VA 22310-4957, USA, Tel. +1 703-924-9370, Fax +1 703-313-4179, E-mail Robert.L.Gardner@verizon.net (111)
- GAVAN, Prof. J., Zamenhof 3, Natania 42309, ISRAEL, E-mail gavan@hit.ac.il (108,111)
- GEORGIADIS, Dr. A., Institute of Sensors, Signals and Systems, Heriot-Watt University, Edinburgh EH14 4AS,United Kingdom, E-mail apostolos.georgiadis@ieee.org (107,111)
- GERTSVOLF, Dr. M., Measurement Science and Standards, National Research Council Canada, Building M-23A 1200 Montreal Road, Ottawa, Ontario K1A 0R6, CANADA, E-mail marina.gertsvolf@canada.ca (106)
- GEZICI, Dr. S., Department of Electrical and Electronics Engineering, Bilkent University, Bilkent, Ankara 06800, TURKEY, Tel. +312 290 3139, Fax +312 266 4192, E-mail gezici@ee.bilkent.edu.tr (108)
- GHANDI, Dr., SINGAPORE, E-mail gandhi@ihpc.a-star. edu.sg (110)
- GILMORE, Dr. J., Department of Electrical and Electronic Engineering, Stellenbosch University, , Cape Town Area, SOUTH AFRICA, E-mail jackivdm@sun.ac.za (110)
- GIMM, Prof. Y.M., School of Electronics and Electrical Engineering, Dankook University, Jukjeon-dong 126, Suji-gu, YONGIN-SI 448-701, SOUTH KOREA, Tel. +82 2 793 8732, Fax +82 2 793 1150, E-mail gimm@dku.edu (110)
- GIRALDEZ, Prof. A., LIARA, avda. del Libertador 327, 1638 VICENTE LOPEZ, B.A., ARGENTINA, Tel. +54 1-791-5001, Fax +54 1-776-0410 (109)
- GOUGH, Dr. P.T., Dept. of Electrical and Computer Engineering, University of Canterbury, Private Bag 4800, CHRISTCHURCH 1, NEW ZEALAND, Tel. +64 3364-2297, Fax +643364-2761, E-mail peter.t.gough@gmail.com (107)
- GRADONI , Dr. G., School of Mathematical Sciences, University of Nottingham, University Park, Nottingham NG7 2RD, UNITED KINGDOM, Tel. +44(0)7745368300 , Fax +44(0)1159514951 , E-mail gabriele.gradoni@gmail.com, gabriele.gradoni@nottingham.ac.uk (108,111)
- GRAINGE, Prof. K., School of Physics and Astronomy, The University of Manchester, Room 3.211 Alan Turing Building, Manchester M13 9PL, UNITED KINGDOM, Tel. +44 161 3069507, +44 161 2754690, Fax, E-mail keith.grainge@manchester.ac.uk (110)
- GRANUCCI, Dr. G., Istituto di Fisica del Plasma 'Piero Caldirola', Consiglio Nazionale delle Ricerche, Via Roberto Cozzi, 53, 20125 Milano, ITALY, Tel. 02 661 73 266, E-mail granucci@ifp.cnr.it (109)
- GRAY, Dr. A.D., National Research Council Canada, NRC Herzberg, P.O. Box 248, PENTICTON, BC V2A 6J9, CANADA, Tel. +1 250 497 2313, Fax +1 250 497 2355, E-mail Andrew.Gray@nrc-cnrc.gc.ca (113)
- GRONWALD, Professor F., Fakultät IV Elektrotechnik und Informatik, Universität Siegen, Hölderlinstr. 3, 57076 Siegen, Germany, Tel. +49271/740-4417, Fax

- +49-(0)40-42878-2385, E-mail frank.gronwald@unisiegen.de (108,111)
- GUEVARA DAY, Dr. W.R., National Commission on Aerospace Research and Development (CONIDA), , Felipe Villaran 1069, San Isidro, LIMA 27, PERU, Tel. +51 1-4429973, Fax +51 1-4419081, E-mail walter@ conida.gob.pe (109)
- GUHA, Dr D., Electronics & Electrical Communication Engineering, Indian Institute of Technology Kharagpur, West Bengal, 721302, India, Tel. (+91) 3222 283522, Fax (+91) 92313 53055/8697571084, E-mail dguha@ieee.org (106)
- GULYAEV, Prof. S., Auckland University of Technology, Institute For Radio Astronomy And Space Research, Private Bag 92006, 1142 Auckland, NEW ZEALAND, Tel. +64 9 921 9999 ext 8709, 9541, Fax +64 9 921 9973, E-mail sergei.gulyaev@aut.ac.nz (110)
- GULYAEV, Prof. Yu. V., Institute of Radioengineering and Electronics, Russian Academy of Sciences (IRE RAS), 11 Mokhovaya str, MOSCOW 125009, RUSSIA, Tel. +7 495 629 3591, Fax +7 495 629 3678, E-mail gulyaev@cplire.ru, irvermol@gmail.com (110)
- GUO, Dr. H., Director, Center for Quantum Information Technology, Peking University, , Beijing, 100871, CHINA (CIE), Tel. +86 10 6275 7035, Fax +86 6275-7035-3208, E-mail hongguo@pku.edu.cn (107)
- GUTIERREZ DE LA CRUZ, Dr. C.M., Instituto de Astrofisica de Canarias, C/ Via Lactea, s/n, 38205 LA LAGUNA, TENERIFE, SPAIN, E-mail cgc@iac. es (110)
- HABARULEMA, Dr. J.B., Space Science Directorate, South African National Space Agency, P.o Box 32 Hermanus, 7200 Hermanus, South Africa, Tel. +27283121196, Fax +27283122039, E-mail jhabarulema@sansa.org. za (111)
- HÄGGSTRÖM, Dr. I., Headof Operations, EISCATS cientific Association, Box 812, SE-98128 KIRUNA, SWEDEN, Tel. +46 98079155, E-mail ingemar.haggstrom@eiscat. se (109)
- HALEVY-POLITCH, Dr. J., P.O. Box 7205, 31071 HAIFA, ISRAEL, Tel. +972 4-879 4862, Fax +972 4-879 4875, E-mail aeryapo@techunix.technion.ac.il (106)
- HALLIKAINEN, Prof. M.T., Dept. of Radio Science and Engineering, Aalto University, P.O. Box 13000, FI-00076 AALTO, FINLAND, Tel. +358 9 470 22371, E-mail Martti.Hallikainen@aalto.fi (108)
- HAMNERIUS, Prof. Y., Vasagatan 48, SE- 411 37 GÖTEBORG, SWEDEN, Tel. +46 70 308 80 31, E-mail yhamnerius@yahoo.com (110)
- HAN, Dr. S-T, Korea Astronomy & Space Science Institute, 667 Daeduckdae-ro, Yuseong-gu, DAEJEON 305-340, SOUTH KOREA, Tel. +82 42 865 3283, Fax +82 42 865 5610, E-mail sthan@kasi.re.kr (110)
- HASHIMOTO, Dr., Paleological Association of Japan, Inc., 48 Hishiya-cho, Sanjo and Takakura, Nakagyo, 604-813 Kyoto, Japan, Tel. +81-252-3000, Fax +81-252-3001, E-mail kozo@rish.kyoto-u.ac.jp (111)
- HATTORI, Dr. K., Department of Earth Sciences, Faculty of Science, Chiba University, Yaoi, 1-33, Inage, CHIBA

- 263-8522, JAPAN, Tel. +81 43 290 28 01, Fax +81 43 290 28 59, E-mail hattori@earth.s.chiba-u.ac.jp (111)
- HAUPT, Dr. R.L., Brown Building 249, Colorado School of Mines, 1510 Illinois Street, Golden, CO 80401, USA, Tel.+1303 273 3721, E-mail rhaupt@mines.edu (114)
- HE, Prof. R., Room 0512, XueYuan 3 Building, Beijing Jiaotong University, No. 18 JiaoDa East Road, Beijing 100044, CHINA, E-mail ruisi.he@ieee.org (107)
- HELEU, Mrs. Inge, URSI Secretariat, Ghent University
 INTEC, Technologiepark-Zwijnaarde 15, B-9052
 GHENT,BELGIUM, Tel. +32 9-264.33.20, Fax +32
 9-264.42.88, E-mail info@ursi.org (105,114)
- HEITZMAN GABRIELLI, Prof. L., FEEC DECOM, Universidade Estadual de Campinas (UNICAMP), Av. Albert Einstein 400 - Room 328a, 13083-852 Campinas SP, BRAZIL, Tel. +55 19 3521 3813, E-mail lucashg@decom.fee.unicamp.br (113)
- HERAUD, Dr. J., Instituto de Radioastronomia INRAS-PUCP, Pontificia Universidad Catolica del Peru, Av. Universitaria 1801, San Miguel, LIMA 32, PERU, Tel. +51 1 6262000 (ext. 4735), E-mail jheraud@pucp.edu. pe (110)
- HERPIN, Dr. F., Laboratoire d'Astrophysique de Bordeaux, Observatoire Aquitain des Sciences de l'Univers, Allée Geoffroy Saint-Hilaire, CS 50023, F-33615 PESSAC Cedex, FRANCE, Tel. +33540003275, E-mail fabrice. herpin@u-bordeaux.fr, fabriceherpin@yahoo.fr (110)
- HEYMAN, Prof. E., The Iby and Aladar Fleischman Faculty of Engineering, Tel Aviv University, , 69978 TELAVIV, ISRAEL, Tel. +972 3 6408738/8736/8147, Fax +972 3 6407221, (113)
- HJELMSTAD, Dr. J.Fr., Department of Electronics and Telecommunications, NTNU, O.S. Bragstads plass 2, 7491 TRONDHEIM, NORWAY, Tel. +47 45 249613, E-mail jens@hjelmstad.no (108)
- HO, Prof. T.P., Academia Sinica, Institute of Astronomy and Astrophysics, P.O. Box 23-141, TAPEI 106, TAIWAN, Tel. +886 2 33652200 x700, Fax +886 2 23677849, E-mail pho@asiaa.sinica.edu.tw (110)
- HOBARA, Prof. , Dept. Of Communication Eng. And Informatics, The University Of Electrocommunications, 1-5-1, Chofugaoka, 182-858 Chofu, Japan, Tel. +81-424435154, E-mail hobara@ee.uec. ac.jp (111)
- HORESH, Dr. A., Racah Insitute of Physics, The Hebrew University of Jerusalem, , JERUSALEM 91904, ISRAEL, Tel. +972 2 658 48928, E-mail assafh@mail. huji.ac.il (110)
- HOUMINER, Dr. Z., Asher Space Research Institute, Technion, Israel Institute of Technology, 32000 HAIFA, ISRAEL, Tel. +972 4-829 3512, Fax +972 4-823 0956, E-mail zwih@tx.technion.ac.il (109)
- HØEG, Prof. P., DTU Space, Technical University of Denmark, National Space Institute, Department for Geodesy, Juliane Maries Vej 30, 2100 Copenhagen, DENMARK, Tel. +45 3532 5702, E-mail hoeg@space. dtu.dk, per.hoeg@gmail.com (109)
- HUBBARD, Mr. R., EMC/EMF, Eskom Resources & Strategy, Johannesburg, SOUTHAFRICA, Tel. +27 11 629 5236, E-mail roy.hubbard@eskom.co.za (110)

- ILMONIEMI, Prof., Dept. Biomedical Eng. and Computational Science, Aalto University, P.O. Box 12200, FI-00076 AALTO, Finland, Tel. +358 50 5562964, Fax +358 9 470 23182, E-mail risto. ilmoniemi@aalto.fi (110)
- ITO, Prof. K., Center for Frontier Medical Engineering, Chiba University, 1-33 Yayoi-cho, Inage-ku, Chiba-shi 263-8522,Japan, Tel. +81-43-290-3326, Fax +81-43-290-3327, E-mailito.koichi@faculty.chiba-u.jp (110)
- IVANOV, Prof. D.V., Volga State University of Technology, Yoshkar-Ola, RUSSIA, Tel. +7 906 334 7755, E-mail dvivanov77@gmail.com (109)
- JACARD, Prof. B., Depto. de Ingenieria Electrica,Universidad de Chile, Casilla 412-3, SANTIAGO 3,CHILE, Tel. +56 2-698 2071 ext. 204, Fax +56 2-695 3881 (106)
- JANARDHAN, Prof. P., Physical Research Laboratory, Ahmedabad 380009, INDIA, Tel. +91 79 2631 4505, E-mail jerry@prl.res.in (110)
- JAYACHANDRAN, Prof. P.T., Department of Physics, University of New Brunswick, 8 Bailey Drive, P.O. Box 4440, Fredericton, NB E3B 5A3, CANADA, Tel. +1 506 447 3330, Fax +1 506 453 4581, E-mail jaya@ unb.ca (109)
- JIRICKA, Dr. K., Astronomical Institute, Academy of Sciences of the Czech Republic, Fricova 1, ONDREJOV 25165, CZECH REPUBLIC, Tel. +420 323 620 154, Fax +420 323 620 110, E-mail jiricka@asu.cas.cz (110)
- JOHANSSON, Dr. J.F., RUAG Space AB, SE-405 15 GÖTEBORG, SWEDEN, Tel. +46 31 735 4286, Fax +46 31 735 4000, E-mail joakim.johansson@ruag. com (113)
- JONAS, Prof J., Department of Physics and Electronics, Rhodes University, PO Box 94, 6140 GRAHAMSTOWN,SOUTH AFRICA, Tel. +27 46 603 8452, Fax +27 46 622 5049, E-mail j.jonas@ru.ac. za (110)
- KALOUPTSIDIS, Prof. N., Division of Communications and Signal Processing, Dept. of Informatics, University of Athens, TYPA Buildings, Panepistimiopolis, GR-15771 ILISSIA, ATHENS, GREECE, Tel. +30 210 727 5304, Fax +30 210 727 5601, E-mail kalou@di.uoa. gr (107)
- KANELLOPOULOS, Prof. J., Division of Information Transmission Systems and Material Technology, School of Electr. & Computer Eng., National Technical University of Athens, Iroon Polytechniou 9, GR-15773 ATHENS, GREECE, Tel. +30 210 772 3524, Fax +30 210 772 2281, E-mail ikanell@cc.ece.ntua.gr (109)
- KASAHARA, Prof. Y., Information Media Center, Kanazawa University, Kakuma-machi, KANAZAWA 920-1192, JAPAN, Tel. +81 76 234 49 52, Fax +81 76 234 49 52, E-mail kasahara@is.t.kanazawa-u.ac.jp (109)
- KASMI, Dr. C., Laboratoire Sécurité des Technologies Sans Fil, Agence Nationale de la Sécurité des Systèmes d'Information - ANSSI, 51 boulevard de la Tour Maubourg, 75007 Paris, FRANCE, Tel. +333171758493,Fax+333184824060,E-mailChaouki. kasmi@darkmatter.ae (108)

- KASTNER, Prof. R., Dept. Electrical Eng.-Physical Electronics, TelAviv University, 243 Wolfson Electrical Eng Bldg, 62978 TELAVIV, ISRAEL, Tel. +972 3-640 7447, Fax +972 3-642 3508, E-mail kast@eng.tau. ac.il (106)
- KATAMZI, Ms. Z., Space Science, South African National Space Agency (SANSA), P O Box 32, Hermanus 7200, SOUTH AFRICA, Tel. +27 (0)28 312 1196, Fax +27 (0)28 312 2039, E-mail zkatamzi@sansa.org. za (109)
- KATULSKI, Prof. Ryszard J., Radiocommunication Systems and Networks, Gdansk University Of Technology, Narutowicza Street 11/12, PL-80-233 Gdansk, Poland, Tel. +48 58 347 21 08, Fax +48 58 347 25 62, E-mail rjkat@eti.pg.gda.pl (106)
- KELLERMANN, Dr. Na, Nrao, 520 Edgemont Rd., Charlottesville, VA 22903, USA, Tel. 434 296 0240, Fax 434 296 0385, E-mail kkellerm@nrao.edu (112)
- KENDERESSY, Prof. M., Ribary u. 7, H-1022 BUDAPEST, HUNGARY, Tel. +36 1-461-3348 (106)
- KHALIL, Dr. D.A., Faculty of Engineering, Ain Shams University, 1 Elsarayat St. - Abbasia, CAIRO, EGYPT, E-mail Diaa.khalil@ieee.org (107)
- KILIFARSKA, Dr. N., National Institute of Geophysics, Geodesy and Geography (NIGGG), Bulgarian Academy of Sciences, Acad. G. Bonchev St., bl. 3, 1113 SOFIA, BULGARIA, Tel. +359 2 979 3329, E-mail nkilifarska@ geophys.bas.bg (109)
- KILLAT, Prof. Dr. D., Lehrstuhl Mikroelecktronik, Brandenburgische Technische Universitaet Cottbus, Konrad-Wachsmann-Allee 1, D-03046 Cottbus, GERMANY, Tel. +49 (0) 355 692811, Fax +49 (0) 355 69 28 12, E-mail killat@tu-cottbus.de (107)
- KIM, Dr. J.H., Electromagnetic Wave Center, Korea Research Institute of Standards & Science, 267 Gajeongro, Yuseong-gu, DAEJEON 305-340, SOUTH KOREA, Tel. +82 42 868 5170, Fax +82 42 868 5018, E-mail kimjh@kriss.re.kr (106)
- KISHK, Prof. A, Electrical And Computer Engineering, Concordia University, 1455 De Maisonneuve Blvd, H3G 1M8 Montreal, Canada, Tel. 5148482424 ext 3024, E-mail ahmed.kishk@concordia.ca (106)
- KNEE, Dr. Lewis B.G., Herzberg Astronomy and Astrophysics, National Research Council Canada, 5071 West Saanich Road, Victoria BC, V9E 2E7, CANADA, Tel. +1-250-363-3075, E-mail Lewis.Knee@nrc-cnrc. gc.ca, Lewis.Knee@canada.ca (110)
- KNEPPO, Prof. I., Faculty of Special Technology, Alexander Dubcek University of Trencin, Pri parku 19, TRENCIN 911 06, SLOVAKIA, Tel. +421 32 7400 275, E-mail ivan.kneppo@gmail.com (106)
- KNUDE, Dr. J., Astronomical Observatory, University of Copenhagen, Juliane Maries Vej 30, DK 2100 COPENHAGEN, DENMARK, Tel. +45 3532 5986, Fax +45 3532 5989, E-mail indus@astro.ku.dk (110)
- KOBAYASHI, Prof. K., Department of Electrical, and Communication Engineering, Chuo University, 1-13-27 Kasuga, Bunkyo-ku, TOKYO, 112-8551, JAPAN, Tel. +81 3 3817 1846/69, Fax +81 3 3817 1847, E-mail kazuya@tamacc.chuo-u.ac.jp (105,106,113,114)

- KOLMASOVA, Dr. Ing. I., Dpt. Of Upper Atmosphere, Institute Of Atmospheric Physics, Czech Academy of Science, Bocni II 1401, 141 31 Prague 4 Sporilov, Czech Republic, Tel. +420267103081, E-mail iko@ufa.cas.cz (113)
- KOMJATHY, Dr. A., , Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, USA, Tel. +1 818-393-6828, E-mail attila.komjathy@jpl.nasa.gov (109)
- KONOVALENKO, Prof. A.A., Institute of Radioastronomy, NASU, ul. Krasnoznamennaya 4, KHARKOV 61002, UKRAINE, Tel. +380 572-47-1134, Fax +380 572-47-6506, E-mail rian@rian.kharkov.ua (110)
- KORENSTEIN, Prof. R., Physiology And Pharmacology, Tel-Aviv University, Haim Levanon 5000, 69978 TEL AVIV, ISRAEL, Tel. +972 3640 6042, Fax +972 3640 9113, E-mail korens@post.tau.ac.il (110)
- KOSCH, Prof. M.J., Communication Systems, Lancaster University, Alexandra Square, LANCASTER, LA1 4YR, UNITED KINGDOM, Tel. +44-1524-510404, E-mail m.kosch@lancaster.ac.uk (111)
- KOUDELKA, Prof. O., Institute of Communication Networks and Satellite Communications, Graz University of Technology, Inffeldgasse 12, 8010 Graz, AUSTRIA, Tel. +43 316 873 7440, Fax +43 316 873 7941, E-mail koudelka@tugraz.at (107)
- KOYAMA, Prof. Y., Space-Time Standards Group, New Generation Network Research Center, National Institute of Information and Communication Technology (NICT), 4-2-1, Nukuikitamachi, Koganei, TOKYO 184-8795, JAPAN, Tel. +81 42 327 7557, Fax +81-42-3276128, E-mail koyama@nict.go.jp (106)
- KRAJCUSKOVA,Dr.Z.,Fac.ofElectricalEng.&Information Technology, Slovak University of Technology, Ilkovicova 3, BRATISLAVA 812 19, SLOVAKIA, Tel. +421-2-6029 1137, Fax+421-2-6542 9683, E-mail zuza. krajcu@gmail.com (113)
- KRANKOWSKI, Prof. A., University of Warmia and Mazury, ul. Prawochenskiego 9, 10720 Olsztyn, POLAND, Tel. +48 895233836, E-mail kand@uwm. edu.pl (111)
- KRAUS, Dr. A., Max-Planck-Institut fuer Radioastronomie, Radioobservatorium Effelsberg, Max-Planck-strasse 28, D-53902 Bad Muenstereifel-Effelsberg, GERMANY, Tel. +49 (0)2257 301 120, Fax +49 (0)2257 301 105, E-mail akraus@mpifr.de (110)
- KRAWCZYK, Prof. A., Military Institute of Hygiene & Epidemology, 29 Lokalna Street, 04-903, POLAND, Tel. +48 22 8724 282, E-mail ankra.new@gmail.com (110)
- KRIEZIS, Prof. E., Dept. of Electrical and Computer Engineering, Aristotle University of Thessaloniki, , GR- 54124 THESSALONIKI, GREECE, Tel. +30 2310 995920, Fax +30 2310 996312, E-mail mkriezis@auth.gr (107)
- KUCHARSKI, Prof. A., Faculty of Electronics, Wroclaw University of Technology, 27 Wybrzeze, Wyspianskiego Street, 50-370 Wroclaw, POLAND, Tel. +48 71 320 29 12, E-mail andrzej.kucharski@pwr.wroc.pl (106)

- KUDELA, Prof. K., Institute of Experimental Physics, Slovak Academy of Science, Watsonova 47, KOSICE 040 01, SLOVAKIA, Tel. +421 55-622 4554, Fax +421 55-633 6292, E-mail kkudela@kosice.upjs.sk (109)
- KUERNER, Prof., Institut Für Nachrichtentechnik, Tu Braunschweig, Schleinitzstr. 22, D-38092 Braunschweig, Germany, Tel. +495313912416, E-mail kuerner@ifn.ing.tu-bs.de (112)
- KULAH, Assoc. Prof. H., Faculty of Engineering, Middle East Technical University, Balgat, Ankara 06531, TURKEY, Tel. +312 210 2345, E-mail kulah@metu. edu.tr (107)
- KULEMIN, Prof. G.P., Institute of Radiophysics and Electronics, NASU, 12, ac. Proskura Str., KHARKOV 61085, UKRAINE, Tel. +380 572-448508, E-mail secretar@ire.kharkov.ua (108)
- KULPA, Prof. K. K., Warsaw University of Technology, ul. Nowowiejska 15/19, 00-665 WARSAW, POLAND, Tel. +48 606 209 225, E-mail kulpa@ise.pw.edu.pl (108)
- KUNA, Dr. A., Institute of Photonics & Electronics, Academy of Sciences of Czech Republic, Chaberska 57, Praha 8 - Kobylisy 182 51, CZECH REPUBLIC, Tel. +420 266 773 426, Fax +420 266 773 415, E-mail kuna@ufe.cz (106)
- KUROCHKIN, Dr. A.P., NPO VEGA, Kutuzovsky Prospekt 34, MOSCOW 121170, RUSSIA, Tel. +7 499 249 4308, Fax +7 499 258 2504, E-mail kurochkin@vega. su (106)
- KURUM, ASS. Prof. M., Electrical and Computer Engineering, Mississippi State University, 406 Hardy Rd., Simrall Bldg., Room: 236, Mississippi State, MS 39762, USA, Tel. +1 662 325 2148, Fax 01 662 325 2298, E-mail kurum@ece.msstate.edu, mkurum@gmail.com, (108)
- KUSTER, Prof. N., IT'IS Foundation, Zeughausstraße 43, CH-8004 ZURICH, SWITZERLAND, Tel. +41 44 245 96 96, Fax +41 44 245 96 99, E-mail nk@itis. ethz.ch (110)
- KUZMAK, Dr. O.M., Institute of Magnetism, NASU, 36-b, Vernadsky Blvd., KIEV 03142,UKRAINE, Tel. +380 44-4249095, Fax +380 44 4241020, E-mail kuzmak@ imag.kiev.ua (113)
- KUZNETSOV, Prof. Yu. V., Theoretical Radio Engineering Department, State Technical University, Moscow Aviation Institute, Volokolamskoe shosse 4, GSP-3, MOSCOW 125993, RUSSIA, Tel. +7 499 158 68 39, Fax +7 499 158 68 39, E-mail kuznetsov@mai-trt.ru, kuznetsov@ieee.org (107)
- KYRIACOU, Prof. G.A., Lab. of Microwaves, Dept. of Electrical and Computer Engineering, Demokritos University of Thrace, Vas. Sofias 12, 67 100 XANTHI, GREECE, Tel. +30 5410 795 93, Fax +30 5410 272 64, E-mail gkyriac@ee.duth.gr (106)
- LAGASSE, Prof. P., URSI Secretariat, Ghent University, Technologiepark-Zwijnaarde 15, B-9052 GENT,BELGIUM, E-mail paullagasse.pl@gmail.com (105)

- LAKHINA, Dr. G.S., FNA Director, Indian Institute of Geomagnetism, Plot No. 5, Sector 18, Kalamboli Highway, kalamboli, NEW PANVEL, 410218, INDIA, Tel. +91 22 27400700 (O), Fax +91 22 27450703, E-mail lakhina@iigs.iigm.res.in, gslakhina@gmail. com (105,109,113)
- LARKINA, Prof. V.I., IZMIRAN, Moscow Region, TROITSK, MOSCOW REGION 142092, RUSSIA, Tel. +7 496 751 9742, Fax +7 496 751 0124, E-mail larkina@izmiran.ru (108)
- LAUTRU, Prof. D., IUT Ville d'Avray, , 50 rue de Sèvres, F-92410 VILLE D'AVRAY, FRANCE, Tel. 01 40 97 41 00, E-mail david.lautru@u-paris10.fr, dlautru@u-paris10.fr (106)
- LAZAR, Dr. J., Academy of Sciences of Czech Republic, Institute of Scientific Instruments, Kralovopolska 147, BRNO 612 64, CZECH REPUBLIC, Tel. +420 541 514 253, Fax +420 541 514 402, E-mail joe@isibrno. cz (107)
- LAZARIDIS, Mr. P., University of Huddersfield, Queensgate, HD1 3DH Huddersfield, UNITED KINGDOM, Tel. 441484472107, E-mail p.lazaridis@ hud.ac.uk (108)
- LAZAROV, Prof. A., Bourgas Free University (BFU), , 62 San Stefano Str., BG-8000 BOURGAS, BULGARIA, Tel. +359 56 900 485, E-mail lazarov@bfu.bg (106)
- LE, Dr. H., Institut National de la Recherche Scientifique (INRS), University of Quebec, 800 de la Gauchetière West, Suite 6900, Montreal, QC, H5A1K6, CANADA, Tel. 1-514-228-7015, E-mail le@emt.inrs.ca (107)
- LE VINE, Dr. D., Goddard Space Flight Center, Nasa Code 614.1, 8800 Greenbelt Road, Greenbelt, Maryland 20771, USA, Tel. 301 614 5640, E-mail David.M.LeVine@nasa.gov (111)
- LEE, Prof. L-C, President Office, National Central University, No. 300, Jhongda Road, Jhongli City, Taoyuan, CHUNG-Li, TAOYAN 320, CHINA (SRS), Tel. +886 3 422 7151ext. 57000, Fax +886 3 425 4842, E-mail louclee@earth.sinica.edu.tw (105,109,113)
- LEE, Prof. J-S, Research Center for Integrative Neuroimaging and Neuroinformatics, National Yang-Ming University, No. 155, Sec. 2, Linong Street, Beitou District, TAPEI 112, TAIWAN, Tel. +886 2 28267134, Fax +886 2 28224860, E-mailjslee@ym.edu.tw (110)
- LEE, Dr., Hui Min, SINGAPORE, E-mail leehm@ihpc.a-star.edu.sg (108)
- LEGROS, Dr. A., Imaging, LHRI, St. Joseph's Heath Care, 268 Grosvenor Street, London, ON N6A 4V2, Canada, Tel. (519) 646-6100, Fax (519) 646-6399, E-mail alegros@lawsonimaging.ca (110)
- LEMBEGE, Dr. B., Heppi, LATMOS-UVSQ-IPSL-CNRS, Quartier Des Garennes, 11 Boulevard D'alembert, 78280 Guyancourt, 78280 Guyancourt, France, Tel. +331 80 28 50 70, Fax +33 1 80 28 52 97, E-mail bertrand. lembege@latmos.ipsl.fr (112)
- LEYSER, Dr. T.B., Swedish Institute of Space Physics, Uppsala Division, Box 537, SE-75121 UPPSALA, SWEDEN, Tel. +4618-4715941, Fax +4618-4715905, E-mail Thomas.Leyser@irfu.se (109)

- LI, Dr. W., UCLA, 7127 Math Sciences Bldg., 405 Hilgard Ave., Los Angeles, CA, 90095, USA, E-mail moonli@ atmos.ucla.edu (109)
- LI, Dr. L., School of EECS, Peking University, ROOM 2843N, Science Building#2, Beijing 100871, CHINA CIE, Tel. +86-10-62754409-2, Fax +86-10-62754409, E-mail lianlin.li@pku.edu.cn (106,114)
- LICHTENBERGER, Dr. Janos, Dept of Geophysics and Space Sciences, Eötvös University, Pázmány Péter sétány 1/A, H-1117 BUDAPEST, HUNGARY, Tel. +36-1-372 2934, Fax +36-1-372 2927, E-mail lityi@ sas.elte.hu (109)
- LIEVENS, Mrs. I., URSI Secretariat, Ghent University
 INTEC, Technologiepark-Zwijnaarde 15, B-9052
 GENT,BELGIUM, Tel. +32 9-264.33.20, Fax
 +32 9-264.42.88, E-mail ingeursi@intec.ugent.be
 (105,114)
- LIGTHART, Prof. dr. Ir. L.P., Director IRCTR, Delft University, Microwaves Laboratory, Mekelweg 4, NL-2628 CD DELFT, NETHERLANDS, Tel. +31 15-278 1034, Fax +31 15-278 4046, E-mail leoligthart@kpnmail.nl (108)
- LILJE, Prof. P., Institute of Theoretical Astrophysics, University of Oslo, P.O. Box 1029 Blindern, N-0315 OSLO, NORWAY, Tel. +47 22 856517, E-mail per. lilje@astro.uio.no (110)
- LIN, Prof. J.C., Electrical Eng. & Computer Science (M/C 154), University of Illinois at Chicago, 851 South Morgan Street, Chicago, IL 60607-7053, USA, Tel. +1-312 413-1052, Fax +1-312 413-0024, E-mail lin@uic.edu ()
- LIN, Dr. K-H, Dept. of Electrical Engineering, National Sun Yat-Sen University, 70 Lien Hai Road, KAOHSIUNG 80424, CHINA SRS, Tel. +886 7 5252000 ext 4165, E-mail khlin@mail.nsysu.edu.tw (108)
- LIN, Mr. R-H, , Chinese Institute of Electronics, P.O. Box 165, Beijing 100036, CHINA CIE, Tel. +86 10 6827 6577, E-mail linrunhua@cie-info.org.cn (113)
- LIN, Dr., W., SINGAPORE, E-mail wul@ihpc.a-star.edu. sg (110)
- LINDQVIST, Dr. M., Onsala Space Observatory, Chalmers University of Technology, SE-439 92 ONSALA, SWEDEN, Tel. +46 31 772 55 08, Fax +46 31 772 55 90, E-mail Michael.Lindqvist@chalmers.se (110)
- LISZT, Dr. H.S., NRAO, 520 Edgemont Road, Charlottesville VA 22903-2475,USA, Tel. +1 434 227 6356, Fax +1 434 296 0278, E-mail hliszt@nrao. edu (112)
- LITOVCHENKO, Prof. V.G., Institute of Physics of Semiconductors, NASU, prosp. Nauki 45, KIEV 03039, UKRAINE, Tel. +380 44-265-6290, Fax +380 44-265-8342, E-mail mickle@semicond.kiev.ua (107)
- LITSYN, Dr. S., Dept. Electrical Eng./Faculty of Engineering, Tel Aviv University, Ramat-Aviv, 69978 TEL AVIV, ISRAEL, Tel. +972 3-631 4139, Fax +972 3-642 3508, E-mail litsyn@eng.tau.ac.il (107)
- LIU, Dr. M., 514th Institute, China Academy of Space Technology, Zhichun Road, Haidan District, BEIJING 100086, CHINA (CIE), Tel. +86 10 687 44 667, Fax +86 10 683 78 158, E-mail liumin@cast514.com (106)

- LIU, Dr., en-Xiao, Singapore, E-mail liuex@ihpc.a-star. edu.sg (109)
- LOH, Dr. T.H., National Physical Laboratory, Hampton Road, Teddington TW11 0LW, UNITED KINGDOM, Tel. +44 020 8943 6508, E-mail tian.loh@npl.co.uk (106,114)
- LOPEZ MARTIN, Prof. M.E., Departamento de Ciencias Morfologicas, Faculdad de Medicina, Universidad de Santiago de Compostela, 15782 Santiago de Compostela, SPAIN, Tel. +34881812310, Fax +34981 582642, E-mail melena.lopez.martin@usc.es (110)
- LOTZ, Mr. S., South African National Space Agency (SANSA), Space Science, 1 Hospital Street, 7200 HERMANUS, SOUTH AFRICA, Tel. +27 28 312 1196 ext 210, Fax +27 28 312 2039, E-mail Slotz@sansa.org.za (109)
- LOUËT, Prof. Y., CS 47601, SUPELEC Campus de Rennes, Avenue de la Boulaie, F-35576 Cesson-Sévigné, FRANCE, Tel. +33 2 99 84 45 34, Fax +33 2 99 84 45 99, E-mail yves.louet@supelec.fr (107)
- MAEKAWA, Prof. Y., Osaka Electro-Communication University, 18-8 Hatsucho, Neyagawa Osaka 572-8530,JAPAN, E-mail maekawa@maelab.osakac. ac.jp (108)
- MAHARAJ, Mr. B.T.J., Department of Electrical, Electronic and Computer Engineering, University of Pretoria, 0002 Pretoria, SOUTH AFRICA, Tel. +27 12 420 4636, E-mail sunil.maharaj@up.ac.za (107)
- MAHMOUD, Prof. I.I., Nuclear Research Center, Engineering Dept., Atomic Energy Post Office, 13759 Cairo, EGYPT, E-mail imbabyisma@yahoo.com (109)
- MAITRA, Prof A.J.S., Institute of Radio Physics and Electronics, University of Calcutta, 92 Acharya Prafulla Chandra Road, Kolkata, WB, 700009, India, Tel. +91-33-2350-9116 (Extn 56), Fax+91-33-2351-5828, E-mail animesh.maitra@gmail.com, animesh.maitra@ieee.org, am.rpe@caluniv.ac.in (108)
- MALAY, Dr. I.M., VNIIFTRI, Mendeleevo, Moscow Region, RUSSIA, Tel. +7 495526 6355, E-mail malay@vniiftri.ru (106)
- MANEUX, Prof. C., IMS, Laboratoire d'Intégration du Matériau au Système, Université Bordeaux 1, 351, Cours de la Libération, F-33405 TALENCE Cedex, FRANCE, Tel. +33 5 40 00 28 58, Fax +33 5 56 37 15 45, E-mail cristell.maneux@ims-bordeaux.fr, cristell.maneux@u-bordeaux.fr (107)
- MANGUM, Dr. J., National Radio Astronomy Observatory, 520 Edgemont Road, Charlottesville, VA 22903, USA, Tel. +1 510-520-9077, E-mail jmangum@nrao.edu (110)
- MANN, Appl. Prof. Dr. G., , Leibniz Institut fuer Astrophysik Potsdam (AIP), An der Sternwarte 16, D-14482 POTSDAM, GERMANY, Tel. +49 (0)331 749 9292, Fax +49 (0)331 749 9352, E-mail gmann@aip.de (109)
- MANNINEN, Sodankylä Geophysical Observatory Tähteläntie 62, FIN-99600 Sodanskylä, Finland, Tel: +358 400 151503, Fax +358 16 610248, E-mail: Jyrki. Manninen@oulo.fi (106,109)

- MANSO, Prof. M.E., Centro de Fusão Nuclear do IST, Avenida Rovisco Pais, 1049 LISBOA CODEX, PORTUGAL, Tel. +351 21 841 76 96, E-mail emilia@ ipfn.ist.utl.pt (109)
- MANTEGHI, Dr. M., 302 Whittemore (0001), Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, USA, Tel. +1 540-231-6834 (110)
- MARROCCO, Dr. G., Dipartimento di Informatica Sistemi e Produzione, University of Roma Tor Vergata, Via del Politecnico, 1,00133 Roma, ITALY, E-mail marrocco@ disp.uniroma2.it (111)
- MARSALEK, Prof. R., Department of Radio electronics, FEKT, Brno University of Technology, Technika 12, BRNO, 616 00, CZECH REPUBLIC, Tel. +420 54114 6582, Fax +420 5 4114 6597, E-mail marsaler@feec. vutbr.cz (107)
- MARTIN RODRIGUEZ, Prof. E., Facultad de Quimica Dpto. Fisica, Universidad de Murcia Apdo. 4021, 30071 ESPINARDO, MURCIA, SPAIN, Tel. +34 968 367373, Fax +34 968 364148, E-mail ernesto@um.es (106)
- MATERASSI, DR. M., ISC, National Research Council, via Madonna del Piano 10, 50019 Sesto Fiorentino, ITALY, E-mail massimo.materassi@fi.isc.cnr.it (109)
- MATHEWS, Prof J.D., Radar Space Sciences Lab, The Pennsylvania State University, 323A, EE East, University Park, PA 16802-2707, USA, Tel. +1(814) 777-5875, Fax +1 814 863 8457, E-mail JDMathews@psu.edu (114)
- MATSAKIS, Dr. D.N., Time Service Dept, U.S. Naval Observatory, 3450 Massachusetts Avenue, NW, Washington, DC 20392-5420, USA, Tel. +1 202-762 1587, 1 202-653 1823, Fax +1 202-762 1511, E-mail demetrios.matsakis@navy.mil (111)
- MATSUMOTO, Prof. H., President, RIKEN, 2-1 Hirosawa, Wako, Saitama 351-0198, JAPAN, E-mail pr@riken. jp (111)
- MAYORGA MONTOYA, ing. M., Departamento de Ingenieria, Universidad Católica del Perú, Sección Ingeniería de las Telecomunicaciones, Av. Universitaria 1801, San Miguel, LIMA32, PERU, Tel. +51-1-626-2452, Fax+51-1-626-2116, E-mail mayorga.ma@pucp. edu.pe (106)
- MAZZA, Ing. H.F., INTI, CC. 157, , 1650 SAN MARTIN B.A., ARGENTINA, Tel. +54 1-753 4064, Fax +54 1-755 2102, E-mail (106)
- McCARTHY, Dr. K., Dept. of Electrical and Electronic Engineering, University College Cork, CORK, IRELAND, Tel. +353 21 490 2214, Fax +353 1 283 0921/830 921, E-mail K.McCarthy@ucc.ie (108)
- MCCREA, Dr. William, Space Science and Technology, Rutherford Appleton Laboratory, Building R25, Room 1.05 Harwell Science And Innovation Centre, OX136BL Harwell, United Kingdom, Tel. +441235446513, Fax +441235445848, E-mail ian.mccrea@stfc.ac.uk (111)
- McKINNELL, Dr. L.A., South African National Space Agency (SANSA), Space Science, P.O. Box 32, 7200 HERMANUS, SOUTH AFRICA, Tel. +27 28 312 1196, Fax +27 28 312 2039, E-mail lmckinnell@sansa.org.za (112)

- MEDINA-MENA, Prof. F., Departamento de Electronica y Electromagnetismo, Facultad de Fisica, Universidad de Sevilla, Av. Reina Mercedes s/n, 41012 SEVILLA, SPAIN, Tel. +34 954 553891, Fax +34 954 239434, E-mail medina@us.es (106)
- MENDES, Eng. M.L., ANACOM, Av. José Malhoa 12, 1099-017 LISBOA, PORTUGAL, Tel. +351 21 721 2222, Fax +351 21 721 1006, E-mail ursi.por@anacom. pt (113)
- MICHEL, Dr. A., Department of Information Engineering, University of Pisa, via Caruso 16, 56122, Pisa, ITALY, Tel. +390502217671, Fax +39-0502217522, E-mail andrea.michel@iet.unipi.it (106,114)
- MICHELSON, Prof. David G., Dept of Electrical & Computer Engineering, University of British Columbia, 441 2356 Main Mall, Vancouver BC V6T 1Z4, CANADA, Tel. 604 822-3544, Fax 604 822-5949, E-mail davem@ece.ubc.ca (108,113)
- MIR, Dr. L.M., UMR 8203 CNRS, Gustave Roussy PR2, 114 rue Edouard Vaillant, 94805 VILLEJUIF Cedex, FRANCE, Tel. +33 1 42 11 47 92, E-mail Luis.MIR@cnrs.fr (110)
- MISHRA, Dr. A. K., Electrical Engineering Department, Menzis Building, University of Cape Town, , Rondebosch 7700 Cape Town, SOUTH AFRICA, E-mail akmishra@ieee.org (108,111)
- MODELSKI, Prof. J., Institute of Radioelectronics, Warsaw University of Technology, ul. Nowowiejska 15/19, 00-665 WARSAW, POLAND, Tel. +48 22 825 39 29, Fax +48 22 825 5248, E-mail j.modelski@ire.pw.edu. pl (113)
- MOITRA, Dr. A., Indian National Science Academy, Bahadur Shah Zafar Marg, NEW DELHI, 110 002, INDIA, Tel. +91 11-322 1931/1950, Fax +91 11-323 5648/1095, E-mail insacouncil@gmail.com (113)
- MOJABI, Prof. P., Room E3-504B, EITC Building, Electrical and Computer Engineering Department, University of Manitoba, Winnipeg, R3T5V6, Canada, Tel. +1 204 474 6754, Fax +1 204 261 4639, E-mail Puyan.Mojabi@umanitoba.ca (110)
- MOKOLE, Dr. Eric L., Signal Processing/T823, The MITRE Corporation/Programs & Technology, Mail Stop: J710, 7515 Coleshire Drive, McLean, VA 22102-7508, USA, Tel. +1 703-983-3349, E-mail eric. mokole@outlook.com (107)
- MOLINACUBEROS, Prof. G.J., Dpto. Electromagnetismo y Electronica, Facultad de Quimica, Universidad de Mucia, 30100 Espinardo, MURCIA, SPAIN, Tel. +34 868 887533, Fax +34 868 884 148, E-mail gregomc@um.es (108)
- MOLINAFERNANDEZ, Dr. I., Departamento de Ingenieria de Communicaciones, E.T.S.I. Telecomunicacion, Universidad de Malaga, Campus Universitario de Taetinos s/n, E-29071 MALAGA, SPAIN, Tel. +34 952 13 13 11, Fax +34 952 13 20 27, E-mail imolina@uma.es (107)
- MOORE, Dr. R., University of Florida, NEB 557 PO Box 116130, Gainesville, FL, 32611, USA, E-mail moore@ce.ufl.edu (109)

- MOREIRA, Prof. F.J.S., Departamento de Engenharia Eletrônica, Universidade Federal de Minas Gerais, Av. Pres. Antonio Carlos, 6627, 31270-901 Belo Horizonte - MG, BRAZIL, Tel. +55 31 3409 3445 (ext. 4848), E-mail fernandomoreira@ufmg.br (106)
- MOSIG, Prof. J., STI-ITOP-LEMA-ELB30, Ecole Polytechnique Fédérale de Lausanne, Station 11, CH-1015 LAUSANNE, SWITZERLAND, Tel. +41 21 693 46 28, Fax +41 21 693 26 73, E-mail Juan.Mosig@ epfl.ch (106)
- MURPHY, Prof. A., Dept. of Experimental Physics, National University of Ireland Maynooth, CO. KILDARE, IRELAND, Tel. +351 1 6285 222 ext. 209, Fax +351 1 708 3771, E-mail anthony.murphy@nuim.ie (110)
- MUSHA, Dr. M., Institute for Laser Science, University of Electro-communications, 1-5-1 Chofugaoka, Chofu-shi, TOKYO 182 8585, JAPAN, Tel. +81 424 435 705, Fax +81 424 858 960, E-mail musha@ils.uec.ac.jp (106)
- NAGY, Dr. L., Department of Broadband Infocommunication Systems, BME - Budapest University of Technology and Economics, Goldmann Gyorgy ter 3, 1111 BUDAPEST, HUNGARY, Tel. +36 1 463 15 59, Fax +36 1 463 32 89, E-mail nagy@mht.bme.hu (107)
- NAH, Prof. W., School of Electronic & Electrical Engineering, Sungkyunkwan University, 2066, Seoburo, Jangan-gu, Suwon, Gyeonggi-Do, 440-746, SOUTH KOREA, Tel. +82 31 290 7136, Fax +82 502 302 0878, E-mail wsnah@skku.edu (108)
- NAM, Prof. S., School of Electrical & Computer Engineering, Seoul National University, San 56-1, Sillim-dong, Gwanak-gu, SEOUL 151-742, SOUTH KOREA, Tel. +82 2 880 8412, Fax +82 2 880 8212, E-mail snam@snu.ac.kr (105,113)
- NAPIERALSKI, Prof. A., Faculty of Electrical, Electronic, Computer and Control Engineering, Technical University of Lodz, 221/223 Wolczanska Street, 90-924 LODZ, POLAND, Tel. +48 42 3127 27, E-mail napier@dmcs.p.lodz.pl (107)
- NAVA, Mr. B., Telecom ICT for Development Laboratory, ICTP, Via Beirut 7, I 34151 Trieste, ITALY, Tel. 390402240340, E-mail bnava@ictp.it (111)
- NEMEC, DR. F., Department of Surface and Plasma Science, Faculty of Mathematics and Physics, V Holesovickach 2, 18000 Prague, CZECH REPUBLIC, E-mail frantisek.nemec@gmail.com (109)
- NEVES, Prof. Dr. J. C. da Silva, Instituto de Telecomunicaçoes, Universidade de Aveiro, Campus Universitario, 3810-193 AVEIRO, PORTUGAL, Tel. +351 23 437 7900, Fax +351 23 437 7901, E-mail jneves@av.it.pt (108)
- NEWKIRK, Dr. Michael H., Applied Physics Laboratory, The John Hopkins University, 11100 Johns Hopkins Road, Laurel, MD 20723, USA, Tel. +1 240 228 6976, Fax +1 240 228 5494, E-mail Michael.Newkirk@ jhuapl.edu (113)
- NGWENYA, Ms. L., Programme Officer, SA International Council for Science, Meiring Naude Road Brummeria, P.O. Box 2600, PRETORIA 0001, SOUTH AFRICA, E-mail lynn.ngwenya@nrf.ac.za (113)

- NICKOLOV, Prof. E., National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences, Acad. G. Bonchev St., bl. 3, 1113 SOFIA, BULGARIA, Tel. +359 2 987 4624, E-mail eugene. nickolov@cu.bas.bg (108)
- NING, Prof. B., Institute of Geology and Geophysics, CAS, Laboratory for Space Environment Probing, No. 19 West Road, Beitucheng, Chaoyang Dist., Beijing 100029, CHINA CIE, Tel. 86-10-82998312, E-mail nbq@iggcas.ac.cn, nbq@mail.iggcas.ac.cn (111)
- NOEL, Prof. Fernando, Depto de Astronomia, Universidad de Chile, Casilla 36-D, SANTIAGO, CHILE, Tel. +56 2-229 4002, Fax +56 2-229 4101 (106)
- NORGREN, Mr. M., ETK, TEKNIKRINGEN 31, SE-100 44 STOCKHOLM, SWEDEN, E-mail martin.norgren@ee.kth.se (106)
- NOVAK, Dr. J., Institute of Electrical Engineering, Slovak Academy of Sciences, Dubravska cesta 9, BRATISLAVA 84104, SLOVAKIA, Tel. +421 2-59222761, Fax +421 2-54775816, E-mail jozef.novak@savba.sk (107)
- O'DROMA, Dr. M., Director Telecommunications Research Centre, Dept. of Electrical & Computer Eng., Electrical and Computer Eng Dept, University of Limerick, LIMERICK, IRELAND, Tel. +353-61-202364, Fax+353-61-338176, E-mail mairtin.odroma@ ul.ie (106,107)
- O'SULLIVAN, Dr J.D., Australian Telescope National Facility, CSIRO Astronomy and Space Science, PO Box 76, Epping, NSW 1710, AUSTRALIA, Tel. +612 9372 4604 (108)
- OH, Prof. Y., School of Electronic and Electrical Engineering, Hongik University, 72-1 Sangsu-Dong, Mapo-Gu, Seoul 121-719, SOUTH KOREA, Tel. +82 2 320 1481, Fax +82 2 320 1193, E-mail yisokoh@hongik.ac.kr (108)
- OJO, Dr. J.S., Department of Physics, Federal University of Technology, P.M.B 704, AKURE, NIGERIA, Tel. +234 806 653 2234, E-mail ojojs_74@futa.edu.ng, josnno@yahoo.com (113)
- OMURA, Prof. Y., Laboratory of Computer Space Science, Kyoto University - RISH, Gokasho, Uji, KYOTO 611-0011, JAPAN, Tel. +81 774 38-3811, Fax +81 744 31-8463, E-mail omura@rish.kyoto-u.ac.jp (112)
- ONUU, Prof. M., Department of Physics/Geology/ Geophysics, Federal University, Ndufu-Alike, Ikwo, Enonyi State, NIGERIA, Tel. 234 803 507 2076, E-mail michaelonuu@yahoo.com (108)
- ÖZEREN, Assist. Prof. F.F., Faculty of Sciences, Erciyes University, Kayseri, TURKEY, Tel. +90 352 207 6666 ext 33256, E-mail ozeren@erciyes.edu.tr (110)
- OZGUN, Prof. O., Dept. Electrical and Electronics Eng., Haceteppe University, , 06532 Ankara, TURKEY, Tel. +90 0312 297 7070, E-mail ozlem@ee.haceteppe.edu. tr (113)
- ØSTERBERG, Prof. U., Department of Electronics and Telecommunications, NTNU, O.S. Bragstads plass 2, N-7491 Trondheim, NORWAY, E-mail ulf.osterberg@ ntnu.no (106)

- PACHECO, DR. E.E., JRO, IGP, Calle Badajoz #169, Mayorazgo IV Etapa - Ate Vitarte, LIMA, PERU, E-mail edgardo.pacheco@jro.igp.gob.pe (113)
- PADULA-PINTOS, Prof. V.H., Director Dept. Coord. R&D, Instituto Tecnologico de Buenos Aires, Pena 2446, 7" A", 1125 BUENOS AIRES, ARGENTINA, Tel. +54 1-314 7779 ext. 263, Fax +54 1-314 0270 (110)
- PALOSCIA, Dr. S., CNR-IFAC, Via Madonna del Piano, 10, I 50019 Sesto Fiorentino, FIRENZE, ITALY, E-mail S.Paloscia@ifac.cnr.it (111)
- PANAYIRCI, Dr. E., Dept. of Electr. & Electronics Eng., Kadir Has University, Faculty of Engineering, Cibali Merkez Kampusu, 34230-01 CIBALI, ISTANBUL, TURKEY, Tel. +90 212 533 6532, E-mail eepanay@ khas.edu.tr, eepanay@Princeton.edu (107)
- PARFITT, Prof. A.J., Pro Vice Chancellor, Division of ITEE, University of South Australia, Mawson Centre, MAWSON LAKES, SA 5095, AUSTRALIA, Tel. +61 8 8302 3310, Fax +61 8 8302 3873, E-mail andrew. parfitt@unisa.edu.au (107)
- PARK, Prof. S-O, EE Department, Korea Advanced Institute of Science and Technology, 291 Daehak-Ro, Yuseonggu, DAEJEON 305-701, SOUTH KOREA, Tel. +82 42 350 7414, Fax +82 42 350 8268, E-mail soparky@kaist.ac.kr (113)
- PARKER, Prof. T., Collaborative Nonlinear Electronics Research Facility, Macquarie University, North Ryde, NSW 2109, AUSTRALIA, Tel. +61 2 9850 9131, Fax +61 2 9850 9128, E-mail tonyp@ics.mq.edu.au (107)
- PARMENTIER, Dr. J-P, ONERA, DEMR (Electromagnetics & Radar Department), CDE group (Electromagnetic Compatibility & Detection), BP 4025, Avenue Edouard Belin, 31055 TOULOUSE Cedex 4, FRANCE, Tel. +33 5 62 25 27 89, Fax +33 5 62 25 27 77, E-mail hipar@onecert.fr, hipar@onera.fr (111)
- PASTORINO, Prof. M., Dept. of Biophysical and Electronic Engineering, University of Genoa, Via Opera Pia 11A, I - 16145 Genova, ITALY, E-mail matteo.pastorino@ unige.it (106)
- PATRA, Dr A.K., Dept. of Space, Govt. of India, National MST Radar Facility, PB No. 123, NMRF Guest House, Tirupati, Andhra Pradesh, 517502,India, Tel. 0877-2248805, Fax 08585-272018, E-mail akpatra@narl. gov.in (109)
- PAVLYUKOVA, Ms. E.R., IRE RAS, Moscow, RUSSIA, E-mail e.pavl@mail.ru (113)
- PAZ RETUERTO, Mr. P., Comisión Nacional de Investigación y Desarrollo Aeroespacial CONIDA, Av. Luis Felipe Villarán 1069, San Isidro - LIMA 27, PERU, Fax + 51 1 441 - 9081 (107)
- PEDERSEN, Dr. Todd R., Rvbxi, Air Force Research Laboratory, 29 Randolph Road, Hanscom AFB, MA 01731-3010, USA, Tel. 781-377-2845, E-mail todd. pedersen@hanscom.af.mil (111)
- PEIXEIRO, Prof. C., Instituto Superior Técnico (Instituto de Telecomunicações), University of Lisbon, Avenida Rovisco Pais n.º 1, 1049-001 Lisboa, PORTUGAL, E-mail custodio.peixeiro@lx.it.pt (106)

- PELLINEN-WANNBERG, Prof. A., Department of Physics, Umea University, BOX 812, SE-90187 UMEA, SWEDEN, Tel. +46 90 786 74 92, Fax +46 90 786 66 76, E-mail asta.pellinen-wannberg@umu.se (113)
- PELOSI, Dr. G., Information Engineering, University of Florence, Via S. Marta 3, I-50139 FLORENCE, ITALY, E-mail giuseppe.pelosi@unifi.it (114)
- PIERRARD, Dr. V., Belgisch Instituut voor Ruimte-Aëronomie (BIRA), , Ringlaan 3, B-1180 BRUSSEL, BELGIUM, Tel. +32 2 3730 418, Fax +32 2 374 84 23, E-mail viviane.pierrard@aeronomie.be (109)
- PIGNARI, Prof. S.A., Dipartimento Elettrotecnica, Informazione e Bioingegneria, Politecnico di Milano, Piazza Leonardo da Vinci 32, I-20133 Milano, Italy, Tel. +39 02 2399 3726, Fax +39 02 2399 3703, E-mail sergio. pignari@polimi.it, s.pignari@ieee.org (108,111)
- PIJOAN VIDAL, Prof. J.L., Dpto. Comunicaciones y Teoria de la Senal, Universidad Ramon Llull, Escuela Tecnica Superior de Ingenieria e Informatica La Salle, 08022 BARCELONA, SPAIN, Tel. +34 93 290 24 00, Fax +34 93 290 24 70, E-mail joanp@salle.url.edu (109)
- PNG CHING ENG, Dr. J., Director, Electronics & Photonics Department, A*Star Institute of High Performance Computing, 1 Fusionopolis Way, #16-16, Connexis 138632, SINGAPORE, E-mail pngce@ihpc.a-star.edu. sg, fiojas@yahoo.com (113)
- POGORILY, Prof. A.N., Institute of Magnetism, NASU, 36-b, Vernadsky Blvd., KIEV 03142, UKRAINE, Tel. +380 44 4249095, Fax +380 44 4241020, E-mail apogorily@aol.com (113)
- POULTER, Dr. E. M., National Institute of Water and Atmospheric Research Ltd, NIWA, P.O.Box 14-901, Kilbirnie, Wellington, NEW ZEALAND, Tel. +64-4-386-0560, Fax +64-4-386-2153 (108)
- PRASAD, Dr. M.V.S.N., Radio & Atmospheric Sciences, National Physical Laboratory, Dr KS Krishnan Marg, New Delhi 110012, INDIA, E-mail mvprasad@nplindia. org (107)
- PRAZERES, Eng. H. P., ICP-ANACOM, ,Av. José Malhoa 12, 1099-017 LISBOA, PORTUGAL, Tel. +351 21 721 2232, Fax +351 21 721 1006, E-mail ursi.por@anacom. pt, helena.prazeres@anacom.pt (113)
- PRICE, Prof C.G., Head of the Porter School of Environmental Studies, the Department of Geosciences, Tel Aviv University, Levanon Road, 69978 Tel Aviv, Israel, Tel. +972-3-6405689, Fax +972-3-6409282, E-mail cprice@flash.tau.ac.il (109,111)
- PRYSE, Dr. E., Department of Computer Science, Aberystwyth University, 3.18, Physical Sciences Building, Aberystwyth, SY23 3BZ, UNITED KINGDOM, E-mail sep@aber.ac.uk (109)
- PULINETS, Prof. S.A., Space Research Institute, Russian Academy of Sciences, 84/32 Profsoyuznaya str., Moscow 117997, RUSSIA, E-mail pulse1549@gmail. com (111)
- QUIJANO, Prof. A., Calle 48 y 116, 1900 LA PLATA, B.A., ARGENTINA, Tel. (54) 21-243 709, Fax (54) 21-250 804, E-mail adrian.quijano@gmail.com (107)

- QUIMBY, Dr. J., National Institute of Standards and Technology, Boulder, CO 80305, USA, Tel. +1 303-497-4217, Fax +1 303-497-3122, E-mail jeanne.quimby@nist.gov (106)
- RABIU, Dr.A.B., Department of Physics, Federal University of Technology, Akure, Ondo State, NIGERIA, Tel. +234 803 070 5787, E-mail tunderabiu2@gmail.com (109)
- RACHIDI, Prof F., EPFL-SCI-STI-FR, ELL-138, Station 11, CH-1015 Lausanne, Switzerland, Tel. +41-21-693 26 20, Fax +41-21-693 46 62, E-mail Farhad.Rachidi@epfl.ch (108,111)
- RADASKY, Dr. William A., Metatech Corporation, 358 S. Fairview Ave., Suite E, Goleta, CA 93117, USA, Tel. +1-805-683-5681, E-mail Wradasky@aol.com (111)
- RADEV, Prof. D., Ruse University, Angel Kanchev, 8 Studentska str., 7017 RUSE, BULGARIA, Tel. +359 82 888 673, E-mail dradev@abv.bg (108)
- RADICELLA, Prof. S.M., Abdus Salam ICTP, ARPL, Via Beirut 7, I-34014 TRIESTE, ITALY, Tel. +390 40 224 0331, Fax +390 40 224 604, E-mail sandro.radicella@ ictp.trieste.it, rsandro@ictp.it (109)
- RAJAMANI, Assoc. Prof. Paulraj, School Of Environmental Sciences, Jawaharlal Nehru University, New Mehrauli Road, New Delhi 110067, India, Tel. 91-11-2670 4162, E-mail paulrajr@mail.jnu.ac.in (110)
- RAKOV, Prof Vladimir A., Department of Electrical and Computer Engineering, University of Florida, 1064 Center Drive, Room#NEB 553, Gainesville, FL 32611-6130, USA, Tel. 1 352 392-4242, Fax 1 352 392-8381, E-mail rakov@ece.ufl.edu (111)
- RAMAKRISHNA, Prof. A., Department of Physics, Indian Institute of Technology, , Kanpur, Uttar Pradesh, 208 016, India, Tel. +91 512 259 7449, Fax +91 512 259 0914, E-mail sar@iitk.ac.in (107)
- RASMUSSEN, Prof. J., RISOE, Optics & Fluid Dynamics Department, P.O. Box 49, DK 4000 ROSKILDE, DENMARK, Tel. +45 4677 4537, Fax +45 4677 4565, E-mail jens.juul.rasmussen@risoe.dk (109)
- RAULIN, Prof. J.-P., Escola de Engenharia, Centro de Radio-Astronomia e Astrofisica Mackenzie CRAAM, Universidade Presbiteriana Mackenzie, Rua da Consolação 896, Consolação, São Paulo SP, 01302-907, BRAZIL, Tel. +55 11 2114 8724, E-mail raulin@craam.mackenzie.br (107,108)
- REINISCH, Prof. B.W., President, Lowell Digisonde International, LLC, 175 Cabot Street Suite 200, Lowell, MA01854, USA, Tel. +1 978 735 4752, Fax +1 978-735 4754, E-mail bodo.reinisch@digisonde.com (112)
- REISING, Prof S.C., Electrical and Computer Engineering Department, Colorado State University, 1373 Campus Delivery, Fort Collins, CO 80523-1373, USA, Tel. +1 970 491 2228, Fax +1 970 491 2249, E-mail Steven. Reising@ColoState.edu (114)
- RENGARAJAN, Prof. S.R., Electrical And Computer Engineering, California State University, 18111 Nordhoff Street, Northridge, CA 91330-8346, USA, Tel. +1 818 677 3571, E-mail srengarajan@csun.edu, sembiam.rengarajan@csun.edu (113)

- RIEH, Prof. J-S, School of Electrical Engineering, Korea University, 145 Anam-ro, Seongbuk-gu, Seoul, 136-713, SOUTH KOREA, Tel. +82 2 3290 3257, Fax +82 2 921 0544, E-mail jsrieh@korea.ac.kr (107)
- ROBINSON, Dr. M.P., Department of Electronics, University of York, Heslington, YORK, YO10 5DD, UNITED KINGDOM, Tel. +44 1904 432 385, Fax +44 1904 433 224, E-mail mpr@ohm.york.ac.uk (113)
- RODGER, Prof. C.J., Department of Physics, University of Otago, Po Box 56, Dunedin 9016, NEW ZEALAND, Tel. +64 3 479 4120, Fax +64 3-479 0964, E-mail crodger@physics.otago.ac.nz (109)
- RODRIGUES, Prof. Dr. A., Instituto Superior Técnico, Instituto de Telecomuniçoes, Avenida Rovisco Pais n°1, 1096 LISBOA CODEX, PORTUGAL, Tel. +351 2 8418484, E-mail antonio.rodrigues@lx.it.pt (107)
- ROGIER, Prof. H., Universiteit Gent-imec, iGent building Dept. Information Technology, Technologiepark-Zwijnaarde 15, B-9052 Ghent, Belgium, Tel. +32 9 264-3343, Fax +32 9 264-9969, E-mail Hendrik. Rogier@UGent.be (106, 113)
- ROMMEL, Prof. T., Microwaves and Radar Institute SAR, Synthetic Aperture Radar, Digital Beamforming, German Aerospace Center (DLR), Linder Höhe, 51147 Cologne, GERMANY, E-mail tobias.rommel@dlr. de (111)
- RÖNNEKLEIV, Prof. Arne, Department of Electronics and Telecommunications, NTNU, O.S. Bragstads plass 2, N-7491 TRONDHEIM, NORWAY, Tel. +4773-594413, E-mail arne.ronnekleiv@iet.ntnu.no (107)
- ROTHKAEHL, Dr H., Space Research Center, Polish Academy of Sciences, Bartycka 18 A, 01-716 Warsaw, Poland, Tel. +48 22 196 64 18, E-mail hrot@cbk.waw.pl (109,111)
- RUBINSTEIN, Prof. M., Institute for Information and Communication Technologies, HEIG-VD, Route de Cheseaux 1, CP 521, 1401 Yverdon-les-bains, SWITZERLAND, Tel. +41 24 557 6296, E-mail marcos. rubinstein@heig-vd.ch (107)
- RUCKER, Prof. H.O., Commission for Astronomy, Austrian Academy of Sciences, Schmiedlstrasse 6, 8042 Graz, AUSTRIA, Tel. +43 316 4120 601, Fax +43 316 4120 690, E-mail rucker@oeaw.ac.at (109,110)
- RYDBERG, Prof. A., Angstrom Laboratory, Uppsala University, Dept. of Engineering Sciences, P.O. Box 534, SE-751 21 UPPSALA, SWEDEN, Tel. +46 18 471 32 28, Fax +46 18 55 50 95, E-mail anders.rydberg@ angstrom.uu.se (107)
- SAAD, Prof. E.M., Faculty of Engineering, Helwan University, Helwan, Cairo, EGYPT, Tel. +202 5048291, Fax +202 2558294, E-mail elsayed012@gmail.com (108)
- SABATH, Dr. F., Wehrwissenschaftliches Institut fuer Schutztechnologien, ABC-Schutz, GB 300, Humboldstrasse100,D-29623MUNSTER,GERMANY, Tel. +49 (0)5192 136 300, Fax +49 (0)5192 136 355, E-mail FrankSabath@bundeswehr.org (111)

- SADEK, Prof. R.A., Faculty of Computers and Information Technology, Helwan University, Helwan, EGYPT, Tel. +201222829644 (cell), E-mail rowayda_sadek@yahoo.com (106)
- SADKHAN, Bay S.B., Chairman of IEEE, Iraq section, University of Babylon, Computer Technology College, Babylon, Iraq, Tel. 00964 7707119529, Fax 00964 7801884154, E-mail drengsattar@yahoo.com (113)
- SAMARAS, Prof. T., Dept. of Physics, Radiocommunications Lab., Aristotle University of Thessaloniki, GR-54124 THESSALONIKI, GREECE, Tel. +30 2310 998232, Fax+302310998069, E-mail theosama@auth.gr (113)
- SANCHO RUIZ, Prof. M., Dep. Fisica Aplicada III Fac. de Fisicas, Universidad Complutense, , 28040 MADRID, SPAIN, Tel. +34 91 394 4388, Fax +34 91 394 5196, E-mail msancho@fis.ucm.es (109)
- SANTOLIK, Prof. O., Institute of Atmospheric Physics, Academy of Sciences of the Czech Republic, Bocni II, 1401, 141 31 PRAGUE 4, CZECH REPUBLIC, Tel. +420 267 103 083, Fax +420 272 762 528, E-mail os@ufa.cas.cz, santolik@gmail.com (105, 109,114)
- SANTUCCI, Prof. F., Dept. of Information Engineering, Computer Science and Mathematics (DISIM) & centre of Excellence DEWS, University of L'Aquila, Via Vetoio snc, 67100 Coppito, L'Aquila, ITALY, E-mail fortunato.santucci@univaq.it (107)
- SARABANDİ, Prof. K., Electrical Engineering And Computer Science, University Of Michigan, 1301 Beal Avenue, 3228 EECS Bldg., Ann Arbor, MI 48109, USA, Tel. +1 734-936-1575, E-mail saraband@umich. edu (108)
- SARANGO, Dr. Martin F., M Sarango CT, Industrias Tecnologicas, Av. Javier Prado Este 3040 Piso 4, San Borja, LIMA 41, PERU, Tel. +51 1-3588700, Fax +51 1-2500969, E-mail ursiperu@msarangoct.com (108)
- SASAKI, Dr. M., NTT Access Network Service Systems Laboratories, NTT Corporation, 1-1 Hikari-no-oka, Yokosuka-Shi, Kanagawa 239-0847,JAPAN, E-mail sasaki.motoharu@lab.ntt.co.jp (108)
- SASAKI, Dr., Electromagnetic Compatibility Laboratory, Applied Electromagnetic Research Institute, 4-2-1, Nukuikitamachi, Koganei, Tokyo, 184-8795, JAPAN, Tel. +81-42-327-5696, Fax +81-42-327-6675, E-mail k_sasaki@nict.go.jp (110)
- SAVORSKIY, Dr. V.P., , FIRE RAS, Fryazino, Moscow Region, RUSSIA, Tel. +7 496 565 25 66, E-mail savor@ ire.rssi.ru (108)
- SCHILIZZI, Prof. R.T., School of Physics and Astronomy, School of Physics and Astronomy, University of Manchester, Alan Turing Building, Manchester M13 9PL, UNITED KINGDOM, Tel. +44 (0) 161 306 9663/9400, E-mail Richard.Schilizzi@manchester. ac.uk (112)
- SCHMID, Ing. G., EMC & Optics, Seibersdorf Laboratories, 2444 SEIBERSDORF, AUSTRIA, Tel. +43 0 50550 2810, Fax +43 0 815 78 64, E-mail gernot.schmid@seibersdorf-laboratories.at (110)

- SCHÖNHUBER, Dr. M., Joanneum Research, Space and Acoustics, DIGITAL Institute of Information and Communication Technologies, Steyrergasse 17-19, 8010 Graz, AUSTRIA, Tel. +43 316 876 2511, Fax +43 316 8769 92511, E-mail Michael.Schoenhuber@joanneum.at (108)
- SCHRADER, Dr. T., Dept. High Frequency and Fields, Physikalisch-Tecnische Bundesanstalt, Bundesallee 100, D-38116 BRAUNSCHWEIG, GERMANY, Tel. +49 (0)531 592-2200, Fax +49 (0)531 592-2205, E-mail thorsten.schrader@ptb.de (106)
- SCHUHMANN, Prof. Dr. Ing. R., Fakultät IV, Elektrotechnik und Informatik, TU Berlin, Fachgebiet Theoretische Elektrotechnik, Einsteinufer 17, D-10587 Berlin, GERMANY, Tel. +49 (30) 314-22188, E-mail rolf.schuhmann@tu-berlin.de (106)
- SEIRADAKIS, Prof. J.H., Department of Physics, Section Astrophysics, Astronomy and Mechanics, Aristotle University of Thessaloniki, , GR-54124 THESSALONIKI, GREECE, Tel. +30 2310 998173, Fax+302310 995384, E-mailjhs@astro.auth.gr (110)
- SELLER, Dr. R., Department of Broadband Infocommunication Systems, BME Budapest University of Technology and Economics, Goldman Gyorgy ter 3, 1111 BUDAPESt, HUNGARY, Tel. +36 1 463 3687, Fax +36 1 463 3289, E-mail seller@mht. bme.hu (108)
- SELLERI, Prof. S., Dipartimento di Ingegneria e Architettura, Università degli Studi di Parma, Viale G.P. Usberti 181/A - Campus Universitario, I-43124 Parma, ITALY, Tel. +39 0521 905763, Fax +39 0521 905758, E-mail stefano.selleri@unipr.it (107)
- SEN GUPTA, Dr. A., Department of Applied Sciences, The Northcap University, Sector 23 A, Gurgaon, Haryana 122017, INDIA, Tel. 01242365811, Fax 01242367488, E-mail sengupta53@yahoo.com (106)
- SERRA, Dr. R., Electrical Energy Systems Group, Department of Electrical Engineering, De Zaale, Building 19, Flux 3.134, 5612 AJ Eindhoven, NETHERLANDS, E-mail r.serra@tue.nl (108,111)
- SHAFAI, Prof. L., Electrical and Computer Engineering, University of Manitoba, 75 Chancellors Circle, Winnipeg Manitoba R3T 5V6, CANADA, Tel. +1 613 990 3204, Fax +1-204 269-0381, E-mail lot.shafai@ umanitoba.ca (108)
- SHIBATA, Prof. K., Kwasan Observatory, Kyoto University, Yamashina, KYOTO 607-8471, JAPAN, Tel. +81 75-581 1235, Fax +81 75-593 9617, E-mail shibata@kwasan.kyoto-u.ac.jp (112)
- SHINOHARA, Prof. Naoki, Research Institute for Sustainable Humanosphere (RISH),, Kyoto University, Uji Campus, RISH, Room S-344H, Uji 611-0011, Kyoto 6110011, JAPAN, E-mail shino@rish.kyoto-u. ac.jp (107,111)
- SHMELEV, Dr. A.B., Radiotechn. Inst. by name of Academic Mints, OAO, 8 Marta Street, bld. 10, MOSCOW 125083, RUSSIA, Tel. +7 495 614 2841, Fax +7 495 614 0662, E-mail abshmelev@yahoo. com (107)

- SHOAIB, Dr. N., Department of Electrical Engineering, RIMMS, National University of Sciences and Technology (NUST), H-12, Islamabad, PAKISTAN, E-mail nosherwan.shoaib@seecs.edu.pk (106)
- SHUM PING, Prof., SINGAPORE, E-mail EPSHUM@ ntu.edu.sg (107)
- SIBILLE, Prof A., Telecom ParisTech / Comelec, , 46 rue Barrault, F-75634 Paris Cedex 13, FRANCE, Tel. +33 01 45 81 70 60, Fax +33 01 45 80 40 36, E-mail alain. sibille@telecom-paristech.fr (113)
- SIERRA-CASTAÑER, Prof. M., ETSIT DPCHO. C410, Universidad Politécna de Madrid, Avenida Complutense 30, SPAIN, E-mail maria@gr.ssr.upm.es, manuel.sierra. perez@upm.es (107)
- SIGALO, Dr. F.B., Department of Physics, Rivers State University of Science and Technology, PMB 5080, Port Harcourt, Rivers State, NIGERIA, Tel. 234 803 342 7133, E-mail fbsigalo@hotmail.com (110)
- SIHVOLA, Prof. A., Dept. Radio Science & Engineering, Aalto University, School of Electrical Engineering, PO Box 13000, FI-00076 AALTO, FINLAND, Tel. +358 50 5871286, E-mail Ari.Sihvola@aalto.fi (105,106,111, 113)
- SIMPSON, Assoc. Prof. J., University of Utah, 50 S. Central Campus Dr., Rm 2210, Salt Lake City, UT 84112, USA, Tel. +1 801-585-6929, E-mail jamesina. simpson@utah.edu (106)
- SINHA, Prof. S., Department of Electrical, Electronic and Computer Engineering, University of Pretoria, SOUTH AFRICA, Tel. +27 12 420 2950, E-mail saurabh.sinha@up.ac.za (107)
- SJÖBERG, Prof. D., Electrical and Information Technology, Lund Institute of Technology, P.O. Box 118, 22100 LUND, SWEDEN, Tel. +46 46 222 75 11, Fax +46 46 222 75 08, E-mail daniel.sjoberg@eit.lth.se (106)
- SKOU, Prof. N., Electromagnetic Systems, Denmarks Technical University, Oersted Plads, Building 348, DK 2800 LYNGBY, DENMARK, Tel. (454) 525-3768, Fax (454) 593-1654, E-mail ns@space.dtu.dk (108)
- SKVOR, Prof. Z., Faculty of Electrical Engineering, Czech Technical University, Technická 2, PRAGUE 6 166 27, CZECH REPUBLIC, Tel. +420 224 352 278, Fax +420 233 339 958, E-mail skvor@feld.cvut.cz (106)
- SLAVOVA POPIVANOVA, Prof. A., Mathematical Physics, Institute Of Mathematics And Informatics, Bulgarian Academy Of Sciences, Acad.g.bonchev Str., Bl.8, 1113 Sofia, Bulgaria, Tel. +359 2 979 2841, Fax +3592 971 3649, E-mail slavova@math.bas.bg (110)
- SLOBODZIAN, Prof. P., Faculty of Electronics, Wroclaw University of Technology, 27 Wybrzeże Wyspiańskiego St, 50-370 Wrocław, POLAND, Tel. +48 71 320 4583, E-mail piotr.slobodzian@pwr.wroc.pl (108)
- SMIESKO, Prof. V., Fac. of Electrical Eng. & Information Technology, Slovak University of Technology, Ilkovicova 3, BRATISLAVA 812 19, SLOVAKIA, Tel. +421 2-60291894, Fax +421 2-65429600, E-mail viktor.smiesko@stuba.sk (108)
- SMITH, Prof. P.D., Department of Mathematics, Head of Department, Macquarie University, Sydney, 2109,

- AUSTRALIA, Tel. +61 2 9850 8944, Fax +61 2 9850 8114, E-mail paul.smith@mq.edu.au (105,106,113)
- SOBIESKI, Prof. P., U.C.L. TELE, Bâtiment Stévin, Place du Levant, 2, 1348 LOUVAIN-LA-NEUVE, BELGIUM, Tel. +32 10-47 23 03, Fax +32 10-47 20 89, E-mail Piotr.Sobieski@uclouvain.be (108)
- SORKO, Ms. K., Institute of Physics, University of Graz, Univ. Platz 5, 8010 Graz, AUSTRIA, Tel. +43 316 380 5255, Fax +43 316 380 4825, E-mail karin.sorko@uni-graz.at (113)
- SORRENTINO, Prof. R., Department of Engineering, University of Perugia, Via G. Duranti 93, I-06125 PERUGIA, ITALY, Tel. +390 75-585 3658, Fax +390 75-585 3568, E-mail roberto.sorrentino@unipg.it, r.sorrentino@ieee.org (113)
- SOUSA, Prof. L., NESC-ID, IST, Universidade de Lisboa, 1096 LISBOA CODEX, PORTUGAL, E-mail las@ inesc-id.pt (107)
- SPANSWICK, Dr. E., Dept. of Physics and Astronomy, University of Calgary, 2500 University Drive, Calgary, Alberta T2N 1N4, CANADA, E-mail elspansw@ ucalgary.ca (111)
- STANISLAWSKA, Dr. I., Polish Academy of Sciences, Space Research Centre, ul. Bartycka 18 A, 00-716 WARSAW, POLAND, Tel. +48 22 496 62 01, E-mail stanis@cbk.waw.pl (109,112)
- STOFANIK, Dr. V., Faculty of Electrical Eng. & Inf. Technology, Slovak University of Technology, Ilkovicova 3, SK-81219 BRATISLAVA, SLOVAKIA, Tel. +421 2 602 91 394, Fax +421 2 654 29 683, E-mail vladimir.stofanik@stuba.sk (108)
- STONE, Dr. W.R., 840 Armada Terrace, San Diego, CA 92106, USA, Tel. +1-619 222 1915, Fax +1-619 222 1606, E-mail r.stone@ieee.org (105,114)
- STRUZAK, Dr. R.G., Z21, Instytut Lacznosci Panstwowy Instytut Badawczy, Ul Swojczycka 38, 51-501 Wroclaw, POLAND, Tel. +48 71 369 98 42, E-mail struzak@ gmail.com (105,111, 114)
- SU, Prof. Y-K, Office of Academic Affairs, National Cheng Kung University, No. 1, Ta-Hsueh Road, TAIWAN 701, CHINA (SRS), Tel. +886-6 2757575ext50109, E-mail yksu@mail.ncku.edu.tw (107)
- SU, Dr. D., Beijing University of Aeronautics & Astronautics, XueYuan Road No.37, HaiDian District, Beijing, CHINA (CIE), Tel. +86 10 8231 7224, E-mail sdl@buaa.edu.cn (106)
- SUMICHRAST, Prof. L., Fac. of Electrical Eng. & Information Technology, Slovak University of Technology, Ilkovicova 3, BRATISLAVA 812 19, SLOVAKIA, Tel. +421-2-65423502, Fax +421-2-65420415, E-mail lubomir.sumichrast@stuba.sk (106)
- SUN, Assoc. Prof. Zhipei, Department of Micro-and Nanosciences, Aalto University, P.O. Box 13500, 00076, FINLAND, Tel. +358 50 4302 820, E-mail zhipei.sun@aalto.fi (107)
- SUWAIYEL, Dr. M.I., Directorate of International Cooperation, KACST, P.O. Box 6086, RIYADH 11442, SAUDI ARABIA, Tel. +966 1 488 3555 ext 3490, Fax +966 1 4813441, E-mail int coop@kacst.edu.sa (113)

- SVOBODA, Dr. M., Czech Metrology Institute, Hvozdanska 3, PRAGUE 4 148 01, CZECH REPUBLIC, Tel. +420 271 192 125, Fax +420 272 934 560, E-mail msvoboda@cmi.cz (108)
- SZEKELY, Prof. V., Department of Electron Devices, BME
 Budapest University of Technology and Economics,
 Goldmann Gy. tér 3., H-1111 BUDAPEST, HUNGARY,
 Tel. +36 1-463-2703, Fax +36 1-463-2973, E-mail
 szekely@eet.bme.hu (107)
- SZULAKIEWICZ, Prof. P., Faculty of Electronics & Telecommunications, Poznan University of Technology, 3A Piotrowo Street, 60-965 Poznan, POLAND, E-mail pawel.szulakiewicz@et.put.poznan.pl (107)
- SZYMCZAK, Prof. M., Nicolaus Coopernicus, Astronomy Center, University in Torun, Piwnice k/Torunia, 87 148 Lysomice, POLAND, Tel. +48 56 611 30 33, E-mail msz@astro.umk.pl (110)
- TANZI, Prof. Joseph, LabSoC, c/o EURECOM, Campus SophiaTech Les Templiers, Institut Mines-Telecom Telecom ParisTech., 450 route des Chappes, 06410 Biot, France, Tel. +33 (0)4 93 00 84 11, Fax +33 (0)4 93 00 82 00, E-mail tullio.tanzi@Telecom-ParisTech. fr (105,108,111,112,114)
- TAO, Dr. R., Department of Electronic Engineering, Beijing Institute of Technology, 5 South Zhongguancan Street, Haidan District, Beijing, 100081, CHINA (CIE), Tel. +0086 10 6891 8332, E-mail rantao@bit.edu.cn (107)
- TAROMARU, Dr. M., ATR, Keihanna Science city, 2-2-2 Hikaridai,, Kyoto 619-0288, Japan, E-mail: taromaru@atr.jp (107)
- TEDJINI, Dr. S., INPG-ESISAR, LCIS, 50, rue B. de Laffemas, BP 54, F-26902 VALENCE CEDEX 9, FRANCE, Tel. +33 4 75 75 9420, Fax +33 4 75 43 5642, E-mail smail.tedjini@lcis.grenoble-inp.fr (111)
- THOMSON, Assoc. Prof. N.R., Department of Physics, University of Otago, P.O. Box 56, DUNEDIN, NEW ZEALAND, Tel. +643-4797802, Fax +643-4790964, E-mail n thomson@physics.otago.ac.nz (105,113)
- THUROCZY, Dr. György, Department. of Non-Ionising Radiation, National Research Institute for Radiobiology and Radiohygiene, Anna u.5, H-1221 Budapest, HUNGARY, Tel. +36 1 482 2019, Fax +36 1 482 2020, E-mail thuroczy@hp.osski.hu (110)
- TIAN, Prof. J., Intelligent Medical Research Center, Institute Of Automation, Chinese Academy Of Sciences, Rm. 933, No. 95, Zhongguancun East Rd., Haidian District, 100190 Beijing, Haidian District, China, Tel. 86-10-52628760, E-mail tian@ieee.org (110)
- TJELTA, Dr. T., Department of Technology Systems, Postboks 70, N 2027 Kjeller, NORWAY, E-mail terje. tjelta@its.uio.no (108,111)
- TOBAR, Prof. M.E., School of Physics M013, Frequency Standards and Metrology Research Group, University of Western Australia, 35 Stirling Highway, CRAWLEY, WA 6009, AUSTRALIA, Tel. +61 8 6488 3443, Fax +61 8 6488 1235, E-mail mike@physics.uwa.edu.au (106)
- TORNIKOSKI, Prof. M., Aalto University, Metsähovi Radio Observatory, Metsähovintie 114, 02540 KYLMÄLÄ, FINLAND, Tel. +358 9-2564 831, Fax +358 9-2564 531, E-mail Merja. Tornikoski@aalto.fi (110)

- TRAINOTTI, Prof. V., Bernardo de Irigoyen 650 2° 10, 1072 BUENOS AIRES, ARGENTINA, Tel. +541 4334 3529, Fax +541 4709 3210, E-mail vtrainotti@ieee.org (106)
- TRETYAKOV, Prof. O.A., Department of Theoretical Radio Physics, Kharkov National University, Svoboda Sq. 4, Kharkov 61077, UKRAINE, Tel. +380 572-457163/457257, Fax +380 572-476506, E-mail tretyakov@penta.gyte.edu.tr (106)
- TRETYAKOV, Prof. S., Radio Science And Engineering, Aalto University, P.O. 13000, 00076 Aalto, Finland, Tel. +358 50 350 2562, E-mail sergei.tretyakov@aalto.fi (108)
- TRICHOPOULOS, Mr. G., Electrical, Computer & Energy Engineering ISTB4 555D, Arizona State University, 781 E Terrace Road, Tempe, AZ 85287, USA, Tel. +1 614 364 2090, E-mail gtrichop@asu.edu (114)
- TRUHLIK, Dr. V., Department Of Upper Atmosphere, Institute Of Atmospheric Physics, Acad. Sci. Czech Rep., Bocni Ii, 1401, 14131 Praha, Czech Republic, Tel. 00420267103058, E-mail vtr@ufa.cas.cz (112)
- TRULSEN, Prof. J., Institute of Theoretical Astrophysics, University of Oslo, P.O. Box 1029 Blindern, N-0315 OSLO, NORWAY, Tel. +47 22 856540, Fax +47 22 856505, E-mail jan.trulsen@astro.uio.no (109)
- TSIBOUKIS, Prof. T., Division of Telecommunications, Dept. of Electrical & Computer Eng., Aristotle University of Thessaloniki, GR-54124 THESSALONIKI, GREECE, Tel. +30 23 1099 6323, Fax +30 23 1099 6312, E-mail tsibukis@auth.gr (106)
- TSUKAMOTO, Prof. K., Department of Information Networks, Faculty of Information Science and Technology, Osaka Institute of Technology, 1-79-1 Kitayama, Hirakata, Osaka 573-0196, JAPAN, Tel. +81 72 866 5389, Fax +81 72 866 5389, E-mail katsutoshi. tsukamoto@oit.ac.jp (107)
- TU, Dr. Y-K, Chunghwa Telecom Laboratories, 12, Lane 551, Min-Tsu Road, Sec. 5, TAOYUAN 326, TAIWAN, Tel. +886 3 4244202, Fax +886 3 4244208, E-mail yktu@cht.com.tw (107)
- TUFVESSON, Dr. F., LTH, Box 118, SE-221 00 Lund, SWEDEN, E-mail frederik.tufvesson@eit.lth.se (107)
- TZIOUMIS, Dr. A., CSIRO, Australia Telescope National Facility, PO Box 76, EPPING, NSW 2121, AUSTRALIA, Tel. +61 2 9372 4350, Fax +61 2 9372 4310, E-mail Tasso.Tzioumis@csiro.au, atzioumi@atnf.csiro.au (114)
- ÜNAL, Assist. Prof. I., Inönü University, 44280 Malatya, TURKEY, Tel. +90 422 377 4210, E-mail ibrahim. unal@inonu.edu.tr (109)
- UNO, Prof. T., Department of Electrical and Electronic Engineering, Tokyo University of Agriculture and Technology, Koganei, 2-24-16, Tokyo 183-8588, JAPAN, Tel. +81 42 388 7146, Fax +81 42 388 7146, E-mail uno@cc.tuat.ac.jp (106)
- USLENGHI, Prof. P.L.E., Dept. of ECE (MC 154), University of Illinois at Chicago, 851 S. Morgan Street, CHICAGO, IL 60607-7053, USA, Tel.+1312996-6059, Fax+13129968664, E-mail uslenghi@uic.edu (105)

- USTUNER, Dr. F., TUBITAK BILGEM, TUBITAK Gebze Campus, Baris Mah. Dr. ZEki Acar Cad. No1, 41470 Gebze KOCAELI, TURKEY, Tel. +90 262 679 5031, Fax +90 262 679 5035, E-mail fatih.ustuner@tubitak. gov.tr (106)
- UZUNOGLU, Prof. N.K., Bio-Medical Informatics Group, National Technical University of Athens, Iroon Polytechniou 9, GR-15780 Zografos ATHENS, GREECE, Tel. +30 210 7722289, E-mail nikolaos. uzunoglu@gmail.com (110)
- VAINIO, Prof. R., Head of Space Research Laboratory, Department of Physics and Astronomy, University of Turku, 20014 Turun yliopisto, FINLAND, E-mail rami. vainio@utu.fi (109)
- VAN ARDENNE, Prof. Ir. A., ASTRON, Oude Hogeveensedijk 4, Postbus 2, NL-7990 AA DWINGELOO, NETHERLANDS, Tel. +31 521 595 134, Fax +31 521 595 101, E-mail Ardenne@astron.nl, brink@astron.nl (110)
- VAN DAELE, Prof. P., Dept. of Information Technology (INTEC), IBBT Ghent University, Technologiepark-Zwijnaarde 15, B-9052 GENT, BELGIUM, Tel. +32 9 331 49 06, Fax +32 9 331 48 99, E-mail peter.vandaele@Ugent.be (105,107,113,114)
- VAN DEN BOGAART, Ir. F.L.M., Ransuillaan 101, 2261DB Leidschendam, NETHERLANDS, E-mail frank.vandenbogaart@tno.nl (107)
- VAN DRIEL, Dr. W., GEPI, Observatoire de Paris, 5, Place Jules Janssen, F-92195 MEUDON CEDEX, FRANCE, Tel. +33 1 4507 7731, Fax +33 1 4507 7709, E-mail wim.vandriel@obspm.fr (114)
- VAN LIL, Prof. E., DIV. ESAT-TELEMIC, K.U. Leuven, Kasteelpark Arenberg 10, Bus 2444, B-3001 HEVERLEE,BELGIUM, Tel. +32 16 32 1113, Fax +32 16 32 1986, E-mail Emmanuel.VanLil@ESAT. KULeuven.Be (106)
- VANDENBOSCH, Prof. G.A.E., DIV. ESAT-TELEMIC, Katholieke Universiteit Leuven, Kasteelpark Arenberg 10, Bus 2444, B-3001 LEUVEN, BELGIUM, Tel. +32 16 32 11 10, Fax +32 16 32 19 86, E-mail Guy. Vandenbosch@ESAT.KULeuven.Be (108)
- VANDENDORPE, Prof. L., UCL, TELE, Batiment Stévin, Place du Levant, 2, B-1348 LOUVAIN-LA-NEUVE, BELGIUM, Tel. + 32 10-47 23 12, Fax + 32 10-47 20 89, E-mail Vandendorpe@tele.ucl.ac.be (107)
- VARJU, Dr. G., Department of Electric Power Engineering, Budapest University of Technology and Economics, Egry J. u., H-1111 BUDAPEST, HUNGARY, Tel. +36 1 463 3016, Fax +36 1 463 3600, E-mail varju.gyorgy@vet.bme.hu (108)
- VAUGHAN, Prof. R., Engineering Science, Simon Fraser University, 8888 University Drive, Burnaby, BC V5A 1S6, CANADA, Tel. +1-7787826889, Fax +001 604 2914951, E-mailrvaughan@sfu.ca, rodney_vaughan@sfu.ca (106)
- VELASQUEZ-LOPEZ, Dr. C. V., Director de la Escuela de Ingeniería Electrónica, Universidad Peruana de Ciencias Aplicadas, LIMA, PERU (108)

- VELINOV, Prof. P., Institute for Space and Solar Terrestrial Research, Bulgarian Academy of Sciences, 6 Moskovska Str., 1000 SOFIA, BULGARIA, Tel. +359 2 979 3434, E-mail pvelinov@bas.bg (110)
- VENA, Assoc. Prof. Arnaud , IES (UMR n°5214 CNRS-UM2) , Université de Montpellier 2 , 860 rue Saint Priest, 34000 Montpellier, FRANCE, Tel. + 33 4 671 44629, E-mail arnaud.vena@univ-montp2.fr (107)
- VERGERES, Mr. D., Head of section Radio Technology, DETEC/OFCOM, Zukunftstrasse 44, CH 2501 BIEL, SWITZERLAND, Tel. +41 58 460 57 20, Fax +41 58 460 55 55, E-mail daniel.vergeres@bakom.admin. ch (108)
- VESZELY, Dr. Gy., Department of Broadband Infocommunication Systems, BME Budapest University of Technology and Economics, , H-1521 BUDAPEST, HUNGARY, Tel. +36 1-463-3188, Fax +36 1-463-3189, E-mail Veszely@evt.bme.hu (106)
- VILCAHUAMAN CAJACURI, Prof. L., Seccion Electricidad y Electricidad, Pontificia Universidad Catolica del Peru, Av. Universitaria 1800, San Miguel, LIMA32, PERU, Tel. +51 16262000 (ext. 5030), E-mail lvilcah@pucp.edu.pe (110)
- VOLAKIS, Prof John L., Dean, College of Engineering and Computing, Florida International University, 10555 W. Flagler Street, Miami, FL 33174, USA, Phone: +1 305-348-1197, Fax: +1 305-348-1401, E-mail: jvolakis@fiu.edu (106,114)
- VOMVORIDIS, Prof. I., School of Electrical & Computer Eng., National Technical University of Athens, Iroon Polytechniou 9, GR-15773 ATHENS, GREECE, Tel. +30 210 7723684, Fax +30 210 7723513, E-mail vomvor@central.ntua.gr (109)
- VRBA, Prof. J., Em Field (k13117), Czech Technical University In Prague, Technicka 2, 16627 Prague, Czech Republic, Tel. +420 224 352 298, Fax +420 233 339 958, E-mail vrba@fel.cvut.cz (110)
- WADA, Prof. O., Department of Electrical Engineering, Graduate School of Engineering, Kyoto University, Kyoto Daigaku Katsura, Nishikyo-ku, KYOTO 615-8510, JAPAN, Tel. +81 75 383 2244, Fax +81 75 383 2245, E-mail wada@kuee.kyoto-u.ac.jp (108)
- WALLEN, Dr. H., Dept. Radio Science and Engineering, Aalto University, P.O. Box 13000, Otakaari 5 A, FI-00076 AALTO, FINLAND, Tel. +358 9 470 25668, E-mail henrik.wallen@aalto.fi (113)
- WANG, K.,, IPS World Data Centre, P O Box 1386, New South Wales 2000, AUSTRALIA, E-mail k.wang@bom.gov.au (111)
- WARNANT, Prof. R., Department of Geography, University of Liege, Geomatics Geodesy and GNSS, Bâtiment B5a, Allée du 6 aôut 19, B-4000 LIEGE, BELGIUM, Tel. +32 4 366 90 16, Fax +32 4 366 56 93, E-mail Rene. Warnant@ulg.ac.be (109)
- WARRINGTON, Prof. M., Department of Engineering, University of Leicester, 3 Long Meadow, Leicester, Leics LE1 7RH, United Kingdom, Tel. +44 116 252 2561, Fax +44 115 252 2619, E-mail emw@le.ac. uk (113)

- WATANABE, Prof. S., Department of Cosmosciences, Hokkaido University, Sapporo 060-0810, JAPAN, Tel. +81 11-706-3827, Fax +81 11-706-2760, E-mail shw@ep.sci.hokudai.ac.jp (112)
- WATERS, Assoc. Prof. C., Centre for Space Physics, School of Mathematical and Physical Sciences, University of Newcastle, University Drive, CALLAGHAN NSW 2308, AUSTRALIA, Tel. +61 2 4921 6907, Fax +61 2 4921 5421, E-mail colin.waters@newcastle.edu. au (109)
- WEN, Prof., Y., Emc Lab., Beijing Jiaotong University, 100044 Beijing, China, Tel. 86-10-51688096x808, E-mail yinghongwen@vip.sina.com (108)
- WIART, Dr. J., Orange Labs, DMR:RMC, 38-40, rue du Général Leclerc, F-92131 ISSY LES MOULINEAUX CEDEX, FRANCE, Tel. +33 1 45 29 58 44, E-mail joe.wiart@telecom-paristech.fr, joe.wiart@mines. org (110)
- WICHMAN, Prof. R., Dept. of Signal Processing and Acoustics, Aalto University, PO BOx 13000, FI-00076 AALTO, FINLAND, Tel. +358 9 470 22484, E-mail Risto.Wichman@aalto.fi (107)
- WICKENS, Ms. M., International Contracts Coordinator, Royal Society of New Zealand, 11 Turnbull Street, P.O. Box 598, Wellington 6140, NEW ZEALAND, Tel. +64 44705756, E-mail International. Unions@royalsociety. org.nz (113)
- WIELEBINSKI, Prof R., Max Plank Institute for Radioastronomy, Auf dem hügel 69, 53121 Bonn, Germany, Tel. +49 228525300, Fax +49 228525436, E-mail rwielebinski@mpifr-bonn.mpg. de, wielebinski36@t-online.de (112)
- WIID, Dr. G., Electrical and Electronic Engineering, Stellenbosch University, Private Bag X1, Matieland 7602, SOUTHAFRICA, Tel. +27218083748, Fax +27846818775, E-mail wiidg@stellenbosch.onmicrosoft.com (108)
- WIJNHOLDS, Prof. Stefan J., R&D, ASTRON, P.O Box 2,7990 AA, Dwingeloo, Netherlands, Tel. +31 521 595 261, E-mail wijnholds@astron.nl, breman@astron.nl (105,110,114)
- WIKLUNDH, Dr. K., FOI, Swedish Defence Research Agency, P. O. Box 1165, 58111 Linkoping, Sweden, Tel. +46 13 37 80 55, Fax +46 13 37 81 00, E-mail kia. wiklundh@foi.se (108)
- WILKINSON, Dr. Phil, 16A Queen Street, Mosman, NSW 2088, AUSTRALIA, Tel. +61 2-9213 8003, Fax +61 2-9213 8060, E-mail phil_wilkinson@internode.on.net, p.wilkinson@bom.gov.au (105,109)
- WILSON, Mrs C., Propagation and Spectrum Wireless Technologies Lab., CSIRO ICT Centre, P.O. Box 76, EPPING, NSW 1710, AUSTRALIA, Tel. +61 29 372 42 64, Fax +61 29 372 44 90, E-mail carol.wilson@csiro.au (108)
- WITCZAK, Dr. A., Institute of Radioelectronics, Military University of Technology, Ul. Kaliskiego 2, 00-908 WARSAW, POLAND, Tel. +48 22 683 96 46, Fax +48 22 683 74 61, E-mail andrzej.witczak@wat.edu.pl, awitczak@wat.edu.pl (113)

- WU, Dr. Jian, President of CIE-URSI, CRIRP, P.O. Box 138,195 Rongxiao Road, 453003 XINXIANG, HENAN PROVINCE, CHINA (CIE), Tel. +86 10 68207371, Fax +86 10 68218354, E-mail jian.wu@263.net, wu.jian@139.com (113)
- YAGITANI, Prof. S., Faculty of Electrical and Computer Engineering, Institute of Science & Engineering, Kanazawa University, Kakuma-machi, Kanazawa 920-1192, Japan, Tel. +81-76-234-4858, Fax +81-76-234-4859, E-mail yagitani@is.t.kanazawa-u.ac.jp (113)
- YAMAMOTO, Dr M., Research Institute for Sustainable Humanosphere, Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan, Tel. +81 774 38 3814, Fax +81 774 31 8463, E-mail yamamoto@rish.kyoto-u.ac.jp (109)
- YAMPOLSKY, Prof. Yu. M., Institute of Radioastronomy, NASU, ul. Krasnoznamennaya 4, KHARKOV 310002, UKRAINE, Tel. +380 572-44-8579, Fax +380 572-44-6506, E-mail yampol@rian.kharkov.ua (109)
- YAN, Dr. Y., National Astronomical Observatories, Chinese Academy of Sciences, A20 Datun Road, Chaoyang District, BEIJING 100012, CHINA (CIE), Tel. +86 10 6485 1674, Fax +86 10 6486 3314, E-mail yyh@nao. cas.cn (105,110)
- YARLEQUE MEDINA, Dr. M., Departamento de Ingenieria, Pontificia Universidad Católica del Perú, Sección Ingeniería de las Telecomunicaciones, Av.Universitaria 1801, San Miguel, LIMA32, PERU, Tel. +51-1-626-2452, Fax +51-1-626-2116, E-mail myarleq@pucp.edu.pe (106)
- YAROVOY, Prof. dr. A., Faculteit Elecktotechniek, Wiskunde en Informatica, Technische Universiteit Delft, Mekelweg 4, 2628 CD DELFT, NETHERLANDS, Tel. +31 15 278 2496, Fax +31 15 278 4046, E-mail a.yarovoy@ewi.tudelft.nl (106)
- YOSHIDA, Mr. S., YOKOWO CO., LTD., 1112 KANOHARA, TOMIOKA, GUNMA, 370-2495, JAPAN, Tel. +81-274-62-7133, Fax +81-274-62-7133, E-mail mc@yokowo.co.jp (111)
- ZAGHLOUL, Dr. A., Ece, Virginia Tech, 7121 Arrowood Rd, 20817 Bethesda, USA, Tel. +1-301-394-0886, E-mail amirz@vt.edu, amir.i.zaghloul.civ@mail.mil (107)
- ZAGORODNIY, Prof. A.G., Institute for Theoretical Physics, NASU, 14b, Metrologichna street, KIEV 03143, UKRAINE, Tel. +380 44 492 1423, Fax +380 44 526 5998, E-mail azagorodny@bitp.kiev.ua (109)
- ZAIN-EL-DEEN, Prof. S., Faculty of Electronic Engineering, Menufia University, Menufia, EGYPT, E-mail anssaber@yahoo.com (109)
- ZAW ZAW, Dr., SINGAPORE, E-mail zawzo@ihpc.a-star. edu.sg (106)
- ZEDDAM, Dr. A., FT R&D, DTD/SFE, 2 avenue Pierre Marzin, BP40, F-22307 LANNION CEDEX, FRANCE, Tel. +33 2-9605 3938, Fax +33 2-9605 3427, E-mail ahmed.zeddam@orange-ftgroup.com (111)
- ZERROUKI, Dr. Chouki, Laboratoire de physique, 2, rue Conté, F-75003 PARIS Cedex, FRANCE, Tel. 01 58 80 84 34, Fax 01 58 80 84 34, E-mail zerrouki@cnam. fr, chouki.zerrouki@cnam.fr (106)

- ZHANG, Prof. H., Department of Communications Engineering, University of Science and Technology Beijing, Beijing, 100083, CHINA CIE, E-mail haijunzhang@ieee.org (107)
- ZHAO, Prof. Z., School Of Electronic Information, Wuhan University, 129 Luoyu Road, Wuhan, Hubei, China, Wuhan, China, Tel. 86-27-68756343, Fax 86-27-68756343, E-mail dicilab@yahoo.com.cn (109)
- ZHELYAZKOV, Prof. I., Faculty of Physics, Sofia University, 5 James Boucher Blvd., BG-1164 SOFIA, BULGARIA, Tel. +359 2 816 1641, E-mail izh@phys. uni-sofia.bg (109)
- ZINCHENKO, Dr. Igor, Radio Engineering And Millimeter Wave Astronomy, Institute Of Applied Physic, Russian Academy of Sciences, 46 Ulyanov Str., Nizhny Novgorod 603950, Russia, Tel. +7 831 4367253, Fax +7 831 4160616, E-mail zin@appl.sci-nnov.ru (110)
- ZOMBORY, Prof. L., Department of Broadband Infocommunication Systems, BME Budapest University of Technology and Economics, Goldmann Gy. tér 3., H-1111 BUDAPEST, HUNGARY, Tel. +36 1-463-1559/1824, Fax +36 1-463-3289, E-mail zombory@mht.bme.hu (113)
- ZOZULYA, Prof. Yu.P., Academy of Medical Sciences of Ukraine, Inst. of Neurosurgery, Acad. A. Romodanov, 32, Manuilsky st., KIEV 04050, UKRAINE, Tel. +380 44-213 9573, Fax +380 44-213 9573, E-mail cho72@ ukr.net (110)
- ZVANOVEC, Assoc. Prof. S., Faculty of Electrical Engineering, Czech Technical university, Technicka 2, Prague 6 16627, Czech Republic, Tel. +420 224 355 966, Fax +420 233 339 958, E-mail xzvanove@fel. cvut.cz (108)
- ZWAMBORN, Prof. dr. ir A.P.M., TNO Defence, Security and Safety, Postbus 96864, 2509 JG 'S-GRAVENHAGE, NETHERLANDS, Tel.+3170374 0033, Fax+31703740653, E-mail Peter. Zwamborn@ tno.nl (110)

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