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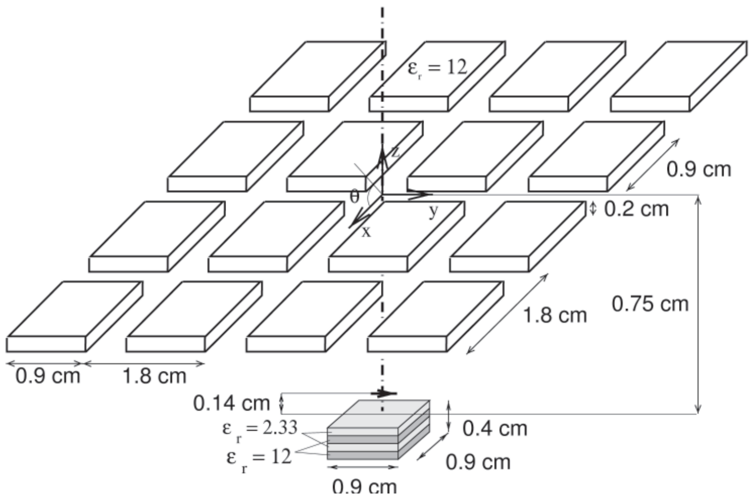

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Front cover: Figure 12 from"Advanced Applications of the Field Equivalence Principle in Numerical Electromagnetic Modelling Techniques (more on pp. 22-29)

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The International Union of Radio Science (URSI) is a foundation Union (1919) of the International Council of Scientific Unions as direct and immediate successor of the Commission Internationale de Télégraphie Sans Fil which dates from 1913.

Editorial

A Very Special Issue

This issue and the next are special issues of the *Radio Science Bulletin*. The specially invited technical papers in these issues are dedicated to and have been written in honor of Jean Van Bladel, on the occasion of his 80th birthday. Jean is an Honorary President of URSI, was Secretary General of URSI for more than 14 years, and has been teacher, mentor, and friend to many, many radio scientists. I am personally grateful for his help and many kindnesses to me over the years.

This issue and the September issue are being guest-edited by Chalmers Butler, Daniel de Zutter, Ken Mei, and Paul Lagasse. Their initiative and efforts are greatly appreciated. Chalmers has written a separate introduction to this issue, and has taken over the editing of the invited papers in this issue. I will therefore forego the usual introductions to the papers, and instead let him concentrate in his comments on the purpose of these special issues.

Some Special Opportunities

The URSI Scientific Committee on Telecommunications (the SCT) is an important opportunity. The efforts within URSI it now encompasses can be traced back over 80 years. It is a vital link whereby URSI's science can provide guidance and find applications within the telecommunications community, primarily as now embodied in the International Telecommunications Union (ITU). Martin Hall, the Chair of the SCT, has done a tremendous job since the last General Assembly in reorganizing the SCT, in helping to define and refine its mission, and in getting key people involved. In this issue, he has provided a comprehensive report on the status of the SCT, and on the opportunities available for radio scientists to become involved. Please read this: you need to be aware of the important work going on here, and you may find a valuable opportunity, either to contribute or to benefit from the SCT's work.

URSI is not an organization that is well known by other than those working directly in radio science. It should be: our science directly affects many aspects of the health, safety, and technological foundations of modern society. François Lefeuvre has undertaken the important task of trying to identify ways to increase the "exposure" of URSI: the public's awareness of what the Union is, and of what it does and can do. He undertook a study of URSI's Resolutions and Recommendations over the past two decades, and that led to a number of questions about how these are used and can be used, and about other ways in which URSI's science can be made available to benefit society in general. One exciting possibility, suggested by Paul Lagasse at the May meeting of the URSI Board, would be for URSI to issue *white papers* on radio-science topics of interest and importance to the general public. These would seek to provide objective documents, with all major pros and cons known on the topic, in a format that might satisfy and be useful to scientists as well as non-scientists. François has developed a questionnaire relating to these various aspects affecting URSI's exposure. It appears in this issue. It's an important opportunity for you to help URSI: Please read it and respond to it.

Jim Lin's "Radio Frequency Radiation Safety and Health" column looks at the important question of what is known (and what isn't known) regarding the risks of mobile communication to children. In many countries, children are by far the fastest growing segment of the population to use cell phones (in some countries, they are already the largest segment). Cellular telephony providers target children with their advertising and service offerings. There is surprisingly little scientific data related to the potential effects of cellular telephones on children, and some of the most important studies seem to contradict each other. You should be aware of what is in this column.

I'll close these comments with one more special opportunity: the opportunity for you to share your work and results with our readers. We need *your* papers. With invited papers such as are in these two special issues, invitations to the authors of the best papers at several URSI-sponsored and URSI-related conferences, the General and Tutorial Lectures from the General Assembly, and the *Reviews of Radio Science* that will start appearing with the December issue, your *Radio Science Bulletin* is becoming a substantial source of important papers of general interest within our field. I was very grateful to the URSI Board at its May meeting when the members gave their strong support to this expanded role of the *Bulletin*. We are fully peer-reviewed, and indexed and abstracted in INSPEC. You can be a part of this, and we need you to be a part of this.

Ross

Erratum

It is unfortunate that an error has occurred in the list of texts of URSI Resolutions from the GA held in Maastricht in 2002. Somehow the text shown for Resolution "U.3." was that of the draft text prepared by the French delegation in advance of the meeting. During the Council meeting on Saturday 24 August, the French delegation withdrew this Resolution in favour of the Resolution agreed at the SCT Open Meeting held on 22 August. The latter text was the one agreed by Council. It reads as follows:

U.3. the Scientific Committee on Telecommunications

The URSI Council

Considering that

a) Scientific aspects of telecommunications are present in the terms of reference of most Commissions and that this situation calls for some liaison,
b) It would be appropriate for the SCT to now be associated with more entities than ITU-R alone,
c) The interests of Science Services in the frequency allocation process are represented by IUCAF,

Resolves

1. To extend the terms of reference as defined below,
2. That the SCT will include a representative of each Commission, appointed by the Chairs of the Commissions, and participants in the work of the ITU-R and such other entities as it may decide. It may co-opt up to eight other individuals active in work covered by its terms of reference. It will appoint its own Chair, the relevant Commission to then nominate a replacement representative.

Terms of Reference

1. To initiate, promote and co-ordinate inter-commission activities in the telecommunications area on specified topics to be identified, and through the organisation of joint symposia.
2. To identify areas of common interest to URSI and to ITU-R or similar entities, and, where appropriate, to exchange relevant information between the URSI Commissions and the working groups (e.g. ITU-R Study Groups), and to promote collaborative activities.
3. To keep the URSI community informed on ITU-R and similar matters through the Radio Science Bulletin.
4. To initiate, co-ordinate and liaise any formal URSI contributions to ITU-R or similar bodies."

The French version (with our special thanks to Professor Hanuise for the French translation) :

U.3. le Comité Scientifique pour les Télécommunications

Le Conseil de l'URSI

Considérant que

a) les aspects scientifiques des télécommunications sont présents dans les termes de référence de la plupart des Commissions, et que cette situation demande une forme de liaison,
b) qu'il serait approprié que le CST soit maintenant associé à d'autres entités que la seule UIT-R,
c) que les intérêts des services scientifiques dans le processus d'allocation des fréquences sont représentés par l'IUCAF,

décide

1. d'étendre les termes de référence comme défini ci-dessous,
2. que le SCT comprendra un représentant de chaque Commission, nommé par les présidents des Commissions, ainsi que les participants aux travaux de l'UIT-R et d'autres entités qu'il pourra définir. Il peut co-opter jusqu'à huit autres personnes actives dans des travaux couverts par ses termes de référence. Il nommera son propre président, sa Commission d'appartenance nommant alors un représentant en remplacement.

Termes de Référence

1. Initier, promouvoir et coordonner les activités inter-commissions dans le domaine des télécommunications sur des sujets précis à identifier et par l'organisation de symposiums communs.
2. Identifier les domaines d'intérêt commun à l'URSI et à l'UIT-R ou autres organisations, et échanger les informations relevantes entre les Commissions de l'URSI et les groupes de travail (e.g. Groupes d'Etude de l'UIT-R), et promouvoir les activités de collaboration.
3. Informer la communauté de l'URSI des activités de l'UIT-R et similaires par l'intermédiaire du 'Bulletin des Sciences Radio'.
4. Initier, coordonner et transmettre toute contribution formelle de l'URSI à l'UIT-R ou organismes similaires.

With our apologies for the inconvenience caused.

URSI Accounts 2002

As usual in a year of a General Assembly, the accounts of URSI show a deficit. This is a normal situation in the 3 years cycle of URSI and is compensated during the intervening years. However, the deficit is high because the revenue of the GA2002 has not been paid as yet. In addition to that, new ICSU policy for use of funds resulted in relinquishment of its support of URSI activities. To partly compensate the loss, the Board decided to change ICSU category for URSI. It should also be noted that several member committees delay payment of their dues. Nevertheless the finances of URSI are still sound and we are ready to continue support of our scientific activities and publications.

Paul Lagasse
Secretary General

Andrzej W. Wernik
Treasurer

BALANCE SHEET: 31 DECEMBER 2002

ASSETS	USD	USD	EURO	EURO
Dollars				
Merrill Lynch WCMA	12,491.41		13,094.75	
Fortis	14,850.44		15,567.72	
Smith Barney Shearson	-1.38		-1.45	
		27,340.47		28,661.02
Euros				
Banque Degroof	1,731.00		1,814.61	
Fortis	61,189.60		64,145.06	
		62,920.60		65,959.67
Investments				
Demeter Sicav Shares	22,794.75		23,895.74	
Rorento Units	111,969.73		117,377.87	
Aqua Sicav	64,103.22		67,199.41	
Merrill-Lynch Low Duration (305 units)	3,117.59		3,268.17	
Massachusetts Investor Fund	277,478.91		290,881.14	
	479,464.20		502,622.33	
684 Rorento units on behalf of van der Pol Fund	12,476.17		13,078.77	
		491,940.37		515,701.10
Petty Cash		455.36		477.35
Total Assets		582,656.80		610,799.14
Less Creditors				
IUCAF	28,761.92		30,151.12	
ISES	4,971.50		5,211.62	
		-33,733.42		-35,362.74
Balthasar van der Pol Medal Fund		-12,476.14		-13,078.77
NET TOTAL OF URSI ASSETS		**536,447.24**		**562,357.63**

The net URSI Assets are represented by:	USD	USD	EURO	EURO
Closure of Secretariat				
Provision for Closure of Secretariat		72,500.00		76,001.75
Scientific Activities Fund				
Scientific Activities in 2003	32,000.00		33,545.60	
Publications in 2003	30,000.00		31,449.00	
Young Scientists in 2003	50,000.00		52,415.00	
Administration Fund in 2003	64,500.00		67,615.35	
I.C.S.U. Dues in 2003	9,000.00		9,434.70	
		185,500.00		194,459.65
XXVII General Assembly 2002 Fund:				
During 2003-2004-2005		p.m.		p.m.
Total allocated URSI Assets		258,000.00		270,461.40
Unallocated Reserve Fund		278,447.24		291,896.23
		536,447.24		**562,357.63**

Statement of Income and expenditure for the year ended 31 December 2002

I. INCOME	USD	USD	EURO	EURO
Grant from ICSU Fund and US National				
Academy of Sciences	0.00		0.00	
Allocation from UNESCO to ISCU Grants Programme	0.00		0.00	
UNESCO Contracts	0.00		0.00	
Contributions from National Members	154,646.94		162,116.39	
Contributions from Other Members	0.00		0.00	
Special Contributions	0.00		0.00	
Contracts	0.00		0.00	
Sales of Publications, Royalties	1,907.85		2,000.00	
Sales of scientific materials	0.00		0.00	
Bank Interest	293.87		308.06	
Other Income	8,235.21		8,632.97	
Total Income		**165,083.87**		**173,057.42**

II. EXPENDITURE

A1) Scientific Activities		164,132.47		172,060.07
General Assembly 2002	142,581.80		149,468.50	
Scientific meetings: symposia/colloqiua	13,450.35		14,100.00	
Working groups/Training courses	0.00		0.00	
Representation at scientific meetings	8,100.32		8,491.57	
Data Gather/Processing	0.00		0.00	
Research Projects	0.00		0.00	
Grants to Individuals/Organisations	0.00		0.00	
Other	0.00		0.00	
Loss covered by UNESCO Contracts	0.00		0.00	

A2) Routine Meetings		9,207.89		9,652.63
Bureau/Executive committee	9,207.89		9,652.63	
Other	0.00		0.00	
A3) Publications		31,964.14		33,508.01
B) Other Activities		4,682.00		4,908.14
Contribution to ICSU	4,682.00		4,908.14	
Contribution to other ICSU bodies	0.00		0.00	
Activities covered by UNESCO Contracts	0.00		0.00	
C) Administrative Expenses		72,703.89		76,215.49
Salaries, Related Charges	53,043.17		55,605.16	
General Office Expenses	11,698.77		12,263.82	
Office Equipment	0.00		0.00	
Audit Fees	5,251.86		5,505.52	
Bank Charges	2,110.49		2,212.43	
Loss on Investments	599.60		628.56	
Total Expenditure:		**282,690.39**		**296,344.34**
Excess of Income over Expenditure		-117,606.52		-123,286.92
Currency translation difference (USD => EURO) - Bank Accounts		-1,948.25		-2,042.35
Currency translation difference (USD => EURO) - Investments		-34,208.49		-35,860.76
Currency translation difference (USD => EURO) - others		35,880.21		37,613.22
Accumulated Balance at 1 January 2002		654,330.29		685,934.44
		536,447.24		**562,357.63**

Rates of exchange:

January 1, 2002	$ 1 = 1.123 EUR
December 31, 2002	$ 1 = 1.0483 EUR

	USD	EURO
Balthasar van der Pol Fund		
684 Rorento Shares: market value on December 31, 2000		
(Aquisition Value: USD 12.476,17)	25,009.75	26,217.72
Market Value of investments on December 31, 2001		
Demeter Sicav	49,975.66	52,389.48
Rorento Units (1)	475,331.49	498,290.00
Aqua-Sicav	72,682.01	76,192.55
M-L Low Duration	3,147.60	3,299.63
Massachusetts Investor Fund	163,611.86	171,514.31
	764,748.62	**801,685.97**

(1) Including the 684 Rorento Shares of the van der Pol Fund

APPENDIX: Detail of Income and Expenditure

	USD	USD	EURO	EURO
I. INCOME				
Other Income				
Income General Assembly - support YS Japan	4,000.00		4,193.20	
Income General Assembly - grant UK Panel	2,218.43		2,325.58	
Interest on Short Term Deposito	1,731.01		1,814.62	
Interest on M-L Short Term	285.74		299.54	
Interest on Massachusetts Investor Fund	0.03		0.03	
		8,235.21		8,632.97
II . EXPENDITURE				
General Assembly 2002				
Organisation	46,573.41		48,822.91	
Vanderpol Medal	1,100.92		1,154.09	
Expenses officials	50,962.36		53,423.84	
Young scientists	43,945.11		46,067.66	
		142,581.80		149,468.50
Symposia/Colloquia/Working Groups:				
Commission A	2,575.60		2,700.00	
Commission B	0.00		0.00	
Commission C	615.28		645.00	
Commission D	558.05		585.00	
Commission E	476.96		500.00	
Commission F	0.00		0.00	
Commission G	1,478.58		1,550.00	
Commission H	1,259.18		1,320.00	
Commission J	2,861.78		3,000.00	
Commission K	3,624.92		3,800.00	
		13,450.35		14,100.00
Contribution to other ICSU bodies				
IUCAF	0.00		0.00	
		0.00		0.00
Publications:				
Printing ‘The Radio Science Bulletin’	14,966.59		15,689.48	
Mailing ‘The Radio Science Bulletin’	16,997.55		17,818.53	
		31,964.14		33,508.01

Guest Editors' Comments

The June and September, 2003, issues of the URSI *Radio Science Bulletin* are published in honor of Professor Jean Van Bladel to celebrate his eightieth birthday. Four former students of Professor Van Bladel's chose the publication of these two special issues as a way to express their long-term affection and gratitude to their mentor and friend. As guest Editors of the two special issues, they issued invitations to participate to former students and selected professional colleagues and friends who are close to Professor Van Bladel. Although several invitees no longer work in radio science or related areas of electromagnetics and some preferred to decline our invitation due to other commitments, the response has been most gratifying. We hope you, the reader, derive as much pleasure from the papers in these two issues as we have derived in the opportunity to honor our former teacher, and, if you infer devotion to him on the parts of the Editors and authors, your senses do not deceive you.

Jean G. Van Bladel was born eighty years ago in Antwerp, Belgium, on July 24, 1922. Brussels University conferred the Electromechanical Engineer and the Radio Engineer degrees upon him in 1947 and 1948, respectively, and he received the MS and PhD degrees in electrical engineering in 1949 and 1950 from the University of Wisconsin, Madison. He was Head of the Radar Department of the Manufacture Belge de Lampes et de Matériel Electronique in Brussels during 1950 to 1954 and was an associate professor at Washington University, St. Louis, MO, from 1954 to 1956. In 1956, Professor Van Bladel became an associate professor at the University of Wisconsin, Madison, where he rose to the rank of full professor in 1960. In 1964 he returned home to Belgium to become Professor of Electrical Engineering and Director of the Laboratory for Electromagnetism and Acoustics at the University of Ghent, which he founded. In addition, during 1976 through 1978, Professor Van Bladel served as Dean of the Faculty of Applied Science of the University of Ghent and, from 1981 to his mandatory retirement in 1987, he was a member of the University Board.

In 1962-63, Professor Van Bladel was a Guggenheim fellow and a visiting professor at the Royal Institute of Technology, Stockholm, and was the Brittingham Visiting Professor at the University of Wisconsin in 1974. He was a visiting professor at the National University of Zaire in 1976 and held the Francqui Chair at the Free University of Brussels in 1978-79 and, again, in 1982.

Among numerous other international offices of importance that he has held, Professor Van Bladel was for more than ten years Secretary General of the International Union of Radio Science and now holds the title, Honorary President of URSI. He is a fellow of the IEEE and of the IEE, has served as Chairman of the European Microwave Conference, was the recipient of the Montefiore Prize in 1965, and has been a member of several editorial boards. He is a member of the Royal Academy of Sciences of Belgium (1984), a member of the Electromagnetics Academy (1990), a foreign member of the Real Academia de Ciencias, Spain (1989), and is a Corresponding Astronomer of the Royal Observatory of Belgium (1990). In 1987, the University of Liège conferred the Honorary Doctor's Degree upon Professor Van Bladel. From the IEEE, Professor Van Bladel received the 1995 Heinrich Hertz Medal and the Antennas and Propagation Society's 1997 Distinguished Achievement Award. A complete list of his noteworthy professional service and other honors and awards is simply too lengthy to delineate here.

As an author of textbooks and monographs, Professor Van Bladel has guided many of us to a better understanding of electromagnetics and has revealed to us a storehouse of techniques for solving a variety of problems. He is the author of *Les Applications du Radar à l'Astronomie et à la Météorologie* (Gauthier-Villars, Paris, 1955), *Relativity and Engineering* (Springer-Verlag, Berlin, 1984), and *Singular Electromagnetic Fields and Sources,* (Oxford University Press, Oxford, 1991; reprinted by IEEE Press, Piscataway, 1995). To those of us in the radio science community his best-known work is *Electromagnetic Fields* (McGraw-Hill, New York, 1964; reprinted by Hemisphere, New York, 1985), a tome on analytical methods for solving boundary-value problems in fields and waves. An extensive revision of the last volume has been completed, so we all look forward to seeing the second edition on our bookshelves in the not-too-distant future. In addition, Professor Van Bladel has contributed chapters to several books edited by others. He also has published many papers in leading research journals.

Professor Van Bladel is a man of truly remarkable achievement in the international community of electrical scientists, radio scientists, and electrical engineers, and, by any measure, he must be listed among the handful of leading researchers of the past thirty years in electromagnetic theory and numerous of its applications. In several facets of electromagnetics – guided waves, aperture theory, dielectric resonator theory, the concept of field singularities near edges, among others – Professor Van Bladel's contributions have had significant influence on subsequent researchers and their work. In addition to fundamental contributions in the above areas, Professor Van Bladel has made relativity accessible to electrical engineers. He has shown us the utility of this arcane concept in solving everyday problems in electrical engineering, ranging from rotational and translational media to electromagnetic scattering from moving objects. In the early 1960s, it was Professor Van Bladel who first advanced a method for solving an electrodynamic integral equation by numerical methods. At the time, electrostatic and magnetostatic integral equations had been solved by Professor Van Bladel and several others, but he was the first to lead us to the use of a digital computer to solve a time-harmonic integral equation.

Professor Van Bladel's research contributions to electromagnetic theory and applications are vast. His books and papers have been important resources to researchers and teachers alike, and they will stand the test of time with grace. Over a long and distinguished career, which continues at a frantic pace today, he has exhibited a rare depth of understanding and originality. Professor Van Bladel commands the respect of everyone in the electromagnetics community and he enjoys rapport with his colleagues around the world. He is exceptionally articulate, perceptive, personable, and reflects genuine concern for his friends and professional colleagues. He appreciates the arts and music and has a deep sense of history. These qualities are intricately woven into an exquisite and rare Belgian fabric.

Jean Van Bladel and his wife Hjördis (Pettersson) reside in Deurle, Belgium, and spend their summers in Nieuwpoort on the Belgian coast. Their three children, Vivica, Eric, and Sigrid, live in the US.

The authors, the Editors, his former students, and many colleagues dedicate the June and September, 2003, issues of the URSI *Radio Science Bulletin* to Jean Van Bladel on the occasion of his eightieth birthday. We hope this modest tribute to a distinguished scientist conveys to our gentle friend the intensity and depth of our gratitude, affection, and admiration.

Chalmers M. Butler
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On the Horton-Weigel-Sprott Model of the Solar-Wind-Driven Magnetosphere-Ionosphere System

Ahmet Uçar
Er-Wei Bai
K.E. Lonngren

Abstract

The solar-wind-driven magnetosphere-ionosphere is a system that exhibits a variety of dynamical states. These include low-level steady plasma convection, intermittent releases of stored plasma energy into the ionosphere that are known as sub-storms, and states of continuous strong unloading. The WINDMI model consisting of a set of six nonlinear coupled ordinary differential equations has been used to describe the energy flow through this system. This model has recently been reduced to a set of three nonlinear coupled ordinary differential equations that has been shown to admit chaotic solutions. The present calculation demonstrates that it is possible to synchronize this reduced nonlinear system with another system that may even be linear.

1. Introduction

The solar-wind-driven magnetosphere-ionosphere is a system that exhibits a variety of dynamical states. These include low-level steady plasma convection, intermittent releases of stored plasma energy into the ionosphere that are known as sub-storms, and states of continuous strong unloading. There are several models that have been used in order to interpret the observed physical phenomena. One of these models is the WINDMI model that consists of six coupled nonlinear ordinary differential equations describing the temporal evolution of the energy flux throughout the system [1]. Chaotic solutions were obtained using the system that appeared to agree with experimental observations.

With certain approximations, this set of six coupled nonlinear ordinary differential equations that comprise the WINDMI model was reduced to a set of three coupled nonlinear ordinary differential equations [2]. There was a comparison between the predictions obtained from the full six dimensional WINDMI model and the reduced three-dimensional model with excellent agreement.

The reduced three-dimensional model is a member of a large family of three coupled nonlinear ordinary differential equations that has recently received attention [3]. This family is known to admit chaotic solutions [3]. Also, this family has been used to describe "jerky dynamics" that one would encounter in mechanical and electrical systems. This set of equations is a member of a large family of sets of nonlinear equations that include various non-linear terms. This family has been shown to admit chaotic solutions. The resulting third-order ordinary differential equation in one dependent variable that can be derived from this set is called the "jerk" equation and it describes the time derivative of the acceleration. The jerk equation is of the form

$$\frac{d^3x}{dt^3} = F\left(\frac{d^2x}{dt^2}, \frac{dx}{dt}, x\right).$$

Sprott recently described and experimentally verified the properties of the jerk equation using various non-linear electronic circuits [4]. Electronic circuits have been designed and constructed whose experimental results confirm the theoretical predictions that one would expect from this three-dimensional model [4]. Recently, it has been shown that it is possible to synchronize this particular model either with a similar model containing different parameters and different initial conditions or with a completely different system including a linear system [5]. In the latter case, it was observed that the chaotic solutions would come under the influence of and quickly follow the signals generated by the linear system. The synchronization procedure could have many practical implications [6].

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Dedicated to Professor J. Van Bladel on the occasion of his 80th. birthday

The purpose of the present investigation is to analyze the reduced three-dimensional model that was derived from the six dimensional WINDMI model. The analysis will be based on techniques that are found in nonlinear control theory and have been of recent interest to the authors. The analysis along with the results of a numerical simulation is described in Section 2. In Section 3, we summarize the procedure of creating a nonlinear controller that will permit the synchronization of the chaotic reduced three-dimensional model with a linear three-dimensional model. Numerical results confirm the efficacy of the nonlinear controller that has been proposed. Section 4 contains the concluding comments.

2. The Reduced Model

It was shown in reference [2] that the six-dimensional WINDMI model can be reduced to the following three-dimensional model consisting of three coupled dimensionless ordinary differential equations. The normalizations and the justification leading to this reduction are also included in the reference.

$$\frac{dx}{dt} = -y\,,$$
$$\frac{dy}{dt} = c_1 x - b_3 y - z\,, \tag{1}$$
$$\frac{dz}{dt} = -c_2 - c_3 \tanh(x)\,\cdot$$

The constants that appear in (1) are defined as follows:

$$c_1 = a_1 b_1$$
$$c_2 = \frac{1}{4} a_1 d_1 (b_1 - b_3 V_{SW})^{3/2} \left(\frac{V_{SW}}{b_2}\right)^{1/2}$$
$$-a_1 b_2^2 d_1 \frac{V_{SW}^2}{2(b_1 - b_3 V_{SW})} \tag{2}$$
$$c_3 = \frac{1}{4} a_1 d_1 (b_1 - b_3 V_{SW})^{3/2} \left(\frac{V_{SW}}{b_2}\right)^{1/2}.$$

Numerical values were assumed for all of the parameters in order to simulate the response of the reduced three-dimensional model. The numerical values that were used in reference [2] as well as in our simulation are presented in (3):

$$a_1 = 0.247,\; a_2 = 0.391,\; b_1 = 10.8,$$
$$b_2 = 0.0752,\; b_3 = 1.06,\; d_1 = 2200, \tag{3}$$
$$f_1 = 2.47,\; g_1 = 1080,\; g_2 = 4,$$
$$g_3 = 3.79.$$

There is one additional parameter that is yet to be specified. This is the value of the normalized solar wind voltage V_{SW}. This voltage assumed values that were in the range between 0 and 10. The initial conditions for all of the dependent variables were chosen to be

$$\left(x(0), y(0), z(0)\right) = (0,0,0)\,\cdot \tag{4}$$

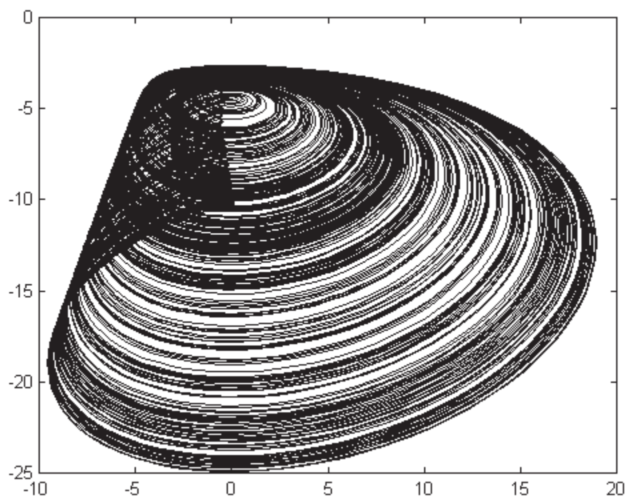

Figure 1. A phase-space diagram with the solar wind voltage having the value $V_{SW} = 4.8$. This figure is similar to Figure 4 in reference [2].

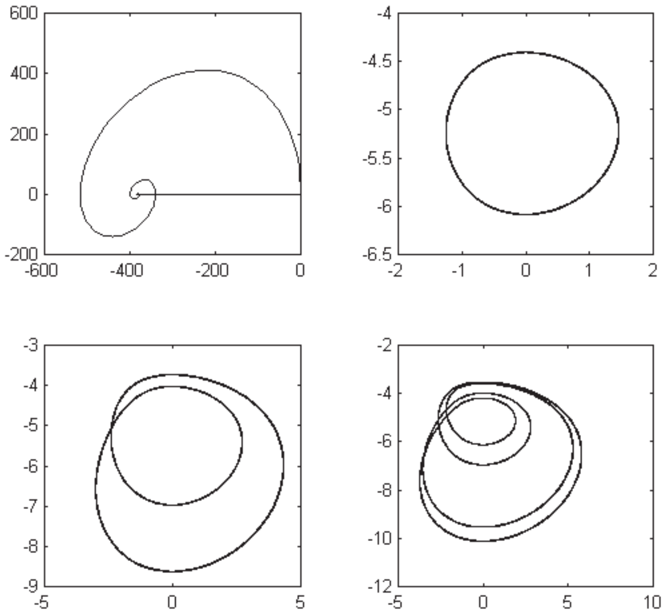

Figure 2. Phase-space diagrams for various values of the solar wind voltage, V_{SW} : (a) $V_{SW} = 2$, (b) $V_{SW} = 3$, (c) $V_{SW} = 3.7$, and (d) $V_{SW} = 3.9$.

We found that it was convenient to present the results in a phase plane format of two of the dependent variables rather than presenting the temporal evolution of all three dependent variables.

The first calculation that we performed incorporated a particular choice for the value of the parameter V_{SW} in order to obtain preliminary results that could be directly compared with those presented in the original Horton-Weigel-Sprott model simulation [2]. The value of this parameter was chosen to be $V_{SW} = 4.8$, which is sufficiently large to cause the system to evolve into chaotic behavior. A comparison on Figure 4 of their simulation with the results that we have obtained that are shown in Figure 1 indicates that the program that we have developed is correct. Therefore, we are able to proceed with other values to obtain a catalog for the expected behavior on the system for different values of the reduced solar wind voltage parameter V_{SW} .

We found that there is a stable point in the reduced model of the magnetosphere if the normalized solar wind voltage has the normalized value $V_{SW} = 2.0$ and this is shown in Figure 2a. The evolution of the response produces a stable oscillation that is indicated by the limit cycle in the phase plane as the solar wind voltage assumes the value $V_{SW} = 3$ as presented in Figure 2b. This evolution of the response eventually produces multiple oscillations for the values of $V_{SW} = 3.7$ and $V_{SW} = 3.9$. This behavior is summarized in Figure 2c and Figure 2d, respectively.

Increasing the value of the parameter V_{SW} still further led to a more complicated phase space pattern. The results that were obtained for the parameter $V_{SW} = 4$ and $V_{SW} = 5.5$ are respectively shown in Figure 3a and Figure 3b. The results of both figures indicate that the system has evolved into a chaotic behavior for these values. A further increase of the parameter to a value of $V_{SW} = 6.5$ and $V_{SW} = 9.5$ produces multiple oscillations. The results of the last two calculations are shown in Figure 3c and Figure 3d respectively.

Therefore, we realize that the evolution of the response of the reduced three-dimensional model is very complicated. In the summary, we examined the dependence of the evolution only in that it depends very critically upon just one parameter – the value of the solar wind voltage V_{SW} . We suspect, but have not yet verified, that the variation of different parameters would also lead to similar behavior.

However, the observation that just the variation of one parameter leads to very interesting effects that warrant further investigation. In particular, the possible interaction between two identical systems with different values of the solar wind voltage could be examined. In addition, one of the systems could be a system that leads to a linear oscillation and the other system would be the reduced solar wind model. We subsequently call the linear systems the "master" and the reduce solar wind system the "slave" following the nomenclature of nonlinear control theory. The results of this investigation suggest that the solar wind model can be synchronized with and to a linear oscillator. This observation suggests that an investigation of a possible interaction between two identical systems that have different values of the solar wind voltage was warranted. In particular, would it be possible to synchronize the two systems together such that one could be considered to be the "master" system and the other would be the "slave" system? The answer to this question is presented below.

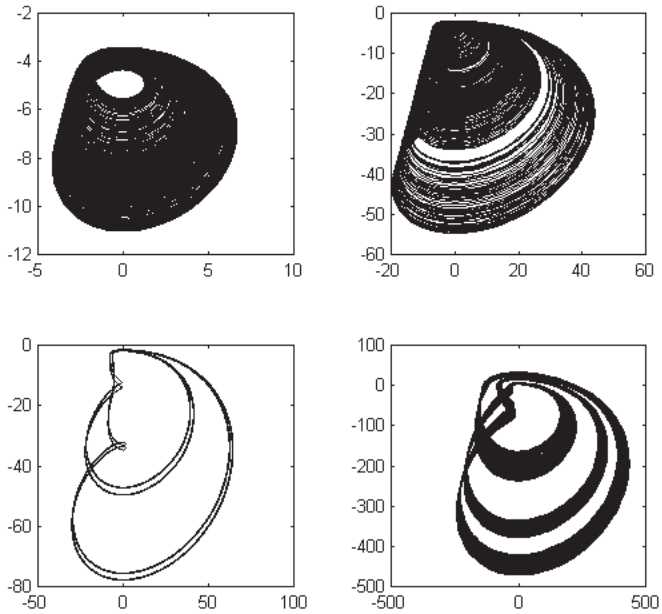

Figure 3. Phase-space diagrams for various values of the solar wind voltage V_{SW} : (a) $V_{SW} = 4$, (b) $V_{SW} = 5.5$, (c) $V_{SW} = 6.5$, and (d) $V_{SW} = 9.5$

3. Synchronization

The goal of synchronization is to force the slave system to follow the master system. In the control literature, this is called *one-way synchronization* [6]. We are interested in having a chaotic reduced solar wind system follow a linear system that can be defined with the following three ordinary differential equations.

$$\frac{dx_1}{dt} = y_1 ,$$
$$\frac{dy_1}{dt} = -\omega^2 x_1 , \qquad (5)$$
$$\frac{dz_1}{dt} = -\omega^2 y_1 .$$

This set of three equations produces time-harmonic signals that have a frequency of oscillation ω .

The gain of the signal is defined by the magnitude of the initial conditions of both x_1 and z_1 states and the oscillation frequency, $z_1(0) = -\omega^2 x_1(0)$. In actuality, this corresponds to a second-order system for these particular initial conditions.

The reduced solar wind system (1) is rewritten as

$$\frac{dx_2}{dt} = -y_2 + \mu_a(t)$$
$$\frac{dy_2}{dt} = c_1 x_2 - b_3 y_2 - z_2 + \mu_b(t) \qquad (6)$$
$$\frac{dz_2}{dt} = -c_2 - c_3 \tanh(x_2) + \mu_c(t)$$

where we have introduced control signals $\mu_a(t)$, $\mu_b(t)$, and $\mu_c(t)$. The control signals are not yet known and have to be determined. Once determined, they force the reduced solar wind system (6) to follow the linear system (5).

The control signals are obtained from an examination of the differences between the dependent variables of slave system given by (6) and master system of (5). This difference that is called the "error system" is given by

$$e_x = x_2 - x_1$$
$$e_y = y_2 - y_1 \qquad (7)$$
$$e_z = z_2 - z_1 .$$

These error signals can be easily computed by subtracting the linear system (5) from the nonlinear system (6) and using (7) to define the differences of the dependent variables. We write

$$\frac{de_x}{dt} = -y_2 - y_1 + \mu_a(t)$$
$$\frac{de_y}{dt} = c_1 x_2 - b_3 y_2 - z_2 + \omega^2 x_1 + \mu_b(t) \qquad (8)$$
$$\frac{de_z}{dt} = -c_2 - c_3 \tanh(x_2) + \omega^2 y_1 + \mu_c(t)$$

If we choose the control signals to have the following values

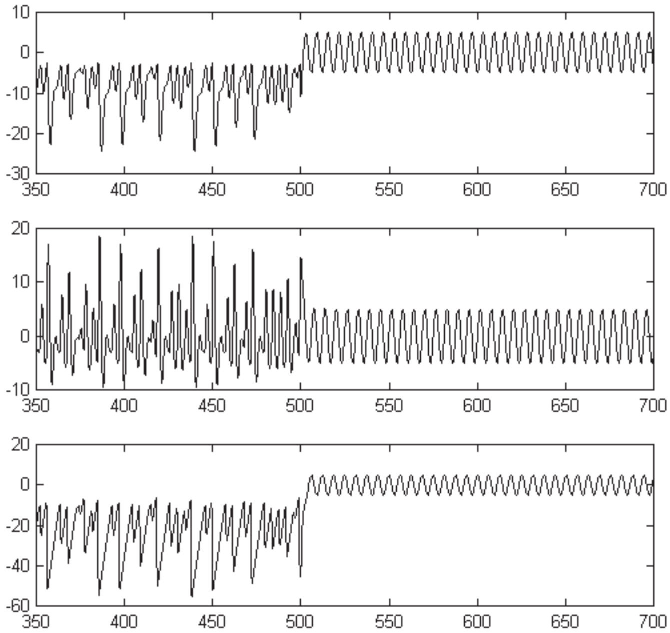

Figure 4. The temporal evolution of the three variables as a control signal is activated at the time $t = 500$: (a) The variable x_2 ; (b) the variable y_2 ; (c) the variable z_2 .

$$\mu_a(t) = -e_x + (y_2 + y_1)$$
$$\mu_b(t) = -e_y - (c_1 x_2 - b_3 y_2 - z_2 + \omega^2 x_1) \quad (9)$$
$$\mu_c(t) = -e_z - (-c_2 - c_3 \tanh(x_2) + \omega^2 y_1)$$

then the error dynamics converge to zero asymptotically.

The validity of the synchronization process was verified numerically. For the simulation, the value of the solar wind voltage was chosen to be $V_{SW} = 4.8$. The response of two of the variables was described previously with the phase space diagram presented in Figure 1. The frequency of oscillation of the linear signal was arbitrarily chosen to be $\omega = 1$. The values of the initial conditions for the linear oscillation (5) were

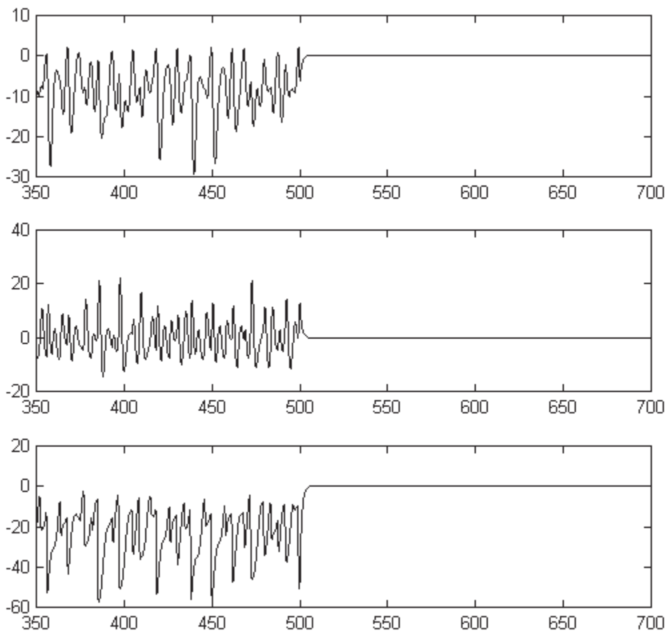

Figure 5. The temporal evolution of the three error signals as the control signal is activated at the time $t = 500$: (a) The variable e_x ; (b) The variable e_y ; (c) The variable e_z .

$$z_1(0) = -\omega^2 x_1(0) \, , \; x_1(0) = 5 \, . \quad (10)$$

The control signal was activated at the time $t = 500$.

The temporal evolution of a three variables x, y, and z is shown in Figure 4. The results of the simulation clearly indicate that the synchronization of the chaotic signals with the corresponding linear signals is achieved very quickly after activation at the time $t = 500$. The corresponding error signals are shown in Figure 5.

4. Conclusion

In this investigation, we have illustrated the procedure to synchronize the reduced model of the solar wind with a linear time system. Numerical confirmation of the method clearly indicates the validity of the technique. The actual creation of the nonlinear control signals and the introduction of these signals into the solar wind is beyond the scope on the present investigation. The goal of this project was to just suggest a possible concept that could be employed and to provide a methodical procedure to obtain the synchronizing mechanism.

The authors wish to congratulate Professor Jean van Bladel on the occasion of his 80th birthday. One of the authors (KEL) had the good fortune to have Professor van Bladel as a teacher and an adviser in his academic career. He wishes to say: “Thank you.”

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2003 International Electromagnetics Prize

In the opinion of the review panel none of the submissions for the 2003 Prize were in accord with the objectives of the competition, and because of this, the 2003 Prize is not awarded.

For the benefit of those competing for the 2004 and subsequent prizes, it may be desirable to restate the objectives of the International Electromagnetics Prize.

The overall purpose is to encourage the use of the computer to treat fundamental scattering and antenna problems and to employ the data so obtained to develop usable, physically-based, approximate analytical expressions for, for example, the scattering, radiation pattern, surface field, or whatever is of practical interest. To be successful, a submission must contain such expressions. A key feature is the specification of bounds establishing the accuracy of the expressions. The bounds may be developed either from first principles or by appeal to properties that can be traced to first principles. The expressions should be as general as possible for which the accuracy can be specified. In the case of a right circular cone, quantities of particular interest are the scattering as a function of incidence and scattering angles for a particular cone, the axial backscattering as a function of cone angle, and the bistatic scattering as a function of the scattering and cone angles for axial incidence. Expressions for one or more of these quantities would be useful even for restricted ranges of the parameter(s), provided the accuracy is specified.

A successful submission must contain such expressions, and the development of a new formulation of the specified problem, worthy though it may be, is not in accord with the objectives of the competition.

T.B.A. Senior
Chair, review panel

A Time-Domain Uniqueness Theorem for Electromagnetic Wavefield Modeling in Dispersive, Anisotropic Media

Adrianus T. de Hoop

Abstract

A uniqueness theorem for the initial-/boundary-value problem arising in the (analytic or computational) modeling of electromagnetic wavefields in arbitrarily dispersive and anisotropic media is presented. It is known that for media where the dispersion takes place via electrically conductive and/or linear magnetic hysteresis losses only, a uniqueness theorem for the initial-/boundary-value problem can be constructed by using direct time-domain arguments in the pertaining energy balance (Poynting's theorem). The case of arbitrary dispersion in the medium's electric and magnetic behavior, however, withstands such an approach. Here, as an intermediate step, the one-to-one correspondence between the causal time-domain field components and material response functions in the constitutive relations on the one hand and their time Laplace transforms for (a set of) real, positive values of the transform parameter on the other hand, seems a necessary tool. It is shown that this approach leads to simple, explicit, sufficiency conditions on the relaxation tensors describing the medium's electric and magnetic behavior, in which the property of causality proves to play an essential role.

1. Introduction

One of the issues one is confronted with in the mathematical modeling – be it with analytical or numerical techniques – of electromagnetic wave phenomena is the question about the uniqueness of the solution to the problem as it is formulated mathematically. Evidently, such a uniqueness should be expected on account of the underlying physics. When investigating wave propagation and scattering problems one expects the pertaining partial differential equations, constitutive relations, boundary conditions at interfaces, excitation conditions at exciting sources, initial values at the time window one considers and the causal relationship that is to exist between the exciting sources and the generated wavefield to play a role. For simple media with instantaneous relations between the intensive quantities (that carry the power flow in the wavefield) and the extensive quantities (that carry the momentum of the wavefield), i.e., for lossless media, the time-domain power balance provides a tool to prove uniqueness. This is also the case when simple loss mechanisms (such as electrically conductive and/or linear magnetic hysteresis losses) are incorporated. A uniqueness proof for the case of arbitrary relaxation effects in the media seems to withstand such a direct time-domain approach. Since for the class of linear, time-invariant, causally reacting media the constitutive relations are expressed via time convolutions, it can be expected that the time Laplace transformation (under which transformation the convolution operation transforms into a simple product of the constituents) might provide a useful tool. This approach is followed in the present paper and applied to the general class of linear, time-invariant, causal, locally reacting, inhomogeneous, anisotropic media. For this class of media, sufficient conditions for the uniqueness of the electromagnetic wavefield problem are specified for the electric and magnetic relaxation tensors in the time Laplace transform domain at real, postitive values of the transform parameter. In the procedure, Lerch's theorem of the one-sided (= causal) Laplace transformation plays an essential role.

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Dedicated to Professor J. Van Bladel
on the occasion of his 80th. birthday.

2. Description of the configuration

The configuration for which the uniqueness of the electromagnetic wavefield problem will be proved consists of a linear, time-invariant, locally reacting, inhomogeneous, anisotropic medium with arbitrary electric and magnetic relaxation properties and of bounded support $\mathcal{D} \subset \mathcal{R}^3$. This part of the configuration is embedded in a linear, time-invariant, locally reacting, homogeneous, isotropic, instantaneously reacting medium with permittivity ϵ_∞ and permeability μ_∞. The unbounded domain occupied by the embedding is denoted as $\mathcal{D}^\infty$. The common boundary of $\mathcal{D}$ and $\mathcal{D}^\infty$ is the bounded closed surface $\partial\mathcal{D}$ (Figure 1). The constitutive relaxation functions in $\mathcal{D}$ vary piecewise continuously with position with finite jump discontinuities at a finite number of piecewise smooth, bounded surfaces (interfaces). Position in the configuration is specified by the coordinates $\{x_1, x_2, x_3\}$ with respect to an orthogonal Cartesian reference frame with the origin $\mathcal{O}$ and the three mutually perpendicular base vectors $\{\boldsymbol{i}_1, \boldsymbol{i}_2, \boldsymbol{i}_3\}$ of unit length each. In the indicated order, the base vectors form a right-handed system. The subscript notation for Cartesian vectors and tensors is used and the summation convention for repeated subscripts applies. Whenever appropriate, vectors are indicated by boldface symbols, with $\boldsymbol{x}$ as the position vector. The time coordinate is t. Partial differentiation with respect to x_m will be denoted by ∂_m; ∂_t is a reserved symbol indicating partial differentiation with respect to t. Volume source distributions of electric polarization and/or magnetization, with bounded supports, excite a transient electromagnetic field in the configuration. They start to act at the instant $t = 0$. The field that is causally related to the action of these sources then vanishes throughout space for $t < 0$.

3. Formulation of the EM wavefield problem

At any point in the configuration where the electromagnetic field quantities are differentiable they satisfy the Maxwell field equations [1, p. 611]

$$\varepsilon_{k,m,p}\partial_m H_p - \partial_t D_k = 0, \quad (1)$$
$$\varepsilon_{j,n,q}\partial_n E_q + \partial_t B_j = 0, \quad (2)$$

where

$$\begin{aligned} E_q &= \text{electric field strength (V/m)}, \\ H_p &= \text{magnetic field strength (A/m)}, \\ D_k &= \text{electric flux density (C/m}^2), \\ B_j &= \text{magnetic flux density (T)}, \end{aligned}$$

and $\varepsilon_{k,m,p}$ is the completely antisymmetrical unit tensor of rank three: $\varepsilon_{k,m,p} = 1$ for $\{k,m,p\}$ = even permutation of $\{1,2,3\}$, $\varepsilon_{k,m,p} = -1$ for $\{k,m,p\}$ = odd permutation of $\{1,2,3\}$, $\varepsilon_{k,m,p} = 0$ in all other cases.

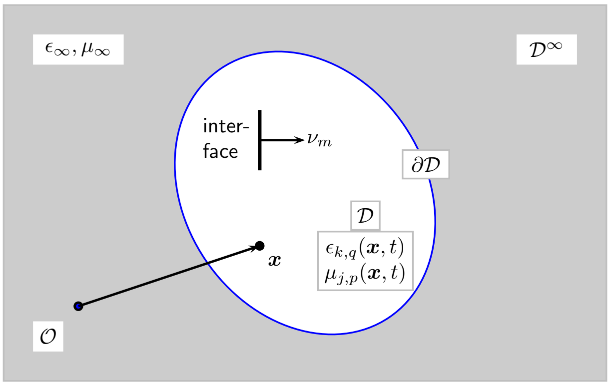

Figure 1: Configuration with inhomogeneous, anisotropic, dispersive medium (with bounded support $\mathcal{D}$) embedded in a homogeneous, isotropic, non-dispersive medium (with unbounded support $\mathcal{D}^\infty$).

The constitutive relations are:

$$D_k(\boldsymbol{x},t) = P_k(\boldsymbol{x},t) + \epsilon_{k,q}(\boldsymbol{x},t) \overset{(t)}{*} E_q(\boldsymbol{x},t) \quad \text{for } \boldsymbol{x} \in \mathcal{D}, \quad (3)$$

$$B_j(\boldsymbol{x},t) = M_j(\boldsymbol{x},t) + \mu_{j,p}(\boldsymbol{x},t) \overset{(t)}{*} H_p(\boldsymbol{x},t) \quad \text{for } \boldsymbol{x} \in \mathcal{D}, \quad (4)$$

where $\overset{(t)}{*}$ denotes time convolution, and

$$D_k(\boldsymbol{x},t) = \epsilon_\infty E_k(\boldsymbol{x},t) \quad \text{for } \boldsymbol{x} \in \mathcal{D}^\infty, \quad (5)$$
$$B_j(\boldsymbol{x},t) = \mu_\infty H_j(\boldsymbol{x},t) \quad \text{for } \boldsymbol{x} \in \mathcal{D}^\infty. \quad (6)$$

In these relations,

$$\begin{aligned} P_k &= \text{electric source polarization (C/m}^2), \\ M_j &= \text{source magnetization (T)}, \end{aligned}$$

represent the active parts (source distributions) of the medium in $\mathcal{D}$,

$$\begin{aligned} \epsilon_{k,q}(\boldsymbol{x},t) &= \text{electric relaxation function (F/m·s)}, \\ \mu_{j,p}(\boldsymbol{x},t) &= \text{magnetic relaxation function (H/m·s)}, \end{aligned}$$

of the medium in $\mathcal{D}$, and

$$\begin{aligned} \epsilon_\infty &= \text{electric permittivity (F/m)}, \\ \mu_\infty &= \text{magnetic permeability (H/m)}, \end{aligned}$$

of the medium in $\mathcal{D}^\infty$. In the representation of the constitutive behavior of the media we have chosen to incorporate the action of field exciting source distributions in them through field-independent excitation terms as is done in the Kirchhoff theory of active networks (Thevenin and Norton representations for the action of source voltages and source electric currents, respectively). Across any interface Σ of jump discontinuity in constitutive properties the boundary conditions of the continuity type

$$\varepsilon_{k,m,p}\nu_m H_p = \text{continuous across } \Sigma, \quad (7)$$
$$\varepsilon_{j,n,q}\nu_n E_q = \text{continuous across } \Sigma, \quad (8)$$

hold, where ν_m is the unit vector along the normal to Σ. This implies that the tangential components of the electric and magnetic fields strengths are continuous across the interface. The constitutive relaxation functions are subject to the causality condition

$$\epsilon_{k,q}(\boldsymbol{x},t) = 0 \quad \text{for } t<0 \text{ and all } \boldsymbol{x}\in\mathcal{D}, \tag{9}$$
$$\mu_{j,p}(\boldsymbol{x},t) = 0 \quad \text{for } t<0 \text{ and all } \boldsymbol{x}\in\mathcal{D}. \tag{10}$$

Further conditions to be laid upon them with regard to the uniqueness of the electromagnetic wavefield problem are investigated further on. On the constitutive coefficients of the embedding we impose the conditions $\epsilon_\infty > 0$ and $\mu_\infty > 0$.

In the embedding the Green's tensors (point-source solutions) can be determined analytically [1, Sections 28.8 and 28.12]. From the corresponding Huygens surface source representations over the surface $\partial\mathcal{D}$ it follows that the outgoing fields in $\mathcal{D}^\infty$ admit the far-field expansions

$$\{E_q,H_p\}(\boldsymbol{x},t) = \frac{\{e_q,h_p\}(\boldsymbol{\theta},t-|\boldsymbol{x}|/c_\infty)}{4\pi|\boldsymbol{x}|} \left[1+O(|\boldsymbol{x}|^{-1})\right] \quad \text{as } |\boldsymbol{x}|\to\infty, \tag{11}$$

where $\boldsymbol{x}$ is the position vector from the chosen far-field reference center to the point of observation, $\boldsymbol{\theta}=\boldsymbol{x}/|\boldsymbol{x}|$ is the unit vector in the direction of observation and $c_\infty=(\epsilon_\infty\mu_\infty)^{-1/2}$ is the electromagnetic wavespeed in $\mathcal{D}^\infty$. The far-field radiation characteristics are mutually related via

$$e_q = -(\mu_\infty/\epsilon_\infty)^{1/2}\boldsymbol{\varepsilon}_{q,m,p}\theta_m h_p, \tag{12}$$
$$h_p = (\epsilon_\infty/\mu_\infty)^{1/2}\boldsymbol{\varepsilon}_{p,n,q}\theta_n e_q. \tag{13}$$

In the following it will be shown that the problem thus formulated has at most one solution, assuming that, for each type of excitation at least one solution exists. The proof puts restrictions on the relaxation functions representing the electric and magnetic properties of the medium in $\mathcal{D}$. For the medium in $\mathcal{D}^\infty$ these simply are $\epsilon_\infty > 0$ and $\mu_\infty > 0$ (as indicated already).

4. The electromagnetic field problem in the time Laplace-transform domain

For the general type of dispersive media considered in the present paper there is, as far as is known, no direct uniqueness proof in the space/time domain based on energy considerations as is the case for media with simple constitutive behavior [2, Section 9.2]. However, because of the causality of both the media's passive field reponse and the field's relation to its activating sources, the time Laplace transformation with real, positive transform parameter offers a tool to specify certain conditions to be imposed on the constitutive relaxation functions in order that the wavefield problem has a unique solution. The relevant transformation is given by

$$\{\hat{E}_q,\hat{H}_p\}(\boldsymbol{x},s) = \int_{t=0}^{\infty}\exp(-st)\{E_q,H_p\}(\boldsymbol{x},t)\mathrm{d}t. \tag{14}$$

For the case of physical interest of excitation functions and relaxation functions that show at most a Dirac delta distribution time behavior, the time Laplace transforms of the field vectors and the relaxation tensors exist for all $\{s\in\mathcal{C};\mathrm{Re}(s)>0\}$, i.e., for all values of the transform parameter in the right half of the complex s-plane. Furthermore, since all time functions involved are real-valued, their Laplace transforms take on real values for real values of s. In relation to our uniqueness proof we now take s to be a *Lerch sequence*: $\{s\in\mathcal{R};s=s_0+nh,s_0>0,h>0,n=0,1,2,\ldots\}$. Lerch's theorem [3, p. 63] states that if the transformation expressed by Equation (14) is to hold for all s belonging to this sequence, only one (causal) time-domain original corresponds to its related transform. Under the transformation, the time derivative is replaced with a multiplication by s (if zero-value initial conditions apply, as is the case) and the time convolution transforms into the product of the constituents. Using these properties, Equations (1) - (6) lead, upon time Laplace transformation, to

$$\boldsymbol{\varepsilon}_{k,m,p}\partial_m\hat{H}_p - s\hat{\epsilon}_{k,q}\hat{E}_q = s\hat{P}_k \quad \text{for } \boldsymbol{x}\in\mathcal{D}, \tag{15}$$
$$\boldsymbol{\varepsilon}_{j,n,q}\partial_n\hat{E}_q + s\hat{\mu}_{j,p}\hat{H}_p = -s\hat{M}_j \quad \text{for } \boldsymbol{x}\in\mathcal{D}, \tag{16}$$

and

$$\boldsymbol{\varepsilon}_{k,m,p}\partial_m\hat{H}_p - s\epsilon_\infty\hat{E}_k = 0 \quad \text{for } \boldsymbol{x}\in\mathcal{D}^\infty, \tag{17}$$
$$\boldsymbol{\varepsilon}_{j,n,q}\partial_n\hat{E}_q + s\mu_\infty\hat{H}_j = 0 \quad \text{for } \boldsymbol{x}\in\mathcal{D}^\infty. \tag{18}$$

The interface continuity conditions (7) - (8) are upon Laplace transformation replaced by

$$\boldsymbol{\varepsilon}_{k,m,p}\nu_m\hat{H}_p = \text{continuous across } \Sigma, \tag{19}$$
$$\boldsymbol{\varepsilon}_{j,n,q}\nu_n\hat{E}_q = \text{continuous across } \Sigma, \tag{20}$$

and the far-field expansion (11) by

$$\{\hat{E}_q,\hat{H}_p\}(\boldsymbol{x},s) = \frac{\{\hat{e}_q,\hat{h}_p\}(\boldsymbol{\theta},s)}{4\pi|\boldsymbol{x}|}\exp(-s|\boldsymbol{x}|/c_\infty) \left[1+O(|\boldsymbol{x}|^{-1})\right] \quad \text{as } |\boldsymbol{x}|\to\infty. \tag{21}$$

Upon contracting Equations (15) and (17) with $\hat{E}_k$ and Equations (16) and (18) with $\hat{H}_j$ and combining the results we construct the relations

$$\boldsymbol{\varepsilon}_{m,k,j}\partial_m(\hat{E}_k\hat{H}_j) + s\hat{E}_k\hat{\epsilon}_{k,q}\hat{E}_q + s\hat{H}_j\hat{\mu}_{j,p}\hat{H}_p = -s\hat{E}_k\hat{P}_k - s\hat{H}_j\hat{M}_j \quad \text{for } \boldsymbol{x}\in\mathcal{D}, \tag{22}$$

and

$$\boldsymbol{\varepsilon}_{m,k,j}\partial_m(\hat{E}_k\hat{H}_j) + s\hat{E}_k\epsilon_\infty\hat{E}_k + s\hat{H}_j\mu_\infty\hat{H}_j = 0 \quad \text{for } \boldsymbol{x}\in\mathcal{D}^\infty. \tag{23}$$

Integration of Equation (22) over $\mathcal{D}$ and application of Gauss' divergence theorem yields

$$\int_{\partial\mathcal{D}} \varepsilon_{m,k,j}\nu_m \hat{E}_k \hat{H}_j \mathrm{d}A(\boldsymbol{x}) + \int_{\mathcal{D}} (s\hat{E}_k \hat{\epsilon}_{k,q} \hat{E}_q + s\hat{H}_j \hat{\mu}_{j,p} \hat{H}_p)\mathrm{d}V(\boldsymbol{x}) = -\int_{\mathcal{D}} (s\hat{E}_k \hat{P}_k + s\hat{H}_j \hat{M}_j)\mathrm{d}V(\boldsymbol{x}), \quad (24)$$

where ν_m is the outward unit vector along the normal to $\partial\mathcal{D}$. Next, Equation (23) is integrated over the domain that is bounded internally by $\partial\mathcal{D}$ and externally by the sphere $\mathcal{S}_\Delta$ of radius Δ and center at the far-field reference center, where Δ is chosen so large that $\mathcal{S}_\Delta$ completely surrounds $\partial\mathcal{D}$ (Figure 2). Subsequent application of Gauss' divergence theorem leads to

$$\int_{\mathcal{S}_\Delta} \varepsilon_{m,k,j}\nu_m \hat{E}_k \hat{H}_j \mathrm{d}A(\boldsymbol{x}) - \int_{\partial\mathcal{D}} \varepsilon_{m,k,j}\nu_m \hat{E}_k \hat{H}_j \mathrm{d}A(\boldsymbol{x}) + \int_{\mathcal{D}^\infty \cap \mathcal{D}_\Delta} (s\hat{E}_k \epsilon_\infty \hat{E}_k + s\hat{H}_j \mu_\infty \hat{H}_j)\mathrm{d}V(\boldsymbol{x}) = 0, \quad (25)$$

where $\mathcal{D}_\Delta$ is the domain interior to $\mathcal{S}_\Delta$. With the use of the far-field representation (21) in the integration over $\mathcal{S}_\Delta$, the limit $\Delta \to \infty$ in Equation (25) leads to (note that the integral over $\mathcal{S}_\Delta$ goes to zero as $\Delta \to \infty$)

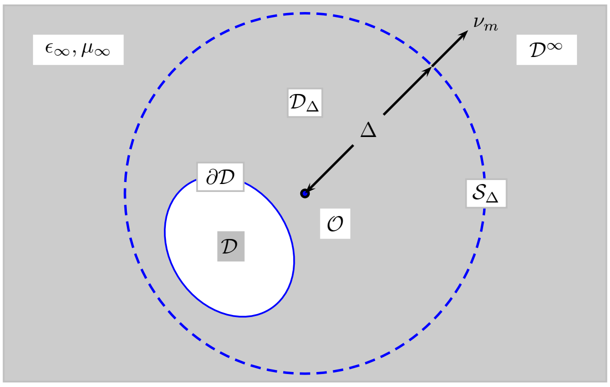

Figure 2: Configuration used in the derivation of the time Laplace-transform domain uniqueness identity. (The limit $\Delta \to \infty$ is taken.)

$$-\int_{\partial\mathcal{D}} \varepsilon_{m,k,j}\nu_m \hat{E}_k \hat{H}_j \mathrm{d}A(\boldsymbol{x}) + \int_{\mathcal{D}^\infty} (s\hat{E}_k \epsilon_\infty \hat{E}_k + s\hat{H}_j \mu_\infty \hat{H}_j)\mathrm{d}V(\boldsymbol{x}) = 0. \quad (26)$$

Addition of Equations (24) and (26) finally yields

$$\int_{\mathcal{D}} (s\hat{E}_k \hat{\epsilon}_{k,q} \hat{E}_q + s\hat{H}_j \hat{\mu}_{j,p} \hat{H}_p)\mathrm{d}V(\boldsymbol{x}) + \int_{\mathcal{D}^\infty} (s\hat{E}_k \epsilon_\infty \hat{E}_k + s\hat{H}_j \mu_\infty \hat{H}_j)\mathrm{d}V(\boldsymbol{x}) = -\int_{\mathcal{D}} (s\hat{E}_k \hat{P}_k + s\hat{H}_j \hat{M}_j)\mathrm{d}V(\boldsymbol{x}), \quad (27)$$

where the surface integrals over $\partial\mathcal{D}$ have canceled in view of the continuity of $\varepsilon_{m,k,j}\nu_m \hat{E}_k \hat{H}_j$ across $\partial\mathcal{D}$. Equation (27) will be used in the construction of the uniqueness proof.

5. The uniqueness proof

The uniqueness proof starts by assuming that in the given configuration, for one and the same excitation, there exist at least two non-identical field solutions, which we will distinguish by the superscripts $^{[1]}$ and $^{[2]}$. Obviously, $P_k^{[1]} = P_k^{[2]} = P_k$ and $M_j^{[1]} = M_j^{[2]} = M_j$. Consider the differences in value in the field quantities $\Delta E_q = E_q^{[2]} - E_q^{[1]}$ and $\Delta H_p = H_p^{[2]} - H_p^{[1]}$. Their time Laplace transforms then satisfy the equations (cf. Equations (15) - (18))

$$\varepsilon_{k,m,p}\partial_m \Delta\hat{H}_p - s\hat{\epsilon}_{k,q}\Delta\hat{E}_q = 0 \quad \text{for } \boldsymbol{x} \in \mathcal{D}, \quad (28)$$

$$\varepsilon_{j,n,q}\partial_n \Delta\hat{E}_q + s\hat{\mu}_{j,p}\Delta\hat{H}_p = 0 \quad \text{for } \boldsymbol{x} \in \mathcal{D}, \quad (29)$$

and

$$\varepsilon_{k,m,p}\partial_m \Delta\hat{H}_p - s\epsilon_\infty\Delta\hat{E}_k = 0 \quad \text{for } \boldsymbol{x} \in \mathcal{D}^\infty, \quad (30)$$

$$\varepsilon_{j,n,q}\partial_n \Delta\hat{E}_q + s\mu_\infty\Delta\hat{H}_j = 0 \quad \text{for } \boldsymbol{x} \in \mathcal{D}^\infty. \quad (31)$$

The same operations that have led to Equation (27) now yield

$$\int_{\mathcal{D}} (s\Delta\hat{E}_k \hat{\epsilon}_{k,q} \Delta\hat{E}_q + s\Delta\hat{H}_j \hat{\mu}_{j,p} \Delta\hat{H}_p)\mathrm{d}V(\boldsymbol{x}) + \int_{\mathcal{D}^\infty} (s\Delta\hat{E}_k \epsilon_\infty \Delta\hat{E}_k + s\Delta\hat{H}_j \mu_\infty \Delta\hat{H}_j)\mathrm{d}V(\boldsymbol{x}) = 0. \quad (32)$$

Evidently, for real, positive values of s the integrand in the integral over $\mathcal{D}^\infty$, and hence the integral itself, is positive for any non identically vanishing $\Delta\hat{E}_k$ and/or any non identically vanishing $\Delta\hat{H}_j$ throughout $\mathcal{D}^\infty$. The integral over $\mathcal{D}$ shares this property if we impose on $\hat{\epsilon}_{k,q}$ and $\hat{\mu}_{j,p}$ the condition that throughout $\mathcal{D}$ they are positive definite tensors of rank two for all real, positive values of s. Under this condition, also the integral over $\mathcal{D}$ is positive for any non identically vanishing $\Delta\hat{E}_k$ and/or any non identically vanishing $\Delta\hat{H}_j$ throughout $\mathcal{D}$. For non identically vanishing $\Delta\hat{E}_k$ and/or non identically vanishing $\Delta\hat{H}_j$ throughout $\mathcal{D} \cup \mathcal{D}^\infty$ Equation (32) leads, in view of the value zero of the right-hand side to a contradiction. Under the given conditions we therefore have $\Delta\hat{E}_k = 0$ and $\Delta\hat{H}_j = 0$ for $\boldsymbol{x} \in \{\mathcal{D} \cup \mathcal{D}^\infty\}$, which implies $\hat{E}_k^{[2]} = \hat{E}_k^{[1]}$ and $\hat{H}_j^{[2]} = \hat{H}_j^{[1]}$ for $\boldsymbol{x} \in \{\mathcal{D} \cup \mathcal{D}^\infty\}$. In view of Lerch's uniqueness theorem of the one-sided Laplace transformation this implies that $E_k^{[2]} = E_k^{[1]}$ and $H_j^{[2]} = H_j^{[1]}$ for $\boldsymbol{x} \in \{\mathcal{D} \cup \mathcal{D}^\infty\}$ and all $t \geq 0$, i.e., there is only one electromagnetic field in the configuration that is causally related to the action of its exciting sources.

It is noted that the conditions imposed on the constitutive relaxation functions are specified through their time Laplace transforms. Strictly speaking the pertaining conditions need only hold on a Lerch sequence. In view of the analyticity of the transforms in $\{s \in \mathcal{C}; \mathrm{Re}(s) > 0\}$, however, they hold for all real, positive values of s. The conditions thus specified are *sufficient ones*, but at present no weaker conditions seem to be in existence. Also, a simple time-domain counterpart does not seem to exist. This, however, is the same situation as in linear, time-invariant, causal system's theory.

6. Examples of relaxation functions

Some examples of relaxation functions that arise in the physics of electric and magnetic materials are given below. They all apply to the simple case of isotropic materials.

Permittivity relaxation function of an isotropic plasma

For an isotropic plasma the (isotropic, scalar) s-domain permittivity relaxation function as based on the Lorentz theory of electrons model is [1, pp. 639-640]

$$\hat{\epsilon} = \epsilon_0 \left[1 + \frac{1}{s} \frac{{\omega_\mathrm{p}}^2}{s + \nu_\mathrm{c}} \right], \qquad (33)$$

where ϵ_0 is the permittivity of vacuum, ω_p the electron angular plasma frequency of the plasma and ν_c the collison frequency. The corresponding time-domain relaxation function is

$$\epsilon = \epsilon_0 \{ \delta(t) + ({\omega_\mathrm{p}}^2/\nu_\mathrm{c})[1 - \exp(-\nu_\mathrm{c} t)] H(t) \}, \qquad (34)$$

where $\delta(t)$ is the Dirac delta distribution and $H(t)$ is the Heaviside unit step function. The time-domain magnetic relaxation function is $\mu = \mu_0 \delta(t)$, where μ_0 is the permeability of vacuum.

Lorentzian absorption line of a dielectric material

For the Lorentzian absorption line of a dielectric material the (isotropic, scalar) s-domain permittivity relaxation function is [1, pp. 639-640]

$$\hat{\epsilon} = \epsilon_0 \left[1 + \frac{{\omega_\mathrm{p}}^2}{(s + \Gamma/2)^2 + \Omega^2} \right], \qquad (35)$$

where Γ is a phenomenological damping coefficient, $\Omega = (\omega_0^2 - {\omega_\mathrm{p}}^2/3 - \Gamma^2/4)^{1/2}$ is the natural angular frequency of the oscillations of the movable electric charge, ω_0 is the resonant angular frequency of the (Coulomb force) mechanical model of the atom and ω_p is the angular plasma frequency of the movable electric charge distribution. The corresponding time-domain relaxation function is

$$\epsilon = \epsilon_0 [\delta(t) + ({\omega_\mathrm{p}}^2/\Omega) \exp(-\Gamma t/2) \sin(\Omega t) H(t)]. \qquad (36)$$

The time-domain magnetic relaxation function is $\mu = \mu_0 \delta(t)$, where μ_0 is the magnetic permeability of vacuum.

Linear hysteresis in a magnetic material

Linear hysteresis in an isotropic magnetic material can be modeled via a Debije type of relaxation function

$$\hat{\mu} = \mu_0 \mu_\mathrm{r} (1 + \Gamma/s), \qquad (37)$$

where μ_r is the relative permeability of the material and Γ is a phenomenological (Landau) damping coefficient. The corresponding time-domain relaxation function is

$$\mu = \mu_0 \mu_\mathrm{r} [\delta(t) + \Gamma H(t)]. \qquad (38)$$

The electric properties of the material need further specification.

It is observed that all these relaxation functions satisfy the conditions for uniqueness discussed in Section 5,

7. Conclusion

A time-domain uniqueness theorem for electromagnetic wavefield modeling in arbitrarily dispersive and anisotropic media is presented. Sufficient conditions for the uniqueness to be laid upon the electric and magnetic tensorial relaxation functions are formulated in the (causal) time Laplace-transform domain for real, positive values of the transform parameter. Some simple relaxation functions arising from physical models on an atomic level in plasma and solid-state physics are shown to be in accordance with the criteria developed.

8. References

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Advanced Applications of the Field Equivalence Principle in Numerical Electromagnetic Modelling Techniques

Hendrik Rogier

Abstract

The field equivalence principle plays a very important role in a large variety of full-wave electromagnetic field solvers, since it permits partitioning the simulation domain into a number of subregions that can have separate electromagnetic descriptions. These formulations can consist, for example, of boundary integral equations with different Green's function kernels, but also finite elements and finite-difference time-domain techniques can be used for certain subdomains, resulting in hybrid formalisms. In this contribution, we first review the field equivalence theorem in a very general form. We then present some advanced applications of this principle in some of our recent work. Both pure boundary integral equation approaches, as well as hybrid techniques that combine the boundary integral equation method with finite elements and finite-differences in time-domain are discussed.

1. Introduction

In this contribution, we review the classical Huygens principle [1,2], stating that each point on a wavefront can be regarded as a new source of waves. This principle, introduced by Huygens in 1690 in connection with optical effects, plays a fundamental role in any part of physics that can be treated by means of field theory. Although the principle is of fundamental importance in electromagnetics, only a limited number of papers have dealt with the subject. Existing literature on the Huygens principle is closely related to the reaction concept [3] and to surface integral representations [4–6]. We show that the more general form of the Huygens principle, i.e. the principle of field equivalence, can be applied to a wide range of state-of-the-art numerical modelling problems. Our paper is structured as follows. We start by reviewing the Huygens principle in Section 2. Following Lindell, a mathematical foundation can be given to the field equivalence theorem [7]. We show in Section 2 that applying field equivalence allows one to partition a complex simulation domain into several subregions that can be treated by different modelling techniques, provided that unknown virtual currents are introduced at the subdomains' boundaries. In this contribution we focus on rigorous full-wave techniques such as the finite element (FE) method, the boundary integral equation (BIE) technique and the finite-difference time-domain (FDTD) approach, but, within the same framework, asymptotic techniques can also be incorporated, such as geometrical or physical optics and diffraction theories [8]. The basic application of this subdomain technique for a hybrid FE-BIE method (as, for example, described in [9,10]) is discussed in Section 3. For the boundary integral equation subdomains, Love's field equivalence principle is used whereas for the finite element subregions, Schelkunoff's field equivalence theorem is applied. In Sections 4 and 5, we present more advanced applications in recent formalisms that we have developed. First, the boundary integral approach is applied to model shielding enclosures in an efficient way [11]. Finally, the application of field equivalence is illustrated for the FDTD part of a new hybrid FDTD-BIE formalism [12–14].

2. The Huygens principle – Field equivalence

Let us now review the Huygens principle applied to a very simple configuration, as shown in Fig. 1. We consider a simple source configuration radiating in free space. A closed surface S is placed around the source, partitioning the simulation domain into an interior and an exterior subdomain. Following Huygens principle, we can replace the original source configuration by virtual current sources $\mathbf{J}_{\text{virtual}}$ and $\mathbf{K}_{\text{virtual}}$ on S. These current soures are called equivalent sources for the exterior field problem, since they

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Dedicated to Professor J. Van Bladel on the occasion of his 80th. birthday.

produce the same field in V_e as the original source. Furthermore, they lead to a zero field inside S.

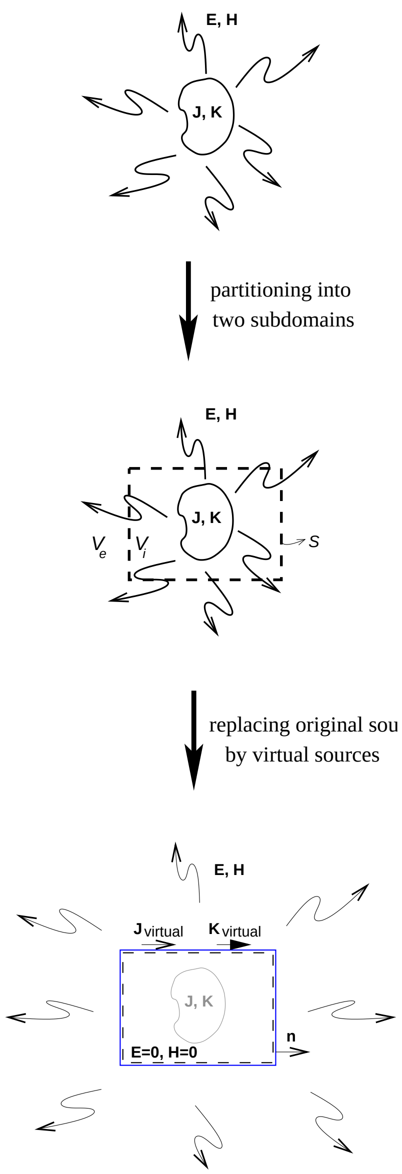

Figure 1: The Huygens principle.

Although the Huygens principle has been known for a long time, not much attention has been devoted to a rigorous proof of the field equivalence principle. Rumsey [3] used the reaction principle to derive the Huygens principle, whereas Tai [4] relied on Green's function theory. Quite recently, Lindell derived a direct rigorous mathematical formulation to state the principle of field equivalence [7]. He starts by defining a truncation function, which is zero inside S and one in the exterior subdomain.

$$P_{V_e}(\mathbf{r}) = 1, \quad \mathbf{r} \in V_e; \qquad P_{V_e}(\mathbf{r}) = 0, \quad \mathbf{r} \notin V_e$$

The left- and right-hand sides of Maxwell's curl laws are then multiplied with this function, yielding

$$\begin{aligned} (\nabla \times \mathbf{E})\, P_{V_e} &= -j\omega\overline{\overline{\mu}} \cdot \mathbf{H}\, P_{V_e} - \mathbf{K}\, P_{V_e} \\ (\nabla \times \mathbf{H})\, P_{V_e} &= j\omega\overline{\overline{\epsilon}} \cdot \mathbf{E}\, P_{V_e} + \mathbf{J}\, P_{V_e} \end{aligned}$$

The equations can then be rewritten in terms of truncated fields $(P_{V_e}\mathbf{E}, P_{V_e}\mathbf{H})$ and sources $(P_{V_e}\mathbf{J}, P_{V_e}\mathbf{K})$ as follows:

$$\begin{aligned} \nabla \times (P_{V_e}\, \mathbf{E}) =& -j\omega\overline{\overline{\mu}} \cdot P_{V_e}\, \mathbf{H} - P_{V_e}\, \mathbf{K} \\ & - [\mathbf{E} \times (-\mathbf{n})]\ \delta_S \\ \nabla \times (P_{V_e}\, \mathbf{H}) =& j\omega\overline{\overline{\epsilon}} \cdot P_{V_e}\, \mathbf{E} + P_{V_e}\, \mathbf{J} \\ & + [(-\mathbf{n}) \times \mathbf{H}]\ \delta_S \end{aligned}$$

In the right-hand sides, two new sources appear. They represent an electric current layer $\mathbf{J}_{\text{virtual}} = (-\mathbf{n}) \times \mathbf{H}$ and a magnetic current layer $\mathbf{K}_{\text{virtual}} = \mathbf{E} \times (-\mathbf{n})$ on S. Because of the definition of the truncation function, the truncated fields and sources are zero in the interior subregion. A dual formalism can be applied for the inner subregion V_i. Now, an electric current layer $\mathbf{J}_{\text{virtual}} = \mathbf{n} \times \mathbf{H}$ and a magnetic current layer $\mathbf{K}_{\text{virtual}} = \mathbf{E} \times \mathbf{n}$ are introduced on S. Because of these currents, the fields and sources are now set to zero in the exterior subregion.

The introduction of the equivalent currents on S cancels fields inside V_i. This means that the original materials and sources inside V_i may be changed without affecting the fields in the exterior subregion. Placing equivalent currents on S thus allows us to change the original configuration into a new problem which is easier to model. Unfortunately, these equivalent current sources are in fact unknown, since they depend upon the tangential fields on S. The exact value of the virtual current sources thus requires the solution of the global EM problem. We can, however, consider the equivalent current sources as unknowns of the problem to solve. Now, an EM field description can be found for each subregion defined in the global simulation space. This description does not depend on the materials and sources present in the other subdomains. The global EM problem is finally obtained by expressing the continuity of the tangential electric and magnetic fields at all the interfaces between the different subregions. This results in a global matrix system, the solution set of which comprises the equivalent current sources at all the interfaces. It may seem suprising that the effect of the entire field distribution inside V_i can be replaced by electric are magnetic current sources only located at its boundary S. The theorem of field unicity, however, shows that knowledge of the tangential electric and magnetic boundary fields on S is indeed sufficient to reconstruct the unique field distribution inside V_i. At frequencies that do not correspond to a resonance frequency of the cavity V_i, even the knowledge of only the tangential electric field or the tangential magnetic field leads to a unique field distribution in V_i. Similar conclusions can be formulated for the exterior subregion V_e, provided the radiation condition is enforced at infinity [15].

3. Application to hybrid FE-BIE techniques

The concepts of field equivalence and partitioning of the simulation domain can be applied to model complex electromagnetic (EM) configurations more efficiently. These structures, which typically combine inhomogeneous features with an open three-dimensional simulation space, can be described with hybrid techniques that combine a rigorous boundary integral equation (BIE) for the open domain with the finite element method (FE) or the finite difference-time domain (FDTD) technique for the inhomogeneous part of the problem. Let us first focus on a hybrid technique, combining the finite element method with the boundary integral approach.

3.1. The BIE subdomain– Love's Field Equivalence Theorem [16]

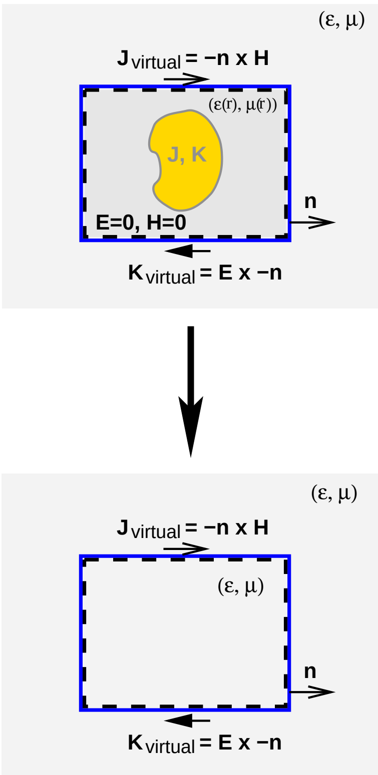

Figure 2: Love's field equivalence theorem.

Let us first discuss the use of field equivalence when applying the boundary integral equation technique to the exterior subdomain. Let the exterior subregion V_e be homogeneous with parameters (ϵ, μ). The unknowns of the integral equation are the equivalent sources introduced on S. Applying the Huygens principle then allows us to replace the arbitrary materials of the interior subregion V_i with the same homogeneous dielectric as in the exterior subdomain, as shown in Fig. 2. In the resulting homogeneous free-space problem, one easily obtains a boundary integral equation description with the free-space Green's function as the kernel.

3.2. The FE part– Schelkunoff's Field Equivalence Theorem [17]

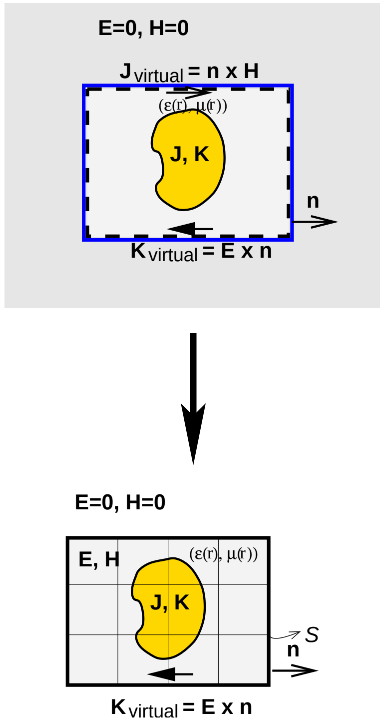

Figure 3: Schelkunoff's field equivalence theorem.

The interior subdomain can be described by a finite element method after invoking field equivalence following Schelkunoff. Because of the introduction of virtual sources on S, fields are zero in the exterior domain. Thus, we are free to place a perfectly conducting metallic box in this domain, completely enclosing the interior subregion, as shown in Fig. 3. This box can then be placed arbitrary close to the surface S. For the closed configuration, one easily obtains an FE description. This description is coupled to the boundary integral equation for the exterior subproblem through the unknown virtual magnetic currents K_{virtual} on S.

3.3. Extension to periodic structures

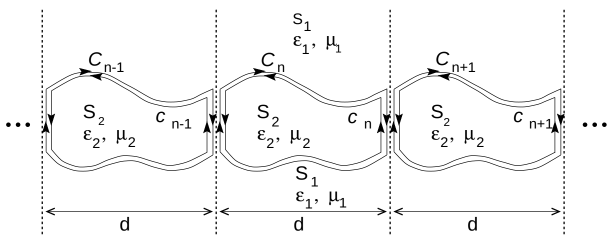

Figure 4: A simple periodic configuration.

By invoking of the Floquet-Bloch theorem, which limits the analysis to a single unit cell, the hybrid FE-BIE approach can be easily extended to periodic structures. The analysis of these structures is of importance in practical configurations, such as gratings in optical applications and absorbers in anechoic chambers [18–20]. Application of the field equivalence principle provides several mechanisms to express periodicity of the field within the unit cell. For illustration purposes, we consider the simple periodic configuration shown in Fig. 4. The unit cell of the periodic structure consists of a homogeneous and unbounded subregion S_1 and a bounded but potentially inhomogeneous subregion S_2. For the n^{th} unit cell, subdomain S_1 is bounded by contour C_n, whereas S_2 is bounded by contour c_n. Both contours conincide, but their orientation is different.

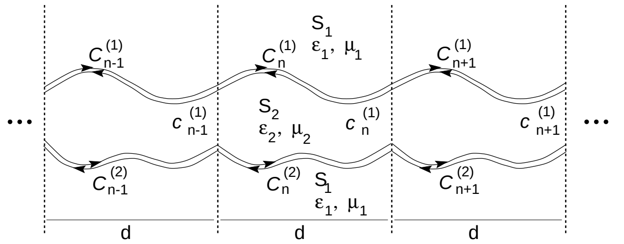

Figure 5: Boundary integral representation with periodic Green's function.

A rigorous treatment of subregion S_1 is obtained by means of a boundary integral representation, applied over all contours C_n. Since this formulation is obtained by means of field equivalence, the virtual electric and magnetic currents along C_n appear as unknowns. By means of the Floquet-Bloch theory, the analysis can be limited to the contour C_n of a single unit cell, provided a periodic Green's function [21] is used as the integral kernel in the boundary integration. Assuming for now that subdomain S_2 is homogeneous as well, one can give a similar boundary integral description for S_2, now integrating over the contour c_n. Since the contributions of contours C_n and c_n along the boundaries of the unit cell cancel out in neighbouring cells, the final description is schematically represented in Fig. 5. The boundary integral representation with periodic Green's function kernel proceeds along contours $C_n^{(1)}$ and $C_n^{(2)}$ for the unbounded domain S_1 and along contours $c_n^{(1)}$ and $c_n^{(2)}$ for the bounded domain S_2.

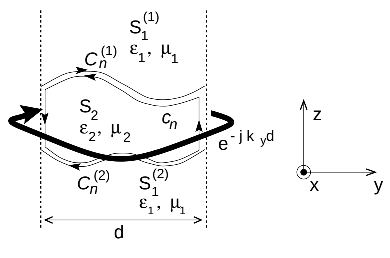

Figure 6: Boundary integral representation with free space Green's function and periodic boundary condition.

An alternative formulation can be derived for subregion S_2 as follows: In the previous analysis we started from an integral representation for the field inside S_2. The integral was taken over all contours c_n present in the periodic configuration. Now focus on region S_2 in the n^{th} unit cell. From the field equivalence principle, it is knowns that only the virtual electric and magnetic currents on c_n contribute to the field inside S_2 of the n^{th} unit cell, whereas the contributions of the virtual currents on all other contours give rise to a zero field. This proves that an integral representation with a much simpler free space Green's function kernel leads to equivalent results. However, this formulation results in a higher number of unknowns, since the unknowns on the boundary do not cancel out in the present formulation. Instead, the Floquet-Bloch condition should be applied for these virtual currents on the unit cell boundary, giving rise there to a periodic boundary condition, as shown in Fig. 6. This line of reasoning also holds when S_2 is inhomogeneous and an FE description is applied. The FE formulation proceeds as in free space. Only the periodic boundary condition must be imposed along the boundaries of the unit cell.

Which of the two mechanisms described above is more efficient depends on the simulation geometry at hand. A more detailed discussion together with some examples can be found in [20].

4. An Advanced application: A BIE technique for modelling enclosures

The problem of a metallic structure with a slot represents one of the oldest practical configurations for which the application of field equivalence is relevant as a means for solving the EM problem (see, for example, [22,23]). Here we consider a metallic enclosure S_{encl} with apertures S_{aper}. These structures play a very important role in electromagnetic compatibility issues. We are interested in the efficiency of the shielding when there is a current inside the enclosure. A straightforward approach proceeds by replacing all metallic parts of the enclosure with unknown electric currents and by invoking Love's field equivalence theorem as in Section 3.1, both inside and outside the enclosure [24]. Quite recently, we have developed a more efficient technique for such configurations [11]. The domains inside and outside the enclosure are modelled with the BIE approach. To restrict the number of unknowns, we do not use a conventional boundary integral equation, since this requires discretizing the complete enclosure. Magnetic virtual current sources $\mathbf{K}$ are placed over the aperture only. We then invoke Schelkunoff's field equivalence theorem.

4.1. Field equivalence applied to the enclosure problem

To solve for the unknown aperture currents, we appeal to the field equivalence and first partition the configuration into two subproblems. A boundary integral equation formulation is then derived for both subdomains with specific kernel functions. For the interior problem we use the Green's function of the closed metallic enclosure. This kernel function can be obtained in the form of a three-dimensional series by modal expansion. The convergence of this series is accelerated by means of the Ewald transform technique [25].

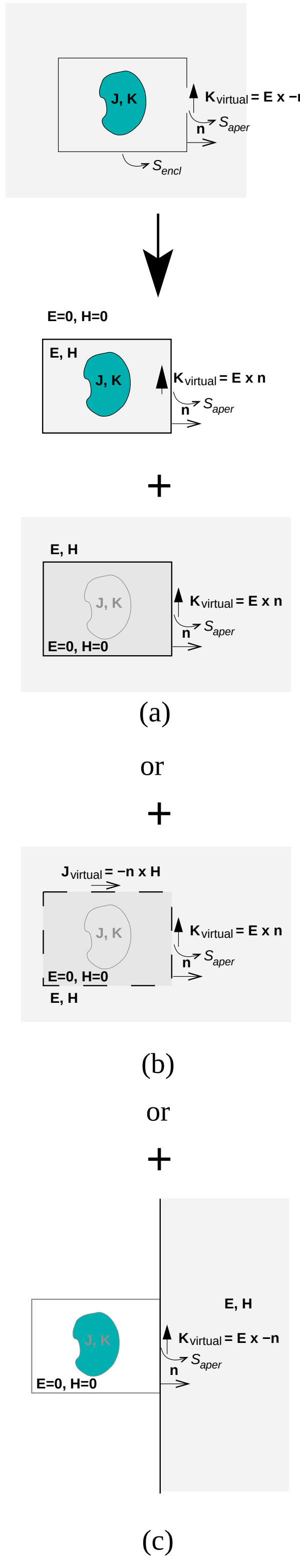

Figure 7: Field equivalence principle for modelling enclosures.

The exterior problem can be treated in a similar fashion, by considering the magnetic currents **K** over the apertures as unknowns and by using the Green's function of a PEC metallic box in free space as the kernel of the integral equation, as shown in Fig. 7a. Contrary to the interior problem, however, no analytic solutions can be found for an elementary dipole radiating in free space in the presence of a PEC box. A numerical technique proceeds by defining electric currents **K** on S to replace the box and by applying Love's field equivalence principle, as in Section 3.1 and illustrated in Fig. 7b, to find a BIE description for the Green's function. This approach, however, drastically increases the number of unknowns. The introduction of additional unknowns on the PEC box can be avoided by approximating the exterior region by a half-space (Fig. 7c), for which a simple analytical Green's function can be used. This approximation gives satisfactory results for apertures of moderate size that are not too close to the edges of the box and are sufficiently far away from the enclosure.

4.2. Example: Enclosure with vertical aperture

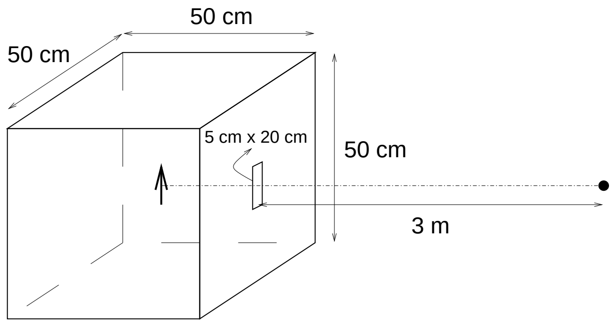

Figure 8: Enclosure with vertical aperture.

Let us now illustrate the technique by means of an example. We consider a metallic enclosure with a vertical aperture, as shown in Fig. 8. We are interested in the shielding effiency at 3m with a dipole source placed in the middle of the enclosure.

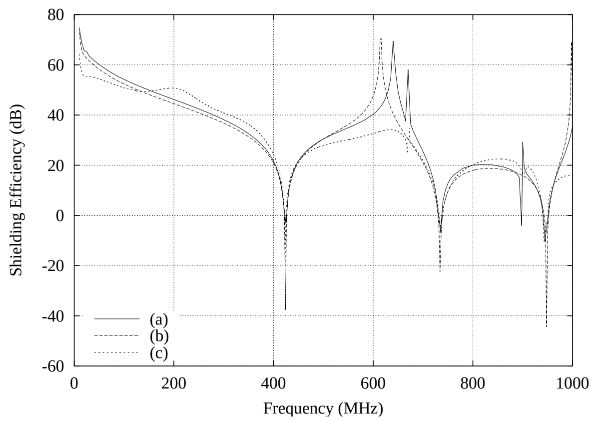

Figure 9: Shielding efficiency.

For the 50cm enclosure, we calculate the shielding efficiency up to 1 GHz by means of three different techniques. In Fig. 9, good agreement is seen between the hybrid BIE technique (curve (a)) discussed in the previous subsection, a low frequency approximation (curve (b)) and a boundary integral equation approach in which the complete enclosure is discretised (curve (c)).

5. Another advanced application: The FDTD-BIE formalism

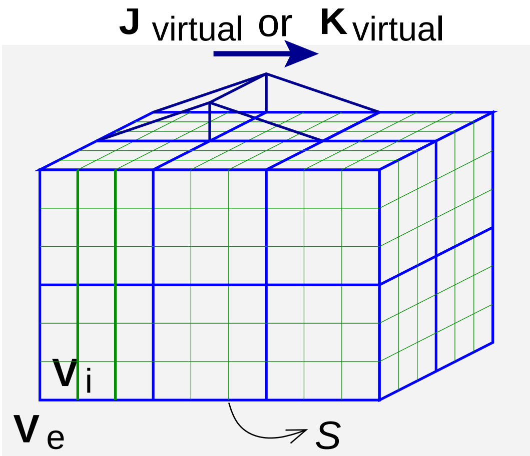

Figure 10: Modelling a subdomain with the FDTD-BIE technique.

Another part of our recent research activities focused on combining the boundary integral equation formulation with the finite-difference time-domain technique. Again consider a simulation domain subdivided by a closed surface S into an interior and exterior subregion, as shown in Fig. 10. We start by applying field equivalence with equivalent currents on S. We then discretize the currents on S by using subdomain expansion functions. Therefore, S is divided into rectangular cells and the electric and magnetic currents on its surface are expanded in rooftop basis functions. First, a BIE description under the form of a system matrix is derived for the exterior domain V_e. The Love field equivalence principle is invoked as discussed in Section 3.1. We then proceed by modelling the interior subdomain by means of FDTD. This is done by bringing each rooftop basis function for expanding the electric or magnetic currents into an FDTD simulation. This leads to a system matrix which describes the EM field for V_i.

5.1. Field equivalence applied to the FDTD subdomain

To find such a system matrix, the number of FDTD simulations to describe V_i can be quite large. Indeed, the number of required FDTD runs equals the number of basis functions to represent the magnetic and electric currents on S. Therefore, special measures are taken to limit the CPU-time for each FDTD simulation. This is done by reducing transients by lowering the quality factor of the closed simulation domain. We invoke Schelkunoff's field equivalence theorem, but now, the metallic boundary does not coincide with S. In the region formed by the boundary of the simulation domain and the surface S, fields are zero. In this region, absorbing material can be inserted. This reduces transients without affecting the global EM field behavior.

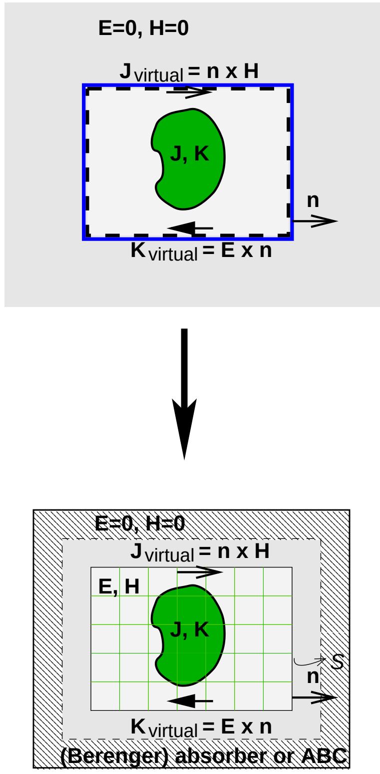

Figure 11: Field equivalence principle for modelling an FDTD subdomain.

5.2. Example: An FE-FDTD-BIE technique

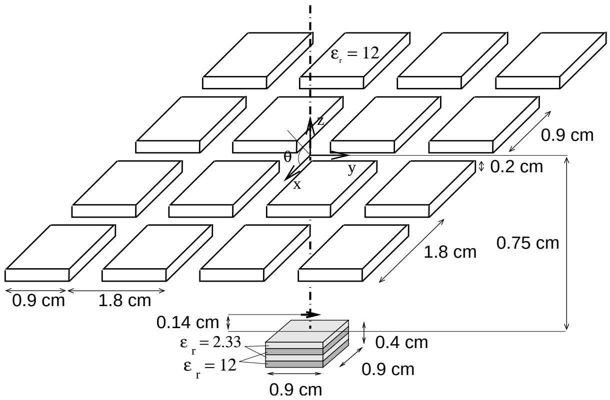

Figure 12: A dipole radiating above a substrate in the presence of an FSS.

The techniques of combining the boundary integral equation with the FDTD technique can be extended with a finite element part. This example illustrates our formalism that combines the three full-wave techniques, based on the theory presented in Sections 3.1, 3.2 and 5.1. Let us consider a Hertzian dipole located on the central axis above a multilayered substrate, as shown in Fig. 12. The substrate has dimensions 0.9cm × 0.9cm × 0.4cm and is composed of four dielectric layers with alternating relative permittivity of 2.33 and 12. The elementary dipole is located 0.14cm above the substrate. The subtrate together with the dipole is placed into one subregion modelled with finite elements. Above the substrate and dipole, a frequency selective surface (FSS) is placed, consisting of a 4 by 4 array of dielectric patches. Each patch has dimensions 0.9cm by 0.9cm by 0.2cm and consists of a dielectric with permittivity 12. Each patch is embedded in an FDTD-subregion. Finally all the subregions are coupled by applying the BIE technique.

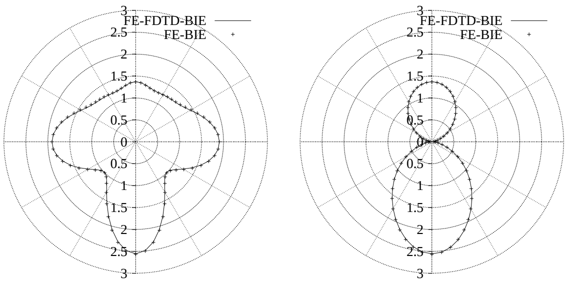

Figure 13: Radiation pattern in the xz-plane (left) and in the yz-plane (right).

Now consider the configuration with the dipole oscillating at 8 GHz. In Fig. 13, the radiation patterns in the xz-plane and yz-plane are shown at a frequency of 8GHz. Good agreement is observed in the results obtained with FE-FDTD-BIE and FE-BIE code.

6. Conclusions

In this contribution, we have reviewed the Huygens principle under the form of the field equivalence theorem. We have proposed some basic and advanced applications of field equivalence to electromagnetic modelling techniques. These formalisms include the boundary integral equation method, the finite element method, a new modelling technique for enclosures, and a new hybrid FDTD-boundary integral equation method.

7. Acknowledgement

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Closed Form Solutions of Maxwell's Equations in the Computer Age

Frank Olyslager
Ismo V. Lindell

Abstract

We consider four closed form solutions of Maxwell's equations that have been derived or were revisited during the past decade. First we focus on two problems from electrostatics: the electrostatic image for the dielectric sphere and a generalisation of the Thompson and Lampard capacitor. Then we give two solutions of the full Maxwell equations in the time-harmonic regime: the Green dyadics for a homogeneous bianisotropic medium with similar medium dyadics and the scattering of a plane wave at a diaphanous wedge. Although we have studied these problems with some rigour in the past we present, in each case, a new, shorter and more direct solution.

1. Introduction

In this paper we present closed form solutions of a number of electromagnetic field problems for which closed form solutions were constructed by the authors during the past ten years. Professor Van Bladel himself, has devoted a considerable amount of his scientific studies to closed form solutions of Maxwell's equations. Another motivation to bring this subject in honour of the eigthieth birthday of Professor Van Bladel is the fact that Professor Van Bladel brought the present authors together in 1992. This has led to a fruitful cooperation resulting in numerous publications on theoretical electromagnetics.

In an age where powerful simulation techniques run on powerful computers allowing the accurate solution of exeedingly complex field problems one could wonder about the usefulness of closed form solutions of Maxwell's equations. This argument can be countered by the following motivations:

- Closed form solutions provide insight in electromagnetic field behaviour and immediately reveal the influence of parameters to the fields.
- Closed form solutions are forever. Once a problem is solved, it is solved. This in contrary to a new numerical solution technique which is most often open for improvements. Once an improvement is found the old technique looses its usefulness.
- Closed form solutions are good benchmark cases for numerical simulation techniques or for the calibration of measurements.
- Constructing closed form solutions gives a certain satisfaction, which was perhaps our most important motivation.

In this paper we present four recent solutions of electromagnetic problems that allow closed form solutions:

- The first problem is a new approach to the solution of the electrostatic image for the dielectric sphere.
- The second problem is a two-dimensional electrostatic problem. In the 1950s an interesting capacitance relation was found between four almost touching conductors, the so-called Thompson and Lampard capacitor. This relation was generalised by the authors to symmetric configurations with M conductors.
- The third problem is a closed form Green dyadic for a certain class of homogeneous bianisotropic media.
- The fourth problem is the scattering at a diaphanous wedge. The field singularity at the tip of wedges has been one of the key problems that were tackled by Professor Van Bladel.

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Dedicated to Professor J. Van Bladel
on the occasion of his 80th. birthday.

2. Electrostatic image for the sphere revisited

2.1. Historic preamble

The basic problem of an electric point charge outside a PEC sphere in terms of an image point charge was solved by Thomson (Kelvin) in 1845 [1] by noticing that two point charges of opposite sign produce a potential function whose zero potential surface is a sphere and, thus, one of the point charges could be replaced by a PEC sphere at zero potential. The same principle was independently found in 1861 by Carl Neumann [2] who also subsequently solved the magnetostatic image problem. Because the perfect magnetic conductor was not known at the time, his solution was actually a generalization of the Kelvin image because it assumed finite permeability. The image solution consisting of a point source and a line source was published in 1883 in an appendix of a book on hydrodynamics [3].

Because Neumann's solution was not widely known for a century, it was reinvented by many authors. The first of these known to the present authors was Yossel in 1971 [4] who used a method similar to that of Neumann. Others followed without reference to any of the previous ones, Efremov and Prosvirnii in 1985 [5,6], Poladian in 1988 [7] and Lindell in 1992 [8]. Finally, reviewing papers on image theories [9], the authors found Neumann's original work through a reference in an old review article [10], p.321. Still, even after this, other independent work on this topic appeared [11]. That Neumann's image principle was really not known, was reflected by a sentence in the much cited monograph by Smythe [12], p.127:

> We find that there is not, as in the analogous two-dimensional case, a simple image solution for the dielectric sphere and the point charge. We have to use spherical harmonics to solve this problem.

Other similar statements can be found in more recent texts [13,14].

2.2. Operational solution

The solution for a point charge Q defined by the charge density

$$\varrho(\mathbf{r}) = Q\delta(\mathbf{r} - \mathbf{u}_z b) \tag{1}$$

in air in front of a dielectric sphere centered at the origin with permittivity $\epsilon_r\epsilon_o$ and radius a (Figure 1), can be derived in many ways. Expanding the potential function in spherical harmonics we can easily solve the potential reflected (scattered) from the sphere as [15]

$$\phi^r(\mathbf{r}) = -\frac{Q}{\epsilon_o}\sum_{n=1}^{\infty}\frac{(\epsilon_r-1)n}{(\epsilon_r+1)n+1}\frac{a^{2n+1}}{b^{n+1}}\frac{P_n(\cos\theta)}{4\pi r^{n+1}}, \tag{2}$$

for $r > a$. The image of the point source is basically the source of this potential confined inside the region $r < a$ in air. Its expression can be identified from (2) by manipulating the sum and comparing the result with the potential from a line source or by deriving an integral equation for the unknown source. Another method is to expand in the θ and φ coordinates only and solve the remaining differential equation in the r variable as that of a transmission line [16]. Let us use yet another method applying Heaviside operator calculus [17]. This technique also is close to Engheta's representation [18] but does not require any fractional differentiations.

Let us invoke the differentiation rule from Maxwell's *Treatise* [19], p.209

$$\partial_z^n\frac{1}{r} = (-1)^n n!\frac{P_n(\cos\theta)}{r^{n+1}}. \tag{3}$$

This inserted into (2) gives us

$$\phi^r(\mathbf{r}) = -\frac{\epsilon_r-1}{\epsilon_r+1}\frac{Qa}{\epsilon_o b}\sum_{n=1}^{\infty}\frac{(-c\partial_z)^n}{(n-1)!(n+\alpha)}\frac{1}{4\pi r}, \tag{4}$$

where we denote for brevity $c = a^2/b$, $\alpha = 1/(\epsilon_r+1)$. Now, the source of the reflected potential is the reflection image $\varrho^r(\mathbf{r})$ which can be obtained from the Poisson equation as

$$\varrho^r(\mathbf{r}) = -\epsilon_o\nabla^2\phi^r(\mathbf{r})$$

$$= \frac{\epsilon_r-1}{\epsilon_r+1}\frac{Qa}{b}\sum_{n=1}^{\infty}\frac{(-c\partial_z)^n}{(n-1)!(n+\alpha)}\nabla^2\frac{1}{4\pi r}. \tag{5}$$

Inserting

$$\nabla^2\frac{1}{4\pi r} = -\delta(\mathbf{r}) = -\delta(z)\delta(\boldsymbol{\rho}), \tag{6}$$

we can write (5) in the form

$$\varrho^r(\mathbf{r}) = -\frac{\epsilon_r-1}{\epsilon_r+1}\frac{Qa}{b}\sum_{n=1}^{\infty}\frac{(-c\partial_z)^n}{(n-1)!(n+\alpha)}\delta(z)\delta(\boldsymbol{\rho})$$

$$= -\frac{\epsilon_r-1}{\epsilon_r+1}\frac{Qa}{b}\left(-\frac{c}{\alpha+1}\partial_z + \frac{c^2}{\alpha+2}\partial_z^2 - \frac{c^3}{2!(\alpha+3)}\partial_z^3 + \cdots\right)\delta(z)\delta(\boldsymbol{\rho}). \tag{7}$$

(7) represents a solution as a multipole expansion at the origin. It is known how extended sources can be replaced by multipoles [20,21]. Here we wish to do the opposite: replace a multipole expansion by an extended source to get a simpler expression for the image source. The actual polarization in the dielectric sphere is dipolar which is shown by the fact that there is no monopole term in (7). Thus, it appears natural to express the image charge in terms of the dipole moment density function $p^r(z)$ as

$$\varrho^r(\mathbf{r}) = \partial_z p^r(z)\delta(\boldsymbol{\rho}). \tag{8}$$

In operational form the moment density can be identified from (7) as

$$p^r(z) = \frac{\epsilon_r - 1}{\epsilon_r + 1}\frac{Qa}{b}\sum_{n=0}^{\infty}\frac{c^{n+1}(-\partial_z)^n}{n!(n+\alpha+1)}\delta(z). \qquad (9)$$

Proceeding as

$$\partial_c[c^\alpha p^r(z)] = \frac{\epsilon_r - 1}{\epsilon_r + 1}\frac{Qa}{b}\partial_c\sum_{n=0}^{\infty}\frac{c^{n+\alpha+1}(-\partial_z)^n}{n!(n+\alpha+1)}\delta(z)$$

$$= \frac{\epsilon_r - 1}{\epsilon_r + 1}\frac{Qa}{b}\sum_{n=0}^{\infty}\frac{c^{n+\alpha}(-\partial_z)^n}{n!}\delta(z)$$

$$= \frac{\epsilon_r - 1}{\epsilon_r + 1}\frac{Qa}{b}c^\alpha e^{-c\partial_z}\delta(z) = \frac{\epsilon_r - 1}{\epsilon_r + 1}\frac{Qa}{b}z^\alpha\delta(z-c), \qquad (10)$$

we have a differential equation for the moment density. Requiring as an additional condition vanishing of $p^r(z)$ for $z > a$, we write the solution as

$$p^r(z) = \frac{\epsilon_r - 1}{\epsilon_r + 1}\frac{Qa}{b}(z/c)^\alpha U(c-z)U(z), \qquad (11)$$

where $U(x)$ denotes the Heaviside unit step function. In terms of original parameters we have

$$p^r(z) = \frac{\epsilon_r - 1}{\epsilon_r + 1}\frac{Qa}{b}(zb/a^2)^{1/(\epsilon_r+1)}U(c-z)U(z), \qquad (12)$$

which finally gives Neumann's image charge density function as

$$\varrho^r(\mathbf{r}) = \frac{\epsilon_r - 1}{(\epsilon_r + 1)^2}\frac{Qa}{b}(z/c)^{-\epsilon_r/(\epsilon_r+1)}U(c-z)U(z)$$

$$-\frac{\epsilon_r - 1}{\epsilon_r + 1}\frac{Qa}{b}\delta(c-z). \qquad (13)$$

Thus, the image of a point charge in a dielectric sphere consists of a point charge at the Kelvin image point and a line charge between the center and the Kelvin image point as shown in Figure 1. The line image has an integrable singularity at the center of the sphere.

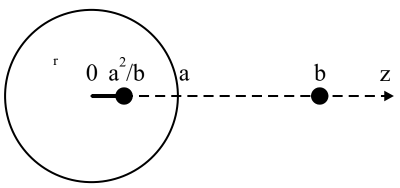

Figure 1: Point charge in front of a dielectric sphere showing the Kelvin image and image line charge.

3. A generalisation of the Thompson and Lampard capacitor

3.1. An introduction

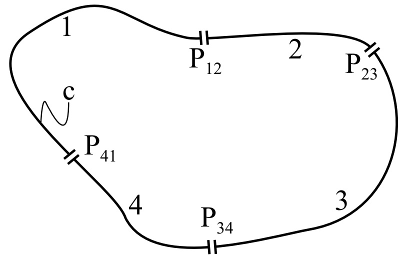

Figure 2: Four almost touching conducting shells.

In 1956 another remarkable problem in two-dimensional electrostratics was solved [22,23]. It was shown that a special relation holds between the elements in the capacitance matrix of four almost touching conducting shells of arbitrary shape (Figure 2). The elements C_{13} and C_{24}, due to the fields inside the shell of conductors, always satisfy

$$\exp(-\frac{\pi|C_{13}|}{\epsilon_0}) + \exp(-\frac{\pi|C_{24}|}{\epsilon_0}) = 1. \qquad (14)$$

If from symmetry it follows that $C_{13} = C_{24}$ then these capacitances are fixed, $|C_{13}| = |C_{24}| = (\epsilon_0/\pi)\ln 2$. These fixed values for the capacitance elements are used to build capacitance standards consisting of a number of metal cylinders embedded in a metal box and isolated from each other by thin pieces of mica. The result for four conductors derived [22,23] was generalised to five and six almost touching conductors by Fiebiger and Fleischhauer [24] and Elnékavé [25]. The present authors have recently revisted the Thompson and Lampard theorem and generalised it to an arbitrary number of conductors [26]. A summary of these results are presented here. First we give a short proof of (14) and then consider symmetric configurations of an arbitrary number of conductors. Recently also Jackson [27] revisited this interesting problem.

3.2. The Schwarz-Christoffel conformal mapping

The Schwarz-Christoffel conformal mapping [28] allows the mapping of the interior of an arbitrary polygon, and by extension every closed curve, to a half-plane. This means that we can map the configuration of Figure 2 to the upper-half of the complex $z = \zeta + j\eta$-plane as indicated on Figure 3. The freedom in the transformation is used to map the point P_{41} on $z_{41} = \pm\infty$ and the point P_{23} on $z_{23} = 0$. The mapping of the points P_{12} and P_{34} is then fixed and given by $z_{12} = -a$ and $z_{34} = b$ where a and b depend on the particular geometry of the curve c in Figure 2.

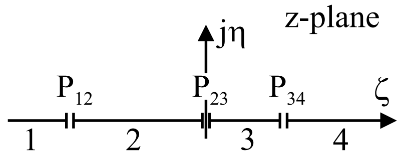

Figure 3: Complex z-plane with the conductors of Figure 2 mapped to the real axis.

Let us now determine C_{13} and C_{24} for the configuration in Figure 3 or quivalently Figure 2. For C_{13} we place conductor 1 at a potential $1V$ and the other conductors at zero potential. The complex potential $w(z)$ is then

$$w(z) = \phi(z) + j\psi(z) = \frac{j}{\pi} \ln \frac{\sqrt{1+a^2}}{z+a}. \qquad (15)$$

The capacitance C_{13} is now readily found to be

$$C_{13} = \epsilon_0[\psi(z=b) - \psi(z=0)] = \frac{\epsilon_0}{\pi} \ln \frac{a}{a+b}. \quad (16)$$

The capacitance C_{24} is found by interchanging the role of a and b

$$C_{24} = \frac{\epsilon_0}{\pi} \ln \frac{b}{a+b}. \qquad (17)$$

Combining (16) and (17) immediately yields the relation (14).

3.3. Symmetric configuration of M-conductors

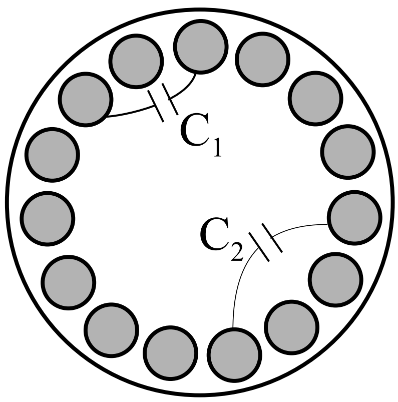

Figure 4: Symmetrical configuration with M conductors.

Let us consider a symmetric configuration of $M > 3$ conductors such as shown in Figure 4. We look only at the fields and capacitances for the interior problem. The external capacitances can be short circuited by embedding the whole structure in a metal casing as illustrated in Figure 4. All the conductors, inclusive the casing, are isolated from each other by infinitesimal gaps. If no metal casing is added all the capacitances derived below have to be multiplied by a factor of two. Remark that the capacitance matrix for such a symmetric configuration is a circulant matrix. Such capacitance matrices have special properties as has been studied by Nitsch *et. al.* [29]. Let C_1 denote the capacitance between a conductor and its second neighbour, C_2 the capacitance between a conductor and its third neighbour, etc.. When M is an even number there are $N = (M-2)/2$ different such capacitances C_i $(i = 1, 2, ..., N)$ and when M is an odd number there are $N = (M-3)/2$ different capacitances. We now present equations to determine these values C_i. Let us first introduce new quantities x_i

$$x_i = \exp(-\frac{\pi C_i}{\epsilon_0}), \qquad (18)$$

$i = 1, 2, ..., N$. From (14) one can show that

$$x_i + \prod_{j=1}^{N} x_j^{\tau_{ij}} = 1, \qquad (19)$$

with $\tau_{ij} = 2\min(i, j)$ except when M is even and $j = N$ in which case $\tau_{ij} = \tau_{iN} = i$. Using the relation (19) one finds it possible to express x_{i-1} as a function of x_j with $j \leq i$ alone,

$$x_{i-1} = 1 - \frac{1-x_i}{x_N^{\sigma}} \prod_{j=i}^{N-1} \frac{1}{x_j^2}, \qquad (20)$$

with $\sigma = 1$ when M is even and $\sigma = 2$ when M is odd. Applying this expression recursively allows us to express each x_i $(i = 1, 2, ..., N)$ as a rational function of x_N only. A polynomial expression for x_N is then found by inserting all the rational expressions for the x_i in (19) for $i = 2$. When M is even it is possible to determine x_N, and by iterative use of (20) all x_i, in closed form. When $M = 2L$ with L even one can show that

$$x_N = \frac{1+\sqrt{\alpha}}{2}, \qquad (21)$$

with $\alpha = x_{L/2-1}$ for the configuration with L conductors. When $M = 2L$, with L odd, one can show that

$$x_N = \frac{\alpha+3}{4}, \qquad (22)$$

with $\alpha = x_{(L-1)/2-1}$ for the configuration with L conductors. When M is odd it is in general not possible to solve for the values of x_i in closed form. In Table 1 the values of x_N are listed for M up to 20. The equation (20) then allows the determination of the other values x_i with $i < N$.

M	x_N
4	$\frac{1}{2}$
5	$\frac{\sqrt{5}-1}{2}$
6	$\frac{3}{4}$
7	$-\frac{2}{3}+\frac{2\sqrt{7}}{3}\cos\frac{\pi-\arctan(3\sqrt{3})}{3}$
8	$\frac{2+\sqrt{2}}{4}$
9	$-1+2\cos\frac{\pi}{9}$
10	$\frac{5+\sqrt{5}}{8}$
11	0.91898594722899477978
12	$\frac{2+\sqrt{3}}{4}$
13	0.94188363485210405210
14	$\frac{7}{12}+\frac{2\sqrt{7}}{12}\cos\frac{\pi-\arctan(3\sqrt{3})}{3}$
15	0.95629520146761127586
16	$\frac{2+\sqrt{2+\sqrt{2}}}{4}$
17	0.96594619936780355656
18	$\frac{1+\cos\frac{\pi}{9}}{2}$
19	0.97272260680544474721
20	$\frac{4+\sqrt{2}\sqrt{5+\sqrt{5}}}{8}$

Table 1: Values of x_N for a symmetric configuration of M conductors.

4. Closed form Green dyadics for bianisotropic media

4.1. The quest

During the past twenty years the electromagnetic field in bianisotropic media [30] has been the subject of considerable analyses. The present authors have been mainly interested in closed form field solutions in homogeneous bianisotropic media. It turns out that only specific classes of bianisotropic media allow some progress toward closed form solutions of Maxwell's equations. An overview of our findings can be found in [31].

The basic field problem is the Green function problem. Indeed it presents the field due to an elementary Dirac source, i.e., it presents the impulse response of the medium. The Green function for an homogeneous isotropic medium was perhaps first published in [32]. As is explained in [31] this has been generalized in several steps to several classes of anisotropic and bianisotropic media. To give a flavor of our work on this matter we consider a special bianisotropic medium where all the medium parameters are proportional to the same dyadic [33]. We opted for this medium because it is a good illustration of many other cases we have studied without requiring excessively complicated manipulations. The consitutive relations of the medium are given by

$$\mathbf{D}=\overline{\overline{\epsilon}}\cdot\mathbf{E}+\overline{\overline{\xi}}\cdot\mathbf{H}, \tag{23}$$

$$\mathbf{B}=\overline{\overline{\zeta}}\cdot\mathbf{E}+\overline{\overline{\mu}}\cdot\mathbf{H}, \tag{24}$$

with $\overline{\overline{\epsilon}}=\epsilon\overline{\overline{\tau}}$, $\overline{\overline{\mu}}=\mu\overline{\overline{\tau}}$, $\overline{\overline{\zeta}}=\zeta\overline{\overline{\tau}}$ and $\overline{\overline{\xi}}=\xi\overline{\overline{\tau}}$. In [33] the Green dyadic for this medium was derived only in closed form for the special case where $\zeta+\xi=\pm2\sqrt{\epsilon\mu}$. However, in [34] a more general medium was studied that allowed a closed form without any further restrictions, seemingly a contradiction with the result of [33]. In [34] a very different approach was used to solve the Green dyadic problem. Here we resolve this contradiction by showing that it is indeed possible to derive the Green dyadic for the medium in [33] without any restrictions. We do this using a new approach.

4.2. Solution

The Green dyadic $\overline{\overline{G}}(\mathbf{r})$ relates electric current densities to the electric field through the relation

$$\mathbf{e}(\mathbf{r})=-j\omega\int_V\overline{\overline{G}}(\mathbf{r}-\mathbf{r}')\cdot\mathbf{J}(\mathbf{r}')dV', \tag{25}$$

and satifies the equation

$$\overline{\overline{L}}\cdot\overline{\overline{G}}(\mathbf{r})=-\delta(\mathbf{r})\overline{\overline{I}}, \tag{26}$$

with

$$\overline{\overline{L}}=-(\nabla\times\overline{\overline{I}}-j\omega\overline{\overline{\xi}})\cdot\overline{\overline{\mu}}^{-1}\cdot(\nabla\times\overline{\overline{I}}+j\omega\overline{\overline{\zeta}})+\omega^2\overline{\overline{\epsilon}}. \tag{27}$$

For the medium under consideration we can write this as

$$\overline{\overline{L}}=\frac{1}{\mu}\overline{\overline{\tau}}\cdot(\overline{\overline{\tau}}^{-1}\cdot\nabla\times\overline{\overline{I}}-j\omega A_+\overline{\overline{I}})\cdot(\overline{\overline{\tau}}^{-1}\cdot\nabla\times\overline{\overline{I}}-j\omega A_-\overline{\overline{I}}), \tag{28}$$

with

$$A_\pm=\frac{\xi-\zeta\pm\sqrt{(\xi+\zeta)^2-4\epsilon\mu}}{2}. \tag{29}$$

The Green dyadic, i.e., the solution of (26), is given formally by

$$\overline{\overline{G}}(\mathbf{r})=-(\overline{\overline{\tau}}^{-1}\cdot\nabla\times\overline{\overline{I}}-j\omega A_-\overline{\overline{I}})^{-1}$$
$$\cdot(\overline{\overline{\tau}}^{-1}\cdot\nabla\times\overline{\overline{I}}-j\omega A_+\overline{\overline{I}})^{-1}\mu\overline{\overline{\tau}}^{-1}\delta(\mathbf{r}). \tag{30}$$

Using a partial fraction expansion for matrices, we can write this in an alternative form as

$$\overline{\overline{G}}(\mathbf{r})=\frac{A_+-A_-}{j\omega}[\overline{\overline{G}}_-(\mathbf{r})-\overline{\overline{G}}_+(\mathbf{r})], \tag{31}$$

with

$$\overline{\overline{G}}_\pm(\mathbf{r})=(\nabla\times\overline{\overline{I}}-j\omega A_\pm\overline{\overline{\tau}})^{-1}\delta(\mathbf{r}). \tag{32}$$

We assume that $A_+\neq A_-$. The contrary case ($A_+=A_-$) is exactly the case for which a closed form solution was obtained in [33]. Let us now decompose $-j\omega A_\pm\overline{\overline{\tau}}$ into a symmetric part $\overline{\overline{S}}_\pm$ and an anti-symmetric part $\mathbf{a}_\pm\times\overline{\overline{I}}$. This allows us to write (32) as

$$\overline{\overline{G}}_\pm(\mathbf{r})=[(\nabla+\mathbf{a}_\pm)\times\overline{\overline{I}}+\overline{\overline{S}}_\pm]^{-1}\delta(\mathbf{r})=e^{-\mathbf{a}_\pm\cdot\mathbf{r}}\overline{\overline{H}}_\pm(\mathbf{r}), \tag{33}$$

with $\overline{\overline{H}}_\pm(\mathbf{r})$ given by

$$\overline{\overline{H}}_\pm(\mathbf{r})=(\nabla\times\overline{\overline{I}}+\overline{\overline{S}}_\pm)^{-1}\delta(\mathbf{r}). \tag{34}$$

Using dyadic analysis [21] one can write (34) as

$$\overline{\overline{H}}_\pm(\mathbf{r}) = [\nabla\nabla - (\nabla\cdot\overline{\overline{S}}_\pm)\times\overline{\overline{I}} + \overline{\overline{S}}_\pm^{-1}\det\overline{\overline{S}}_\pm]h_\pm(\mathbf{r}), \quad (35)$$

where $h_\pm(\mathbf{r})$ is a scalar Green function that is the solution of

$$(\overline{\overline{S}}_\pm : \nabla\nabla + \det\overline{\overline{S}}_\pm)h_\pm(\mathbf{r}) = \delta(\mathbf{r}), \quad (36)$$

given by

$$h_\pm(\mathbf{r}) = \frac{e^{-jD_\pm}}{4\pi D_\pm}, \quad (37)$$

with $D_\pm = \sqrt{\det\overline{\overline{S}}_\pm}\sqrt{\overline{\overline{S}}_\pm^{-1} : \mathbf{rr}}$. Substitution of (37) in (35), (33) and (31) results in the requested closed form expression for $\overline{\overline{G}}(\mathbf{r})$.

5. The diaphanous wedge

5.1. The Meixner series

Van Bladel has devoted a considerable amount of his scientific energy to the study of singular fields in electromagnetics [20]. Singular fields not only occur in the source region of Green dyadics but also at the tips of wedges and cones. The study of wedges turns out to be a very difficult problem and full closed form solutions for the scattering of plane waves at wedges only exist for impenetrable wedges, e.g., perfectly conducting wedges. There is one exception [35] of a penetrable wedge that allows a closed form solution for the plane wave scattering problem. This wedge is the so-called diaphanous wedge. A scatterer is called diaphanous [36] if the phase velocity of waves inside the scatterer is the same as the phase velocity of waves outside the scatterer. Diaphanous scatterers are also called isorefractive [37]. The importance of this closed form result for a penetrable wedge is enormous. Indeed, one of the discussion points in the literature has been the question of whether or not the Meixner series correctly predicts the singular behaviour of the fields at the edge of a wedge and whether or not this series converges. Meixner [38,39] assumed that the fields near the wedge could be expanded radially as a Taylor series multiplied by a singular factor. From the analysis in [35] it follows that the Meixner technique indeed correctly predicts the singular behaviour of the fields but that the series is not correct.

In this paper we do not introduce the whole machinery of [35] but rather we consider a more direct approach. We limit the discussion to the perpendicular incidence of a TM plane wave on a wedge. This problem is solved using a Kantorovich-Lebedev transform.

5.2. Solution

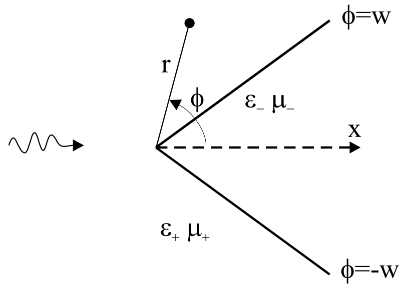

Figure 5: A diaphanous wedge with opening angle $2w$.

Consider the geometry of Figure 5 consisting of a wedge oriented parallel to the z-axis with opening angle $2w$. Inside the wedge $-w < \phi < w$ the medium parameters are ϵ_- and μ_-. Outside the wedge $w < |\phi| < \pi$ the medium parameters are ϵ_+ and μ_+. For a diaphanous wedge, $k = \omega\sqrt{\epsilon_-\mu_-} = \omega\sqrt{\epsilon_+\mu_+}$. A TM plane wave $e_z^i(r,\phi) = e^{jkr\cos(\phi)}$ is incident on the wedge. The fields inside and outside the wedge satisfy the Helmholtz equation

$$\nabla^2 e_z(r,\phi) + k^2 e_z(r,\phi) = 0. \quad (38)$$

At the wedge interface, i.e., at $\phi = \pm w$, $e_z(r,\phi)$ and $\frac{1}{\mu}\frac{\partial}{\partial\phi}e_z(r,\phi)$ are continuous.

Let us now introduce the Kantorovich-Lebedev transform [36] and its inverse

$$F(\nu) = \int_0^{+\infty} \frac{f(r)}{r} H_\nu^{(2)}(kr)dr, \quad (39)$$

$$f(r) = -\frac{1}{2}\int_{-j\infty}^{j\infty} \nu J_\nu(kr)F(\nu)d\nu, \quad (40)$$

in which capital letters imply Kantorovich-Lebedev domain quantities. After transformation the equation (38) simply becomes

$$\frac{d^2}{d\phi^2}E_z(\phi) + \nu^2 E_z(\phi) = 0. \quad (41)$$

The Kantorovich-Lebedev transform of the incident field is [40]

$$E_z^i(\phi) = -\frac{2j}{\nu}\frac{e^{-j\frac{\pi}{2}\nu}}{\sin(\pi\nu)}\cos(\nu\phi) = \alpha\cos(\nu\phi), \quad (42)$$

where the second identity defines the parameter α. Due to the symmetry of the problem the fields inside and outside the wedge are symmetric about the x-axis. This means that we can represent the total fields inside the wedge as

$$E_z(\phi) = A\cos(\nu\phi), \quad (43)$$

and the scattered fields outside the wedge as

$$E_z^s(\phi) = B\cos[\nu(\phi-\pi)], \tag{44}$$

for $w < \phi < \pi$. We now determine A and B. The continuity relations at $\phi = w$ yield

$$B\cos[\nu(w-\pi)] + \alpha\cos(\nu w) = A\cos(\nu w), \tag{45}$$

$$-\frac{B}{\mu_+}\sin[\nu(w-\pi)] - \frac{\alpha}{\mu_+}\sin(\nu w) = -\frac{A}{\mu_-}\sin(\nu w). \tag{46}$$

Solving for A yields

$$A = -\frac{2j(\Gamma+1)}{\nu}\frac{e^{-j\frac{\pi}{2}\nu}}{g(\nu)}, \tag{47}$$

with

$$g(\nu) = \sin(\nu\pi) + \Gamma\sin[\nu(\pi-2w)], \tag{48}$$

and

$$\Gamma = \frac{\mu_- - \mu_+}{\mu_- + \mu_+} = \frac{\epsilon_+ - \epsilon_-}{\epsilon_+ + \epsilon_-}. \tag{49}$$

From (47), (43) and (40) the fields inside the wedge are then found to be

$$e_z(r,\phi) = -j(\Gamma+1)\int_{-j\infty}^{j\infty}\frac{e^{-j\frac{\pi}{2}\nu}}{g(\nu)}J_\nu(kr)\cos(\nu\phi)d\nu$$
$$= \sum_{n=0}^{+\infty}\frac{\pi(\Gamma+1)\tau_n e^{-j\frac{\pi}{2}\nu_n}J_{\nu_n}(kr)\cos(\nu_n\phi)}{\pi\cos(\nu_n\pi)+\Gamma(\pi-2w)\cos[\nu_n(\pi-2w)]}, \tag{50}$$

with $\tau_n = 2$ when $n > 0$ and $\tau_0 = 1$ and where ν_n are the solutions of $g(\nu) = 0$. To evaluate the integral we have applied Cauchy's theorem. The poles ν_n are the so-called Greenberg static modes [41,42]. The fields outside the wedge are found in a similar manner. From (50) it is seen that a single Taylor series multiplied by one singular factor is not sufficient to represent the fields as was proposed by Meixner.

6. Conclusions

It has been shown that closed form solutions of Maxwell equations are not relics from the nineteenth or first half of the twentieth century. No, we have shown that this is an active and facinating domain of research. We hope that the reader has grasped some of the beauty of Maxwell's equations and their solutions, a beauty which is and has been admired by Professor Van Bladel!

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SCT
URSI's Scientific Committee on Telecommunications

How did we get to be where we are now?

Communication between peoples is vital to their development. Telecommunication is central to this. One of the most valuable areas of research by URSI scientists is on aspects of telecommunications. Application of the results from such research is essential. The SCT has an important role to play in this.

The current SCT has its roots in early days of association between individuals actively involved in both URSI and the ITU-R. These roots were established in the 1920s. More recently, that had a formal (but low-key) recognition in the URSI-CCIR-CCITT Liaison Committee and then, since 1990, in the SCT. (Prior to March 1993, ITU (International Telecommunication Union) was divided into the International Radio Consultative Committee (CCIR), the International Telegraph and Telecommunication Consultative Committee (CCITT), and the International Frequency Registration Board. These have since been replaced by the Radiocommunication Sector (ITU-R) and the Telecommunication Standardisation Sector (ITU-T), alongside the Telecommunication Development Sector (ITU-D).)

Radiowave propagation has featured strongly in the SCT. At the first Commission F Open Symposium, in 1977, and since held every three years, John Saxton gave a presentation on the importance and achievements of the links between URSI and the CCIR (see above). In Commission F, this strong link has been further strengthened in recent memory by leading URSI/ITU-R individuals including Les Barclay, Pedro Baptista, Lucien Boithias, Gert Brussaard, Bob Crane, Francesco Fedi, Martin Hall, Kevin Hughes, Pierre Misme, Rod Olsen, Terje Tjelta, Carol Wilson and many others. In Commission G, the link has been maintained by Les Barclay, Peter Bradley and others. The individuals in this association:

- have helped pass results from research in radio science and radio engineering to the Recommendations and other advice produced by ITU-R,
- have helped communicate to the scientific community an outline of current major requirements for research,
- have helped awareness of international needs from which organisations have prepared cases for sponsorship of their research.

In all this, the Liaison Committee and the SCT were low-key activities, with ad hoc meetings when appropriate. Although they were not the prime liaison mechanism, but a background forum for the contact between ITU-R and URSI, they stimulated, endorsed, encouraged and drew attention to what was working well at the personal level. This low-key style of activity was criticised by some, but it achieved what was essential without unnecessary complications.

In particular, there was a criticism that URSI's interests in frequency protection for radio astronomy, space science and remote sensing were not adequately taken care of, and there was a move to exert a stronger influence within ITU-R. However, URSI has been well provided for in this through the good work of the Scientific Committee on Frequency Allocations for Radio Astronomy and Space Science (IUCAF) *(see Radio Science Bulletin March 2003 pp 74-77 and page 101 of the Records of the URSI General Assemblies, Volume XXV, Toronto, 13.VIII-21.VIII 1999 (ISSN 0074-9516); also Records of URSI General Assemblies - Volume XXVI - in press)* in association with ITU-R. IUCAF operates as a standing committee of the International Council for Science Unions (ICSU) and also represents the interests of the International Astronomical Union (IAU) and the Committee for Space Research (COSPAR).It was also felt that URSI should have a higher profile in telecommunications, including influence in ITU-R. This led to direct representation by an URSI observer at the 1995 WRC and to "Commsphere" meetings in 1995, 1997, 1999 and 2000 *(see Radio Science Bulletin March 1995 p28, September 1997 p 15, June 1999 p 30 and September 2000 p 9)*. It is recognised that these meetings examined basic issues, but attempts to involve Commissions and the SCT have not been successful as the proceedings were not seen as being science-oriented.

The URSI General Assembly (GA) in 2002 ended on 24 August and on the same day Council agreed in Resolution U.3.[1] on the SCT:

1. To extend the terms of reference as defined below,
2. That the SCT will include a representative of each Commission, appointed by the Chairs of the Commissions, and participants in the work of the ITU-R and such other entities as it may decide. It may co-opt up to eight other individuals active in work covered by its terms of reference. It will appoint its own Chair, the relevant Commission to then nominate a replacement representative.

Terms of Reference

1. To initiate, promote and co-ordinate inter-commission activities in the telecommunications area on specified topics to be identified, and through the organisation of joint symposia.
2. To identify areas of common interest to URSI and to ITU-R or similar entities, and, where appropriate, to exchange relevant information between the URSI Commissions and the working groups (e.g. ITU-R Study Groups), and to promote collaborative activities.
3. To keep the URSI community informed on ITU-R and similar matters through the Radio Science Bulletin.
4. To initiate, co-ordinate and liaise any formal URSI contributions to ITU-R or similar bodies.

An Open Meeting on the SCT had been held two days earlier, agreeing the Resolution to be put to Council, and it was also agreed that there was no need then to send an Addendum or Corrigendum to the Report to Council, which had been on the SCT website prior to the GA (see currently http://www.ursi.org/SCT.htm).

That was the situation immediately after the GA, but quite a lot has happened since, which brings us to the next part.

OK, so what's it for?

The **Objectives of the SCT** are to carry out the Terms of Reference (which are set out above), aiding and encouraging the necessary exchange of information.

Both shortly before and at the GA, the SCT was requested to broaden its interaction with other bodies. As well as developing relations with the ITU-R, relations with ITU-T and ITU-D are being explored (see the second paragraph of this article), and with the World Health Organisation (WHO).

Currently there are seen to be seven main **Activities** of the SCT. Perhaps in some of these there may be a common **priority** given to matters relating to Radio Frequency Interference and Electromagnetic Compatibility (RFI and EMC), but without conflicting with the good work of the IUCAF (see above). The Activities are as follows: Inter-Commission WGs, Preparation of URSI Recommendations and White Papers, Contacts with the ITU-R, Contacts with the ITU-T and ITU-D, Contacts with the WHO, Specialist meetings and Web forum interaction. These are elaborated on below.

Yes, fine, but what's it going to do?

Mission statements and initial comments on the seven Activities are as follows:

Activity 1 - Inter-commission WGs

Mission statement: This Activity is designed to promote URSI Inter-Commission Working Groups (ICWGs) where this is appropriate.

Proposals to Council for formation and continuance of WGs is the sole responsibility of Commissions and several ICWGs already exist, but this Activity of the SCT is expected to relate to setting up new topic areas similar to that of the Solar Power Satellite (SPS) WG. This Activity remains central to Item 1 of the Terms of Reference, but we need to explore how the SCT can make it more effective, notably how the Activity can help in the SPS WG. If it can, are there other ICWGs where the SCT can help, and how? It is particularly important that all WGs report periodically to their Commissions, and especially so at General Assemblies.

Activity 2 - Preparation of URSI Recommendations and White Papers

Mission statement: This Activity is designed to propose and to prepare URSI positions to be communicated outside the Union in the form of Resolutions and Recommendations or of "White Papers" for presentation to Council and/or the President.

This does not remove from Commissions or other URSI bodies the right to prepare such documents. The Activity is expected to cover Resolutions similar to those at GA'2002 from Commission J on redefinition of UTC and International Radio Quiet Reserves. This Activity is central to Item 4 of the Terms of Reference and has also been regarded as essential to SCT business, but it will have to be made clear as to how consensus is to be achieved and how such Resolutions are to be used. (By way of example, guidelines for the production of ICSU position statements may be found on the ICSU website: www.icsu.org.)

White papers are information papers giving all pros and cons in a format which may be useful for national or international organizations and administrations as well as for scientists. They must present a synthesis and not one opinion. A first white paper has been forecast on solar power satellites and transmission of energy via electromagnetic waves.

Activity 3 - Contacts with ITU-R

Mission statement: This Activity is designed to exchange information between those in URSI concerned with radio science research, and those in ITU-R concerned with applying results of such research.

The work is intended to progress by building a Network of those actively involved both in URSI and in ITU-R WGs, and by exchanging ideas and means of working. This is a long-standing activity in the SCT, but is to have new impetus by the setting up the Network; it should show how to make better use of URSI Sector Membership in ITU-R. The SCT role is to make known to URSI scientists the ITU-R needs from research studies, and help make known to ITU-R results from such studies. The first newsletter has been distributed.

An early need will be to update the list of topics considered to be of mutual interest to URSI and ITU-R (see Appendix 1). These would be expected to have relevance to most Commissions within URSI and the task is to be undertaken in parallel with efforts made within Commissions (see also under "Commission Representative Members", below).

In the broadest terms, URSI promotes the exchange of information between those engaged in radio science research, whilst the ITU-R coordinates the efficient use of the radio frequency spectrum and satellite orbits, which is done largely through the means of Radiocommunication Conferences and the development of Recommendations and Handbooks

Activity 4 - Contacts with ITU-T and ITU-D

Mission statement: This Activity is designed to exchange information between those in URSI concerned with radio science research, and those in ITU-T and ITU-D concerned with applying results of such research.

This is at an early stage, but there may be close parallels with Activity 3, not least in the extension of the list of topics given in Appendix 1. Initial progress with ITU-T is indicated on the SCT website, but it is intended that suitable material will be added to the list in Appendix 1 as soon as the results of major reorganisation of ITU-T are known. As there are considerably fewer URSI people involved in ITU-T than in ITU-R (and possibly very few indeed associated with ITU-D), Activity 4 is the more difficult to get going.

Activity 5 - Contacts with the WHO

Mission statement: This Activity is designed to exchange information between those in URSI concerned with radio science research, and those in WHO concerned with applying results of such research.

This work is expected mainly to involve Commission K (but also see below in relation to Commission A). Here too there are parallels with Activity 3 to be explored and extensions to be made to the list of topics in Appendix 1. The WHO plays a key role in organising and promoting research in bioeffects and EM research in health assessment. There are many links of individuals between WHO and Commission K, but it will be a help to formalise the relationship – notably to organise joint scientific meetings, such as the one on 20-22 May 2004, on topics common to ICNIRP, WHO and Commission K. URSI (SCT) will be represented at the 2003 annual meeting of the EMF project. URSI was also involved in the "EMF and cardiac pacemakers defibrillators" meeting in Paris in October 2002, and will sponsor other similar meetings worldwide. (Parallels are with the Climpara workshops/colloquia as in Activity 6.) Also the SCT could promote liaison between WHO and other URSI Commissions when needed. In addition to ensuring protection against potentially dangerous radiation, consideration could be given to beneficial radiation.

Proposed formalising of involvement with WHO has led to making initial contacts. Commission K and WHO have for many years had joint interests in determining the health effects of EM exposure, but recent proposals have been to see whether closer association might be beneficial to both parties. A very pertinent General Lecture at GA2002 by Dr. Michael Repacholi has been published in RSB *(June 2002 pp 14-24)*. It draws attention to the work of WHO's International EMF Project, results so far and gaps in knowledge needing further research.

Commission A also has a major contribution to make in this area in the research of the biological effects of radio waves. Dosimetry (the measurement of RF energy deposition in humans, animals and biological preparations) is often the weak spot of the bioresearch. At low exposure levels (say less than 1W/kg), a reliable cause-effect relationship cannot be established between RF and a biological outcome unless there is a research effort to establish accurate dosimetry for the exposed biosample. Both in vitro and in vivo dosimetry have progressed substantially in the past 10 years, but more accurate dosimetric methods are required. Now, dosimetry for epidemiology needs to be developed to provide a strong dosimetric underpinning to the large epi studies that WHO has begun or wants to initiate. All these dosimetric difficulties will be overcome by accurate measurements or estimation of E and H fields in tissue and accurate dielectrometry of living tissue. These tasks require utmost precise measurement methodologies and are directly linked to the biological outcome of the RF exposure of humans, animals and cells.

Activity 6 - Specialist meetings

Mission statement: This Activity is designed to organise meetings to exchange information between those in URSI concerned with radio science research and those in other organisations concerned with applying results of such research.

ClimDiff'03, a meeting sponsored by Commission F, will extend earlier Climpara meetings linking URSI with ITU-R, and there may be opportunities for similar meetings in areas covered by other Commissions too, see those for Activity 5 above. (ClimDiff'03 is to be a workshop colloquium of URSI-associated experts active in research on (i) the use of climatic parameters in the prediction of radiowave propagation characteristics and (ii) applications of diffraction modelling. It will be held in Brazil on 17-19 November, immediately prior to parallel meetings of three ITU-R Working Parties. See www.climdiff.com.) Organisation and participation in jointly-sponsored specialist technical meetings is required.

Activity 7 - Web forum interaction

Mission statement: This Activity is the main means of spreading and exchanging information relating to the SCT Objectives.

This work is conducted through the SCT website (which has been expanded considerably) and its associated web forum (which forms Appendix 2 to that website). There is a password entry to certain areas (notably where personal email addresses are given) to ensure the information is available only to those concerned with URSI. All interested are invited to contribute to the discussion, modifying their own contributions from time to time if they so wish. The means of contributing is by e-mail to "SCT discussion" <Martin.Hall@rl.ac.UK>.

As an **additional task**, the URSI President asked the SCT to offer a proposal for an URSI contribution to ICSU Discussions on Emerging Issues, but this did not prove possible.

That sounds fine, but who's going to do it?

Well, you are of course, please! The success of organisations depends on the expertise and enthusiasm of those willing to participate. URSI is fortunate in this respect. Please contact <Martin.Hall@rl.ac.UK> if you feel able to help.

The **Membership** of the SCT comprises a number of individuals having specific jobs to do. The prime immediate job of the ten **Commission Representative Members** is to examine the list of topics considered to be of mutual interest to URSI and other organisations (see Appendix 1), and to advise as to how this appendix can be brought up to date and used to improve relations at the working level. Those topics currently in the list (being developed from that prepared in 1996) relate mainly to ITU-R needs, but once revisions have been completed to include further developments in ITU-R and interests with other organisations, the topics would be expected to have relevance to all Commissions within URSI. The list was developed from what are considered to be the needs of the other organisations that URSI might well help with, rather than what URSI feels good at or would like to talk about – reference on the website to ITU-R Questions illustrates this. Further development is sought urgently.

In addition, two of the first **Co-opted Members** are among those responsible for progressing the Activities mentioned above. This currently gives us:

Chair: Mr. Martin Hall,
Commission Representative Members:
- A Dr. Quirino Balzano
- B Prof. Lot Shafai
- C Prof. Masami Akaike
- D Prof. Peter Russer
- E Dr. Ahmed Zeddam
- F Mr. Jean Isnard
- G Dr. Patrick Lassudrie-Duchesne
- H Dr. Bo Thidé
- J Dr. Willem Baan
- K Prof. Bernard Veyret

Members leading SCT Activities:
1. Prof. Hiroshi Matsumoto (co-opted)
2. Dr. François Lefeuvre (co-opted)
3. Mr. Jean Isnard (CR)
4. Dr. Ahmed Zeddam (CR) & Mr. Martin Hall
5. Prof. Bernard Veyret (CR)
6. Mr. Martin Hall
7. Mr Martin Hall

(where "CR" indicates those who are already Commission Representative Members, as above).

Also **co-opted**, Dr. Kevin Hughes (staff member of the Radiocommunication Bureau, which is the secretariat for ITU-R) has kindly agreed to continue his valuable contributions to URSI's Radio Science Bulletin giving information on ITU-R's relevant activities. Parallels may be sought as the SCT forges links with other entities.

In addition, **Participants** in SCT essentially have the role of advisors, though they are also strongly encouraged to participate in aspects of the work indicated above and below. We were most fortunate that four URSI members of IUCAF were present at the SCT Open Meeting held during the GA in August 2002, including its Chairman.

Anybody who would care to register as **an SCT Correspondent** will receive an e-mail notification each time the website changes to avoid monitoring this individually and frequently.

Further specific points on the Terms of Reference

The four items of the SCT Terms of Reference are given above.

On **Item 1**, there has been intensive activity between General Assemblies in steering and co-ordinating areas of mutual interest, in order to produce interesting and informative joint sessions at General Assemblies. But this has not been an SCT activity and nor is it intended to be so in future. SCT activity is expected to concentrate on new Inter-Commission WGs (see under Activity 1 above).

On **Item 2**, it should be noted that two experiments were conducted within Commission F. In 1980, an unsuccessful experiment was to require certain sessions of the Commission F Triennial Open Symposium to prepare input documents to the next meeting of (what is now) ITU-R Study Group 3 on specific aspects of radiowave propagation. This resulted in somewhat stilted and uninformative conservative statements on current knowledge in the fields selected. This information was already well known to many and was not very helpful. The successful experiment (initiated in Rio de Janeiro in 1990) was to find a topic area that was topical to both URSI and ITU-R (the use of radioclimatological parameters in the prediction of radiowave propagation characteristics) and to hold a symposium on this ("Climpara") in 1994 *(See Radio Science Bulletin September 1994 p 8)* with sessions relating to the radio science of URSI and others concerned with the applications of ITU-R. This led to a series of similar successful meetings, again each one followed immediately by limited-agenda meetings of the relevant ITU-R Working Parties in 1996, 1998 and 2001 *(See Radio Science Bulletin September 1996 p24 and December1999 p37)*. A further such meeting, ClimDiff'03, is to be held in November 2003 in Brazil, but this time to include aspects of diffraction (see under Activity 6 above).

The message would seem to be that specific impromptu questions to URSI members on ITU-R issues are not appropriate (though it was well worth trying), but identification of specific areas of common interest can be of considerable mutual interest. Lists of topics considered to be of joint interest are reproduced in Appendix 1 hereto. They need further updating, but would be expected to have relevance to most commissions.

On **Item 3**, regular informative reports have been incorporated in the Radio Science Bulletin, *(see most recently: September 1999 p 65, March 2000 pp 25-26, September 2000 pp 4-5, March 2001 p 7 and September 2001 p 16)*. Apart from these, it is difficult to report background information fully here without overburdening the reader. In the broadest terms, URSI promotes the exchange of information between individual scientists engaged in radio science research whilst in ITU-R representatives of governments coordinate the efficient use of the radio frequency spectrum and satellite orbits, which is done largely through the means of Radiocommunication Conferences and the development of Recommendations and Handbooks by the ITU-R Study Groups. (As mentioned above, some people are active in both organisations.) Advice is therefore to visit website www.itu.int/ITU-R/ and to be aware that the ITU-R Study Groups (SGs), Working Parties (WPs) and Task Groups (TGs) address the following topics:

- SG1 - Spectrum Management – 5 WPs and TGs
- SG3 - Radiowave Propagation – 4 WPs (*see Radio Science Bulletin June 2002 page 10)*
- SG4 - Fixed-Satellite Service – 6 WPs and TGs
- SG6 - Broadcasting Services (terrestrial and satellite) – 10 WPs and TGs
- SG7 - Science Services – 5 WPs (plus WPs and TGs already listed above, i.e. more than one SG involved)
- SG8 - Mobile, Radiodetermination, Amateur and related Satellite Services – 4 WPs (plus WPs and TGs already listed above, i.e. more than one SG involved)
- SG9 - Fixed Service – 5 WPs (plus WPs and TGs already listed above, i.e. more than one SG involved)

The main work is carried out in the 38 Working Parties and Task Groups as indicated above (see for each SG in turn via website http://www.itu.int/ITU-R/study-groups/index.asp), though some changes may have been introduced in the last few months.. Basic needs for research are spelt out in some 395 formalised Questions (each being a statement of a technical, operational or procedural problem, generally seeking a Recommendation) totalling some 631 pages of text (details being available for each SG in turn via website http://www.itu.int/ITU-R/study-groups/index.asp), but more information on current studies is given in reports from WP chairmen (see for example Docs 3J/56 (31 May 2002), 3K/60 (7 November 2001), 3L/1 (31 August 2000) and 3M/82 (31 May 2002) from SG3 Working Party Chairmen, or their recent Executive Reports in SG3 Docs. 3/95, 3/93, 3/82 and 3/94, respectively, in June 2002). Working documents *(*such as these) are normally available only to those active in ITU-R (through TIES) and an approach in this direction is best made through national administrations or other members (see website www.itu.int/GlobalDirectory/index.html). However, URSI is a Sector Member and TIES documents should also be available by this route. A list of forthcoming meetings is on website http://www.itu.int/events/upcomingevents.asp?lang=en.

Initial comments relating to ITU-T and ITU-D, to parallel those for ITU-R above, are given in an appendix of the SCT website, but these need some revision.

On **Item 4**, availability of radio frequencies for radio science may be specific areas where URSI should express an opinion directly through agreed formal input documents. These areas include (a) radio astronomy, (b) remote sensing of the ground, atmosphere and ionosphere, and (c) direct sensing, using radio techniques or telemetry, of the atmosphere and space. Much of this is covered by the work of IUCAF (as mentioned above), but the position could be strengthened with regular URSI participation. Other aspects of radio science do not directly need access to spectrum. The ITU might benefit in such areas by making use of the research results, but this does not directly benefit URSI. In its relations with ITU, URSI should concentrate on pursuing its own needs for spectrum, though normally it is to be expected that matters would be attended to through National Administrations *(National Administration contacts may be found through "The Global Directory" via "ITU Member Services" on the ITU web home page)*. Other direct personal contacts between ITU-R and URSI have been outlined above. Such activity should be supported and extended in the interests of URSI participants.

A recent case of interest is in relation to the definition of UTC where URSI and other interested bodies have been asked to advise an ITU-R Special Rapporteur Group. This was the subject of a Resolution from Commission J agreed by Council at the 2002 GA in Maastricht. SCT work is intended to concentrate through Activity 2, as above.

Conclusion

Broadening of the SCT Terms of Reference was first requested by the URSI President and Board early in 2002. This was adopted by Council at GA 2002, and some progress has been made, but a lot remains to be done.

Although development of the list of topics in Appendix 1 should be extended, it is to be hoped that in our second year, starting in August 2003, individuals will begin to seek out results to be communicated from these topic areas, notably within the Networks of Activity 3 (URSI/ITU-R), Activity 4 (URSI/ITU-T and URSI/ITU-D) and Activity 5 (URSI/WHO).

Offers of help would be very welcome, especially from those already involved in aspects of the seven activities, whether or not they are known to SCT Members. Please contact the SCT Chair and/or present your ideas through the web forum (see above).

Martin P. M. Hall.
(SCT Chair)

Appendix 1
ITU-R and WHO topics identified for consideration by URSI

(The basis for this list was compiled in 1996, but some recent changes have been introduced. Considerable further development of this appendix is needed. In particular, it is intended to delete Appendix 3 from the comparable website (concerning ITU-T and ITU-D) and take topics into this appendix, but this will not be done until major changes to ITU-T have been completed.)

The development of telecommunications moves towards terrestrial short-range communication and satellite communications. Ionospheric terrestrial propagation is becoming less important since short wave services are replaced by satellite services. Ionospheric Earth-to-space propagation is of prime importance for the development of the Global Navigation Satellite Service (GNSS). Matters of growing importance are broad-band communications, spread-spectrum communications and pulsed broadband communications. These technologies, in connection with novel modulation and coding schemes will have considerable influence on network planning. High-altitude platforms in connection with smart antennas are an interesting option between terrestrial communications and satellite communications and deserve consideration. Smart antennas as well as MIMO (multiple input multiple output) systems should be considered and the frequency range should be extended up into the millimetre wave region (up to 70 GHz).

1. Topics concerning Spectrum Management and Planning (ITU-R Study Group 1)

Spurious emissions - Spurious emissions from a transmitter provided for one service may interfere with other services in other parts of the frequency spectrum. Information on the propagation models used for modelling spurious and unwanted emission interference are required.

Spectrum management aspects of short-range communications systems - Information is required on what spectrum management techniques are appropriate for short-range (operating range less than about 200 m) communications, including how modulation and access techniques relate to spectrum efficiency, and the influence of environmental noise and strong undesired signals, etc.

Interference to digital radiocommunication services - Sources of interference to digital radiocommunication services need to be identified and characterized according to their interference effect; procedures are required also to measure (weight) the interference sources according to their effect.

Methods and algorithms for frequency planning - Such methods are required in automated systems.

Network planning and frequency assignment techniques - Information is required on the principles for optimum network planning and frequency assignment in the various frequency bands, for the various services.

2. Topics concerning Radiowave Propagation in and through the Ionosphere (ITU-R Study Group 3)

- Development of a recommended solar wind/magnetosphere/ionosphere coupled model suitable for the prediction of ionospheric parameters on a global scale;
- Maps of ionospheric characteristics most appropriate to monthly median and instantaneous conditions;
- The representation of foF1 and F1-region ionization at high solar-zenith angles;
- Electron-density height profiles most appropriate to monthly median and instantaneous conditions for use in HF propagation assessments and for TEC determination;
- Improved models for quantifying the distribution of ionospheric scintillation in time and space;
- How to model ionospheric Doppler shift and Doppler spread;
- Development of ionospheric propagation models that can be updated by use of real-time information;
- Improvement of models of short-term variations of the low-latitude ionosphere suitable for radiocommunications.

3. Topics concerning RadiowavePropagation in and through the Neutral Atmosphere (ITU-R Study Group 3)

- Radiometeorological parameter mapping; there is a need for improved world-wide maps of radio refractivity (in particular its vertical gradient), rainfall intensity, cloud cover, water vapour density, etc.;
- Radio ducts; information is required on the geometrical dimensions of ducts as a function of region and time percentage;
- Rain structure; information is needed regarding the height and lateral dimensions of rain cells for different types of precipitation;
- Modelling of terrain, buildings and vegetation for

propagation prediction at UHF and SHF;
- Radiowave propagation between high-altitude platforms and Earth.

4. Topics concerning Radio Noise (ITU-R Study Group 3)

- The impulse characteristics of atmospheric radio noise;
- Man-made noise, particularly at UHF;
- Noise in spread spectrum communications;
- Noise in pulsed broadband communications.

5. Topics concerning Antenna Radiation Patterns (ITU-R Study Group 6)

- *Antenna radiation patterns* - the radiation characteristics are required to be defined for transmitting and receiving antennas from 150 kHz up to 70 GHz, including antennas for satellite operation. Methods of calculation of the electric and magnetic fields in the vicinity of transmitting antennas are also required;
- *Smart antennas*;
- *MIMO* (Multiple input multiple output) communication systems.

6. Topics concerning Frequency Standards, Time Signals and Time Transfer (ITU-R Study Group 7)

Frequency standards and time signals - Information is required on the performance and reliability of frequency standards and their use in time-scales.

Time transfer - Techniques need to be recommended for satisfying time transfer requirements at various performance levels; present and projected requirements for high precision time for various applications are needed, in particular for VLBI.

7. Topics concerning Radio Astronomy (ITU-R Study Group 7)

What are the characteristics of orbits in the vicinity of the L_2 Lagrangian point technically suitable for permanent space observatories?

Unwanted emissions radiated from and received by stations of the science services. Technical factors involved in the protection of radio astronomical observations and for radio astronomy observations from space. Criteria for evaluation of interference to radio astronomy. Frequency sharing between the radio astronomy service and other services in bands above 70 GHz. Technical and operational characteristics of applications of space science services operating above 275 GHz. Technical and operational factors relating to the interference mitigation practices at radio astronomy stations. Possibility and relevance of including in the Radio Regulations frequency bands above 3000 GHz.

8. Topics concerning Earth exploration-satellite systems and meteorological systems (ITU-R Study Group 7)

Again, unwanted emissions radiated from and received by stations of the science services. Data transmission for Earth exploration-satellite systems and meteorological satellite systems. Compatibility of spaceborne active sensors and systems in the services allocated above the Band 5,250-5,460 MHz. Frequency sharing studies with systems operating in other services at around 440 MHz and 5,300 MHz, with airborne altimeters in the aeronautical radionavigation service in the band 4,200-4,400 MHz, with other services in the 36-37 GHz band, and other services around 35.5-36.0 GHz, and around 1,215-1,300 MHz band. Preferred frequencies for the Earth exploration satellite (passive) and space research (passive) services above 70 GHz and the feasibility of sharing with other services in these bands. EESS (active) and SRS (active) operating above 100 GHz and applications of space science services operating above 275 GHz.

9. Topics concerning Biological Effects of Radiowaves (WHO)

Bioeffects of radiowaves and EM research in health assessment.

10. Comment

The topics proposed above are related to the following terms of reference:
- Commission A: Bioeffects of radiowaves;
- Commission B: Wave propagation; Antennas and radiation;
- Commission C: Telecommunication systems; Spectrum and medium utilisation; Signal processing; Information theory, coding, modulation and detection;
- Commission D: Electronic devices and applications;
- Commission E: Spectrum management/utilisation and wireless telecommunications;
- Commission F: Radiowave propagation through the neutral atmosphere;
- Commission G: Radiowave propagation through the ionosphere;
- Commission J: Radio astronomy;
- Commission K: Bioeffects of radiowaves and EM research in health assessment.

[1] Initially URSI publications recorded in place of this Resolution an earlier text taken from a quite different source, but errata have since been made available.

An URSI Questionnaire: How Can We Improve URSI's Image ?

Dear Colleague,

The problem of URSI "exposure" was raised at the Maastricht General Assembly by European National Committees and by Kristian Schlegel, President of URSI. Despite strong societal concerns about the electromagnetic environment and the expertise of numerous Union members, URSI is too often ignored by national and international organizations

In order to identify ways to improve URSI's image, a questionnaire has been prepared. It is addressed to all URSI officials and, via the *Radio Science Bulletin*, to all URSI members. Three tools are considered (if you have additional ideas, do not hesitate to mention them!): Resolutions and Recommendations, URSI publications and meetings and a new initiative: URSI white papers.

1. Resolutions and Recommendations

Among the Resolutions and Recommendations adopted at each General Assembly, several are addressed to national and international scientific organizations or administrations, agencies, etc. The point is to know if they are useful or useless, and if there is a way to improve them.

1.a How do you use Resolutions and Recommendations directed to other organizations ?
(As a source of information for new topics and new development? As guidelines in your domains of interest? As a support for funding radio science activities or/and equipment? As support to draw the attention of appropriate entities to new domains of research and/or to risks? Other uses?)

1.b Have you in the past transmitted Resolutions and Recommendations to other Unions, or to national and international organizations? if yes, what are these organizations? What feedback did you receive?

1.c In which domains do you believe that URSI's expertise may be recognized, and thus its Resolutions and Recommendations may be followed?
(Protection of scientific frequency bands? Protection of the electromagnetic environment of the Earth? Contribution to regulation and standardization of telecommunication services? Transmission of energy via electromagnetic waves? Others?)

1.d List the national and international organizations with which URSI must or should interact.

2. Publications and meetings

2.a What types of papers do you expect in the *Radio Science Bulletin* (*RSB*)?
Starting from December, 2003, the reviews that were published in the *Review of Radio Science* (*RRS*) will be published in the *Radio Science Bulletin* (*RSB*). Other refereed papers will also continue to be published. What types of papers do you expect in *RSB*: Reviews? Technical papers? Regular columns (presently there is a column on "Radio Frequency Radiation Safety and Health")? reports from URSI-sponsored meetings? News from the URSI community? Others?

2.b What is your interest in *RSB* papers downloadable from the URSI Web site as PDF files?
Since the September, 2002, issue, the *RSB* has been available on the URSI Web site as a downloadable PDF file. What do you think about this new service? What do you suggest to improve it?

2.c What is the value of sponsoring meetings for URSI exposure?
Numerous workshops, meetings, and colloquia are sponsored by URSI. What is the most efficient procedure: to support a limited number of well-identified URSI manifestations, or to co-sponsor a maximum number of manifestations?

3. White papers

During the May, 2003, meeting of the URSI Board of Officers, it was decided to issue "white papers" on topics sensitive to society (the public as a whole). The objective is to provide objective documents, with all pros and cons, in a format that may satisfy scientists as well as non-scientists. A first white paper has been forecast on solar power satellites and transmission of energy via electromagnetic waves.

3.a What could be the use of URSI white papers?
(To provide documents to international or national scientific organizations, agencies, national administrations? To inform radio scientists? To provide material for science journalists? To provide teaching support for radio scientists? Others?)

3.b What could be other topics for which URSI white papers would seem to be relevant?
(The health effects of cell phones? Radio interference with medical equipment? Others?)

Answers should be sent by **December 1, 2003**, to

URSI secretariat c/o Ghent University (INTEC)
Sint-Pietersnieuwstraat 41, B-9000 Gent
Belgium
Fax: (32)9 264 42 88
E-mail: ursi@intec.rug.ac.be.

Radio-Frequency Radiation Safety and Health

James C. Lin

Children and the Risk of Mobile Telecommunication

While the market-penetration rate of mobile telephones has reached 80% or higher in many parts of Asia and Europe, the statistic for the US is stuck firmly in the 50% range. However, it might not stay there for much longer, if the European and Asian companies have anything to say about it. Faced with a nearly saturated market and difficulties with the third-generation rollout, many companies are gawking at the US market, especially its youth. They are looking for business models that would allow them to transplant the phenomenal hit mobile telephones have had with youth in certain parts of Asia and Europe, perhaps with inexpensive service plans. Mobile-phone manufacturers and service providers are investing in handsets that are cheap and chic, and they are expending advertising dollars on the younger set.

Unlike many Japanese youth with I-mode-enabled phones – which let them get, for example, movie information, or find the nearest "hot spot" – only a small percentage of US teens own their own mobile phones. Instead, a large number of teenagers use their parents' mobile phone, making them a potentially lucrative market: the most significantly under-penetrated group with identifiable interest in cellular mobile telephony.

However, the marketing of mobile phones to youngsters has been controversial. A particular issue of interest is the question of whether there is a risk to children from mobile-phone radiation. Opinions vary from, "There's no biological reason to think that children are any more at risk than adults," to "There are gaps in knowledge about mobile-phone safety."

Nevertheless, a group set up by the British Minister for Public Health, to assess the current state of research into possible health risks from mobile phones, published a report in May, 2000 (the Stewart Report), which urged that children be discouraged from using mobile phones, and that companies stop marketing to kids. Several panels from other countries have since recommended that children limit their use of mobile phones, but a few also have stated that children need not be treated differently than adults.

In response to an ABC *Prime Time* report – in which some scientists criticized the mobile-telephone industry for marketing phones to children at a time when there are gaps in knowledge about mobile-phone safety – the Walt Disney Co. disclosed, in November, 2000, that it would stop licensing its cartoon characters for mobile telephones. The company had stated that, "Because the well-being of our customers is our priority, we have decided to discontinue the licensing of our characters for use on cellular telephones until there is reliable scientific evidence establishing the absence of any such risk."

Most practicing biomedical scientists accept the fact that children's anatomy and physiology are different from those of adults. The structural and functional changes in cells, tissues, and organs are spectacular during growth and development. Abnormal reactions of cells, tissues, and organs to extrinsic physical, chemical, and biological challenges are major causes of acquired diseases.

Are children more vulnerable to the microwave radiation from cellular mobile telephones? This is an open question. The paucity of laboratory results should make anyone hesitate in making definitive remarks on the health and safety of mobile-phone radiation for children. On the other hand, there have been plenty of computational studies on deposition of mobile-phone radiation and on the specific absorption rate (SAR) in head models of youngsters and adults.

Intuitively, the computation of SAR in the head seems like a rather cut-and-dried topic. In typical usage, the handset of a mobile telephone is held against the ear.

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Barring any computational glitches, it should be a straightforward task: One constructs a computer-friendly head model with a handset, codes an executable numerical algorithm, and then computes and displays the SAR distribution throughout the head model. However, the computed SARs in the heads of youngsters and adults have become nearly as controversial as the biological reasons – or lack thereof – for thinking that children are any more or less at risk than adults. Since SAR is a metric for microwave-power deposition, a higher SAR inside the head of a child may be associated with an increased hazard from mobile-phone use. This is a bit different from the question of whether or not children are biologically more vulnerable.

Numerical dosimetry – the computation of SAR distribution in humans exposed to microwave radiation from cellular mobile telephones – has been one of the most productive research areas during the past decade. It attracted many researchers, both from across the Atlantic and the Pacific oceans [1-4]. A major reason for this is the availability of the Finite-Difference Time-Domain (FDTD) algorithm for analyzing complex biological bodies with internal details. The capability and accuracy furnished by FDTD algorithms permit more efficient computations – in terms of computer time and resources – of SAR distribution in intricate biological bodies that are large compared to a wavelength.

A subset of these dosimetric studies addresses SARs in the heads of children, and makes comparisons between SARs in heads of children and adults. Instead of providing a consensus, these SAR studies have spawned diverse opinions on whether the smaller heads of children, exposed to mobile phones, absorb more microwave radiation than those of adults, and on whether or not the microwave radiation penetrates deeper into their heads. The disagreement is most conspicuous between the published and presented works of two research laboratories: One at Salt Lake City, Utah [7, 8], and the other at Zurich, Switzerland [9, 10]. This disagreement became ever more conspicuous at the most recent scientific meeting of the Bioelectromagnetics Society, held at Quebec City, Canada, in June, 2002, and at the General Assembly of the International Union of Radio Science (URSI), held in Maastricht, the Netherlands, in August, 2002.

The Utah group has employed monopole antennas and a 2-mm-resolution anatomically based model of the human body to compute power deposition in the head due to mobile telephones operating at 835 and 1900 MHz [7]. They used magnetic-resonance-image-based (MRI-based) models of the adult male, and their reduced-scale models of 10- and 5-year-old children. Using these, they reported that peak SARs are higher for the smaller models of children, particularly at 835 MHz, whether averaged over one voxel (a volume element in the computational model) or 1 g of tissue mass. For example, the peak SARs in the brain were higher by 35% and 50% for the 10- and 5-year-old children, respectively, using an 835-MHz phone with a quarter-wave antenna, and by 17% and 55%, respectively, at 1900 MHz. Much higher SARs have been registered for smaller sized voxels, and for other tissues in the body, such as the ear. Also, considerably higher SARs were obtained in deeper head tissues, both at 835 MHz and 1900 MHz, for the smaller models used for children.

Their results were expanded in a recent study, in which a different anatomically-based model of the adult head, namely the "Visible Man" model, was utilized. Moreover, the voxel size of the "Visible Man" model was increased or reduced by 11.1% or 9.1% in all dimensions, to obtain head models larger or smaller, respectively, compared to adults [8]. The peak 1-g tissue SAR calculated for the smaller models was up to 20% higher at 835 MHz, and up to 56% higher at 1900 MHz, compared to the larger models, with the intermediate models providing intermediate SAR values.

Later, the Swiss laboratory published results from a study that was "motivated" by the Utah study, but revealed no significant differences in the absorption of microwave radiation between adults and children [9]. This study was conducted using a Finite-Integration-Technique code. It involved head models derived from MRI scans of an adult (voxel size 2 × 2 × 1 mm) and two children (voxel size 2 × 2 × 1.1 mm) at ages of 3 and 7 years. Moreover, the authors suggested that the same conclusion holds when children are approximated as scaled adults. The antennas used were 0.45-wavelength dipoles, instead of actual mobile phones, operating either at 900 MHz or 1,800 MHz. (The FDTD algorithm was employed in another paper from the Swiss group [10]. A difference of about ±10 % of SARs in head models representing adults and children at 3 and 7 years of age was shown.)

Given the differences in frequencies, antennas, and head models, a direct, quantitative, numerical comparison would be inappropriate. (Also, the two computational schemes were different, in one case.) However, a qualitative conclusion about results from these two laboratories could be meaningful, especially since the Swiss study indicated that their conclusion also holds when models for children are obtained from a reduction of the adult model. Assuming that all results are self-consistent and correct on their own basis, the contradiction is glaring! The simple explanation could be a difference in the averaging volume or mass, such as 1 g verses 10 g of tissue. This is not the explanation, since they all presented SAR data based on the same averaging volumes. There must then be some other explanation.

Microwave absorption in the head is a rather complex subject. For typical patterns of mobile-phone usage, the position of the pinna, or external ear, also demands special attention. However, we shall set aside microwave absorption in the external ear for the time being, and consider the implications of head-model differences between children and adults.

The dependence of microwave-power deposition and SAR distribution on head size were investigated analytically years ago, using Mie equations for plane waves, and for both homogeneous and layered inhomogeneous spherical models [11]. These two factors are known to vary widely with sphere sizes and frequencies. In general, at a given frequency, the absorption increases rapidly with an increase in the radius. This is followed by some resonances for $0.5 < ka < 1.5$, and then decreases as the size of the head-sphere increases further such that $ka > 1.5$, where k is the wave number, and a is the sphere's radius. The equivalent head spheres of children and adults range from 5 to 10 cm in radii. Thus, SARs in a child-sized head should be higher compared to those for adults for plane waves (far field) at both sets of frequencies used for cellular mobile telephony.

Likewise, the dependence of SAR and its distribution on tissue structures inside the head was initially investigated using the layered, inhomogeneous spherical models, irradiated by plane waves. It was found that the tissue composition and thickness present in anatomical variations impact microwave deposition in the brain. The peak SARs in some head models may be several times as great as in other models with different composition and tissue-layer thicknesses.

However, in situations involving near-field exposures, such as mobile telephones, the distance between the antenna and the head plays a dominating role in microwave absorption. (Indeed, the relative position of the antenna feed point and the pinna is another significant factor. As mentioned earlier, for this discussion we will set aside microwave absorption in the external ear, and consider the implications of head-size differences between children and adults.) A recent study showed that the spatial peak SAR inside both homogeneous and inhomogeneous head models, exposed to a 0.45-wavelength dipole, varied for different distances between the dipole and the surface of the head model. In particular, the 1-g SARs were 8, 6, and 4 W/kg per 100 mA of 900 MHz antenna-feed-point current at distances of 2, 5, and 10 mm from the dipole to nearest point on the pinna surface, respectively [12]. These results confirmed an expected decrease in SAR as a function of antenna distance farther away from the head surface. The publication presented only a few line distributions (relative to two-dimensional distributions) of SAR inside the head models. For example, using SARs along a line normal to the 900 MHz antenna at a 15-mm spacing from the head surface, it showed that spatial peak SAR is strongly dependent on the internal anatomy of the head model.

The most important lesson to be learned from these near- and far-field studies is that SARs inside human heads exposed to a given mobile telephone are functions of the size of the head model, its detailed anatomical composition and structure, and the distance of separation between the antenna and the head.

In one study, the Utah group employed MRI data-based head models of the adult male, and smaller models of 10- and 5-year-old children that were scaled from adults. In a more recent study, they used the "Visible Man" model, and the voxel size of the "Visible Man" model was increased or reduced in all dimensions to obtain larger or smaller head models. The distance of separation between the antenna and the head surface was not explicitly described in the publication. It likely was between 5 and 20 mm in these studies. While the exact SAR values obtained for these models were somewhat different, the conclusions were the same, namely, peak SARs in the heads of 10- and 5-year-old children are higher than those in the adult model.

On the other hand, while the Swiss study also used MRI-data-based head models, the models for children were actual scans taken from children, as was the case for the adult. Thus, their models were "anatomically correct" for these children. The structural composition and tissue distributions were different from reduced-scale models of the adult head. The distance of separation between the dipole antenna and the head surface was 15 mm. The study reported only minor differences in the peak SARs between adults and the two models used for children.

It is noteworthy that they also indicated that the same conclusion was reached when reduced-scale models were used for children. Therefore, while anatomic details may play some role in SAR variations, size scaling, with potentially altered tissue composition and thickness, may not explain the divergence of computed SARs. In other words, the uses of anatomically correct models derived from MRI data of children may not be the cause of the difference in the conclusions reached.

The disparity in distances of separation between the antenna and the head, employed by the different laboratories in their computer simulations, may be a pivotal factor. Specifically, the separation distances reported varied substantially. Available computational data showed that these distances of separation between a mobile-phone antenna and the head can have profound influences on the SAR peak values and distributions (as mentioned above). It is more likely than not that a given combination of head model, size, and antenna spacing could have produced the results reported by these investigators. Thus, the disagreement may have arisen from a limited number of computations that were unique to the specific nature of each of their modeling and simulation efforts. In particular, the exploration of a wider range of antenna distances used in the computations, both for models of children and for adults, might disperse much of the contention.

Another approach that could potentially help in resolving this and related issues is to adopt a realistic set of standards or references for models, antennas, and exposure configurations. However, the implementation of such an approach may not be as simple as the suggestion.

It is worthy of note that COST-281 has recently initiated a task to review the literature on mobile communication and children, and to identify gaps in scientific knowledge and the research needed to fill the knowledge gaps. The European Cooperation in the Field of Scientific and Technical Research (COST) is a framework for international research and development cooperation and coordination of national research in Europe. COST-281 is an action group on "Potential Health Implications from Mobile Communication Systems," within the COST-Telecommunication Information Science and Technology.

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Conferences

CONFERENCE REPORT

Third International School on Atmospheric Radar
ISAR -3

Abdus Salem International Center for Theoretical Physics, Trieste, Italy, 25 November - 13 December 2002

This school was the third in its role following ISAR-1 in 1988 in Kyoto, Japan, and ISAR-2 in 1995 in Hilton Head, USA. These schools are part of the activities in the scientific and engineering community using radars for studies of the Earth's atmosphere and ionosphere. In particular the mesosphere-stratosphere-troposphere (MST) radars have become major research tools in these applications. A proper knowledge of the basic methods, proper analysis, validation and interpretation of the acquired data, basing on the main theoretical background of atmospheric physics, informatics and technology is demanded for such efficient applications. The school ISAR-3 was particularly held for the purpose of training young researchers and students, who are active in or have proven relations to this area, or could certify a solid interest and a sound perspective on this research and this technique.

The school covered the main subjects of fundamentals of atmospheric radar, hardware and basics of signal acquisition, data analysis and special applications such as interferometry, scattering of radar waves, atmospheric winds waves and turbulence, meteorology of the troposphere and the stratosphere, the mesosphere and the aeronomy of the lower ionosphere. Besides lectures also interactive computer training was applied, intense group and individual discussions were held, and the participants were given opportunity to present short papers on their own research or education.

The school ISAR-3 was held at the excellent premises of the abdus salam International Center for Theoretical Physics (ICTP), which also provided the majority of funding for these school activities. Additionally the ISAR-3 was sponsored and funded by the Scientific Committee on Solar Terrestrial Physics (SCOSTEP) and the International Union of Radio Science (URSI). From a total of 140 applicants 28 participants were selected. These were from 17, mostly developing, countries.

The lecturers, well known as researchers in the MST radar field, were Prof. P. Chilson, USA , Prof. S. Fukao, Japan, Prof. W. Hocking, Canada, Prof. R. Palmer, USA, Prof. S. Radicella, Italy, Prof. D.N. Rao, India, and Prof. J. Röttger, Germany. The latter three acted as school directors.

Our thanks are directed to ICTP for providing the funding, facilities, housing, food, administration and school secretariat as well as outstanding computing support and well-equipped lecture and training halls. This helped very impressively to hold the ISAR-3 in a very suitable environment and most pleasant atmosphere.

The highly positive response of the students of ISAR-3 on the performance of this school and the obvious great demand for this kind of education and training let us hope that we may have ISAR-3 at the same place in 2004 or 2005.

Jürgen Röttger
For all ISAR-3 lecturers

CONFERENCE ANNOUNCEMENT

Atmospheric Remote Sensing using Satellite Navigation Systems

Special Symposium of the URSI Joint Working Group FG

Matera, Italy, 13 - 15 October 2003

The workshop aims to bring together researchers working in the fields of the URSI Commissions "F" (Wave Propagation and Remote Sensing) and "G" (Ionospheric Radio and Propagation) in order to exchange knowledge and ideas relating to the use of satellite navigation systems for atmospheric and ionospheric remote sensing. It is also intended to cover new remote sensing techniques derived from related concepts. Contributions are particularly welcome from research topics simultaneously covering aspects of both the neutral and ionised atmosphere. The workshop will take the form of invited tutorial, review and young scientist oral presentations and contributed posters. All participants presenting either through the oral or poster medium will be invited to submit their paper for inclusion in the proceedings.

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ClimDiff'03
Fortaleza, Brazil, 17-19 November 2003
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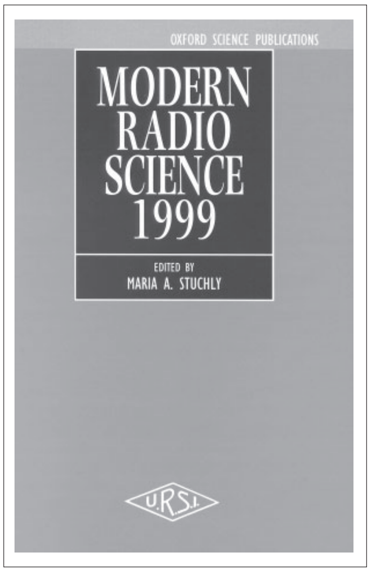

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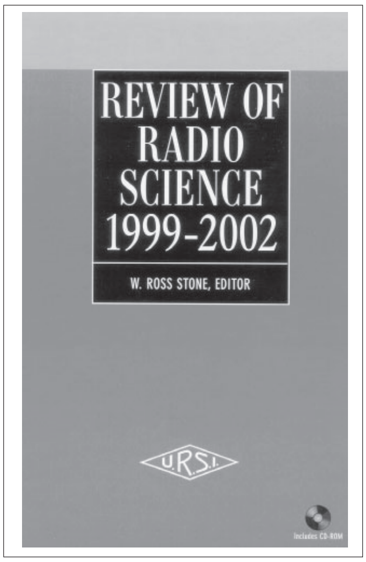

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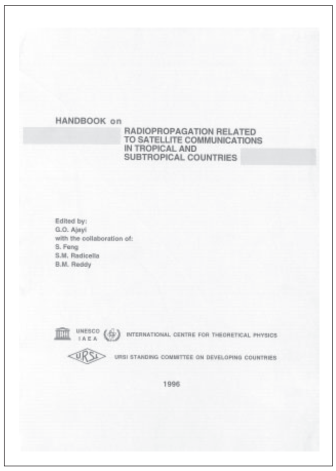

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