Modelling the Human Body Exposure to ELF Electric Fields
Topics in Engineering

This series provides a rapid and informal dissemination of significant new work in engineering. It is aimed at high level coverage across a broad field of engineering including mechanical, civil, hydraulic and structural, as well as other associated topics.

Managing Editors

C.A. Brebbia
Wessex Institute of Technology
Ashurst Lodge
Ashurst
SO40 7AA
UK

J.J. Connor
Department of Civil Engineering
Massachusetts Institute of Technology
Cambridge
MA 02139
USA

Consulting Editors

E.R. de Arantes e Oliveira
Instituto Superior Tecnico
Portugal

M.A. Celia
Princeton University
USA

S.K. Chakrabarti
Offshore Structure Analysis
USA

E.L. Ortiz
Imperial College London
UK

J. Dominguez
University of Seville
Spain

S. Rinaldi
Politecnico di Milano
Italy

S. Elghobashi
University of California Irvine
USA

G. Schmid
Ruhr-Universität Bochum
Germany

W.G. Gray
University of Notre Dame
USA

M. Tanaka
Shinshu University
Japan

H. Lui
State Seismological Bureau Harbin
China

H. Tottenham
Tottenham & Bennett, Consulting Engineers
UK

K. Onishi
Ibaraki University
Japan

J.R. Whiteman
Brunel University
UK
Modelling the Human Body Exposure to ELF Electric Fields

Cristina Peratta
&
Andres Peratta

*Wessex Institute of Technology, UK*
Modelling the Human Body Exposure to ELF Electric Fields

Series: Topics in Engineering

Cristina Peratta & Andres Peratta
Wessex Institute of Technology, UK

Published by

WIT Press
Ashurst Lodge, Ashurst, Southampton, SO40 7AA, UK
Tel: 44 (0) 238 029 3223; Fax: 44 (0) 238 029 2853
E-Mail: witpress@witpress.com
http://www.witpress.com

For USA, Canada and Mexico

WIT Press
25 Bridge Street, Billerica, MA 01821, USA
Tel: 978 667 5841; Fax: 978 667 7582
E-Mail: infousa@witpress.com
http://www.witpress.com

British Library Cataloguing-in-Publication Data

A Catalogue record for this book is available from the British Library

ISSN: 0952-5300

Library of Congress Catalog Card Number: 2009930796

No responsibility is assumed by the Publisher, the Editors and Authors for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions or ideas contained in the material herein. The Publisher does not necessarily endorse the ideas held, or views expressed by the Editors or Authors of the material contained in its publications.

© WIT Press 2010

Printed in Great Britain by MPG Books Group, Bodmin and King’s Lynn.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of the Publisher.
Contents

PREFACE xi

CHAPTER 1 INTRODUCTION 1
  1.1 EXTREMELY LOW FREQUENCY EXPOSURE 2
    1.1.1 Different areas of research 2
    1.1.2 Evidences of harmful effects 2
  1.2 COMPUTATIONAL DOSIMETRY AT ELF 4
    1.2.1 Models of the human body 6

CHAPTER 2 ELF ELECTROMAGNETIC EXPOSURE 9
  2.1 INTRODUCTION 9
  2.2 EM EXPOSURE. BASIC CONCEPTS 9
    2.2.1 Non-ionising radiation 10
    2.2.2 Dosimetry 12
  2.3 THEORETICAL MODEL FOR ELF 13
    2.3.1 Interface matching conditions 16
  2.4 DIFFERENT SOURCES OF EXPOSURE AT ELF 17
  2.5 SUMMARY 19

CHAPTER 3 DIELECTRIC PROPERTIES OF BIOLOGICAL TISSUES 21
  3.1 INTRODUCTION 21
  3.2 MODELLING BIOLOGICAL SYSTEMS 22
    3.2.1 The scale 22
    3.2.2 Coupling different scales problems 23
  3.3 AVAILABLE DATA ON DIELECTRIC PROPERTIES 23
    3.3.1 Measurements 23
  3.4 THEORETICAL ASPECTS. BIOLOGICAL MATTER IN ELECTRIC FIELD 24
    3.4.1 Definition of the dielectric properties 24
    3.4.2 Dispersions 27
  3.5 GENERAL DIELECTRIC PROPERTIES OF SOME TISSUES 28
  3.6 BIOLOGICAL TISSUE AT ELF 30
    3.6.1 Relative importance of conductive and displacement currents 31
    3.6.2 Dielectric data below 100 Hz 33
    3.6.3 Estimation of effective conductivity 35
Preface

The objective of this work is to investigate the behaviour of electric fields and induced currents in the human body exposed to different scenarios of extremely low-frequency (ELF), high-voltage, low-current electromagnetic fields by means of numerical modelling with improved boundary element methods (BEM). A variety of three-dimensional anatomically shaped human body models under different exposure conditions were examined.

The background for human exposure to ELF electromagnetic fields departing from Maxwell equations and for the electrical properties of biological tissue are provided. Then, a new improved BEM approach is introduced in order to solve this type of problems. This novel strategy, based on mixing continuous and discontinuous nodes and a new analytical integration scheme for the single and double layer potentials, has helped to speed up the calculations in the preprocessing and assembly schemes with respect to the classical BEM, leading at the same time to more accurate results. In particular, the integration method maintains high accuracy even when the internal observation points approach to the boundary of the domain. The developed methodology is applied to three different case studies: (i) overhead power transmission lines, (ii) power substation rooms and (iii) pregnant woman including foetus and evolving scenarios.

In all the cases, a sensitivity analysis investigating the influence of varying geometrical and electrical properties of the tissues has been conducted.

The results obtained in all cases allow to identify situations of high and low exposure in the different parts of the body and to compare with existing exposure guidelines.

M. Cristina Peratta and Andres Peratta