Power Line Communications

Theory and Applications for Narrowband and Broadband Communications over Power Lines

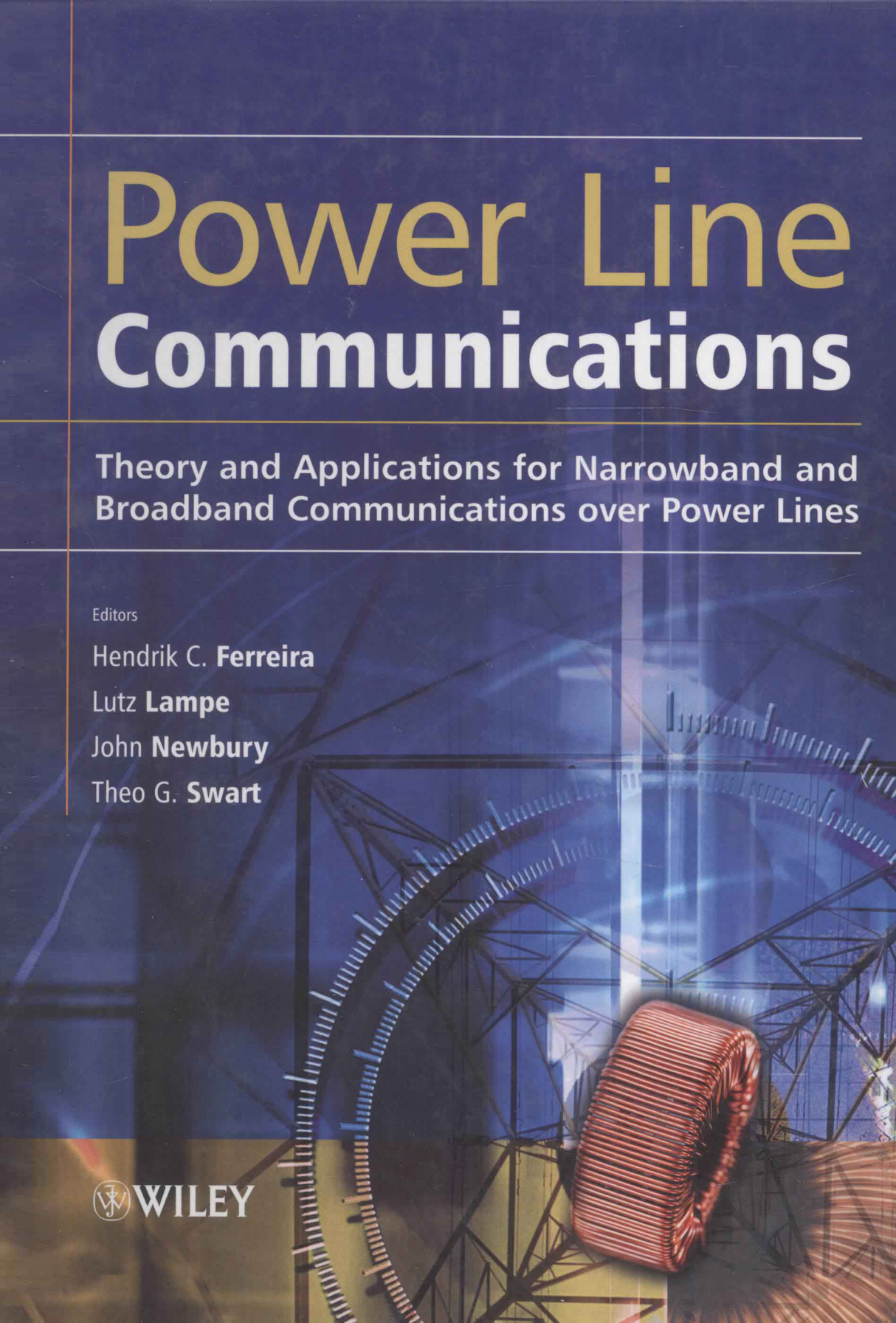
Editors

Hendrik C. **Ferreira**

Lutz **Lampe**

John **Newbury**

Theo G. **Swart**



WILEY

Power Line Communications

Theory and Applications for Narrowband and Broadband Communications over Power Lines

Editors

Hendrik C. Ferreira
University of Johannesburg, South Africa

Lutz Lampe
University of British Columbia, Canada

John Newbury
The Open University, UK

Theo G. Swart
University of Johannesburg, South Africa

WILEY
A John Wiley and Sons, Ltd, Publication

This edition first published 2010

Registered office
John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom

Library of Congress Cataloging-in-Publication Data

Power line communications : theory and applications for narrowband and broadband communications over power lines / editors, H.C. Ferreira . . . [et al.]
p. cm.
Includes bibliographical references and index.
ISBN 978-0-470-74030-9 (cloth)
1. Electric lines–Carrier transmission. I. Ferreira, H. C. (Hendrik C.)
TK5103.15.P695 2010
621.382–dc22

2009053133

A catalogue record for this book is available from the British Library.

ISBN 978-0-470-74030-9

Set in 10/12pt Times by Sunrise Setting Ltd, Torquay, UK.
Printed in Singapore by Markono Print Media Pte Ltd.

Power Line Communications

List of Contributors

Pouyan Amirshahi
Shared Spectrum
Section 2.4

Masoud Ardakani
University of Alberta
Section 5.3.4

Inigo Berganza Valmala
Iberdrola
Sections 8.2 and 8.3

Gerd Bumiller
iAd GmbH
Sections 6.3 and 8.2

Francisco J. Cañete
Universidad de Málaga
Section 2.5

Giulio Colavolpe
University of Parma
Section 5.3.3

Klaus Dostert
University of Karlsruhe
Sections 2.2.5, 2.3, 2.7, 2.8, 2.9 and 5.3.1

Hendrik C. Ferreira
University of Johannesburg
Editor, Section 5.2.5

Dario Fertonani
Scuola Superiore Sant'Anna
Section 5.3.3

Stefano Galli
Panasonic
Section 2.2 (except 2.2.5), Section 7.3

Holger Hirsch
University of Duisburg-Essen
Chapter 3

Halid Hrasnica
Eurescom GmbH
Sections 6.2 and 6.3

Piet A. Janse van Rensburg
Walter Sisulu University
Chapter 4

Masaaki Katayama
Nagoya University
Section 2.6

Mohsen Kavehrad
The Pennsylvania State University
Section 2.4

Michael Koch
Devolo AG
Chapter 3, Sections 7.4 and 7.5

Lutz Lampe
University of British Columbia
Editor, Section 6.3

Haniph A. Latchman
University of Florida
Sections 7.2 and 8.4

Sunguk Lee
University of Florida
Section 7.2

Maxim Lobashov
Vienna University of Technology
Section 6.3

John Newbury
The Open University
Editor

Vladimir Oksman
Infineon Technologies
Section 7.3

Moisés V. Ribeiro
Federal University of Juiz de Fora
Section 8.6

Alberto Sendin Escalona
Iberdrola
Sections 8.2 and 8.3

Thomas Stockhammer
Nomor Research GmbH
Section 6.4

Theo G. Swart
University of Johannesburg
Editor, Section 5.2.5

Andrea M. Tonello
University of Udine
Section 5.3.2

Daisuke Umehara
Kyoto University
Section 5.3.3

A. J. Han Vinck
University of Duisberg-Essen
Section 5.2 (except 5.2.5)

Eric R. Wade
University of Southern California
Section 8.5

Lawrence W. Yonge III
Intellon Corporation
Section 8.4

Preface

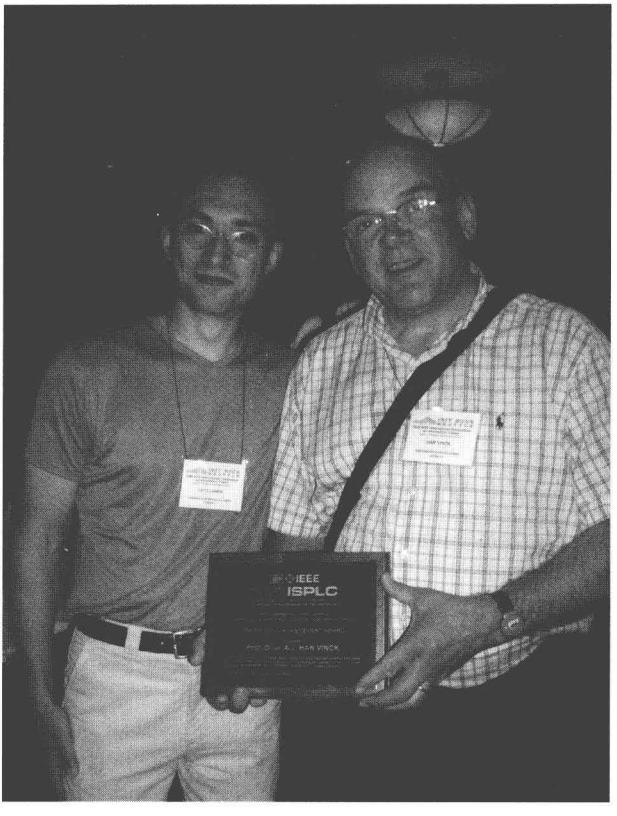
With this book we took on the challenge to cover most of the technical field of Power Line Communications (PLC) with wide-ranging contributions on selected topics. The scope of this book is thus uniquely wide, not only for a book on PLC, but also to our knowledge for any book in the general field of Telecommunications. The inspiration for this wide coverage came from a survey of the many papers contributed to the International Symposium on Power Line Communications from 1997. The reader will thus find information widely dispersed in the literature, including research publications, standards documentation and even trade literature. We have attempted a coverage of both techniques and information on which there is currently consensus, as well as a limited selection of promising ones still under investigation.

The goal of this book is thus to inform newcomers to the exciting field of PLC, to inspire further research and perhaps to contribute to future consensus. This book may also pave the way for future books focusing more deeply on perhaps just one individual subfield of the various subfields covered here.

During this ambitious project, we involved 31 technical contributors from 27 institutions and 11 countries. Coordination was a huge task. The editors would like to express their sincere thanks to all our contributors.

As stated, this book was inspired by the International Symposium on Power Line Communications, which since 2006 has been an IEEE conference sponsored by the IEEE Communications Society. Much material included in our book evolved from the proceedings of this conference (refer to http://www.isplc.org/docsearch).

The editors would thus like to dedicate this book to Professor A. J. Han Vinck from the University of Duisburg-Essen, Germany, for his contributions to PLC. The organization of the first International Symposium on Power Line Communications in 1997 at the University of Essen was one of his many leadership initiatives during his career.



Han Vinck (right) receives the 2006 IEEE International Symposium on Power Line Communications Achievement Award. Lutz Lampe (left) presents the plaque at the 2006 IEEE International Symposium on Information Theory in Seattle, WA, USA.

List of Acronyms

1D	One-dimensional
2D	Two-dimensional
3D	Three-dimensional
AC	Alternating current
ACF	Autocorrelation function
ADSL	Asymmetric digital subscriber line
ADTDM	Advanced dynamic time division multiplexing
AES	Advanced encryption scheme
AFE	Analog front end
AGC	Automatic gain control
AL-FEC	Application layer forward error correction
AM	Amplitude modulation
AMM	Automatic meter management
AMN	Artificial mains network
AP	Access point
ARQ	Automatic repeat request
AVLN	AV logical network
AWGN	Additive white Gaussian noise
BBC	Broadband bad case
BER	Bit-error rate
BGC	Broadband good case
BH	Burst header

BICM	Bit-interleaved coded modulation
BPC	Bits per carrier
BPL	Broadband over power lines
BPRS	Binary pseudo-random sequence
BPSK	Binary phase shift keying
BSS	Basic service set
C-CDF	Complementary cumulative distribution function
CCF	Cross-correlation function
CCL	Common convergence layer
CCo	Central coordinator
CDF	Cumulative distribution function
CDMA	Code division multiple access
CENELEC	Comité Européen de Normalisation Electrotechnique
CEPCA	Consumer Electronics Powerline Communication Alliance
CEPT	European Conference of Postal and Telecommunications Administrations
CF	Conductive fabrics
CFP	Contention free period
CISPR	Comité International Spécial des Perturbations Radioélectriques
CL	Convergence layer / Compatibility level
CM	Connection manager
CP	Cyclic prefix
CPCS	Common part convergence sublayer
CPE	Customer premise equipment
CPS	Consolidated power-signal
CRC	Cyclic redundancy code
CRP	Collision resolution protocol
CS	Critically sampled
CSI	Channel-state information

CSMA	Carrier sense multiple access
CSMA/CA	Carrier sense multiple access with collision avoidance
CTS	Clear to send
C/DWDM	Coarse/dense wavelength division multiplexing
DC	Direct current
DCM	Distance-conserving mapping
DCT	Discrete cosine transform
DCT-OFDM	Discrete cosine transform orthogonal frequency division multiplexing
DDS	Direct digital synthesis
DFT	Discrete Fourier transform
DIM	Distance-increasing mapping
DLMS/COSEM	Device language message specification/companion specification for energy metering
DMT	Discrete multitone
DPM	Distance-preserving mapping
DRM	Distance-reducing mapping
DSSS	Direct sequencing spread spectrum
DUT	Device under test
DWMT	Discrete wavelet multitone
EMC	Electromagnetic compatibility
EMI	Electromagnetic interference
EN	European norm
ERC SE	European Radiocommunications Committee Spectrum Engineering
ES	ETSI specification
ESI	Encoding symbol ID
ETSI	European Telecommunications Standards Institute
EUT	Equipment under test
EXIT	Extrinsic information transfer
FB	Filter bank

FBA	Forward-backward algorithm
FC	Frame control
FDMA	Frequency division multiple access
FEC	Forward error correction
FFT	Fast Fourier transform
FH	Frequency hopping
FH-CDMA	Frequency-hopping code division multiple access
FIR	Finite impulse response
FMT	Filtered multitone
FPGA	Field-programmable gate array
FSK	Frequency shift keying
FTTx	Fiber to the x
GI	Guard interval
GPRS	General packet radio service
GPS	Global positioning system
HD-PLC	High definition power line communication
HDTV	High definition television
HE	Head end
HF	High frequency
HPPA	Homeplug powerline alliance
HV	High voltage
ICI	Inter-carrier interference
IDFT	Inverse discrete Fourier transform
IFFT	Inverse fast Fourier transform
IFT	Inverse Fourier transform
IH	In-home
INL	Interfering network list
IP	Internet protocol
IPTV	Internet protocol television

ISDN	Integrated services digital network
ISN	Impedance stabilization network
ISO/OSI	International Standardization Organization/Open Systems Interconnection
ISP	Inter-system protocol
ISI	Inter-symbol interference
JWG	Joint working group
LA	Latin America
LAN	Local area network
LCL	Longitudinal conversion loss
LDPC	Low-density parity-check
LF	Low frequency
LID	Link identifier
LLC	Logical link control
LLR	Log-likelihood ratio
LPTV	Linear periodically time-varying
LT	Luby transform
LTI	Linear time invariant
LTV	Linear time varying
LV	Low voltage
LVDN	Low voltage distribution network
LVDS	Low voltage differential signaling
MAC	Media access control
MAP	Maximum-a-posteriori
MC	Multicarrier
MCSS	Multicarrier spread-spectrum
MFBO	MAC frame boundary offset
MMSE	Minimum-mean-square-error
MoCA	Multimedia over Coax Alliance

MPDU	MAC protocol data unit
MSDU	MAC service data units
MTBA	Mean time between artifacts
MTL	Multi-conductor transmission line
MV	Medium voltage
NCo	Neighbor central coordinator
NCS	Non-critically sampled
NEK	Network encryption key
NL	Network layer
NLS	Non-linear system
NORM	NACK-oriented reliable multicast
NTU	Network termination unit
OFDM	Orthogonal frequency division multiplexing
OOK	On-off keying
OPERA	Open PLC European Research Alliance
O-QAM-OFDM	Offset quadrature amplitude modulation orthogonal frequency division multiplexing
PAM	Pulse amplitude modulation
PB	PHY block
PBB	PHY block body
PBH	PHY block header
PBCS	PHY block check sequence
PBER	PHY block error rate
PC	Personal computer
PCB	Printed circuit board
PCS	Physical carrier sense
PCo	Proxy coordinator
PCO	Pre-code only
PDF	Probability density function

PDH	Plesiochronous digital hierarchy
PDU	Protocol data unit
PER	Packet error rate
PGA	Programmable gain amplifier
PHY	Physical or Physical layer
PLC	Power line communications
PLT	Power line telecommunications
PPDU	PHY protocol data unit
PR	Perfect reconstruction
PSD	Power spectral density
PSK	Phase shift keying
PVC	Polyvinyl chloride
QAM	Quadrature amplitude modulation
QoS	Quality of service
QPSK	Quaternary phase shift keying
R&TTE	Radio and telecommunications terminal equipment
RADAR	Radio aircraft detection and ranging
RAM	Random access memory
REMPLI	Real-time Energy Management via Powerlines and Internet
RF	Radio frequency
RMS-DS	Root mean square delay spread
ROBO	Robust modulation
RRC	Root-raised cosine
RS	Reed–Solomon
RTP	Real-time transport protocol
RTS	Request to send
RUN-M	RENESAS ubiquitous network layer for metering
SACK	Selective acknowledgment
SALA	Slotted Aloha with local acknowledgments

SAP	Service access point
SAR	Segmentation and reassembly
SCADA	Supervisory control and data acquisition
SCP	Shared contention period
SD	Standard definition
SDH	Synchronous digital hierarchy
SDU	Service data unit
SFN	Single frequency network
S-FSK	Spread-frequency shift keying
SISO	Soft-input soft-output
SNR	Signal-to-noise ratio
SOF	Start of frame
SOT	Start of transmission
S/P	Serial-to-parallel
SP	Service provider
SPA	Sum-product algorithm
SSCL	Service specific convergence layer
SSCS	Service specific convergence sublayer
SST	Spread spectrum techniques
STF	Special task force
TA	Token announce
TC	Technical committee
TCC	Turbo convolutional coding
TCL	Transverse conversion loss
TCP	Transmission control protocol
TCTL	Transverse conversion transfer loss
TDM	Time division multiplexing
TDMA	Time division multiple access
TEM	Transversal electromagnetic

T-ISN	T-shaped impedance stabilization network
TH-CDMA	Time-hopping code division multiple access
TL	Transmission line / Transport layer
TLT	Transmission-line transformer
TMI	Tone map identifier
TS	Technical specification
TXOP	Transmission opportunity
UDP	User datagram protocol
UPA	Universal power line association
UWB	Ultra wide band
VCS	Virtual carrier sense
VDSL	Very high speed digital subscriber line
VHF	Very high frequency
VoIP	Voice over Internet protocol
WNG	White noise generator

Contents