White Space Communication Technologies

Increase the efficient use of time-varying available spectrum with this unique book, the first to describe RF hardware design for white space applications, including both analog and digital approaches. Emerging technologies are discussed and signal processing issues are addressed, providing the background knowledge and practical tools needed to develop future radio technologies.

Real-world examples are included, together with global spectrum regulations and policies, for a practical approach to developing technologies for worldwide applications. Cross analog and digital design guidelines are provided to cut design time and cost.

This holistic, system level view of transceiver design for white space technologies is ideal for practicing engineers and students and researchers in academia.

Nuno Borges Carvalho is a Full Professor and Senior Research Scientist in the Institute of Telecommunications at the University of Aveiro, Portugal. He has co-authored two previous books, including *Microwave and Wireless Measurement Techniques* (Cambridge University Press, 2013). He is Associate Editor of *IEEE Transactions on Microwave Theory and Techniques*, *IEEE Microwave Magazine*, and *Wireless Power Transfer*.

Alessandro Cidronali is an Associate Professor of Electronics in the Department of Information Engineering at the university of Florence, Italy, where he teaches courses on electron devices and integrated microwave circuits. He was Associate Editor of *IEEE Transactions on Microwave Theory and Techniques*, and he currently serves on IEEE MTT-S Technical Committees. He also has over five years of experience in industry, having held positions at Motorola Labs (Tempe, AZ) and the National Insitute of Standards and Technology (Boulder, CO).

Roberto Gómez-García is an Associate Professor in the Department of Signal Theory and Communications at the University of Alcalá, Spain. He is Associate Editor of *IEEE Transactions on Microwave Theory and Techniques*, *IEEE Transactions on Circuits and Systems*, and *IET Microwaves, Antennas and Propagation*.

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NUNO BORGES CARVALHO
University of Aveiro

ALESSANDRO CIDRONALI
University of Florence

ROBERTO GÓMEZ-GARCÍA
University of Alcalá

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Contents

Contributors

Daniel Albuquerque
Departamento de Electrónica Telecomunicações e Informática, Instituto de Telecomunicações, Universidade de Aveiro, Portugal

Nuno Borges Carvalho
Departamento de Electrónica Telecomunicações e Informática, Instituto de Telecomunicações, Universidade de Aveiro, Portugal

Alessandro Cidronali
Dept. Information Engineering, University of Florence, Florence, Italy

Giovanni Collodi
Dept. Information Engineering, University of Florence, Florence, Italy

Pedro Cruz
Departamento de Electrónica Telecomunicações e Informática, Instituto de Telecomunicações, Universidade de Aveiro, Portugal

Erick Emmanuel Djoumessi
Intel Corporation, 600 North U.S. Highway 45, Libertyville, IL 60048, United States

José Angel García
Dept. of Communications Engineering, Universidad de Cantabria (UNICAN), Santander, Spain

Kevin Gard
Analog Devices, USA

Fadhel M. Ghannouchi
University of Calgary, Calgary, Canada

Pere L. Gilabert
Dept. of Signal Theory and Communications, Universitat Politécnica de Catalunya (UPC), Barcelona, Spain

Roberto Gómez-García
Department of Signal Theory and Communications, University of Alcalá, Polytechnic School, 28871 Alcalá de Henares, Madrid, Spain

Abul Hasan
University of Calgary, Calgary, Canada

Mohamed Helaoui
University of Calgary, Calgary, Canada

Stefano Maddio
Dept. Information Engineering, University of Florence, Florence, Italy

José Pedro Magalhães
Departamento de Electrónica Telecomunicações e Informática, Instituto de Telecomunicações, Universidade de Aveiro, Portugal

Gianfranco Manes
Dept. Information Engineering, University of Florence, Florence, Italy

Gabriel Montoro
Dept. of Signal Theory and Communications, Universitat Politécnica de Catalunya (UPC), Barcelona, Spain

António Morgado
Departamento de Electrónica Telecomunicações e Informática, Instituto de Telecomunicações, Universidade de Aveiro, Portugal

José-María Munoz-Ferreras
Department of Signal Theory and Communications, University of Alcalá, Polytechnic School, 28871 Alcalá de Henares, Madrid, Spain

Arnaldo S. R. Oliveira
Departamento de Electrónica Telecomunicações e Informática, Instituto de Telecomunicações, Universidade de Aveiro, Portugal

Manuel Sánchez-Renedo
Department of Signal Theory and Communications, University of Alcalá, Polytechnic School, 28871 Alcalá de Henares, Madrid, Spain

Nelson Silva
Departamento de Electrónica Telecomunicações e Informática, Instituto de Telecomunicações, Universidade de Aveiro, Portugal

José Vieira
Departamento de Electrónica Telecomunicações e Informática, Instituto de Telecomunicações, Universidade de Aveiro, Portugal

Ke Wu
Ecole Polytechnique (University of Montreal), Montreal, Canada

Preface

White space technologies is an area of great interest in the technology, information, and communication field, due mainly to the possibility to have cooperating radios that will optimize the transmission parameters to achieve the best possible performance. This area achieved even greater importance due to the possibility to use frequency bands that are under-utilized, or are used sparsely – one of the cases being the TV band that was empty after the analog-to-digital TV switch over.

White space radios should be agile and adapt to the radio interface with a clear view and optimized operation; that is why special care should be taken with these types of radio and a special design procedure should be followed and discussed. It is exactly in this area that this book fits, by discussing technological implementation details and processes that are fundamental for building cognitive radios that will be the basis of white space devices.

The book is divided into three parts, each one with three chapters. The first part is focused on the general problems we face in white space technology and signal processing. The second part will focus on adaptable receivers for white space devices, and the final part will be focused on adaptable transceivers.

The first chapter of the book "White space technology, the background" will start the discussion of these radios and give some technological views. In this chapter, white space technology will be discussed and the operational details of cognitive radio architectures, how these new radio systems will be able to adapt themselves to the environment, and how they will be able to manage conveniently the data transmission speed with optimum spectrum occupancy, but also energy awareness, will be discussed. A brief explanation of white space technologies, addressing the main hardware limitations of cognitive radio architectures, will be presented. Special attention will also be given to multi-carrier and noncoherent OFDM approaches, and the impact these new kinds of signal could have on front-ends.

The second chapter "Transceiver challenges for white space radio" provides an overview of transceiver challenges and solutions specific to cognitive and software-defined radio. Interference scenarios for white space radio are developed as a model for receiver linearity requirements. Transmitter linearity requirements for white space radio transceivers are reviewed along with the implications for transmitter power efficiency. State-of-the-art architectures and circuit solutions for configurable high dynamic range CMOS integrated transceivers are presented. Specific approaches to high dynamic range receivers that are tolerant of large amplitude off-channel interfering signals are also reviewed.

The third chapter "Front-ends for software-defined radio" will discuss front-ends, inspired by the human cochlea, that could solve dynamic range and bandwidth problems by using a hybrid filter bank to convert the RF signal to the digital domain. The main advantages of this solution will be presented and will demonstrate how digital signal processing machinery could help. A review of spectrum sensing techniques and dynamic spectrum aggregation will be performed, and the operation of the hybrid filter bank will be discussed and how it can have a key role to make these operations effective.

The fourth chapter "Reconfigurable RF front-ends for cognitive and software-defined radio" presents and discusses RF-front-end components designed for cognitive and software-defined radio systems, with emphasis on receiver solutions for high dynamic range and re-configurability. An overview of classical and emerging RF analog front-end receiver architectures such as heterodyne and zero-IF is presented in terms of related advantages and drawbacks per system requirements. The performances of main RF front-end receiver components such as filters, and active and passive tunable mixers, are studied and compared. Different design techniques and technological processes used for the development of tuning elements are also presented with performance comparisons in terms of frequency tuning range, loss, supply voltage, and linearity. The design methodology and implementation of frequency-agile multi-port interferometer techniques made of tunable bandpass filters, diplexers and couplers based on available semiconductor and ferroelectric materials are examined as a potential and cost-effective solution for a reconfigurable direct-conversion receiver platform. Performance comparisons of different tunable receiver architectures are presented and analyzed in this chapter; one structure relying on a tunable bandpass filter, and the other system based on a semiconductor varactor-based tunable passive mixer, with the latter showing better sensitivity and dynamic range. In summary, an integrated circuit level of electronically tunable mixers based on interferometer techniques presents great potential and a cost-effective solution for cognitive and software-defined radio platforms, with particular interest for advanced multi-mode, multi-band wireless transceivers with carrier aggregation capability.

Next, the fifth chapter will discuss filtering strategies, "Filtering stages for white space cognitive/software-defined radio receivers", and presents a description of the necessities of filtering stages for receiver modules in the white space communications scenario. Specifically, two different receiver configurations are studied, with focus on the filtering blocks carrying out the signal selection. The first one is a mixed-domain receiver structure simultaneously exploiting both analog and digital signal processing concepts under the "hybrid filter bank" philosophy. The key principle for the proper operation of this receiver solution is the exhaustive channelization of the incoming desired signal into narrower signal subbands. This must be performed through sophisticated contiguous-band high-order multiplexers at both the RF and IF levels. The second one is a direct-sampling receiver solution for multi-channel communications working at subNyquist rates. The core part of this class of receiver is the multi-band filter that acquires all the signal subbands at the same time, which are subsequently sampled at subNyquist rates. This type of multi-band filter should be designed by means of signal-interference techniques, since classic coupled-resonator networks can exhibit serious deficiencies for this application. For all the filtering devices reported in this chapter, main issues about their theoretical design are detailed. Furthermore, real proof-of-concept prototypes are developed and characterized.

The sixth chapter “Subsampling multi-standard receiver design for cognitive radio systems” will discuss the requirements for a cognitive radio system and how multi-standard requirements come into the picture, conventional receiver architectures and their problems, how a subsampling receiver solves these problems, and gives a description of a subsampling receiver, including its advantages and disadvantages. In this chapter, a close view is given of subsampling receivers and how their impact on white space technology will be fundamental; furthermore, there will also be a discussion on why optimization is required for basic subsampling receiver architecture for the multi-standard case, as well as on the typical requirements that force optimization.

The seventh chapter will be focused on “White spaces exploration using FPGA-based all-digital transmitters” and will discuss the design challenges inherent in flexible RF transmitters for exploring the TV white spaces and the recent advances in FPGA-based multi-mode and multi-channel all-digital transmitters. The chapter starts with an introduction to the design challenges of RF transmitters targeting white space systems followed by a discussion on how all-digital transmitters implemented on FPGA technology will address some important requirements, such as flexibility, integration, and power efficiency. The second part of the chapter is devoted to the presentation and discussion of the operation principles, architectures, and design of all-digital transmitters based on different approaches. The recent techniques for improving important figures of merit, such as bandwidth, in-band and out-of-band noise, filtering requirements, coding and power efficiency are also described and compared. The chapter ends with a discussion on promising future research directions.

The eighth chapter will discuss “Interference active cancelation techniques for agile transceivers” starting with a review of the basic and advanced transceiver architectures suitable for cognitive radios. It first introduces the figures of merit of the transceivers along with the main effects which degrade overall performance. Receiver desensitization due to the combined effects of both interference and the transmitter leakage signal at the receivers is explained by system-level analysis. This impairment makes the design of transceivers for white spaces more challenging than for conventional application and can be solved by either sharp notch filters or dynamic signal cancelation at the receiver input. The latter is covered in detail along with an explanation of the related algorithm. The architectures under consideration largely share the digital IF technique as an effective way to ensure high flexibility with respect to modulation modes and spectra.

Finally the book will end with a thorough analysis of “highly efficient transmitter architectures” and there will be a discussion on the several highly efficient transmitter architectures that have been proposed, and even revived, aimed at enhancing typical Class AB PA efficiency figures in Cartesian transmitters. The chapter addresses state-of-the-art, highly efficient transmitter architectures that are potential candidates to be used in white space scenarios. Hence, architectures such as linear amplification with nonlinear components (LINC), Doherty PAs, polar transmitters with pulsed/delta-sigma modulation, envelope elimination and restoration (EER), and envelope tracking (ET) will be examined in the chapter.

The work to write and finish a book is not exclusively that of the authors, but includes the help and collaboration of many people who somehow cross our paths during this process. So we would like to express our gratitude to many people who directly, or indirectly, helped us to carry on this task.

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Abbreviations

ADC	analog-to-digital converter
AFB	analogue filter bank
AGC	analog gain control
AMI	advanced metering infrastructure
ASIC	application-specific integrated circuit
ASSP	application-specific standard product
BER	bit-error rate
CEPT	European Conference of Postal and Telecommunication Administrations
CIFB	cascade of integrator with distributed feedback
CMOS	complementary metal oxide semiconductor
CMRS	commercial radio service
CR	cognitive radio
CSDR	cognitive and software defined radio
DAC	digital-to-analog converter
DCR	direct conversion receiver
DFB	digital filter bank
DFT	discrete Fourier transform
DPD	digital pre-distortion
DSP	digital signal processor (processing)
DTT	digital terrestrial TV
DTV	digital television
DUC	digital up-conversion
EC	European Commission
ECA	European Common Allocation
ECC	Electronic Communications Committee
EIRP	equivalent isotropic radiated power
ENOB	effective number of bits
ERP	effective radiated power
EVM	error vector magnitude
FCC	Federal Communications Commission
FDD	frequency division duplex
FET	field effect transistor
FIR	finite impulse response

FPGA	field programmable gate array
GPP	general-proposed processors
HAAT	height above average terrain
HAGL	height above ground level
HDTV	high definition TV
HFB	hybrid filter banks
IC	integrated cicuit
IF	intermediate frequency
IFVGA	IF variable gain amplifier
IRR	image rejection ratio
ISM	industrial, scientific, and medical
LCM	low common multiple
LCP	liquid crystal polymer
LNA	low noise amplifier
LO	local oscillator
LP	low pass
LPF	low-pass filter
LSB	lower sideband
LTCC	low-temperature co-fired ceramic
LTE	long-term evolution
MER	modulation error ratio
MVPD	multi-channel video programming distributor
NF	noise figure
NTF	noise transfer function
OFDM	orthogonal frequency-division multiplexing
OMUX	output multiplexer
OSR	oversampling ratio
PA	power amplifier
PAPR	peak-to-average power ratio
PLMRS	private land mobile service
PMSE	programme making and special events
POCS	projections on to convex sets
PQN	pseudo quantization noise
PU	primary user
PWM	pulse width modulation
QAM	quadrature amplitude modulation
QBPS	quadrature bandpass sampling
RAN	radio access network
RF	radio frequency
RFIC	radio frequency integrated circuits
RFID	radio frequency identification
RFVGA	RF variable gain power amplifier
RSC	Radio Spectrum Committee
RSPG	Radio Spectrum Policy Group

SASP	sampled analog signal processor
SAW	surface acoustic wave
SDR	software-defined radio
SFB	synthesis filter bank
SFDR	spurious-free dynamic range
SIW	surface integrated waveguide
SMPA	switched-mode power amplifier
SNR	signal-to-noise ratio
SU	secondary user
SQNR	signal-to-quantization noise ratio
SSB	single sideband
STF	signal transfer function
TDD	time-division duplex
TVBD	TV band devices
TVWS	TV white spaces
USB	upper sideband
VCO	voltage-controlled oscillator
VGA	variable gain amplifier
VNA	vector network analyzer
VSA	vector spectrum analyzer
WCDMA	wideband code division multiple access
WiMAX	Worldwide Interoperability for Microwave Access
WSD	white space device