Introduction to the Special Issue

CHAOS THEORY has been drawing a great deal of attention in the scientific community for almost two decades. Remarkable research efforts have been invested in recent years, trying to export concepts from physics and mathematics into real-world engineering applications.

This Special Issue intends to address the growing role of nonlinear dynamics and chaos theory in modern communication systems. The focus is on those elements and algorithms in the transmitter–receiver chain which exploit properties of nonlinear systems and chaos. Chaotic systems are characterized by sensitive dependence on initial conditions, random-like behavior, and continuous broad-band power spectrum. These properties have emerged in several applications in the communication field. Chaos-based communications systems are now in a mature state of development and several possible schemes have been identified and characterized. A crucial step for the implementation of practical communication systems includes a good bit-error rate (BER) performance for high data rate transmission in the presence of noise and distortion, resistance to multipath propagation, multiuser capabilities, and constraining transmission bandwidth/power spectral density. Recently, in these areas, there has been intense research activity. The aim of this Special Issue is to identify those ideas which might lead to some engineering applications. In particular, in this Special Issue, we tried to emphasize those contributions which in addition to being interesting from the nonlinear dynamical theory/systems points of view, bear explicit relationships to communication theory/systems. While in the early days of research on chaotic communication, arguments that some chaos-based circuits and concepts may have relevancy to communication were perhaps justifiable, chaotic communication has matured in the last decade to the point where these simple arguments are no longer warranted.

The present Special Issue has a broad scope. In what follows, we outline the contents of each manuscript in the context of the topics addressed by this Special Issue.

1) Chaos-Based Modulation Techniques: As of today, several chaos-based modulation techniques have been proposed in the literature. "Chaotic communications over radio channels" by Williams reviews the state-of-the-art of modulation techniques exploiting chaos. In particular, the author discusses critically many aspects of chaos-based communication schemes comparing their performances and taking into account the effects of channel noise and bandwidth limitations. Then, Torres, Oppenheim, and Rosales, in "Generalized frequency modulation" present a generalization of frequency modulation in which state trajectories of dynamical systems are used as carrier waves.

2) Coherent Chaos-Based Communication Systems: The possibility of exploiting the self-synchronizing properties of chaotic systems for communication purposes has attracted the attention of several international researcher over the last decade. In "Stability of inverse-system approaches in coherent chaotic communication," Puebla and Alvarez-Ramirez discuss the stability and the effects of noise and distortion on the performance of the inverse-system approach in coherent chaos-based communication. Moreover, Carroll in "Noise-robust synchronized chaotic communications" demonstrates a self-synchronizing chaos-based communication system in which synchronization occurs even when the signal-to-noise ratio is very low.

3) Noncoherent Chaos-Based Communication Systems: Noncoherent chaotic communications have evolved from elementary schemes such as COOK (chaotic on–off keying) and CSK (chaos-shift keying) to the more sophisticated differential coherent detection of DCSK (differential CSK) and to the modern FM-DCSK (frequency modulation DCSK). In "Quadrature chaos-shift keying: Theory and performance analysis," Galias and Maggio propose an improved version of the DCSK scheme based on the generation of orthogonal chaotic signals and characterized by a doubling of the data rate relative to the conventional scheme.

4) Chaotic Pulse-Position Modulation: In the last few years, there has been a rapidly growing interest toward ultra-wide bandwidth (UWB) impulse radio (IR) communication systems. UWB-IR systems are particularly promising for short-range wireless communications as they combine reduced complexity with low power consumption, low probability of detection/interception, insensitivity to multipath propagation, and multiuser capabilities. In "Pseudo-chaotic time hopping for UWB impulse radio," Maggio, Rulkov, and Reggiani apply concepts from symbolic dynamics to develop an innovative modulation scheme for UWB impulse radio presenting a detailed performance analysis. Also, in "Digital communication using chaotic pulse-position modulation," Rulkov, Sushchik, Tsimring, and Volkovskii, report about some recent results regarding a chaotic self-synchronizing scheme designed for the transmission of binary information.

5) Spread-Spectrum Communications Using Chaos: In recent years, chaos theory has been applied to the design of spread-spectrum sequences to enhance the performance of DS-CDMA (direct sequence code-division multiple access) systems. Mazzini, Rovatti, and Setti in "Chaos-based asynchronous DS-CDMA systems and enhanced Rake receivers: Measuring the improvements" summarize the theoretical development and experimental verification of their chaos-based DS-CDMA method. Significant advantages of the proposed method for frequency-selective and nonfrequency-selective channels are reported.

6) Filtering of Chaotic Signals: Noise filtering of chaotic signals exploiting their determinism has received considerable interest in the context of communication systems. Different techniques have been proposed in the literature depending on the degree of knowledge about the underlying dynamical system. In "Noise reduction for human speech signals by local projections in embedding spaces" Hegger, Kantz, and Matassini

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successfully apply a local projective noise-reduction scheme to human speech by exploiting properties of the speech signal which mimics structure exhibited by deterministic chaotic systems.

7) Nonlinear Circuits for Chaos-Based Communications: The future applicability of chaos-based communication systems depends strongly on the development and hardware implementation of reliable nonlinear circuits for generating and processing the chaotic signals. In particular, it is essential to develop efficient and well controllable chaotic generators. In "Mixed-signal map-configurable integrated chaos generator for chaotic communications," Delgado-Restituto and Rodríguéz-Vázquez present a mixed-signal map configurable chaos generator suitable for silicon integration, discussing the possible error sources and tolerance to the onset of saturation.

8) Optical Communications Exploiting Chaos: Recently, researchers from different groups around the world have been trying to develop optical communication systems exploiting chaos. Liu, Chen, and Tang in "Optical communication systems based on chaos in semiconductor lasers" study both numerically and experimentally the dynamics, synchronization, and message encoding/decoding for optically injected single-mode semiconductor lasers and single-mode semiconductor lasers with delayed optoelectronic feedback. In "Communication using synchronization of optical-feedback-induced chaos in semiconductor lasers," by (Y.) Liu, Chen, (J. M.) Liu, Davis and Aida, the authors present numerical and experimental results for a communication system based on synchronization of gigahertz chaotic signals generated in a single-mode semiconductor laser with external ring optical feedback. Davis, Liu and Aida in "Chaotic wavelength-hopping device for multiwavelength optical communications" propose a laser device, wavelength tunable laser with optoelectric feedback, which generates wavelength hopping sequences useful for optical communications. Finally, Garcia-Ojalvo and Roy in "Parallel communication with optical spatiotemporal chaos" explore the potential of chaotic optical waveforms as information carriers in parallel communication systems.

9) Chaos and Cryptography: The highly unpredictable and random-look nature of chaotic signals is the most attractive feature of deterministic chaotic systems that may lead to novel engineering applications. Chaos and cryptography have some common features, the most prominent being sensitivity to variables' and parameters' changes. An important difference between chaos and cryptography lies on the fact that systems used in chaos are defined on real numbers only, while cryptography deals with systems defined on finite number of integers. In "Chaos and cryptography" Dachselt and Schwartz review their results about the conjunction of chaos and cryptography.

In conclusion, the editors would like to express their thanks to all the people who contributed to the success of this project: the Board of Governors of the IEEE Circuits and Systems Society for giving their blessing to this initiative; the researchers who submitted their papers to our consideration; the many diligent reviewers whose thoughtful evaluation were so important during the difficult paper selection process; and, most importantly, the authors of the outstanding articles that have been assembled in this Special Issue. It has been a privilege to work with all, and we hope that you, the reader, will enjoy reading this Special Issue.

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Dr. Ogorzałek has organized numerous special sessions on nonlinear dynamics, chaos and applications (ISCAS; SPIE Photonics East; ECCTD, NOLTA, NDES, MIXDES). He is author or co-author of over 180 technical papers published in journals and conference proceedings, author of the book "Chaos and complexity in nonlinear electronic circuits" (World Scientific: Singapore, 1997). He is a Member of The Association of Polish Electrical Engineers, Polish Society of Theoretical and Applied Electrical Sciences, Member of the Committee on Electrical Engineering, Computer Science and Automatic Control of the Polish Academy of Sciences, Krakow Section, Member of the Section of Electronic Signal and Systems, Committee on Electronics and Telecommunication of the Polish Academy of Sciences. He served as an Associate Editor for IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS I (1993–1995 and 1999–2001); as an Associate Editor for the *Journal of The Franklin Institute* (1997–1999), as Secretary of the Editorial Board for the *Quarterly of Electrical Engineering* (in Polish—Elektrotechnika) (since1993), Member of the Editorial Board of Automatics (in Polish Automatyka). He is currently the Vice-President of the Executive Board of Sniadecki Science Foundation. Dr. Ogorzałek has been Vice-Chairman CAS Chapter Poland, recipient of the Chapter of the Year Award 1995, Chairman of the Technical Committee of Nonlinear Circuits and Systems of CAS Society (1997–1998), Chairman of the Organizing Committee 1994 Workshop on Nonlinear Dynamics of Electronic Systems, member of technical committees of several IEEE sponsored conferences, Special Sessions chairman for ISCAS'2000, and recipient of the IEEE-CAS Golden Jubilee Award.

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In 1977, he was awarded a National Research Council postdoctoral fellowship at the Naval Research Laboratory (NRL), Washington, DC, where he worked on applications of positron annihilation techniques in determining electronic states in copper alloys. This led to a permanent position at NRL in 1979, with continuation of the positron work into areas of reconstruction of momentum densities using novel tomographic techniques in collaboration with the international group at the University of Geneva, Geneva, Switzerland. He is currently a Research Physicist at the NRL, where he heads the recently-formed programs for Nonlinear Dynamics in Solid-State Physics and Nonlinear Dynamics of Coupled Systems in the Materials Physics branch. Since the mid-1980's Dr. Pecora has been working in the field of nonlinear dynamics in solid-state systems. Early work led to the discovery and characterization of chaotic transients in spin-wave behavior in yttrium iron garnets. More recent work has focused on the applications of chaotic behavior, especially the effects of driving systems with chaotic signals. This has resulted in the discovery of synchronization of chaotic systems, control and tracking, and dynamics of many coupled, nonlinear systems.

Dr. Pecora has published over 100 scientific papers and has five patents for the applications of chaos.

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