Nonlinear Dynamics and Systems Theory, **5**(4) (2005) 315–322

PERSONAGE IN SCIENCE

Professor Anthony N. Michel

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1 Education and Career Overview Anthony N. Michel received a B.S. degree in electrical engineering, an M.S. degree in mathematics, and a Ph.D. degree in electrical engineering, all from Marquette University, Milwaukee, WI, in 1958, 1964, and 1968, respectively. He also received a D.Sc. degree in applied mathematics from Technical University of Graz, Austria, in 1973.

Anthony N. Michel has seven years of industrial experience (one year with the U.S. Army, Corps of Engineers, and six years with AC Electronics, a Division of General Motors, both in Milwaukee). From 1968 to 1984 he was on the Electrical Engineering Faculty at Iowa State University, Ames, IA, where he was promoted from an Assistant Professor to an Associate Professor in 1969 and to a Full Professor in 1974. In 1972–1973, while on a sabbatical leave, he worked under the supervision of Professor Wolfgang Hahn at Technical University of Graz, Austria, on his D.Sc. degree in Applied Mathematics. In 1984 he joined the faculty of Electrical Engineering at the University of Notre Dame as Professor and the Department Chair. He served as Chair until 1988. In 1987 he was named Frank M. Freimann Professor of Engineering, and in 1988, he was appointed Matthew H. McCloskey Dean of Engineering. He served two terms as the Dean of the College of Engineering, from 1988 to 1998. From 1998 to December 31, 2002, he was Frank M. Freimann Professor in the Department of Electrical Engineering. Since January 1, 2003, he is Frank M. Freimann Professor of Engineering Emeritus and Matthew H. McCloskey Dean of Engineering Emeritus. He has also held visiting faculty positions at the Technical University of Vienna, Austria (1992), the Ruhr University in Bochum, Germany (1999), and the Johannes Kepler University in Linz, Austria (2004).

2 Research and Scholarly Activities In his distinguished career spanning over forty years, Anthony N. Michel has made seminal contributions in the qualitative analysis of dynamical systems, with an emphasis on stability theory. Specific areas in which he has contributed include finite-time and practical stability, Lyapunov stability of interconnected (resp., large-scale) dynamical systems, input-output properties of interconnected (resp., large-scale) systems, artificial neural networks with applications to associative memories, robust stability analysis, stability preserving mapping theory, and stability

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theory of hybrid and discontinuous dynamical systems. Throughout, he has demonstrated the significance of his work with specific applications to signal processing, power systems, artificial neural networks, digital control systems, systems with state saturation constraints, and other areas.

On the topic of *finite-time* and *practical stability*, in contrast to other workers, Michel utilizes *prespecified time-varying sets* in formulating a notion of *set stability*. His Lyapunov-like results for set stability yield estimates for system trajectory behavior, obtained from the boundaries of prespecified sets [9, 10]. As a radical departure from the existing practices, this approach was subsequently adopted and extended by others.

To circumvent difficulties encountered in the analysis of *large-scale systems* with complex structure, Michel views such systems as interconnections of several simpler subsystems. The analysis is then accomplished in terms of the qualitative properties of the subsystems and the interconnecting structure. Michel advocates the use of *scalar Lyapunov functions* [1, 11, 13, 15, 20, 21] consisting of weighted sums of Lyapunov functions for the free subsystems. This approach has resulted in *significantly less conservative results* than the weak-coupling M-matrix results obtained by others who employ vector Lyapunov functions. These results in turn are applied by Michel in the *analysis and synthesis of artificial neural networks* [8, 23], and he also uses them as the basis of further results involving *computer generated norm-Lyapunov functions* which then are applied successfully in the analysis of *interconnected power systems* and *digital filters* [20]. The theory developed in this work is applicable to continuous-time and discrete-time systems, finite-dimensional and infinite-dimensional systems, and deterministic and stochastic systems [1].

Using the same philosophy as in [1, 11, 13, 15, 20, 21], Michel discovered the *first results* for the *input-output stability of interconnected systems* [12], which subsequently were expanded by many into all kinds of directions [1, 14, 16]. These results make possible the systematic analysis of *multi-loop nonlinear feedback systems* (consisting of interconnections of subsystems that satisfy, e.g., the *small gain theorem*, the *circle criterion*, the *passivity theorem*, or *Popov-like conditions*). In the same spirit, Michel established also results for the *response* (*due to periodic inputs*) *of nonlinear single-loop and multi-loop feedback systems* [17, 18], and results for the *existence*, *nonexistence*, *and stability of limit cycles* for such systems [1, 19, 22]. The proofs of the above results are rather technical and require extensive use of functional analysis results and fixed-point theorems in abstract spaces.

For his work on qualitative analysis of interconnected systems, Michel has received substantial recognition. In response to an invitation by Professor Richard Bellman, Michel co-authored with R.K. Miller the book on *qualitative analysis of large-scale dynamical systems* [1], which appeared in the Bellman Series in Mathematics in Science and Engineering (Academic Press). This book is widely referred to and has had an impact on other areas of large-scale systems (e.g., *power systems*).

Michel has also conducted extensive research in *artificial neural networks* with applications to *associative memories* [8, 23, 24, 30, 31, 35, 36]. This work, which addresses *network architectures*, *qualitative analysis*, *synthesis procedures*, and *implementation issues for several classes of continuous and discrete recurrent neural networks*, is widely referred to and one of their paradigms [24], "LSSM-linear systems in a saturated mode," has been used in the *software tool MATLAB*.

Michel has contributed significantly to robust stability analysis, most notably, for systems with *interval matrices* and *perturbed systems with perturbed equilibria*. He has established several (*Hurwitz* and *Schur*) *stability*, *controllability*, and *observability results*

for linear systems with *interval plants* [27, 33, 34], while for nonlinear systems, he addresses the effects of *parameter perturbations* on the locations (and even existence) of equilibria, along with their *stability properties*, using fixed point theorems and the notion of "*extreme systems*" [28, 32, 37]. The work in [33] was *the first to provide necessary and sufficient conditions for the Hurwitz and Schur stability of interval matrices with a practical computer algorithm*. Michel has further extended the results in [28] to the *robust stability analysis of recurrent neural networks* [8, 30, 36, 37].

Michel has conducted fundamental research in qualitative analysis of dynamical systems using stability preserving mappings. He utilizes *stability preserving mappings* to develop a comparison theory for Lyapunov and Lagrange stability of *general dynamical systems* defined on metric space [5, 44], applicable to systems determined by all types of classical equations encountered in science, as well as to contemporary systems that cannot be described in this way (e.g., *discrete event systems* [29]). Some of this work has been published in Russian (in *Avtomatika i Telemekhanika*) and in a highly original book [5] (co-authored with K. Wang), where the entire Lyapunov and Lagrange stability theory is developed for general dynamical systems, making use of stability preserving mappings.

Michel's more recent research addresses *stability analysis of hybrid and discontinuous dynamical systems*. For such systems, he formulates a *general model* suitable for stability analysis (involving a notion of *generalized time*), which contains most of the hybrid and discontinuous systems considered in the literature as special cases. For this model, he establishes the *Principal Lyapunov and Lagrange stability results*, including *Converse Theorems* [7, 39, 42, 43, 45] and he applies these results in the analysis of several special classes of systems, including *switched systems* [7], *digital control systems* [7, 38], *impulsive systems* [7, 41], *pulse-width-modulated feedback control systems* [7, 46], *systems with saturation constraints* [4, 7, 25, 26, 40], and others.

Currently, Michel is working on *stability issues of infinite dimensional discontinuous dynamical systems*. In particular, he is concerned with discontinuous systems determined by *differential equations in Banach space* and by *linear and nonlinear semigroups*. Specific classes of systems that are considered in this work are those that can be described by *functional differential equations*, *Volterra integro-differential equations*, *certain classes of partial differential equations*, and others [47, 48].

Michel has played a significant role as an *educator*. His eight books [1– 8] which have been well received in the systems and control community around the world, and in many instances have blazed new trails when first introduced, demonstrate his contributions as a teacher. Furthermore, his record of maintaining a highly productive research program while simultaneously serving as an effective *administrator* at Notre Dame, first as *Department Chair* (1984–1988) and then as *Dean* (1988–1998), puts him in rare company. Michel has served as *mentor* to *many outstanding graduate students*. Equal numbers of these are in *academe* and in *industry*, attesting to the fine balance Michel maintains in his research program between theory and practice. These former students have all outstanding careers. (For example, one of them was the Dean of Engineering at Washington State University.)

Anthony N. Michel has sustained a high level of significant research, mostly in control systems. His work is characterized by great depth, as exemplified by his contributions to stability theory of dynamical systems, and by great breadth, as demonstrated by the wide range of problems that he addresses. He has proved to be an excellent teacher and mentor, he has demonstrated to be an effective administrator, and he has rendered more than his share of service to his profession.

3 Service to the Profession Anthony N. Michel served as an Associate Editor of the IEEE Transactions on Circuits and Systems from 1977 to 1979, the Editor of the IEEE Transactions on Circuits and Systems from 1981 to 1983, and the President of the IEEE Circuits and Systems Society in 1989. He also served as an Associate Editor of the IEEE Transactions on Automatic Control in 1981 and 1982, an Associate Editor at Large of the IEEE Transactions on Automatic Control from 1991 to 2000, the Vice President of Technical Affairs (1994, 1995) and the Vice President of Conference Activities (1996, 1997) of the IEEE Control Systems Society. In addition, he served as an Associate Editor of IEEE Transactions on Neural Networks from 1989 to 1991. He currently serves as the Associate Editor for Book Reviews of IEEE Transactions on Automatic Control. He was Program Chair of the 1985 IEEE Conference on Decision and Control, Co-General Chair of the 1990 IEEE Symposium on Circuits and Systems, and General Chair of the 1997 IEEE Conference on Decision and Control.

4 Student Supervision Anthony N. Michel guided the work of 13 Ph.D. students at Iowa State University and 12 Ph.D. students at the University of Notre Dame. He also supervised 10 Master's degree students.

List of Doctoral Dissertations Supervised

(1) Cornick, D.E. *Numerical Optimization of Distributed Parameter Systems by Gradient Methods.* Ph.D. Dissertation, Iowa State University, 1970.
(2) Porter, D.W. *Stability of Multiple-Loop Nonlinear Time-Varying Systems.* Ph.D. Dissertation, Iowa State University, 1972.
(3) Bose, A.B. *Stability and Compensation of Systems with Multiple Nonlinearities.* Ph.D. Dissertation, Iowa State University, 1974.
(4) Oppenheimer, E.P.*Application of Interval Analysis to Problems of Linear Control Systems.* Ph.D. Dissertation, Iowa State University, 1974.
(5) Lasley, E.L. *The Qualitative Analysis of Composite Systems.* Ph.D. Dissertation, Iowa State University, 1975.
(6) Rasmussen, R.D. *Lyapunov Stability of Large-Scale Dynamical Systems.* Ph.D. Dissertation, Iowa State University, 1976.
(7) Vitacco, W.R. *Qualitative Analysis of Interconnected Dynamical Systems Containing Algebraic Loops.* Ph.D. Dissertation, Iowa State University, 1976.
(8) Gutmann, R.L. *Input-Output Stability of Interconnected Stochastic Systems.* Ph.D. Dissertation, Iowa State University, 1976.
(9) Tang, W. *Structure and Stability Analysis of Large Scale Systems using a New Graph-Theoretic Approach.* Ph.D. Dissertation, Iowa State University, 1978.
(10) Peterson, J.N. *Wind Generator Network Methodology and Analysis.* Ph.D. Dissertation, Iowa State University, 1980.
(11) Sarabudla, N.R. *Stability Analysis of Complex Dynamical Systems: Some Computational Methods.* Ph.D. Dissertation, Iowa State University, 1981.
(12) Nam, B.H. *Asymptotic Stability of Large-Scale Dynamical Systems using Computer Generated Lyapunov Functions.* Ph.D. Dissertation, Iowa State University, 1983.
(13) Erickson, K.T. *Stability Analysis of Fixed-Point Digital Filters using a Constructive Algorithm.* Ph.D. Dissertation, Iowa State University, 1983.
(14) Li, J.-H. *Qualitative Analysis and Synthesis of a Class of Neural Networks.* Ph.D. Dissertation, University of Notre Dame, 1988.
(15) Farrell, J.A. *Analysis and Synthesis Techniques for Two Classes of Nonlinear Dynamical Systems: Digital Controllers and Neural Networks.* Ph.D. Dissertation, University of Notre Dame, 1989.

(16) Sun, H.-F. *Two Problems in Finite Dimensional Dynamical Systems: Qualitative Analysis and Synthesis of a Class of Neural Networks and Linear Systems Subject to Parameter Variations.* Ph.D. Dissertation, University of Notre Dame, 1990.
(17) Gray, D.L. *New Paradigms for Feedforward and Feedback Artificial Neural Networks.* Ph.D. Dissertation, University of Notre Dame, 1990.
(18) Si, J. *Analysis and Synthesis of Discrete-Time Recurrent Neural Networks with High Order Nonlinearities.* Ph.D. Dissertation, University of Notre Dame, 1991.
(19) Yen, G. *Learning, Forgetting, and Unlearning in Associative Memories: The Eigenstructure Method and the Pseudo Inverse Method with Stability Constraints.* Ph.D. Dissertation, University of Notre Dame, 1991.
(20) Kuo, C.-H. *Robust Control Strategies for a Class of Large Scale Dynamical Systems: Contaminated Groundwater Remediation.* Ph.D. Dissertation, University of Notre Dame, 1993.
(21) Liu, D. *Qualitative Theory of Dynamical Systems with Saturation Nonlinearities.* Ph.D. Dissertation, University of Notre Dame, 1993.
(22) Ye, H. *Stability Analysis of Two Classes of Dynamical Systems: General Hybrid Systems and Neural Networks with Delays.* Ph.D. Dissertation, University of Notre Dame, 1996.
(23) Hu, B. *Qualitative Analysis of Hybrid Dynamical Systems.* Ph.D. Dissertation, University of Notre Dame, 1999.
(24) Hou, L. *Qualitative Analysis of Discontinuous Deterministic and Stochastic Dynamical Systems.* Ph.D. Dissertation, University of Notre Dame, 2000.
(25) Y. Sun, *Stability Analysis of Discontinuous Dynamical Systems.* Ph.D. Dissertation, University of Notre Dame, 2004.

5 Awards Anthony N. Michel received numerous awards in his career including the 1978 Best Transactions Paper Award of the IEEE Control Systems Society (currently called the Axelby Award) (with R.D. Rasmussen), the 1984 Guillemin-Cauer Prize Paper Award of the IEEE Circuits and Systems Society (with R. K. Miller and B.H. Nam), the 1985 Engineering Distinguished Professional Achievement Award of Marquette University, the 1993 Myril B. Reed Outstanding Paper Award of the IEEE Circuits and Systems Society (with K. Wang), the 1995 Technical Achievement Award of the IEEE Circuits and Systems Society, the 1997 Alexander von Humboldt Research Award (for Senior U.S. Scientists) from the Federal Republic of Germany, the 1998 Distinguished Member Award of the IEEE Control Systems Society, and the 2005 Distinguished Alumnus Award of Marquette University. He received an IEEE Centennial Medal in 1984, the Golden Jubilee Medal of the IEEE Circuits and Systems Society in 1999, and an IEEE Third Millennium Medal in 2000. He was a Fulbright Scholar in 1992 at the Technical University of Vienna in Austria and a Distinguished Lecturer of the IEEE Circuits and Systems Society from 1995 to 1997. He was elected Fellow of the IEEE in 1982 for contributions in the qualitative analysis of large-scale dynamic systems, and he was elected a Corresponding Member of the Russian Academy of Engineering in 1992 for contributions in qualitative analysis of dynamical systems using stability preserving mappings.

6 References Anthony N. Michel has published eight books, 30 chapters in books, 174 journal papers, and 262 conference papers. His work has been cited more than 1500 times (since 1976) in the Science Citation Index.

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[2] Michel, A.N. and Herget, C.J. *Mathematical Foundations in Engineering and Science: Algebra and Analysis.* Prentice-Hall, Englewood Cliffs, NJ, 1981. (Republished after

going out of print as *Applied Algebra and Functional Analysis*. Dover Publications, New York, 1993.)

[3] Miller, R.K. and Michel, A.N. *Ordinary Differential Equations*. Academic Press, New York, 1982.

[4] Liu, D. and Michel, A.N. *Dynamical Systems with Saturation Nonlinearities: Analysis and Design*. Lecture Notes in Control and Information Sciences, Vol. 195, Springer-Verlag, Berlin, 1994.

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