Editorial Preface to Special Issue on Multidimensional Signals and Systems

I. INTRODUCTION

THE theory and practice of multidimensional (m-D) systems grew and flourished during the last two to three decades, largely under the auspices of the IEEE Circuits and Systems (CAS) Society. We have witnessed several edited and authored books, and special issues of IEEE publications during this period. Notable among the latter are two special issues of the Proceedings of IEEE, first in 1977, and then again in 1991, edited by N. K. Bose. It is fair to say, however, that at present, activities in this area within the framework of the IEEE CAS Society are at a low ebb. While other IEEE Societies have long since formalized technical activities on m-D signal processing, the main focus of which have been to foster and promote applications related to image processing, system-theoretic aspects of the subject have been largely ignored. Paradoxically however, during the last decade, there have been many system-theoretic developments in the area, from which the more signal-processing oriented researchers have been benefiting. An example of this phenomenon, that one of us can cite more on the basis of personal experience (but by no means the only one), is the theory and design of m-D filter banks and wavelets, in which several ideas germane to system theory, played critical roles. It is possible to cite many other developments in the m-D systems area, which legitimately fall within the scope of the interests of the IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS (TCAS), and are traditionally not addressed by other relevant IEEE publications either. One of the aims of this Special Issue has been to close this gap. Hopefully, the coming years will see a resurgence of activity in this area within the scope of the this transaction as well.

II. WHAT IS NEW IN m-D SIGNAL AND SYSTEM THEORY?

The field of m-D signals and systems has indeed undergone a steady growth over the last decade. Many new developments, theoretical as well as those motivated by applications, have taken place during this period. Such developments include modeling of linear and nonlinear passive dynamical systems by following principles of m-D filter theory. Examples are simulations of electromagnetic and acoustic-wave propagation, practical applications in music synthesis, nonlinear physical phenomena such as solitons, attempts to model equations of various forms of fluid flow including the Navier-Stokes equation (groups in Bochum, Erlangen, Thesaloniki, Notre Dame, and Warwick). New and broader formulations of the general theory of m-D systems have arisen under the banner of behavioral theory of m-D systems (originated in the work of Jan Willems at Groeningen, and subsequently expanded by several others). These have replaced, in a unified form, the various state-space descriptions of m-D systems that existed in the literature of the previous decades (groups in Groeningen, Southampton, and Linz). This development has not only provided a natural framework for the study of m-D systems, but has also enabled contacts with other areas and applications. A potentially important development is error-correcting codes for storage and transmission of m-D data via extension of convolutional codes to multidimensions (groups in Toronto, Ottawa, and at IBM). As this introductory preface is being written, one of us became aware of recent work on two-dimensional (2-D) channel coding by Richard Blahut, at the University of Illinois, Chicago, that establishes a connection between m-D versions of run-length codes and Eising models in condensed-matter physics, m-D generalizations of the Vitterbi algorithm and several other generalizations motivated by evolving needs in communications theory. The theory of repetitive processes with learning-control applications has been viewed and formulated as the theory of 2-D dynamical systems. Applications of this theory to the control of robot manipulators, flexible structures, and large machinery are being worked on at present by groups at Columbia University, and Dartmouth, and groups located in Sheffield, Southampton, and Zielona Gora. New and important modifications in the theory of robust m-D systems have been made recently by V. L. Kharitonov in Mexico City. The wavelets and filter-bank theory provided a new impetus for m-D filter-design techniques again. While new algebraic problems have been posed from this study, symbolic techniques e.g., Groebner-basis computations have the potential for facilitating investigations in this field (groups at Bell-Labs, Philips Research, Penn State. Southampton, and Nanyang Technological Unversity, Singapore). More on the signal-processing side, novel applications such as modeling of wireless traffic as spatial-temporal stochastic processes, including point processes, are currently being considered in modern communications engineering. Moreover, m-D filtering techniques are routinely used by researchers and practitioners in computer graphics and animation industry for rendering three-dimensional (3-D) objects. The exponential growth of available computational power has opened up possibilities of applications of m-D signals and systems theory in a wider range of practical areas which were not previously feasible. In the above discussion, we have not even touched upon the large amount of ongoing work in the area of image/video processing in the research community.

Needless to say that each of the above-mentioned topics legitimately falls within the purview of the circuits and systems theory in a broad sense. The apparent slowdown in responding to the needs of the community in m-D systems is manifested by the papers published in the IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS (both PARTS I and II), which now have far fewer

Publisher Item Identifier S 1057-7122(02)05590-3.

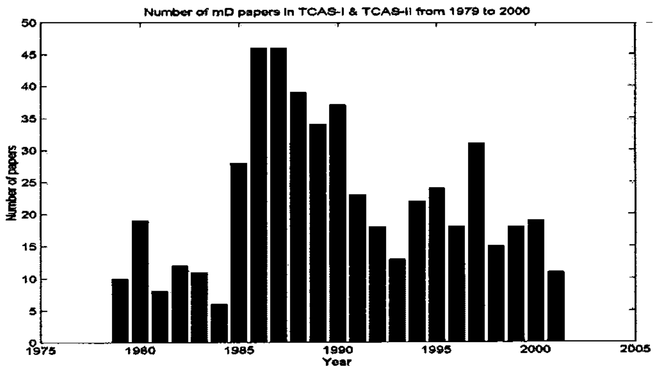


Fig. 1. Statistics of the number of papers appearing in the TCAS in m-D signals and systems area.

papers on the topic than, say, ten or fifteen years ago (Fig. 1), and was even reflected in the composition of the Editorial Board for a number of years in the mid-Nineties.

III. Is There Enough Work in m-D Systems?

Despite this, however, the subject continues to grow heavily. As an evidence of this, the *Journal of Multidimensional Signals and Systems*, is exclusively dedicated to the topic, appears quarterly, and during the last ten years, has established itself as an international journal. In addition to a slew of high-quality papers, it regularly publishes special issues of topical interest. During recent years, the European community has witnessed a resurgence of activity in the m-D systems area, manifested in several conferences and workshops. These include the First International Workshop on n-D Systems (NDS) (Lagow, Poland, July 1998), the Institute for Electrical Engineer Colloquium on Multidimensional Signals and Systems (London, U.K., January 1998), the Second International Workshop on NDS (Czocha Castle, Poland, 2002), and nearly half a dozen special sessions on m-D systems at the Mathematical Theory of Networks and Systems in 1998 and 2000. In addition, the bi-annual IEEE Multidimensional Signal Processing Workshop was also held (Alpbach, Austria, July 1998).

We believe that the IEEE Transactions on Circuits and Systems, in view of its system-theoretic tradition, should take a leading role in patronizing this area of activity among scientists, engineers, and researchers. In order to remedy the situation, special sessions on m-D signals and systems were organized at ISCAS'99 (Orlando, FL), ISCAS'00 (Geneva, Switzerland), and ISCAS'01 (Sydney, Australia). Several of the authors represented in this Special Issue had preliminary versions of their works presented at these meetings.

This Special Issue was proposed given this backdrop of events. Original research as well as tutorial papers involving spatial and spatial-temporal processes were solicited for the Special Issue in the general area of m-D signals and systems. Both signal-processing and system-theoretic papers were to be entertained. Unification of these two somewhat disparate areas was one of the goals of this Special Issue. Given the somewhat theoretical and esoteric nature of the systems aspects of the field, the response to the call for papers was highly encouraging. We received a multitude of very high-quality submissions from truly leading experts in the field. Several other such submissions that were originally promised did not materialize in the end due to lack of time. This resulted in unexpected gaps in the intended coverage of the special issue. For example, important areas such as random fields, applications in computer graphics, etc., remain untouched.

IV. What Is in This Special Issue?

The papers appearing in this Special Issue can be broadly categorized into several sub-areas. While this categorization is somewhat arbitrary and may depend on the taste of the audience, it nevertheless provides a way of introducing to the reader, the contents of the Special Issue. As mentioned elsewhere in this Editorial, we once again alert the reader that neither these categories nor the topics addressed in the Special Issue are by any means exhaustive of all of m-D signals and systems theory and practice. We are aware that there also exist, several other topics which could not be addressed due to constraints of various kinds. In what follows, we make an attempt to introduce the reader to the general area to which each paper belongs, with an exposition of a very brief background against which the reported work should be viewed.

V. Stability and Robustness

Characterization and tests for stability have been studied almost from the beginning of the m-D systems theory. Over the last 20 years or so, the work of V. L. Kharitnov has resulted in a flurry of activity in the domain of robust stability and robust-system theory in general. His extremely surprising result that stability of only a set of four extreme polynomials completely characterizes the stability of an entire family of real polynomials of arbitrary degree whose coefficients are allowed to vary in finite intervals, is largely responsible for an explosion of work in this field. This development had touched upon m-D systems theory as well. While in previous works it had been shown that a variety of different degrees of strictness of stability (e.g., strict-sense Hurwitz, scattering Hurwitz) of multivariate polynomials became relevant in the study of m-D systems, a proper extension of the Kharitonov-like robustness results requires an even stricter class of multivariate stable polynomials. Readers will be delighted to find that V. L. Kharitonov—the progenitor of this field of research—together with J. A. Torres Muñoz undertakes a tutorial review of their recent results on this topic in the paper entitled, *"Recent Results on the Robust Stability of Multivariate Polynomials"*.

The paper by Anton Kummert, *"2-D Stable Polynomials With Parameter-Dependent Coefficients: Generalizations and New Results,"* addresses the problem of stability by appealing to the fact that, loosely speaking in 2-D, every stable polynomial (stable in an appropriate technical sense) can be associated with a synthesizable bivariate lossless linear shift invariant network. Study of stability then becomes, inter alia, a study of parameters of the associated network. Interestingly, it has been argued that robustness of stability could alternatively be approached in this framework as well. *"A New Method for Computing the Stability Margin of Two-Dimensional Continuous Systems,"* by Nikos E. Mastorakis and M. N. S. Swamy presents a method of estimation of the stability margin for 2-D linear continuous-time systems based on the computation of the resultant of a Hermite matrix associated with the system, and its partial derivatives with respect to the frequency parameter.

VI. General m-D System Theory

The first paper in this sub-area, *"On Homomorphisms of n-D Behaviors,"* by Harish Pillai, Jeff Wood, and Eric Rogers is largely of theoretical nature, and can be classified into what is traditionally known as the mathematical system theory. The object of study is the so called system "behaviors" in the sense introduced by Willems. Behavioral description, as opposed to input-output description, pertains to viewing systems as sets with allowable trajectories in the signal space. This way of viewing systems has led to several generalizations and has opened up ways of using system-theoretic notions for problems that were not possible before (see references at the end of the article by Pillai *et al.*). The specific problem studied in the paper by Pillai *et al.* is the extension of the notion of "strict-system equivalence" from one-dimensional (1-D) system theory to the m-D behavioral setting. This is achieved by identifying sets of behaviors that are not identical but have the same structure in a precise mathematical sense. In particular, they are algebraically equivalent (isomorphic). Tools such as zero coprimeness of polynomial matrices, and associated Bezout identities play an important role here. A tutorial contribution of this paper could be the matrix theoretic interpretations of earlier results from abstract mathematical literature to the more familiar systems setting.

The next paper by Kazuyoshi Mori, *"Parameterization of Stabilizing Controllers Over Commutative Rings With Application to Multidimensional Systems,"* addresses an open problem of parameterization of all stabilizing controllers in a plant in the comprehensive setting of systems over rings. The main result of the paper is a parameterization of all closed-loop transfer matrices from which a parameterization of all stabilizing controllers are obtained. A coordinate-free approach to alternatives of well-known Youla parameterization is used.

VII. Linear Repetitive Processes

Discrete linear repetitive processes are a distinct class of 2-D linear systems with applications in areas ranging from long-wall coal cutting to iterative learning control schemes. The feature, which makes them distinct from other classes of 2-D linear systems, is that the information propagation in one of the two distinct directions only occurs over a finite duration. This, in turn, means that a distinct system theory must be developed for them.

Applications in robotic control have provided much impetus for developments in iterated learning control (ILC) for which finite time tracking command is applied repeatedly. The paper by Haluk Elci, Richard Longman, Minh Q. Phan, J. N. Juang, Jer-Nan Phan, and Roberto Ugoletti entitled *"Simple Learning Control Made Ppractical by Zero-Phase Filtering: Applications to Robotics,"* elucidates their experience in using ILC in the senior author's robotics laboratory at Columbia University and explores connections with the 2-D systems theory. It must be noted that the linear iterative controls form a special kind of 2-D process which is of finite time duration in one dimension with no dynamics in the second dimension.

The main contribution of the paper, *"LMIs—A Fundamental Tool in Analysis and Controller Design of Discrete Linear Repetitive Processes,"* by K. Galkowski, Eric Rogers, S. Xu, J. Lam, and D. H. Owens, is in handling "repetitive processes" defined in a very general sense, with the emphasis on creating methods for processes more general than the iterated learning control problem per se. A novel theoretical treatment via the use of linear-matrix inequalities (LMI) is shown to offer promise as a method of addressing these general problems, providing methods for stability analysis and determining stability margins, design methods, and robustness methods.

The technical brief, *"Two-dimensional Analysis of an Iterative Nonlinear Optimal Control Algorithm,"* by Peter D. Roberts provides an innovative use for the stability theory of linear repetitive processes in the area of solution of nonlinear optimal control problems, based on the maximum principle. It is shown that the 2-D systems theory can be potentially applied to analyze the properties of iterative procedures for solving problems of analyzing optimality, local stability and global convergence behavior of a particular ILC method known as the DISOPE.

VIII. m-D Error-Correction Code

Multidimensional (m-D) error-correction codes have recently come into fore due to more than one practical reason. The most obvious one is the need for error correction in transmission of image and video signals over noisy channels. Still another application is precipitated by the newer technologies in large-scale (disc) storage devices in which surface-storage of data is mandated rather than storing data in linear 1-D tracks. On the theoretical side, Willems' behavioral framework for studying system theory mentioned above has contributed much to the development of 1-D error-correcting codes. Turbo-codes on the other hand have revolutionized the1-D coding techniques by nearly achieving the theoretical Shannon limit (capacity) of the channel. Use of these techniques in more than one dimension is just beginning to be seen. The paper by Yun Q. Shi and X. M. Zhang, *"A New Two-Dimensional Interleaving Technique Using Successive Packing,"* is only a tip of the iceberg, and attempts to address the issue of 2-D burst error correction via new interleaving schemes. It is expected that in the future, we will see more developments in the context of what might be called a new 2-D information theory in the making.

IX. Applications to Image Processing

Image processing has been the breeding ground for developments in m-D signal processing for many years. Our coverage for this subfield is indeed narrowly focussed. Murat Meşe and P. P. Vaidyanathan undertake an exposition of digital halftoning and inverse halftoning in an article having largely tutorial flavor. 2-D frequency filtering has a role to play in halftoning techniques, albeit in a somewhat subdued fashion. Their article, *"Recent Advances in Digital Halftoning and Inverse Halftoning*

Methods," will go a long way toward familiarizing the uninitiated in this field via its extensive references and insightful discussions. Super-resolution image reconstruction from low-resolution images is the topic discussed in the paper entitled *"Analysis of Displacement Errors in High-Resolution Image Reconstruction With Multisensors,"* by Michael K. Ng and N. K.Bose. Here, one seeks improvement in the signal-to-noise ratio beyond the performance bound of technologies that constrain the manufacture of imaging devices. The need for such reconstruction techniques has been felt in wide-ranging applications beginning from medical imagery to surveillance and astronomy.

X. m-D Filter Design

Whereas geophysical exploration and image enhancement have been the prime mover of m-D filter design theory in the past, the application domain of interest is known to dictate the geometry of the pass/stop band in m-D filter design. For example, it is well known that fan–shaped filters are needed in geophysical explorations, rotation invariance in imaging application requires spherically symmetric filter responses and notch filters are needed in yet other applications. Newer applications still continue to emerge—a recent one being the use of fan type filters in plenoptic sampling and rendering of 3-D graphics. Voluminous literature exists on filter-design techniques. At the same time, with the advent of new computational techniques and availability of ever more powerful computing devices, further sophistications in optimization algorithms for approximating specified frequency behaviors have surfaced.

The paper by W. S. Lu entitled *"A Unified Approach for the Design of 2-D Digital Filters via Semidefinite Programming,"* explores one such technique. Efficient interior point methods are used to solve a class of semidefinite programming problems arising from design of a large class of 2-D FIR and IIR filters based on minmax as well as the weighted least squares criterion. Nikos E. Mastorakis and M. N. S. Swamy, in their paper, *"Spectral Transformation for Two-Dimensional Filters via FFT,"*, study a more conventional technique to filter design. A short paper by R. Thamvichai, Tamal Bose, and Randy L. Haupt considers the *"Design of 2-D Multiplierless IIR Filters Using the Genetic Algorithm,"* as an application of another exotic optimization algorithm in the domain of filter design. The last paper in this category is yet another techninical brief, *"Analytical Design of Multidimensional IIR Digital Notch Filter,"* by Chien-Cheng Tseng, in which design of a specific type of m-D filter is considered.

XI. Multidimensional Filterbank

The field of wavelet and filterbank design has witnessed an explosive growth in recent years largely propelled by the need for image and video coding applications. Progress in the m-D context has been relatively slow due to the inherent difficulties associated with the mathematics of m-D signals and systems. In the paper entitled *"Multidimensional Causal, Stable, Perfect Reconstruction Filter Banks,"* by Sankar Basu, the issue of 2-D IIR filter bank design, when both the analysis and the synthesis bank are casually stable is addressed. The key to this development is the validity of the celebrated Quillen–Suslin theorem for rings of stable rational fractions—an extremely powerful result that has been known to play a key role in many system theoretic developments. For the more signal-processing minded, it may be remarked that although not explicitly mentioned in the paper, the matrix fraction description technique exploited here is, in fact, a generalization of the much touted 1-D wavelet lifting technique that has now been incorporated in the JPEG image compression standard.

Hyungju Park in his paper, *"Optimal Design of Synthesis Filters in Multidimensional Perfect Reconstruction FIR Filter Banks Using Gröbner Bases,"* considers the problem of optimal m-D FIR filter bank design by exploiting the Gröbner basis techniques (see e.g., the Special Issue of J. Multidimensional Systems and Signal Processing, Dec. 2001 for more on the use of Gröbner basis in system theory). Once again, the Quillen–Suslin theorem over the ring of Laurent polynomials plays an essential role here, and tools from symbolic computation attempts to resolve an otherwise difficult design problem. The short paper by David B. H. Tay on the *"Parametric Bernstein Polynomial for Least Squares Design of 3-D Wavelet Filter Banks,"* also falls in the category of wavelet filter bank design, where properties of 3-D Bernstein polynomials are exploited to achieve trade-off between flatness and sharpness of the wavelet filters.

XII. Modeling of Physical Systems

Numerical solution of partial differential equations (PDEs) by exploiting physically motivated digital filter principles has surfaced as an area of research primarily during the last decade. The field has been largely popularized by the wave digital methods of A. Fettweis, and it has been shown that by using wave digital techniques it is possible to achieve parallelism, robustness and other such desirable properties of the numerical integration algorithm for linear as well as nonlinear partial differential equations of mathematical physics. The paper by Rudolf Rabenstein and L. Trautman, *"Multidimensional Transfer Function Models,"* is somewhat in this vein, albeit it does not use the wave digital principles, nor does it consider nonlinear equations. Nevertheless, it provides a flavor of this important and emerging class of problems by showing how m-D transfer function models can be used to numerically solve linear PDEs. We are aware of interesting applications of this work in modeling sound propagation from musical instruments of various kinds under way by the same authors. Last but not the least of the regular papers in the Special Issue is a most provocative article by Alfred Fettweis, *"The Wave-Digital Method and Some of Its Relativistic Implications,"* in which an alternative formulation of theory of special relativity is discussed, based on the intuition and insights derived from the so-called wave digital filter principles. It will remain up to future researchers to cast the die on whether or not the classical circuit-theoretic principles, on which the WDFs are based, have a role to play in relativity theory as well.

We hope that readers will find the Special Issue exciting, and useful for speculating and conjecturing future trends in the field.

It is perhaps an appropriate time and place to thank all the reviewers without whose help this Special Issue would not have been possible. A list of reviewers in alphabetical order follows.

P. Agathoklis
Pedro M. Q. Aguiar
Guilio Anonini
Richard Baraniuk
Bob Barmish
Peter Bauer
R. Bergamaschi
Yuval Bistriz
Gianluca Bontempi
N. K. Bose
Tamal Bose
Nino Cesar
Li Chai
C. Charoenlarpnopparut
K. J. Dana
P. S. R. Diniz
S. C. DuttaRoy
Craig Fancourt
A. Fettweis
K. Galkowski
A. F. Guillermo
Didier Henrion
T. Hinamoto
Tadeusz Kaczorec
Jacob Kogan
Eduard Krajnik
Anton Kummert
Jerzy Kurek
Stewart Lawson
Xu Lei
Yuan-Pei Lin
Zhiping Lin
Ching-Yung Lin
Wing Kuen Ling
Richard Longman
W. S. Lu
N. E. Mastorakis
Vassilios Mertzios
Joan Mitchell
Kevin Moore
Adrian Nunez-Aldana
T. Ooba
D. H. Owens
Min Q. Phan
Harish Pillai
J. F. Pommerat
P. K. Rajan
Peter Roberts
Eric Rogers
Shiva Shankar
Yang Shi
E. P. Simoncelli
Y. C. Soh
E. Stephanakis
David Tay
Mikhail Tchobanou
Murat Tekalp
Gerry Thompson
Chien-Cheng Tseng
A. N. Venetsanopoulos
Martin Vogels
Zidong Wang
Jan Willems
Jeff Wood
Chai-Wah Wu
Xiang Gen Xia
Xu Jian Xin
Li Xu
R. Yedavalli
Eva Zerz
Yong Zhao
Weiping Zh

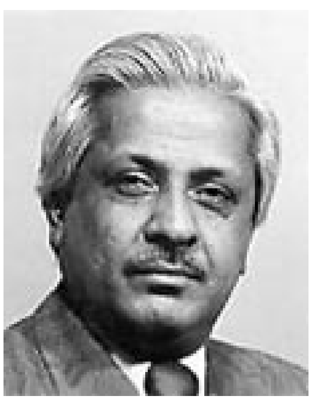
SANKAR BASU, *Research Staff Member*
IBM Thomas J. Watson Research Center
Yorktown Heights, NY 10598 USA

M. N. S. SWAMY, *Research Professor, and holder of Concordia Research Chair in Signal Processing*
Concordia University
Dept. of Electrical & Computer Engineering
Montreal PQ H3G IM8, Canada

Sankar Basu (M'81–SM'91–F'02) was born in Calcutta, India, and received the Ph.D. degree from the University of Pittsburgh, Pittsburgh, PA.

He has been an Alexander von Humboldt Fellow on extended visits to Ruhr University, Bochum, Germany over many years, was a Visiting Scientist at the Laboratory for Informations and Decision Systems (LIDS) at the Massachusetts Institute for Technology, Cambridge and has been a Faculty Member of electrical engineering at the Stevens Institute of Technology, Hoboken, NJ, where he taught and conducted research funded by the U.S. Air-Force and the National Science Foundation, and worked on signals processing. For the last several years he has been with the IBM T. J. Watson Research Center, New York. His main research interests have been in the mathematics of networks and systems theory with particular emphasis on m-D systems. More recently, he has been involved with statistical learning and multimedia signal processing. He has also published in digital filter synthesis, image processing, nonlinear modeling techniques and wavelets and filter banks—a topic in which he co-edited two special volumes.

Dr. Basu was the recipient of 1991 Jess Davis memorial award for excellence in faculty research. He was keynote speaker at the First Int. Workshops on n-D systems (NDS) 1998 in Lagow, Poland as well as at NDS2000 on Czocha Castle, Poland. He has organized and chaired sessions and has been panelist in many IEEE conferences in the areas of m-D systems, statistical learning theory, and human computer interface. He was the General Chair of first IEEE International Conference on Multimedia and Expo (ICME) 2000, New York City, held in August 2000, for which he presently serves as the Steering Committee Chair. He has served as an Associate Editor for the IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS from 1998 to 2001, and is currently an Associate Editor for IEEE TRANSACTIONS ON MULTIMEDIA. He has been a Guest Editor for IEEE TRANSACTIONS ON MULTIMEDIA's special issue on multimedia databases, and the*Journal of VLSI Signal Image Processing on Multimedia Communications*. He is on the editorial board of the *Journal of Applied Signal Processing of the European Signal Processing Association*, and the *Journal of Multidimensional Systems and Signal Processing*. He is an organizer and a Principal Lecturer at the NATO Advanced Study Institute on "Statistical Learning and Applications" to be held at the Katholieke University, Leuven, Belgium in July 2002. Dr. Basu has served as reviewer or panelist on government funding agencies including National Science Foundation and the Engineering and Physical Sciences Research Council of the United Kingdom in the areas of Information Technology, Signal Processing, Data Management,etc. He is a member of SIAM, Eta Kappa Nu and Sigma Xi.



M. N. S. Swamy (S'59-M'62-SM'74-F'80) received the B.Sc. (Hons.) degree in mathematics from Mysore University, India, in 1954, the Diploma in electrical communication engineering from the Indian Institute of Science, Bangalore in 1957, and the M.Sc. and Ph.D. degrees in electrical engineering from the University of Saskatchewan, Saskatoon, Canada, in 1960 and 1963, respectively. In August 2001 he was awarded a Doctor of Science in engineering (Honoris Causa) by Ansted University "In recognition of his exemplary contributions to the research in Electrical and Computer Engineering and to Engineering Education".

He is currently a Research Professor and the Director of the Center for Signal Processing and Communications in the Department of Electrical and Computer Engineering at Concordia University, Montreal, Canada, where he served as the Chair of the Department of Electrical Engineering from 1970 to 1977, and Dean of Engineering and Computer Science from 1977 to 1993. Since July 2001, he holds the Concordia Chair (Tier I) in Signal Processing. He has also taught in the Electrical Engineering Department of the Technical University of Nova Scotia, Halifax, and the University of Calgary, Calgary, as well as in the Department of Mathematics at the University of Saskatchewan. He has published extensively in the areas of number theory, circuits, systems and signal processing, and holds four patents. He is the co-author of two book chapters and three books: Graphs, Networks and Algorithms (New York, Wiley, 1981), Graphs: Theory and Algorithms (New York, Wiley, 1992), and Switched Capacitor Filters: Theory, Analysis and Design (Prentice Hall International UK Ltd., 1995). A Russian Translation of the first book was published by Mir Publishers, Moscow, in 1984, while a Chinese version was published by the Education Press, Beijing, in 1987. He is a member of Micronet, a National Network of Centers of Excellence in Canada, and also its coordinator for Concordia University.

Dr. Swamy is a Fellow of the Institute of Electrical Engineers (U.K.), the Engineering Institute of Canada, the Institution of Engineers (India), and the Institution of Electronic and Telecommunication Engineers (India). Presently, he is Vice-President (Publications) for the Circuits and Systems (CAS) Society. He has served the IEEE in various capacities such as the Vice President of the CAS society in 1976, Editor-in-Chief of the IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS I during 1999 to 2001, Associate Editor of the IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS during 1985 to 1987, Program Chair for the 1973 IEEE CAS Symposium, General Chair for the 1984 IEEE CAS Symposium, Vice-Chair for the 1999 IEEE CAS Symposium and a member of the Board of Governors of the CAS Society. He is the recipient of many IEEE-CAS Society awards including the Education Award in 2000, Golden Jubilee Medal in 2000, and the 1986 Guillemin-Cauer Best Paper Award.