

# Foreword

## Special Issue on Solid-State Image Sensors

**T**HIS is the fourth special issue of the IEEE TRANSACTIONS ON ELECTRON DEVICES on solid-state image sensors. We seem to be on a six-year cycle as the previous issues were published in August 1985, May 1991, and October 1997. As reflected by these papers, during the past six years the focus of image sensor R&D has shifted from charge-coupled devices (CCDs) to CMOS image sensors. While it is only an inaccurate indicator of R&D activity, the number of CMOS image sensor papers rose from 13 in the 1997 issue to 26 in this issue, and the number of CCD papers dropped from 16 to five. CCDs continue to dominate the world's shipment of image sensors in both volume and revenue due to their maturity, concomitant image capture quality and momentum, despite some premature predictions to the contrary (made by myself, I admit). On the other hand, CMOS image sensors have made enormous progress in the same time period with image capture quality now approaching or exceeding CCDs with the additional benefits of reduced power and high levels of "camera-on-a-chip" integration, and are predominate in lower-end image-capture systems and many mobile platforms. Just as the emergence of the consumer camcorder resulted in rapid CCD evolution and improvement in the 1980s, the image sensor business seems about to go through a second phase of rapid growth. This resurgence will be fueled by new applications in mobile personal products, automotive, security, biometrics, and medicine. Most forecasts call for a cross-over point from CCDs to CMOS in shipment volume starting in the next few years. Time will tell if these predictions hold water.

This special issue contains papers discussing improvements in pixel photoelectric conversion, dark current, noise and pixel operation. Reduced power dissipation and alternate readout architectures are also presented. Several papers address very-high-speed sensors. Smart sensors with on-chip functions for target tracking, range finding and other nonvisual applications are re-

ported by several authors. Implementation of imaging in nonsilicon materials is also reported. Finally, some very-large-format and very-high-performance image sensor papers are presented.

I would like to thank Angela McNamee of Micron Technology, and Jo Ann Marsh of the IEEE for their greatly appreciated administrative assistance. I especially wish to thank my Associate Guest Editors, Jerry Hyneczek of ISETEX, Albert Theuwissen of DALSA, and Nobukazu Teranishi of Matsushita, for their time and effort in arranging in the review and selection of papers for this issue. Without their invaluable contributions, this special issue would never have gotten off the ground. I can also not help but observe that all four of us have changed affiliations since publication of the last special issue. Something that is true for many of us in the image sensor community, I suspect, as the industry changes and consolidates.

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**Eric R. Fossum** (S'80–M'84–SM'91–F'98) was born and raised in Connecticut. He received the B.S. degree in physics and engineering from Trinity College, Hartford, CT, in 1979 and the Ph.D. degree in electrical engineering from Yale University, New Haven, CT, in 1984.

As a member of Columbia University's Electrical Engineering faculty from 1984–1990, he and his students performed research on CCD focal-plane image processing and high speed III-V CCDs. In 1990, Dr. Fossum joined the NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, and managed JPL's image sensor and focal-plane technology research and advanced development. He led the invention and development of CMOS active pixel sensor (APS) camera-on-a-chip and subsequent transfer of the technology to US industry. In 1996, he joined Photobit Corporation as Chief Scientist, a company he helped found in 1995, and became CEO of Photobit Technology Corporation in 2000. While at Photobit, he and his staff commercialized the camera-on-a-chip which has been used in Logitech® and Intel® PC cameras, ultra-low-power sensors enabling the swallowable "pill-camera," and very-high-speed, high-resolution sensors used

for Hollywood special effects such as in *The Mummy Returns* and *Pearl Harbor*. In late 2001, Photobit was acquired by Micron Technology, Inc. and he is presently a Senior Micron Fellow. He has also served as Adjunct Professor of electrical engineering at the University of California, Los Angeles (UCLA), and is currently Adjunct Professor of electrical engineering-electrophysics at the University of Southern California (USC), Los Angeles, and teaches undergraduate physical electronics. He has served as primary adviser to 12 Ph.D. candidates. He has published 230 technical papers and holds 53 U.S. patents

Dr. Fossum received Yale's Becton Prize in 1984, the IBM Faculty Development Award in 1984, the National Science Foundation Presidential Young Investigator Award in 1986, the JPL Lew Allen Award for Excellence in 1992, and the NASA Exceptional Achievement Medal in 1996. He was inducted into the U.S. Space Foundation Technology Hall of Fame in 1999. He founded the biannual IEEE Workshops on CCDs and Advanced Image Sensors and the SPIE Conferences on Infrared Readout Electronics. He has served on program committees for the IEDM, ISSCC, and SPIE conferences. He has served as associate editor for IEEE TRANSACTIONS ON VLSI, guest editor for IEEE JOURNAL OF SOLID STATE CIRCUITS, and was Guest Editor-in-Chief for IEEE TRANSACTIONS ON ELECTRON DEVICES Special Issue on Solid-State Image Sensors published in October 1997. He was recently named to the Board of Fellows for Trinity College, CT where he also serves on the college's Engineering Advisory Committee.



**Nobukazu Teranishi** (M'96) was born in 1953. He received the B.S. and M.S. degrees in physics from University of Tokyo, 1976 and 1978, respectively.

He was with the NEC Corporation from 1978 to 2000, involved in the research and development of solid-state image sensors for both visible and infrared. From 1986 to 1987, he was a Visiting Researcher at Arizona State University, Tempe, studying quantum transport. He joined Matsushita Electric Industrial Co., Ltd., Tokyo, in 2000 and is now a General Manager, Development Group at the CCD Division, engaged in solid-state image sensor development. He has authored and co-authored 83 papers and has 80 patent applications.

Mr. Teranishi and his group invented the pinned photodiode, vertical overflow drain, and microlens array, and won the Technology Progress Award in 1986, the Fujio Award in 1993, and the Achievement Award in 2000 from the Institute of Television Engineers of Japan, the Technology Award in 1986 from the Motion Picture and Television Society of Japan, the Emmy Award in 1991, and the Prize of the President of Keidanren of National Invention Awards in 1994, Commendation by Minister of State for Science and Technology in 1997. He is a member of the Institute of Image Information and Television Engineers, where he served as a chairman of the information sensing committee. He served as a guest editor of IEEE TRANSACTIONS ON ELECTRON DEVICES Special Issue on Solid-State Image Sensors published in October 1997. He also served as a general chairman for the 1999 IEEE Workshop on Charge-Coupled Devices & Advanced Image Sensors.



**Albert J. P. Theuwissen** (SM'95–F'02) was born in Maaseik, Belgium, on December 20, 1954. He received the degree in electrical engineering from the Catholic University of Leuven, Belgium, in 1977. His thesis work was based on the development of supporting hardware around a linear CCD image sensor. He received the Ph.D. degree in electrical engineering in 1983. His dissertation was on the implementation of transparent conductive layers as gate material in the CCD technology.

From 1977 to 1983, his work at the ESAT Laboratory of the Catholic University of Leuven focused on semiconductor technology for linear CCD image sensors. In 1983, he joined the Micro-Circuits Division of the Philips Research Laboratories, Eindhoven, The Netherlands, as Member of the Scientific Staff. Since that time he was involved in research in the field of solidstate image sensing, which resulted in the project leadership of respectively SDTV- and HDTV imagers. In 1991, he became Department Head of the Imaging Devices division, including CCD as well as CMOS solidstate imaging activities. He is author or coauthor of many technical papers in the solidstate imaging field and issued several patents. He is a member of editorial board of the magazine *Photonics Spectra*. In March 2001, he became a part-time Professor at the Delft University of Technology, the Netherlands, where he teaches courses in solid-state imaging and coaches Ph.D. students in their research on CMOS image sensors. In 1995, he authored a textbook *Solid State Imaging with Charge Coupled Devices*.

Dr. Theuwissen was a member of the International Electron Devices Meeting paper selection committee in 1988, 1989, 1995, and 1996. He was co-editor of the IEEE TRANSACTIONS ON ELECTRON DEVICES Special Issues on SolidState Image Sensors, May 1991 and October 1997, and of *IEEE Micro* special issue on Digital Imaging, November/December 1998. He acted as general chairman of the 1997 IEEE International Workshop on Charge-Coupled Devices and Advanced Image Sensors. He is a member of the Steering Committee of the aforementioned workshop and founder of the Walter Kosonocky Award, which highlights the best paper in the field of solid-state image sensors. During several years he was a member of the technical committee of the European Solid-State Device Research Conference. Since 1999 he is a member of the technical committee of the International Solid-State Circuits Conference. For the same conference he is acting as vice-chair in the European ISSCC Committee and member of the overall Executive Committee. In 1998 he became an IEEE Distinguished Lecturer. He is a member of SPIE.



**Jaroslav (Jerry) Hyncenek** (M'73–SM'00) was born in Czechoslovakia on November 26, 1940. He received the Dipl. Ing. degree in electrical engineering from Czech Technical University (CTU), Prague, in 1962. In 1969, he immigrated to the United States and received the Ph.D. degree in electrical engineering from Case Western Reserve University (CWRU), Cleveland, OH, in 1974.

From 1962 to 1969, he worked at the A. S. Popov Research Institute, Prague, and as an Assistant Professor of physics at CTU, Podybrady. From 1974 to 1976 he worked at CWRU. In 1976, he joined Texas Instruments, Inc. Dallas. In 1998, he founded a consulting corporation, ISETEX, Inc., Allen, TX, where he is CTO. He has published 51 papers and is author or co-author of 67 U.S. patents.

Dr. Hyncenek received the Paul Rappaport award for the best paper published in any IEEE Electron Devices Society journal during 1983. He has also participated in numerous image sensor related conferences and workshops as a member of the paper selection committees or as a session chairman or cochairman. Currently, he serves as the editor for IEEE TRANSACTIONS ON ELECTRON DEVICES section on Image Sensors and Displays.