Foreword

As MICROELECTRONICS has continued its evolution toward higher speed, greater sophistication, and lower functional cost, it has come to play an ever more important role in a wide range of areas which a decade ago had little or no involvement with electronics. In health care, electronics is being extended beyond record keeping and patient monitoring to a variety of both noninvasive and implantable devices. These include sophisticated imaging systems, programmable pacemakers, implantable drug delivery systems, neurological prostheses, and other developments which are making bionics a reality. In transportation, electronic engine control is now an accomplished fact, and work on a variety of more advanced instrumentation is underway. Finally, a revolution in industrial process control and robotics is being made possible by the continuing progress in integrated electronics.

Virtually all of the above applications share at least one characteristic—as electronic systems they depend as much or more on continued progress in the system periphery as they do on the further development of microcomputers. In particular, their realization will depend on the development of solid-state sensors, actuators, and interface circuits which are capable of working efficiently with a microcomputer to fulfill the system need. In some areas such as health care, high performance and high reliability are paramount concerns, and solid-state process technology is being used to meet these goals along with that of small size. Many of the needed devices are still exploratory or do not yet exist. In other areas such as transportation, high performance, high reliability, high volume, and low cost have all had to be met simultaneously. Again, approaches based on solid-state technology appear to be winning out over competing structures. While many of the sensors needed for robotics have yet to be defined, sophisticated devices for virtually al! of the human senses plus a few more will likely be required.

This Special Issue focuses on recent progress in the development of the solid-state sensors, actuators, and interface electronics which will be needed for future systems. In the two years since the last Special Issue on this topic, the sensor area has made quiet but significant progress. Many companies have moved into sensors in a big way so that production volumes are in themselves high enough to make these devices important even apart from the memory and microprocessor markets they are opening. Over the next few years, many more companies can be expected to follow suit. Perhaps one of the best examples of this evolution is found in the pressure area. Five years ago there were many competing approaches to manifold absolute pressure sensing on the automobile, and some contended that silicon-based devices would never meet the difficult cost/performance/reliability requirements of that environment. Today, the leading approaches to this problem are all based on silicon technology, and some designs are in high-volume production. At least one pressure sensor design has gone fully monolithic, with on-board electronics and laser-trimmed thin-film components directly on the transducer chip.

As solid-state sensors and actuators continue to develop, the trend toward on-board electronics for signal conditioning and microcomputer compatibility is expected to continue. The marriage of silicon circuits to silicon and nonsilicon transducers is only just beginning, and as these sensors evolve it is essential that they be regarded not as isolated componnents but as subsystems capable of two-way communication with the host processor. The development of the needed interface circuitry is challenging, and many issues regarding the optimal partitioning of the system electronics have yet to be resolved. Sensor output formats are still evolving as are the techniques for secondary-parameter (e.g., temperature) compensation. Overall, the sensor area continues to be ripe for innovation. It represents a blending of solid-state materials and processes with novel devices and circuits to meet system needs. The papers in this issue reflect the beginnings of these developments in the periphery and illustrate the tremendous breadth, depth, and challenges of the sensor area.

The issue begins with two papers dealing with infrared devices. The first describes hybrid focal plane imaging arrays using backside-illuminated HgCdTe detectors which are source-coupled to a CCD multiplexer. The noise and temperature properties of such sensors are described in detail. The second paper reports a batch-fabricated thermopile infrared detector realized using silicon technology. The device is attractive for applications requiring broad spectral response, room-temperature operation, and low cost.

Next to visible and infrared imagers and detectors, electromechanical devices for sensing pressure and acceleration have probably seen the most active development efforts recently. The first two papers in this area describe silicon accelerometers. Both use cantilever structures with on-chip MOS detection circuitry. In the first paper, beam deflection is sensed capacitively, while in the second paper a piezoelectric layer deposited on the beam is used as the transducer. These papers offer some interesting contrasts and can be compared with the piezoresistive approach reported two years ago.

The pressure area is represented by six papers dealing with two competing structures (capacitive and piezoresistive). The first paper describes a simulation program capable of calculating the response of both capacitive and piezoresistive devices to pressure and temperature. The program should be a valuable aid in understanding the tradeoffs between these two approaches. The next two papers report silicon capacitive transducers, with the first emphasizing the low temperature coefficients possible in these devices and the second focusing on their high pressure sensitivity. While capacitive pressure sensors in silicon are relatively new and very promising, piezoresistive

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devices are still the more widely used and offer advantages in die size, linearity, and interface simplicity. The next paper reports piezoresistive sensors for use in biomedical catheters and discusses an interesting diaphragm formation technique as well as several packaging alternatives. The following paper reports the piezoresistive coefficients calculated from silicon band theory and provides insights into their dependence on crystallography, doping level, and temperature. Finally, the small nonlinearities associated with piezoresistive devices are explored in a concluding paper in this group.

The issue continues with two papers dealing with magnetic sensors. The first describes a highly linear GaAs Hall device fabricated using ion implantation, while the second discusses transducers which utilize multicollector n-p-n transistors in silicon. The next two papers explore solid-state approaches to moisture monitoring, which is important as the basis of dew-point sensing as well as for humidity applications in many consumer products. The first of these papers describes an ac technique which monitors the surface impedance between a pair of interdigitated surface electrodes, one of which is connected to the gate of a MOSFET. The second paper reports humidity sensors based on the use of chemisorption in ceramic materials.

Ion-sensitive solid-state devices for chemical-concentration monitoring have been the focus of great interest for several years; however, their operation has not been well understood and stability has been a concern. These aspects are addressed in the next two papers. The following paper examines the temperature dependence of a portion of the ion-controlled diode structure as a basis for eventual geothermal applications.

The next two papers deal with gas sensors, the first using a palladium-gate MOS structure for hydrogen and hydrocarbons and the second based on a zirconium oxide-ceramic design for oxygen. The latter device has potential application for monitoring engine air-to-fuel ratios. The issue concludes with a paper describing a flow sensor and two papers describing the application of solid-state processing techniques to biomedical problems. The first of these discusses the development of a flexible electrode array for an auditory prosthesis, while the second paper describes a device for measuring temperature profiles in tissue during cancer hypothermia. Three interesting briefs complete the issue.

As the Guest Editor for this Special Issue, I would like to thank the many individuals who contributed to it. First, my appreciation goes out to the authors, who worked hard to meet the publication deadlines and who provided a set of innovative papers which well represent the present state of the art. Secondly I would like to thank the many reviewers for the issue, who gave unselfishly of their time and contributed a great deal to the accuracy and clarity of the papers presented here. A special word of thanks should also go to my secretary, Mrs. Sophia Houser, who so capably assisted with this issue. Finally, it is hoped that the issue will be of interest to its readers and will perhaps stimulate increased work on the new structures and designs which will be needed to meet the requirements of future electronic systems.

KENSALL D. WISE
Guest Editor

Kensall D. Wise (S'61-M'69) was born in Muncie, IN, on August 1, 1941. He received the B.S.E.E. degree from Purdue University, Lafayette, IN, in 1963, and the M.S. and Ph.D. degrees in electrical engineering from Stanford University, Stanford, CA, in 1964 and 1969, respectively.

From 1963 to 1965 (on leave 1965-1969) and from 1972-1974, he was a Member of Technical Staff at Bell Telephone Laboratories, where his work was concerned with the exploratory development of integrated electronics for use in telephone communications. From 1965 to 1972 he was a Research Assistant and then a Research Associate and lecturer in the Department of Electrical Engineering at Stanford, working on the development of integrated-circuit technology and its application to solid-state sensors. In 1974, he joined the Department of Electrical and Computer Engineering at the University of Michigan, Ann Arbor, where he is now serving as associate professor and Director of the Electron Physics Laboratory. His present research interests focus on integrated circuits and the application of integrated circuit technology to solid-state sensors and microcomputer-controlled instrumentation.

Dr. Wise is presently serving as Chairman of the Technical Subcommittee on Solid-State Sensors of the IEEE Electron Devices Society and as Associate Editor for Solid-State Sensors of this TRANSACTIONS. He is also a member of the Program Committees of the 1981 International Electron Devices Meeting and the 1982 International Solid-State Circuits Conference. He is a member of the Electrochemical Society, Tau Beta Pi, Eta Kappa Nu, and Sigma Xi.