The Role of Government Support for Research in U.S. Academic Institutions

Robert J. Trew, *Fellow, IEEE*, James W. Mink, *Life Fellow, IEEE*, and Usha Varshney, *Senior Member, IEEE*

Invited Paper

***Abstract*—The U.S. government provides support funds for academic research in engineering through a variety of agencies. The majority of the funds for academic research is provided through the U.S. Department of Defense (DoD) and the National Science Foundation (NSF). Together these two U.S. government agencies provide about $5B in total research funding annually to U.S. universities. Support funds for academic microwave-oriented research provided by these two agencies have proved instrumental in development of a strong academic base that has provided the intellectual energy resulting in the development of the U.S. communications, radar, remote sensing, and wireless industries. The history of U.S. government support for basic research is discussed, along with the organization of the DoD and NSF funding offices. Research funding distributions and trends are also discussed.**

***Index Terms*—AFOSR, ARO, basic research, DARPA, defense, DoD, NSF, ONR.**

I. Introduction

The U.S. government has been instrumental in the development of the microwave industry, both through research conducted at government laboratories, primarily by the U.S. Department of Defense (DoD) and by providing support funds to industrial and academic research scientists and engineers. Dating to before World War II, the U.S. government recognized the importance of microwave systems for military applications and invested in microwave research and development at a variety of laboratories, initially those associated with the U.S. Army and U.S. Navy and then laboratories associated with the U.S. Air Force, which originally was a part of the U.S. Army. Work at these laboratories added significantly to the knowledge base and greatly facilitated the rapid development and advancement of the microwave industry. Advances in radar and radio communications, in particular, were greatly assisted by U.S. government research. As important as these contributions were, however, the support funds provided by the U.S. government to industrial and academic researchers provided the base for continued work and permitted the development of a strong knowledge base. Support of academic research, in particular, produced a novel government/academic partnership that has proven extremely effective in development of a strong academic research base that has produced both commercial and military benefits. U.S. government support of research has been a major factor in economic development. This effort continues today and the U.S. government provides the funds for support of the majority of the basic research performed in the U.S. through a variety of agencies. The U.S. DoD and the National Science Foundation (NSF) provide the majority of basic research funds for engineering and science disciplines, particularly those of importance to the microwave industry. In this paper, the history of U.S. government support for academic research is discussed.

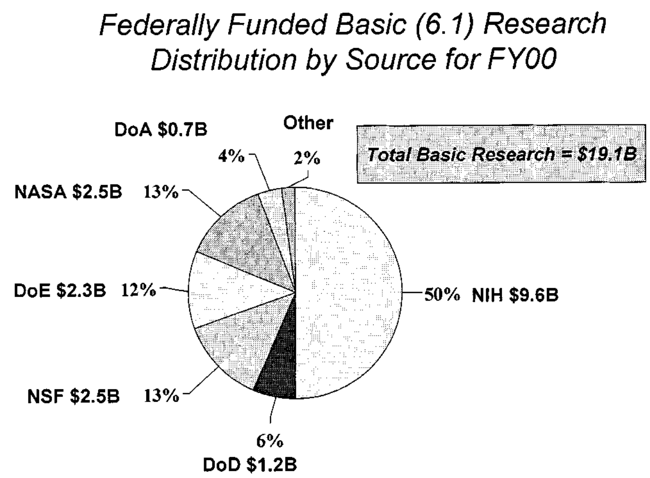

Fig. 1. Distribution of basic research funds by agency for fiscal year 2001.

II. Background

Currently, the U.S. government provides slightly more than $19B for the support of basic research, funded through a variety of agencies. The distribution of the basic research funds for fiscal year 2001 is shown in Fig. 1. As indicated, about one-half of the basic research funds is allocated to the National Institutes of Health (NIH) for research in health sciences, with the other half of the funds distributed to other agencies, primarily for research in the basic sciences and engineering. Although the DoD has only about $1.2B of basic research funds, the DoD provides the majority of support funds for academic research within the U.S. in electrical engineering, materials engineering, computer engineering and science, information technology, and

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R. J. Trew is with the Electrical and Computer Engineering Department, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061 USA.

J. W. Mink and U. Varshney are with the National Science Foundation, Arlington, VA 22230 USA.

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other areas relating to microwave engineering. The NSF also provides significant and growing support for microwave-oriented academic research. Other agencies, such as the National Aeronautics and Space Administration (NASA), perform significant microwave-oriented research, but most of this is performed at U.S. government facilities and the amount of funding provided for academic research is relatively small compared to the DoD and NSF. In order to understand the funding processes, it is interesting to review how government funding for academic research developed.

The U.S. government has not always been a strong supporter of research. Although the government invested in numerous technology projects throughout the history of the country, investment in research was small. The need to have the government significantly invest in basic research was argued in the 1920s and 1930s. Herbert Hoover, while U.S. Secretary of Commerce from 1926 to 1930, campaigned to establish a National Research Endowment. Hoover warned that the United States had heretofore "... depended upon three sources for all the support of pure science research over the years: (1) that the rest of the world would bear this burden of fundamental discovery for us, (2) that universities would carry it as a by-product of education and (3) that men of great benevolence would occasionally endow a Smithsonian or a Carnegie or a Rockefeller Institute." He felt that the future welfare of the country depended upon scientific discovery, which required a stable source of funding provided by the federal government. However, there was opposition to federal support of academic research. In 1934, physicist Karl Compton was president of the Massachusetts Institute of Technology and Head of the Science Advisory Board, which, in the wake of the depression resulting from the stock market collapse in 1929, was established by executive order to address: 1) the ills of unemployed scientists and 2) unmet social problems. Compton argued in an article in *Science*, "If government financial support should carry with it government control of research programs or research workers, or if it should lead to political influence or lobbying for the distribution of funds, or if any consideration should dictate the administration of funds other than the inherent worth of a project of the capabilities of a scientist, or if the funds should fluctuate considerably in amount with the political fortunes of an administration or varying ideas of Congress, then government support would probably do more harm than good ...." These arguments were muted by the events taking place in Europe in the middle to late 1930s and the formal involvement of the U.S. in World War II on December 8, 1941.

During the war years, a very successful collaboration between government and academic researchers and engineers was established. The contribution of academic scientists and engineers to national security, as evidenced in the nuclear work performed during the Manhattan Project and the radar development performed at the Massachusetts Institute of Technology (MIT) Radiation Laboratory, demonstrated the benefit to the country of government and university collaboration and the advantages of government support of academic research. After the war, the U.S. government sought to define, for the post-war era, the role of university scientists for peacetime and national security purposes. President Franklin Roosevelt asked his Science Advisor, Vannevar Bush, to study the issue and, in 1945, Bush delivered his seminal work *Science: The Endless Frontier* to then President Harry S Truman. In this book, and in response to the prewar arguments against federal support of academic research, Bush argued for federal support of "unfettered" basic research and the creation of a self-governing National Research Foundation (NRF) with divisions of medical research, natural sciences, and national defense. He also proposed a linear model for research, consisting of basic research, applied research, and advanced development. The self-governing aspect of his proposal caused significant controversy and President Truman felt that the Constitution did not permit delegation of control over any portion of the federal budget. The NRF was never established. However, the debate that followed resulted in the creation of the NSF in 1950.

III. U.S. DoD Support for Research

The U.S. DoD began support of academic research in areas of interest to the military before and during the World War II period. This collaboration was very successful and encouraged the DoD to continue support with a formalized structure in the post-war era. The formalization of academic research support was established by the U.S. Navy in 1946 when Vice Admiral Harold Bowen created the Office of Naval Research (ONR) to support "advanced research in nuclear physics and other topics of interest to the Navy." The other services soon followed suit and the Army Research Office (ARO) was established in 1951 and the predecessor of the Air Force Office of Scientific Research (AFOSR) was established in 1952. In response to the Soviet launch of Sputnik, the Defense Advanced Research Projects Agency (DARPA) was established in 1958 to focus research and development activity upon high payoff projects of interest to national security. The Office of the Secretary of Defense (OSD) became a direct supporter of academic research beginning in 1986 with the establishment of the University Research Initiative (URI), which currently supports a portfolio of programs in research, education, and infrastructure. The Multidisciplinary University Research Initiative (MURI) and the Defense University Research Instrumentation Program (DURIP), for example, are supported in the URI and managed in the Office of the Director of Defense Research and Engineering (DDRE) in the OSD.

The main focus of the tri-services' research offices is to support basic research and to work with the academic community. When the ONR was established in 1946, it was initially organized to counter the fears that government sponsorship of university research would be restrictive, burdened with bureaucratic rules, or subject to political pressures. Scientists were encouraged to propose their own projects. No progress reports were required and refereed publication in the open literature was sufficient evidence of progress. Support funds were made available for graduate assistants and summer faculty support and awards were multiyear and renewable. The linear model proposed by Bush was adopted and, for the most part, is still in effect today. For example, although the science and technology

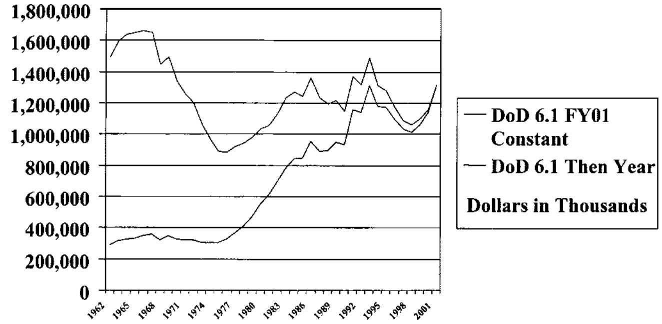

Fig. 2. Historical distribution of DoD basic research funds.

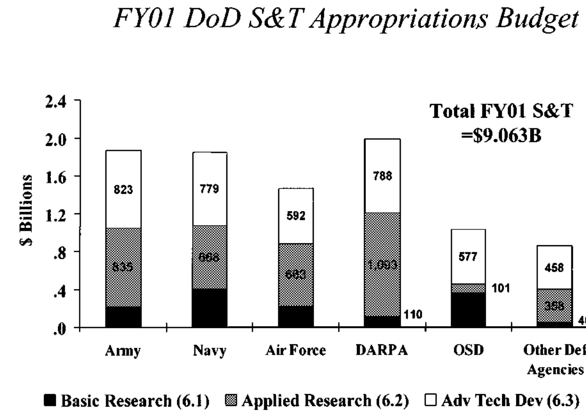

Fig. 3. Fiscal year 2001 DoD budget distribution by budget category.

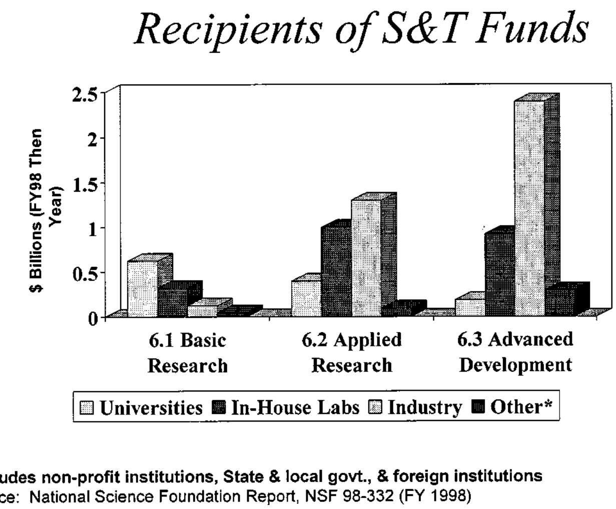

Fig. 4. DoD distribution of S&T funds by performer.

(S&T) support funds provided the department by Congress consist of basic research, applied research and advanced development (denoted as 6.1, 6.2, and 6.3 in the federal budget), the ARO and AFOSR only manage funds in the basic research (6.1) category. The AFOSR manages all of the basic research supported by the Air Force, both at academic institutions and in the Air Force laboratory structure. ARO only manages a portion of the Army's basic research, with the remainder managed by other Army organizations. In an effort to integrate the Army activities, the ARO was incorporated into the Army Research Laboratory in 1999 and now operates as the ARL–ARO. The ONR is vertically integrated and manages funds in the 6.1, 6.2, and 6.3 categories. Although DARPA has the single largest S&T budget, amounting to about $2B annually, most of the funds are in the applied research (6.2) and advanced development (6.3) categories. The basic research (6.1) budget for DARPA is currently on the order of $100M per annum. DARPA does, however, support a significant amount of academic research and provides on the order of $400M annually for such support, which is about 40% of the S&T funds provided by the DoD for academic research. Although the majority of these funds comes from the applied research (6.2) category, a Presidential Directive signed by President Ronald Reagan in 1984 states that all funds provided to U.S. academic institutions by the DoD are considered fundamental research, regardless of the source of the funds, and are considered to be governed by the policies that apply to basic research. Altogether, the DoD provides on the order of $1.3B of S&T funds annually to academic institutions. The OSD basic research budget is currently about $300M, with about one-half of this allocated to the MURI program. The DURIP program provides about $45M of funds for purchase of large instrumentation items that are difficult to obtain under regular single investigator grants. The tri-services (Army, Navy, and Air Force) provide about $300M-$400M annually to university-based researchers, primarily through their research offices. Although many program changes have occurred since the early days, the strong focus upon academic research remains.

Historically, the level of basic research funding has varied, depending upon a combination of budgetary, economic, and political factors. The variation of the DoD basic research (6.1) funds as a function of year is shown in Fig. 2. As indicated, the distribution of basic research funds has varied considerably over time. There are two curves shown in Fig. 2. The line indicated as "then year dollars" refers to the actual value of the appropriations at that time, without consideration of inflation. The curve indicated as "constant year dollars" shows the value of the appropriations when inflation is taken into consideration. The latter figure gives a more accurate evaluation of year-to-year expenditures and indicates that the peak years for investment in basic research were in the mid-1960s. There was a significant decline, extending from 1968 to 1977, which coincides with the Vietnam War. Basic research funding recovered from the late 1970s to about 1986, and has fluctuated with significant year-to-year variation over the past decade. There has been a steady decline since 1994, with some recovery over the past two years. However, current S&T funding is currently well below the peak years.

The distribution of DoD S&T funds for fiscal year 2001 is shown in Fig. 3. As indicated, there is considerable variation in the distribution of funds throughout the services and agencies. DARPA has the largest S&T budget, but the lowest basic research budget. The Navy and OSD have the largest basic research budgets, with most of the OSD funds administered through the URI program.

The distribution of the DoD S&T funds as a function of performer is shown in Fig. 4. About 60% of the basic research (6.1) funds, 14% of the applied research (6.2), and 4% of the advanced development (6.3) funds go to support academic research and development activities.

TABLE I
DoD PERCENTAGE OF TOTAL FEDERAL RESEARCH FUNDING TO U.S. ACADEMIC INSTITUTIONS BY DISCIPLINE (FY1998)

Electrical Engineering	71%
Computer Science	42%
Materials Science & Engineering	44%
Chemical Engineering	14%
Mechanical Engineering	63%
Mathematics	22%
All Engineering	38%
All Federal Funding	9%

The basic research funds are highly focused into a few technical areas and the DoD provides support for work in only 12 areas, consisting of: 1) physics; 2) chemistry; 3) mathematics; 4) computer sciences; 5) electronics; 6) materials science and engineering; 7) mechanics; 8) terrestrial science; 9) ocean science; 10) atmospheric and space sciences; 11) biological sciences; and 12) cognitive and neural sciences.

The DoD basic research funds are instrumental in support of academic research in these highly focused areas and provide a high percentage of the external funds available for university research, as shown in the data listed in Table I.

As the data in Table I indicate, DoD support is instrumental in providing funding for the technical areas important to microwave research. This support has permitted U.S. academic institutions to build effective and productive programs in microwave research. This academic base has, in turn, been fundamental in development of the technology that has resulted in the communications, radar, remote sensing, wireless communications, and other industries based upon microwave technology. This support has served the nation well.

IV. NSF SUPPORT FOR ACADEMIC RESEARCH

The NSF is an independent agency of the federal government and does not fall under any cabinet department. Congress passed legislation creating the NSF in 1950 and President Truman signed that legislation on May 10, 1950, creating a government agency that funds research in the basic sciences, engineering, mathematics, and technology. The NSF is the civilian federal agency responsible for nonmedical research in all fields of science, engineering, education, and technology. The NSF is structured with seven directorates for research disciplines and education. They include: 1) Engineering (ENG); 2) Social, Behavioral, and Economic Sciences (SBE); 3) Biological Sciences (BIO) and Geosciences (GEO); 4) Computer and Information Science and Engineering (CISE); 5) Mathematical and Physical Sciences (MPS); and 6) Education and Human Resources (EHR). The Office of Polar Programs (OPP) funds and coordinates all research efforts in the Arctic and Antarctic.

The roots of the NSF also come directly from the 1945 seminal study by Vannevar Bush, i.e., *Science; The Endless Frontier*. The NSF was established in 1951 and the first 28 research grants were awarded in 1952. Initial funding for these grants was $3.5M. The NSF receives its funding from Congress and the 2001 fiscal year appropriation has grown to $4.4B. The historical, level of funding for support of research by the NSF is shown

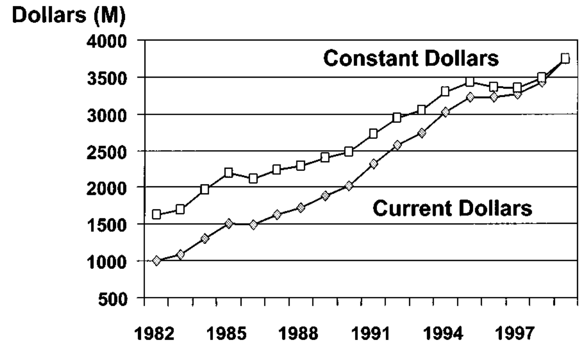

Fig. 5. NSF budget history.

in Fig. 5, where the period between 1982–1999 has shows near monotonic growth.

The NSF has an independent governing body called the National Science Board (NSB) that oversees and helps direct the NSF programs and activities. Members of the NSB are appointed by the President and approved by the Senate. The NSF has a long history of supporting research of direct interest to the microwave community. In the mid-1950s, the NSF moved toward funding "big science." Included were new centers for radio and optical astronomy and for atmospheric sciences. The Soviet Union orbited Sputnik on October 5, 1957. The year following Sputink's launch, the NSF budget more that tripled to $134M. During the early/mid-1970s, a major new program was started—Research Applied to National Needs (RANN), which focused on science research support of engineering, applied, and environmental science. With the recognized and expanding importance of engineering and applied science, in 1979, an independent Engineering Directorate was established. In 1984, the NSF awarded the first Presidential Young Investigators program grants, which continues today in the form of the CAREER/PECASE Awards. Many of these awards were and continue to be focused in the area of microwave research. Due to space limitations here, many other of the NSF's research, education, and resources programs are not discussed.

The NSF's current strategic goals focus on a broad base of research and education activities that provides the nation with the people, ideas, and tools needed to fuel innovation and economic growth.

- **People**—*A diverse, internationally competitive, and globally engaged workforce of scientists, engineers, and well-prepared citizens.*
- **Ideas**—*Discovery across the frontier of science and engineering, connected to learning, innovation, and service to society.*
- **Tools**—*Broadly accessible state-of-the-art shared research and education tools.*

People are the NSF's most important product. People generate the ideas that are the currency of the new knowledge-based economy. Tools enable scientific discovery and provide access to unique educational and innovative application opportunities well beyond the research arena. These goals support the NSF's mission to promote progress across all of science and engineering research and education. Funding levels associated with the NSF's three strategic goals are shown Fig. 6 for fiscal year 2001.

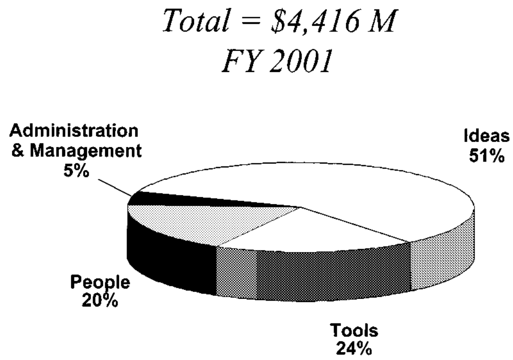

Fig. 6. NSF funding distribution of strategic goals.

The centerpiece of the NSF's research program is its "core" investments. The NSF's core research and education activities sustain the health and vitality of the nation's science and engineering research and education in all fields and education at all levels. These funds support merit-reviewed research and education and help provide balance across all fields. Investments in core research and education activities are essential to developing a diverse science and engineering workforce and to advancing the frontiers of knowledge on a broad front. The NSF supports 33% of basic research in engineering conducted at the nation's academic institutions.

In order to provide additional focus of the core program, the NSF regularly establishes initiatives, which encourages the submission of proposals that address research in specific areas. Within the last three years, the Engineering Directorate in cooperation with other Directorates have established several initiatives of direct interest and focus upon microwave technology. These include the Wireless Information Technology and Networks, the Research for Mixed Signal Electronic Technologies: A Joint Initiative Between NSF and SRC, Sensing and Imaging Technologies for Multi-Use Applications, and the XYZ on Chip initiatives. In addition, the NSF has established several centers that have their focus in areas of strong interest to the microwave community. These centers have their focus upon wireless technology and upon sensing of buried objects.

In addition to its investments in core research and education, the NSF identifies and supports emerging opportunities in priority areas that hold exceptional promise to advance knowledge. The current priority areas are: 1) biocomplexity in the environment; 2) information technology research; 3) nanoscale science and engineering; and 4) learning for the 21st Century. It is envisioned that during the execution of these priority areas of research, microwave research and technology will play a critical role for their success. Funding levels in fiscal year 2001 for each of these priority areas are as follows:

Biocomplexity in the environment	$55M.
Information technology research	$259M.
Nanoscale science and engineering	$150M.
Learning for the 21st Century	$121M.

In conclusion, the NSF has been and continues to be supportive of basic research of interest to the microwave community. For the interested reader, additional information may be obtained from the NSF through its World Wide Web site ([Online]. Available: www.nsf.gov) and publications. Data for this paper were primarily obtained from the two NSF publications *Celebrating 50 Years* and *Summary of FY 2002 Budget Request to Congress*.

V. Summary and Conclusions

The last 50 years have been exciting and prosperous for the microwave community and the future looks equally bright. We have progressed from vacuum tubes to nanotubes, from open wire waveguides to integrated transmission media, from party-line telephones to satellite communications, from microwave systems that once filled a van to systems-on-a-chip. All of these outstanding scientific advancements trace their roots to research that was initially funded by the government. Of course, the research had to transition from government-supported academic research to industry, and industry transformed once research curiosities to practical products that advanced the state of our society. During the next 50 years, one expects microwave technology to play an ever-increasing role in our society as we transform to an information technology dominated environment.

Acknowledgment

The NSF data presented in this paper were taken from *Science and Engineering Indicators 2000*, published by the NSF and available online. [Online] Available: www.nsf.gov/sbe/srs/stats.htm

Robert J. Trew (S'71–M'74–SM'87–F'91) received the Ph.D. degree from the University of Michigan at Ann Arbor, in 1975.

He is currently the Willis G. Worcester Professor of Engineering and Head of the Electrical and Computer Engineering Department of the Virginia Polytechnic Institute and State University, Blacksburg. From 1997 to 2001, he was Director of Research for the U.S. Department of Defense (DoD), with management oversight responsibility for the $1.3 billion yearly basic research programs of the Department of Defense. He was Vice-Chair of the U.S. Government interagency committee that planned and implemented the U.S. National Nanotechnology Initiative. From 1992 to 1997, he served as a Program Manager in the Electronics Division of the Army Research Office (ARO). His academic career includes 17 years with North Carolina State University, and four years as the George S. Dively Distinguished Professor of Engineering and Chair of the Electrical Engineering and Applied Physics Department, Case Western Reserve University. He has authored or co-authored over 140 publications, 14 book chapters, and has given over 280 technical and programmatic presentations. He holds four patents.

Dr. Trew is a member of the Materials Research Society, the Electromagnetics Academy, the American Association for the Advancement of Science (AAAS), the American Society for Engineering Education (ASEE), Sigma Xi, Eta Kappa Nu, and Tau Beta Pi. He serves on the IEEE Microwave Theory and Techniques Society (IEEE MTT-S) Administration Committee. He was editor-in-chief of the IEEE Transactions on Microwave Theory and Techniques (1995–1997), and is currently inaugural co-editor of the *IEEE Microwave Magazine*. He is also a member of the Editorial Board of the Proceedings of the IEEE. He was an IEEE Microwave Distinguished Lecturer (1997–2000). He was the recipient of an IEEE Third Millennium Medal Award, the 1998 IEEE MTT-S Distinguished Educator Award, the 1991 Alcoa Foundation Distinguished Engineering Research Award, and a 1992 Distinguished Scholarly Achievement Award from North Carolina State University.

James W. Mink (S'59–M'65–SM'81–F'91–LF'01) received the Ph.D. degree in electrical engineering from the University of Wisconsin at Madison, in 1964.

In 1999, he joined the National Science Foundation (NSF) as rotating Scientist/Engineer, where he currently serves as a Program Director in the Electrical and Communications Systems Division of the Engineering Directorate. In 1994,

he joined North Carolina State University on a full-time basis were he serves as a Visiting Professor in the Department of Electrical and Computer Engineering. His research interests are in the areas of millimeter-wave systems and devices with a primary focus upon quasi-optical millimeter-wave systems and conformal antennas, with emphasis on wireless communications. From 1994 to 1997, he was Graduate Director of the Department of Electrical and Computer Engineering. From 1988 to 1994, he was the Director and Interim Director of the Electronics Division of the U.S. Army Research Office (ARO). The Electronics Division supported an extramural research program in electronics with research programs in the areas of solid-state electronics, opto-electronics, information processing, electromagnetics, and millimeter-wave devices and systems. In this position, he was the Army Executive for electronics research and served as the principal Army member of the Joint Services Electronics Program. From 1976 to 1988, he was the Associate Director and Program Manager in the Electronics Division. His programmatic responsibility was in the area of "Antennas and EM detection." From 1964 to 1976, he was a Research Physical Scientist in the U.S. Army Electronics Command, Fort Monmouth, NJ. He has authored or co-authored over 90 refereed papers, book chapters, and presentations. He holds six patents. His research focused upon guided-wave techniques for microwave and millimeter-wave communication systems.

Dr. Mink was the editor-in-chief of the IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES (1997–2000) and was a guest editor for two special issues of this TRANSACTIONS. He was a member of the IEEE Microwave Theory and Techniques Society (IEEE MTT-S) and the IEEE Antennnas and Propagation Society (IEEE AP-S) Administrative Committees (AdCom). He was an evaluator for ABET in both the traditional electrical engineering and nontraditional engineering areas. He was the recipient of the Bronze Metal for the Issai Lefkowitz Award and two Bronze Metals for Army Research and Development Achievement Awards from the Department of the Army, the Superior Civilian Service Award from the Department of Army, the IEEE Third Millennium Medal, and a Meritorious Service Award from the IEEE MTT-S. He was also the recipient of the Electrical and Computer Engineering Centennial Medal from the University of Wisconsin.

Usha Varshney (SM'96) received the Ph.D. degree from the Indian Institute of Technology, New Delhi, India, in 1983.

In 1997, she joined the National Science Foundation (NSF), Arlington, VA, as Program Director of the Electronics, Photonics and Device Technologies and Integrative Systems Programs in the Division of Electrical and Communications Systems. Prior to joining the NSF, she was the Director of Research at the American Research Corporation of Virginia. She has also held professional appointments at the Virginia Polytechnic Institute and State University, the Chronar Corporation, and Merrimac Magnetics. She has been involved in research in the areas of electronic materials, thin films and heterostructures, integrated microelectronic components and devices, magnetic materials and monolithic magnetic components, devices, and circuits. She has a strong interest in interdisciplinary science and engineering research in enabling device technologies relating to processing, simulation and modeling, fabrication, characterization and testing of smart materials, structures and devices for next-generation microelectronics, nanoelectronics, molecular electronics, spin electronics, power electronic devices, micromagnetics, integrated circuits, packaging and interconnects, metrology, and integrative systems. She has authored or co-authored over 80 refereed papers, trade journal papers, conference papers, technical reports, and books. She holds seven patents.

Dr. Varshney is a member of the IEEE Electron Devices Society and the Materials Research Society (MRS). She was the recipient of several awards.