Radlab History

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University of Michigan

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In 1946 the University acquired Willow Run airport in Ypsilanti, Michigan from the federal government, and in fulfillment of the requirement that it be operated as a research facility, the Michigan Aeronautical Research Center (MARC) was established. It was administered as part of the Engineering Research Institute (ERI) of the University, which was created in 1920 to facilitate research in the College of Engineering.

Willow Run airport served as the main airport for Detroit and southeastern Michigan, but with the creation of MARC, some of the hangars, peripheral buildings and even part of the Terminal Building itself were used to accommodate a growing research activity. The initial thrust of the research was established in 1946 by project WIZARD, which was concerned with defense against ballistic V-2 type rockets and, later, intercontinental ballistic missiles, and the Center played an important role in the development of the country's entire air defense capability. Analysis, control, system design, simulation and computation were all aspects of the work involved. In 1948 an Upper Atmospheric Physics Group was set up on the second floor of the Terminal Building, and immediately following his graduation with a B.S. degree from Rensselaer Polytechnic Institute in 1948, Keeve M. (Kip) Siegel joined the Group as a research associate. He became Head of the Group the following year, and continued in this position until early 1952, by which time MARC had become the Willow Run Research Center (WRRC).

The Group was part of the Simulation and Computation Department directed by E. K. Ritter, and during his two years as Head, Kip not only found time to complete his M.S. degree, which he received from RPI in 1950, and to get married (1951), but also to recruit such people as Ralph E. Kleinman, who joined in June 1951 on completing his M.S. degree in mathematics at the University, John W. Crispin, Jr., who came that same month from Wayne State University where he had been teaching mathematics, and Andrew L.

Maffett, who had earlier (March 1951) joined the System Analysis Group.

Projects BOMARC and MIRO were two major WRRC programs concerned with the defense of the continental United States against piloted aircraft. They were started in 1950 and 1951 respectively, and required a knowledge of the radar scattering cross section (RCS) of the targets involved. Because of the mathematics and physics backgrounds of most members of the Upper Atmospheric Physics Group, it was not surprising that the task of developing analytical and computational techniques for predicting the RCS of complicated targets became a prime responsibility of this Group. To reflect this emphasis, the Group became the Theory and Analysis Group in early 1952 with Siegel as Head, still reporting to the Simulation and Computation Department, which was itself part of one of the three Divisions of WRRC.

In August 1952 Charles L. Dolph was appointed Head of Division 2000 of WRRC as part of a reorganization into four Divisions. Division 2000 consisted of three analytical groups and three computational groups (which included MIDAC-the Michigan Automatic Digital Computer, an IBM shop, and one of the largest analog computers in the country); and was concerned with the theory, analysis and computation of the mathematical aspects of all WRRC problems. At that time Dolph was an assistant professor of mathematics at the University, and had been associated with WRRC since 1946, initially as a research mathematician at the ERI, and later as a consultant. One of his first acts on becoming Head of the Division was to create a Theory and Analysis Department (Department 2500) with Siegel as Head. The Department had two groups, one in Theory and Analysis and the other in Computation. In effect, the original Department and the subsidiary group had interchanged positions in the hierarchy, but in later years the Groups ceased to have any visibility, and Siegel administered the Department as a single entity. One legacy of the Department is the fact that for more than 20 years our technical memoranda not assigned to a contract were given a number with the prefix 2500.

During the next few years the Department acquired a world-wide reputation in electromagnetic scattering. To predict the RCS of a complicated target, a technique was developed for splitting up a target into components which were then modeled by simpler structures amenable to mathematical analysis, and this in turn led to the detailed investigation of bodies such as the cone, sphere and spheroid. The computation of the backscattering cross section of a prolate spheroid was, in fact, to occupy the attention of the Department for many years. Its reputation was enhanced by the publication of a series of reports entitled "Studies in Radar Cross Sections." The first was "Scattering by a Prolate Spheroid" and was a reissue of a report that had been written in March 1950. Because of this, it is not certain when the series actually began, and it appears that the first report to start out as a Study was issued in February 1953. For the most part, the Studies were limited to reports containing basic and (hopefully) archival work and, as time went on, represented a decreasing fraction of the Department's total publication list. The series terminated in February 1966 with the publication of the fiftieth Study concerned with scattering by a circular cylinder.

The Department achieved further fame and publicity with the hosting of the URSI-sponsored Symposium on Electromagnetic Wave Theory held at the University of Michigan, 20-25 June 1955. Siegel chaired the Organizing Committee, and the majority of the work involved in holding the meeting was performed by members of the Department. The Symposium was attended by most of the scientists active in electromagnetic scattering throughout the world, and the July 1956 special issue of the IRE Transactions on Antennas and Propagation containing the papers is rightly regarded as a standard reference in electromagnetics. The Symposium was the second in a series that started at McGill University in June 1953 and has continued ever since.

Under Siegel's leadership the Department increased in size as well as in the scope of its activities. Claire F. Carlson (later White) was hired in March 1953 as Secretary to the Head of the Department (who, by then, had acquired a reputation of being "impossible" as a boss), Murray L. Barasch came in 1954, Thaddeus B. Curtz transferred in July of that same year (he had previously worked at WRRC as a Systems analyst), and Raymond F. Goodrich and Wayne E. Burdick joined in September. In June 1954 Crispin was appointed Assistant Head of the Department (he had served as Acting Head during the summer of the previous year while Siegel was attending Project Wolverine), and about this time WRRC became known informally (if not formally) as the Willow Run Laboratories (WRL).

By 1956 the increasing use of the airport by the airlines made necessary the renovation of the Terminal Building. To open up the foyer, it was decided to eliminate the office space on the second floor that had previously been occupied by, amongst others, the Theory and Analysis Department. To accommodate these activities, the second floor of Hangar II a quarter of a mile east of the Terminal was subdivided into offices, and the Department moved into the east portion in the Fall of 1956. Within months, an even more significant change took place. On 1 January 1957 the entire Department became a laboratory of the Electrical Engineering (later, Electrical and Computer Engineering) Department under the chairmanship of William G. Dow, with the name Radiation Laboratory. It is not known why the name was selected (and antenna work was not then a significant part of the research activity), but it is reasonable to assume that it was in recognition of the Radiation Laboratory at M.I.T. which had had such an impact on electromagnetics during World War II. On 14 June 1957, Siegel was appointed Professor of Electrical Engineering, two weeks after the author joined the laboratory.

In 1957 it was anticipated that the Electrical Engineering Department and its associated laboratories would soon be consolidated on the North Campus of the University, which was to be the future home of the entire College of Engineering. Just after coming here I was warned to keep this impending move in mind when looking for a house. No sooner had this warning been issued than the Department's move began to recede into the distant future, a process which continued for many years. Nevertheless, it was felt desirable to bring the Laboratory into closer proximity to the Department (then in the East Engineering Building on the Central Campus), and at the very end of 1957 the Laboratory moved into a vacant funeral home at 912 N. Main Street in Ann Arbor. Since most members of the Laboratory lived in Ann Arbor, the move was welcomed not only by those who were also teaching, but there were some misgivings. The Laboratory was about to establish an experimental facility that would have to remain at Hangar II, and the separation of our theoretical and experimental operations continued for the next 20 years. In addition, there were undeniable advantages to working in (or within walking distance of) the airport passenger terminal and its restaurant, Al Green's, which was then one of the best in the area.

By early 1958 the Laboratory had settled into its new home, but the stay proved to be relatively brief. The growing size of the Laboratory soon forced a search for larger quarters, and in the late summer of 1959 most of the laboratory moved into a former laundry at 201 Catherine Street in Ann Arbor, adjacent to the Farmer's Market. Since the new location was a half mile closer to the Central Campus, it was undeniable that we were moving towards consolidation with the EE Department, and the three-story brick building with partial air conditioning promised more desirable working conditions, particularly in the heat of the summer. However, part of the laboratory including all of the computational staff were forced to remain at 912 N. Main Street, and were still there the following year. Indeed, by mid-1960 the Laboratory was operating at four separate locations.

Throughout its history the Laboratory had been heavily involved in developing techniques for RCS calculations and in the interpretation of measured data. The procedures were described in a mammoth report entitled "A Theoretical Method for the Calculation of the Radar Cross Sections of Aircraft and Missiles" published in 1959, and this formed the basis for the book, Methods of Radar Cross Section Analysis, by J. W. Crispin, Jr. and K. M. Siegel, which was published by Academic Press in 1968. Carefully designed experiments were found helpful in guiding the development of both high and low frequency techniques, and in testing their accuracy, but in the absence of an experimental capability, the Laboratory had been forced to rely on data provided by other organizations either freely or under contract. This deficiency was remedied in July 1958 when Ralph E. Hiatt, Chief of the Antenna Laboratory of the Air Force Cambridge Research Center, was hired as Associate Head of the Radiation Laboratory, with prime responsibility to establish an experimental facility. Almost immediately the construction of a large anechoic chamber was begun at the east end of Hangar II. The chamber was initially 63 ft long, 30 ft wide and 15 ft high, but its length was later increased to 100 ft. It was instrumented for cw measurements at S, X and K bands, and a complete microwave laboratory was set up. Although the quality of much of the absorber used in the chamber was not particularly high by today's standards at least, the large size of the room made possible the accurate measurement of extremely small cross sections, and for the next ten years the chamber was in almost continuous use for antenna and cross section measurements. Another experimental facility that was started in 1959 was a physical/organic chemistry laboratory. It occupied an area just to the west of the anechoic chamber and was used to study the properties of materials such as polar liquids that might serve as radar absorbing materials.

In 1960 the Laboratory also branched out on to the North Campus with the establishment of a small experimental facility for the study of plasmas. By March 1960 the Laboratory had 93 employees and had more than doubled in size during the past year. The variety of projects had also increased, and in addition to the more traditional areas, the Laboratory was also involved with passive radiation in connection with the USS American Mariner, remote sensing, lunar studies and the properties and origin of tektites, propagation (including whistlers) and plasmas. This diversity produced some stresses which were sometimes exacerbated by Siegel's manner of directing the Laboratory. With all projects he freely delegated the responsibility but not the necessary authority, and many project directors found themselves undercut by commitments which Siegel had made privately to the sponsor. Because of this it was not surprising that by 1960 many of the early members of the Laboratory had departed—for example, Crispin, Curtz, Maffett and Schensted all left in 1958.

Siegel expected and demanded the highest level of performance from his staff and did his best to ensure that such performance was matched in salary. He sought freedom to operate the Laboratory in any manner that he chose, and when his wishes were hampered or denied by the University administration, he was not loath to point out that any administration should serve for the benefit of those administered. From time to time he even threatened to pull the Laboratory out of the University entirely, and it was a common game to whisper the name of a corporation that we were all going to be working for the next month. But in spite of all this torment and insecurity, it was an exciting period in which to work for the Laboratory.

To most people it was a complete surprise when Siegel convened a meeting of the entire Laboratory in early 1961 to announce that he had formed a corporation. The Conductron Corporation with himself as President was incorporated in the State of Delaware on 21 November 1960 and was authorized to carry on business in Michigan from 29 December 1960. He was going to continue as Head of the Laboratory and expected both organizations to prosper. He would, he said, invite some members of the laboratory to join the Corporation, but had no intention of decimating the Laboratory. His word was kept. Though the Corporation had strong Radiation Laboratory connections, no more than twenty out of the ninety who were present at that meeting ultimately joined Conductron, and several of his early staff were people who had previously left the Laboratory, often as a result of disagreements with him.

For several months the Laboratory continued as before, with Siegel dividing his time between the two groups and Hiatt taking an ever larger role in the day-to-day operation. In April Siegel tried to establish an Advisory Committee to assist in directing the Laboratory but the Committee never functioned; and as Conductron grew and demanded more of his time, friction developed. There were even occasions when the Laboratory and the Corporation were potential competitors for the same work, and in trying to resolve these conflicts, he found it necessary to announce the "hat" that he was wearing at that moment. He would speak first as Head of the Laboratory, but then gesture as though removing that hat, and speak as President of Conductron, or as a Professor—or even as a member of the U.S. Air Force Scientific Advisory

Board, which allowed him to take a purely patriotic stance. It was a situation that could not continue indefinitely, and on 1 November 1961 Siegel resigned from the Radiation Laboratory. The farewell luncheon held at the Elks Club was a bittersweet occasion for all who were present. Subsequently, Hiatt was appointed Head of the Laboratory and Senior as Associate Head. Burton A. Harrison continued as Assistant Head, a position he had held since 1959.

The uncertainty of the past six months had taken its toll on the Laboratory, and during that period its size decreased from 85 to 53, with a few joining Conductron, but most seeking more harmonious conditions elsewhere. The decrease continued for the next six months as some found irresistible the attractions of high salary and even stock options available at Conductron, but under Hiatt's relaxed leadership the Laboratory stabilized. Those who could obtain support were given full authority to do so, and since there was adequate support available for both basic and applied research, the Laboratory prospered. There was, in particular, a growing activity in cross section reduction techniques, as part of which reactive (or impedance) loading was intensively studied. In 1962 a small facility was constructed for measuring the surface fields in a simulated free space environment. A variety of probes were designed and constructed and by 1964 the techniques were sufficiently developed to verify experimentally a theoretical impedance loading prediction. It was felt that this could be a valuable technique for specifying the design and application of absorbing materials for cross section reduction, and the validity of this approach was "sold" to the Ballistic Systems Division of the U.S. Air Force. The result was the three-year project SURF which commenced in December 1964.

During the first year of SURF a specially designed facility for surface field measurements was constructed in that part of Hangar II originally occupied by the chemistry laboratory. The anechoic chamber was a tapered one 44 ft long and 10 ft high, and within a year the new facility was in operation. The sheer magnitude of project SURF soon involved almost all members of the Laboratory to some degree, and it became necessary to increase the staff substantially. By July 1966 the roster had grown to 99, the largest ever, and the rapid increase was causing problems. The Laboratory was not organized to handle a project of this size, and in an effort to staff it, other research projects suffered. There were, indeed, other projects as well—in inverse scattering, the design and evaluation of cross section measurement facilities, radar camouflage techniques, plasmas, antennas (including the construction of an outdoor antenna range across the parking lot from Hangar II), and basic scattering analyses.

In 1967 the University formally celebrated its sesquicentennial, and one event that marked that year was the hosting of the IEEE International Antennas and Propagation Symposium and USNC/URSI Fall Meeting, 16-18 October, in Rackham Auditorium and the Michigan League. The Laboratory was responsible for all of the arrangements and Ralph Hiatt chaired the Steering Committee.

When project SURF ended in December 1967, the Laboratory found itself vastly overextended, and there was also a sense of frustration on the part of many senior members of the staff. Because the staff were divorced from classroom teaching, it was difficult to attract graduate students, and there was little opportunity for the Laboratory to obtain visibility on campus. Without the compensation that teaching (or at least training) has to offer, many were led to question whether the growing struggle to obtain research support was worth the effort, and in 1968 many decided that it was not. Thus, for example, Raymond F. Goodrich left in January, Ralph E. Kleinman and Ronald F. Larson in September (to join the University of Delaware and Georgia Tech, respectively), Burton A. Harrison in October (to become the Assistant to the Dean at Dearborn), and Vaughan H. Weston in December. In that one year, the Laboratory decreased in size by almost 50 percent, and we no longer required all the space available at 201 Catherine Street.

The year 1969 saw the publication of the book, Electromagnetic and Acoustic Scattering by Simple Shapes. It was the culmination of many years' work by many members of the Laboratory, and since we were now entering a period of decreased federal support for basic research in electromagnetics, the book proved to be a swan song for the type of research that the Laboratory was first noted for. In the latter part of that year, some of the vacant office space on the second floor of 201 Catherine Street was taken over by the Institute of Gerontology, and their immediate purchase of new furniture (and carpeting) was a vivid demonstration of the shifting emphasis in the federal support of research. Their increasing need for space coincided with the Laboratory's decrease in size, and in the Fall of 1970 the Laboratory moved into the Space Research Building on North Campus. The move was thirteen years later than had originally been predicted, but since the EE Department was still in the East Engineering Building, we were actually further away from consolidation than we had been before.

At the beginning of 1971 the Laboratory was down to 32 people. We had some experimental facilities nearby in the Automotive Engineering Building and in the G. G. Brown Building, but most were still located in Hangar II. There was insufficient research to support them all and the surface field measurement facility in particular had fallen into disuse. With the smaller staff, the separation of the main experimental facility from the rest of the laboratory was even more unfortunate, and made it difficult to use the available personnel efficiently. The times were also growing increasingly difficult. Research support was hard to obtain, and there was little sympathy on campus for the systems-oriented research that we were forced to go after. By late 1974 we were down to only 18 people (see Fig. 1), and the demise of the Laboratory was a distinct possibility. We were also not fully using the space that we had on North Campus, and at the end of 1974 we moved into the East Engineering Building-in effect, exchanging accommodation with the Atmospheric and Oceanographic Science Department. The move took place just prior to Christmas and brought us for the first time into a student-oriented environment.

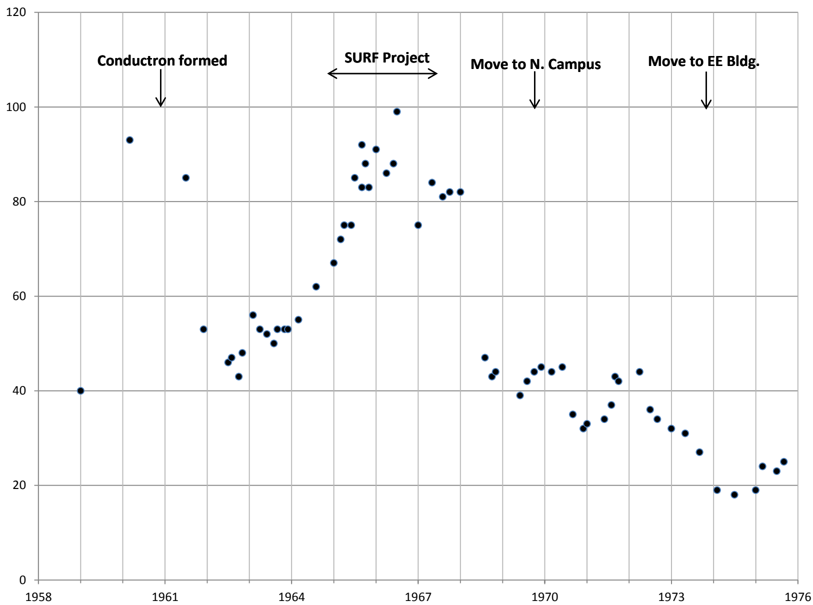


Figure 1: Radiation Laboratory head count, 1959-1976. The year markings are at January of those years.

In the fall of 1975, Hiatt resigned as Director of the Laboratory, and on 15 October Senior was appointed in his place. Valdis V. Liepa, who had obtained his Ph.D. here in 1966, was appointed Assistant Director with primary responsibility for our experimental work. Earlier in 1975 Kip Siegel had died. His love-hate relationship with the University had ended in June 1967 when he resigned in order to accept a visiting professorship at Oakland University. Less than a year later, he resigned from Conductron in a disagreement with the majority stockholder (McDonnell-Douglas) as to how the Corporation should expand, and immediately started KMS Industries. Many of his former employees at Conductron joined him in his new venture, which prospered immediately. In the early 1970s he established KMS Fusion, a wholly owned subsidiary of KMS Industries to push the development of laser-produced nuclear fusion as an energy source. He did so realizing that the enormous expenses involved might force the cannibalization of the parent company, and in the face of federal government resistance to this "intrusion" into the field. He died of a stroke on 14 March 1975 while testifying before a congressional committee about fusion research.

In the East Engineering Building the Laboratory had a visibility that it had not had previously, and it was much easier to attract the talented students that the Laboratory needed. The effect was almost immediate, and within two years the Laboratory had built back up to the 30-35 person level at which it remained for several years. For almost the first time it could truthfully be said that one of the main reasons for the existence of the Laboratory was the training and support of students. Though the maintenance of adequate research funding continued to be a problem, the stability experienced over the next few years was due in large part to two major projects: electromagnetic interference produced by large wind turbines, which was funded by the Department of Energy, and surface field measurements on aircraft, funded by Kirtland AFB in connection with assessments of EMP vulnerability.

The wind turbine study was initiated in response to an inquiry by the CBS Technology Laboratories in 1976. With gas prices escalating and gas shortages occurring in various parts of the country, the federal government embarked on a crash program to develop alternative energy sources, and one component of this program was the use of wind turbines for generating electrical power. CBS was concerned that these would interfere with TV reception, and when our preliminary study confirmed that this could occur, ERDA (Energy Research and Development Administration) provided funding for us to explore this effect. The support continued for the next seven years, and led to our involvement in all major wind turbine installations throughout the country. Ultimately, the decrease in gas prices in the early eighties made wind turbines no longer competitive, but we remained the premier source of all EM data for the environmental impact assessments required of wind turbine installations.

In 1977 the University announced its intention to sell Willow Run Airport, and we were forced to vacate Hangar II. In the summer of that year, a new and improved anechoic chamber was built in Room 525 in the basement of the East Engineering Building.

The chamber was similar to the tapered one in Hangar II and was designed primarily for surface field measurements. The material required was "salvaged" from the two chambers in Hangar II, and the construction was largely a student project, even to the paneling on the outside of the chamber. Thanks to the continued support from Kirtland, the facility was now equipped with an advanced data acquisition and processing system that allowed data to be obtained from 110 to 4400 MHz. By 1983 it seemed that we had measured almost every aircraft of interest to the Air Force, some many times over, and though we continued to use the surface field facility for other studies such as the penetration of fields into cavities, the detection of lightning, and the impact of bridges on LORAN-C, the funding from Kirtland diminished.

With the completion of the new chamber in 1977, the other experimental activities in Hangar II were transferred to the Beck Road side of the airport at Willow Run, and we later took over the old "radio science" anechoic chamber when ERIM's lease expired. The facility was expanded to include outdoor scattering and antenna ranges required for automotive and wind turbine work, and an area was also set aside for RFI measurements.

For the next few years the laboratory enjoyed a stable existence, but in November 1983 the tranquility was disturbed by student sit-ins. A hot issue on campus at the time was so-called weapons research, and a vocal minority of students and faculty was demanding an extension of the "end-use" clause in the Regents-approved classified research guidelines to all University research, with the particular objective of banning research sponsored by the Department of Defense. By virtue of his membership on SACUA and on the Research Policies Committee which was charged with exploring this issue, and because of the very public stance that he had taken in support of DOD research, Senior was a natural target for the demonstrators. On 7 November, 27 members of a group called the Progressive Student Network occupied our experimental facility in 525 East Engineering and vowed to end the "nuclear" research going on. The demonstration continued for two days and attracted considerable publicity, but not the support of other students and faculty that the demonstrators had hoped. To avoid confrontation, the decision had been made to give the demonstrators a reasonable time in which to leave, and they did so after 48 hours. But when a second group calling themselves The Nuclear Saints staged a sit-in a week later on 14 November, a decision was taken to evict them. At 2:30 a.m. the next day Senior read them the trespass law and gave them 10 minutes in which to leave. This they did in the face of a massive force of Ann Arbor police and security personnel, but only after being compelled to identify themselves and have their pictures taken. Though the research issue remained a topic of debate on campus for several years after this, the work of the Laboratory was unaffected.

An interesting postscript to the demonstration came five years later when a half-dozen Nuclear Saints returned to the Laboratory for a reunion. One of them came from as far away as Boston! They again handed out “twinkies” to those in the laboratory, but this time there was no confrontation—only smiles and handshakes.

In spite of the sit-ins, 1983 was a turning point in the fortunes of the Laboratory. With the internal re-allocation of funds in the University, resources became available for the College of Engineering and the ECE Department in particular. The construction of a $30M building on North Campus to house the Department had been approved by the State Legislature, and ground was broken in May 1984. To consolidate the computer engineering and computer science activities, the details of a merger of the ECE Department with the Computer and Communication Sciences Department in LS&A were hammered out, and in July 1984 a new Department of Electrical Engineering and Computer Science was created, consisting of the old ECE and CCS Departments, but also including the Computer Information and Control Engineering interdepartmental graduate program. At this stage, when the new building was only a hole in the ground, the Department to be housed there exceeded the designed capacity!

With the new resources that were available, the Department was given approval to hire two new faculty in electromagnetics. In point of fact, we added three, and in September 1984 P. B. (Linda) Katehi, John L. Volakis and Fawwaz T. Ulaby joined the Laboratory. Katehi had just completed her Ph.D. at UCLA, and soon established a research program in microstrip devices. Volakis had spent two years at Rockwell International after getting his Ph.D. at OSU, and had a major role in re-establishing our former stature in the scattering area. Ulaby came to us from the University of Kansas where he had directed the nationally recognized program in remote sensing. He brought with him M. Craig Dobson, some graduate students and, last but by no means least, major research programs and experimental equipment for the microwave remote sensing of terrain and vegetation. This infusion of new faculty and activities was extremely timely because we were about to lose a few of our EM faculty through retirement: Chen-To Tai in December 1985, Herschel Weil in May 1986, and C. Bruce Sharpe the following year.

In late August 1986 the Department moved into the EECS Building on North Campus, and the Laboratory took over its new space and facilities, which included a 50-ft tapered anechoic chamber. For the first time in our existence, our theoretical and experimental activities were located not only in the same building but adjacent to each other. Our research activities had recovered the national reputation that they formerly had, and student interest in electromagnetics had increased to such an extent that we had more qualified graduate student applications than we could hope to accommodate. Our annual budget was in excess of $1M and growing, supporting over 40 faculty, staff and graduate students.

On the creation of the EECS Department in 1984, Senior was appointed Associate Chairman of the EE Division, and held this position in addition to Director of the Laboratory. On 1 January 1987, however, he also took over as Acting Chairman of the Department, and after 25 years as Associate Director and Director of the Laboratory, prevailed upon Fawwaz Ulaby to assume the position of Director.

In May 1987 the Laboratory hosted the International Geoscience and Remote Sensing Symposium (IGARSS '87), which was attended by about 500 scientists from 21 countries. By then the main areas of research of the Laboratory were electromagnetic scattering from both manmade and natural targets, microwave and millimeter wave remote sensing of terrain and vegetation, and the computer-aided design (CAD) of microwave and millimeter wave circuits.

Further growth of the Laboratory came in 1988 with the addition of three new faculty: Anthony W. England and Yasuo Kuga, both in microwave remote sensing, and Gabriel M. Rebeiz in millimeter and sub-millimeter wave antennas and receivers. England came from NASA where he had been a Space Shuttle astronaut for several years and had flown as a mission specialist on Spacelab 2 in 1985. Kuga came from the University of Washington, to which he later returned in 1991. Rebeiz, who had just completed his Ph.D. at Caltech, proceeded to establish a first-rate experimental laboratory for the design and fabrication of monolithic antenna arrays and receivers in the 100-3000 GHz range. This, as well as other facilities, were made possible by new funding that became available in June 1988 when NASA established a Space Engineering Research Center in Space Terahertz Technology at the University of Michigan under the directorship of Fawwaz T. Ulaby. The NASA Center, whose goal was to develop new techniques for signal generation, control and detection at frequencies above 100 GHz, supported research activities in solid-state electronics, electromagnetics, and space remote sensing. Funding for the Center was $8M for the first four years, and in 1992 this was renewed with an additional $5M for three more years.

The 1990s were a time of great productivity and success. Two new faculty joined us at the beginning of the decade: Brian E. Gilchrist in 1991 and Kamal Sarabandi in 1992 bringing our total faculty to 8. This remained constant for the next few years. In addition, we had about 6 primary research and visiting scientists, 5 support staff and about 70 graduate students, as well as several emeritus faculty and scientists who continued as active members of the Laboratory. The quality of the graduate students was outstanding and we were able to motivate and equip them to explore problems that were academically challenging and relevant to societal needs. The annual budget was $4.5M from a variety of government agencies and industrial concerns, and the Ph. D. output was about 8 per year --- numbers that have remained almost the same to the present day. In

1993 the Laboratory again hosted the IEEE AP-S International Symposium and URSI Radio Science Meeting with almost 1000 participants. All members of the Laboratory, students as well as faculty and staff, were involved in the organization, and Volakis chaired the Steering Committee.

The reputation of the Laboratory was now at an all-time high. The major areas of research were active and passive remote sensing of terrain and vegetation, design and fabrication of microwave and millimeter wave antennas and devices, computational electromagnetics, and scattering by natural and man-made objects, and the faculty were recognized as world leaders in their respective areas. This was reflected in the honors and awards received. In 1993, Senior and Rebeiz received the International Union of Radio Science (URSI) van der Pol and Koga Gold Medals, respectively, and in 1995, Ulaby was elected as a member of the National Academy of Engineering (an honor Chen-To Tai previously received in 1987). Tai also received the IEEE Hertz Medal in 1997 and Ulaby the IEEE Electromagnetics Award in 2001. In 1996 Senior was elected to a 3-year term as president of URSI. Over a four-year period, five textbooks were published. In addition to the usual teaching, the faculty played a key role in the revision of the electromagnetic and circuits programs in the Department, and new leadership positions were taken. Thus, in May 1998, Katehi was appointed Associate Dean of the College. In August of that same year, Volakis took over as the Director of the Radiation Laboratory, and Senior became Emeritus Professor. In 1999 Ulaby was appointed Vice President for Research of the University. However, all continued their research in the laboratory, albeit at a lower level.

On May 26, 1998, Ralph Hialt died in Charlottesville, VA, a day after sustaining a major injury in a fall. He had retired from the Faculty in 1980 and had then moved to Charlottesville with his wife Elloise to be nearer his children.

As the decade ended, the Laboratory underwent significant changes. In Fall 2000 Sarabandi succeeded Volakis as Director of the Laboratory and a year later Amir Mortazawi joined us from North Carolina State University, where he had developed a significant research program in millimeter wave oscillators and amplifiers.

In January 2002, Katehi left to become Dean of Engineering at Purdue University, and the following year Volakis was appointed the Director of the ElectroScience Laboratory at the Ohio State University. On a temporary basis at least, both continued some of their research in the Rad Lab. In 2004, England was appointed Associate Dean for Academic Affairs in the College, Gilchrist became an Associate Chair in the Department, and Rebeiz accepted a position at the University of California, San Diego. It was time for the same sort of renewal that had taken place 20 years earlier. There opened a clear opportunity to move into new areas of electromagnetics.

As a first step in the renewal process, Mahta Moghaddam came to us as an associate professor in September 2003 from JPL, where she had led a major program in radar remote sensing, and she has continued that here. Two years later, Eric Michielssen joined us as a full professor. He came from the University of Illinois, and his work in computational electromagnetics filled the gap that had been created when Volakis left. In January 2006 Anthony Grbic joined us straight after completing his Ph.D. at the University of Toronto, where he had studied under a previous graduate of ours, George Eleftheriades. He rapidly built up a program in metamaterials and planar antennas, and in 2009 the quality of his work was recognized by him receiving the prestigious Presidential Early Career Award for Scientists and Engineers (PECASE).

Figure 2: Radiation Laboratory (below) and its faculty (right), 2007.

First Row (*L-R*): Amir Mortazawi, Mahta Moghaddam, Kamal Sarabandi, Fawwaz Ulaby

Back Row (*L-R*): Adib Nashashibi, Leland Pierce, Eric Michielssen, Thomas Senior, Val Liepa, Dipak Sengupta, Tony England, Brian Gilchrist

Although Ulaby's term as Vice President for Research ended in December 2005, he then became the Founding Provost of the King Abdullah University of Science and Technology (KAUST) in Saudi Arabia, and it was early 2009 before he was back with us. With the help of two textbooks on electromagnetics and circuits that he had just written, he was able to reinvigorate our introductory courses in these areas. In 2009 Gilchrist's terms as Associate Chair and then Interim Chair of the EECS Department also ended, and in 2010 England completed his term as Associate Dean. To have these three back in our midst enabled us to restore the breadth and quality of our teaching and research.

Prior to this we were fortunate to recruit two other new faculty, both joining us in September 2008. Mona Jarrahi came from Stanford after a brief stay at UC Berkeley, and established a research program in microwave photonics and terahertz technology. Mark J. Kushner joined us as a full professor. He had previously served as Dean at Iowa State University, and his research area is plasmas.

In March 2008 Kamal Sarabandi received from the Army Research

Laboratory a $10M contract over 5 years to establish a Center for Objective Microelectronics and Biometric Advanced Technology to develop low-power miniaturized sensors, wireless devices and navigational radars. The contract is extendable for a further five years with an additional $12.5M. A year later Mark Kushner received an HP Labs Innovation Research Program (IHP) award which helped him establish the Michigan Institute for Plasma Science and Engineering. It now holds regular seminars in this area.

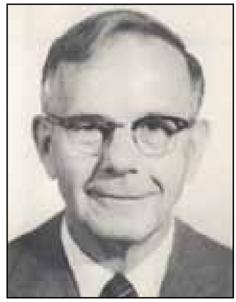
In the last two years several of our faculty received major awards. Fawwaz Ulaby was honored with a Distinguished University Professorship, Mark Kushner was appointed the George I. Haddad Professor of Electrical Engineering and Computer Science, Kamal Sarabandi was made the Rufus S. Teesdale Professor of Engineering, and Tom Senior received the IEEE Electromagnetics Award.

As of 2010 the Laboratory has 10 faculty, 5 research assistants, 2 emeritus faculty and 60 graduate students, most aiming for the Ph.D. degree. These are more than we have had for many years.

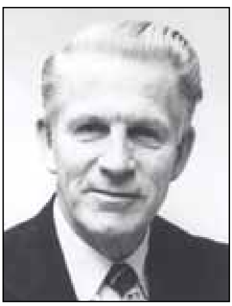
May 2011

Appendix 1: *Radiation Laboratory Directors*

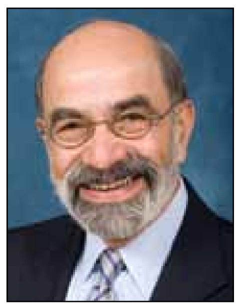
Keeve M. Siegel
1952 – 1961



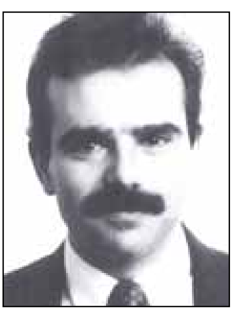
Ralph E. Hiatt
1961 – 1975



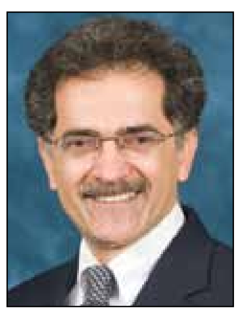
Thomas B.A. Senior
1975 – 1987



Fawwaz T. Ulaby
1987 – 1998



John L. Volakis
1998 – 2000



Kamal Sarabandi
2000 –

Appendix 2: *Radiation Laboratory Books*

The following is a list of books authored, co-authored or edited by faculty while members of the laboratory.

J.W. Crispin and K.M. Siegel, *Methods of Radar Cross-Section Analysis*, Academic Press, New York, 1968, 426 pages.

J. J. Bowman, T. B. A. Senior and P. L. E. Uslenghi, *Electromagnetic and Acoustic Scattering by Simple Shapes*, Norh-Holland Publishing Co., 1969; republished by Hemisphere Publishing Co., 1986, 728 pages.

T. B. A. Senior, *Mathematical Methods in Electrical Engineering*, Cambridge University Press, England, 1986, 272 pages.

F. T. Ulaby, R. K. Moore, and A. K. Fung, *Microwave Remote Sensing: Active and Passive, Vol. III – Volume Scattering and Emission Theory, Advanced Systems and Applications*, Artech House, Inc., Dedham, Mass., 1986, 1100 pages.

F. T. Ulaby and A. Goetz, "Remote Sensing Techniques," in *The Encyclopedia of Physical Science and Technology*, Academic Press, 1986.

J. H. Bryant, *Heinrich Hertz: The Beginning of Microwaves*, IEEE Press, New York, 1988, 50 pages.

F. T. Ulaby and M. C. Dobson, *Handbook of Radar Scattering Statistics for Terrain*, Artech House, Inc., Dedham, Mass., 1989, 362 pages.

F. T. Ulaby and C. Elachi, editors, *Radar Polarimetry for Geoscience Applications*, Artech House, Inc., Dedham, Mass., 1990, 365 pages.

A. K. Bhattacharyya and D. L. Sengupta, *Radar Cross Section Analysis and Control*, Artech House, Norwood, Mass., 1991, 289 pages.

C-T Tai, *Generalized Vector and Dyadic Analysis*, IEEE Press, New York, 1992, 134 pages.

C-T Tai, *Dyadic Green Functions in Electromagnetic Theory*, IEEE Press, New York, 1994, 343 pages.

T. B. A. Senior and J. L. Volakis, *Approximate Boundary Conditions in Electromagnetics*, IEE Press, London, 1995, 353 pages.

F. T. Ulaby, *Fundamentals of Applied Electromagnetics*, Prentice Hall, Upper Saddle River, New Jersey, 1997, 407 pages. Sixth edition, 2010.

M. C. Dobson, F. T. Ulaby, "Mapping Soil Moisture Distribution With Imaging Radar", in Vol. IV, *Manual of Remote Sensing*, American Society of Photogrammetry, Falls Church, Virginia, 1998.

A. Mortazawi, T. Itoh and J. Harvey, *Active Antennas and Quasi-Optical Arrays*, IEEE Press, New York, 1998, 337 pages.

F. T. Ulaby, *Electromagnetics for Engineers*, Prentice Hall, Upper Saddle River, New Jersey, 2005, 398 pages.

D. L. Sengupta and V. V. Liepa, *Applied Electromagnetics and Electromagnetic Compatibility*, John Wiley and Sons, Hoboken, New Jersey, 2006, 486 pages.

T. K. Sarkar, R. J. Mailloux, A. A. Oliner, M. Salazar-Palme and D. L. Sengupta, *History of Wireless*, John Wiley and Sons, New Jersey, 2006, 655 pages.

F. T. Ulaby and M.M. Maharbiz, *Circuits*, NTS Press, 2009, 608 pages.

Appendix 3: *Radiation Laboratory Ph.D. Recipients*

Name	Title	Advisor	Date
Plonus, Martin A.	*A Study of Biconical Antennas*	K.M. Siegel	1961
Samaddar, Surendra N.	*Wave Propagation in an Anisotropic Column with Ring Source Excitation*	K. M. Siegel	1961
Ray, Dale C.	*The Low-Temperature Order-Disorder Transition in Natural Magnetite and Synthetic Magnetite with Varying Degrees of Doping*	D. M. Grimes	1962
Castellanos, Dario	*On a Class of Integral Equations and its Applications to the Theory of Linear Antennas*	C-M Chu	1964
Palais, Joesph C.	*Impedance and Radiation Characteristics of a Ferrite Obstacle in the Aperture of a Rectangular Wave Guide*	J. A. M. Lyon	1964
Burrows, Michael L.	*A Theory of Eddy-Current Flow Detection*	D. M. Grimes	1964
Politis, Demetrios T.	*Analysis of Randomly Varying Propagation Circuits*	C-M Chu	1964

Adams, Arlon T.	*The Rectangular Cavity Slot Antenna with Homogeneous Isotropic Loading*	J. A. M. Lyon	1964
Hong, Soonsung	*Application of Conformal Mapping to Scattering and Diffraction Problems*	C-M Chu	1965
Miller, Edmund K.	*The Excitation of Surface Currents on a Plasma-Immersed Cylinder by Incident Electromagnetic and Electrokinetic Waves*	A. Olte	1965
Wu, Yung-Kuang	*Unified Approach to Excitation Problems in Compressible Plasma*	C-M Chu	1965
Simanyi, Attila I.	*The Synthesis of Linear and Circular Antenna Arrays by Gaussian Quadratures*	C. B. Sharpe	1965
Pyati, Vittal P.	*Radiation Due to an Oscillating Dipole Over a Lossless Semi-infinite Moving Dielectric Medium*	C-T Tai	1965
Liepa, Valdis V.	*Theoretical and Experimental Study of the Scattering Behavior of a Circumferentially Loaded Sphere*	C. B. Sharpe	1966
Heim, Dwight S.	*The Synthesis of Nonuniform Transmission Lines*	C. B. Sharpe	1966

Kalafus, Rudolph M.	*Electromagnetism in Moving, Conducting Media*	C-T Tai	1966
Den, Chi F.	*Admittance of a Wedge Excited Co-Axial Antenna with a Plasma Sheath*	A. Olte	1966
Zwas, Fred	*Wave Propagation in Inhomogeneous Media*	C-M Chu	1966
Rassweiler, George G.	*Helical and Log Conical Helical Antennas Loaded with an Isotropic Material*	J. A. M. Lyon	1966
Wu, Pei-Rin	*A Study of an Interdigital Array Antenna*	J. A. M. Lyon	1967
Walser, Rodger M.	*A Study of Thin Film Magnetodielectrics (TFM)*	D. M. Grimes	1967
Restrick III, Robert C.	*Electromagnetic Scattering by Moving Bodies*	C-T Tai	1967
Laurin, Pushpamala	*Scattering by a Torus*	O. LaPorte	1967
Uslenghi, Piergiorgio L. E.	*Electromagnetic Scattering from Radially Inhomogeneous Media*	O. LaPorte	1967
Becher, William D.	*Vertical Geoelectric Exploration Utilizing Nonuniform Transmission Line Theory*	C. B. Sharpe	1968

Mottl, Thomas O.	*The Three-Dimensional Phased Array: Physical Realizability and Directive Properties*	C-T Tai	1968
Braun, Arthur R.	*Network Function Determination from Partial Specifications*	E. L. McMahon	1968
Alexopoulos, Nicholas G.	*Electromagnetic Scattering from Certain Radially Inhomogeneous Dielectrics*	C-M Chu	1968
Asvestas, John S.	*Iterative Solutions of Maxwell's Equations*	R.E. Kleinman C-T Tai	1968
Chen, Chao-Chun	*An Analysis of the Behavior of the* He_{11} *Mode Ferrite Tube Antenna*	J. A. M. Lyon	1968
Le Vine, David M.	*Wave Propagation Near the Coupling Point in Thin Slabs of Inhomogeneous Warm Plasma*	H. Weil	1968
Chang, Seichoong	*Scattering by a Spherical Shell with a Circular Aperture*	C-T Tai	1969
Digenis, Constantine J.	*Antenna Sidelobe and Coupling Reduction by Means of Reactive Loading of the Ground Plane*	J. A. M. Lyon	1969
Larson, Donald	*Asymptotic Theory of Diffraction*	C-M Chu R. F. Goodrich	1969

Soper, Jon A.	*The Scattering of Electromagnetic Waves by Moving Bodies*	C-M Chu	1969
Ibrahim, Medhat A. H.	*Coupling Analysis of a Loaded and Unloaded Pair of Rectangular Waveguide Cavities Opening in an Infinitely Conducting Ground Plane*	J. A. M. Lyon	1969
Parker, William W.	*The Interdigital Array as a Boundary Value Problem*	J. A. M. Lyon	1969
Mattson, George R.	*Electromagnetic Plane Wave Scattering by a Perfectly Conducting Disk*	C-T Tai	1970
Cha, Alan G.	*A Bifilar Helical Antenna with an Outer Layer of Ferrite*	J. A. M. Lyon	1970
Hansen, Peder M.	*The Radiation Efficiency of a Dipole Antenna Above an Imperfectly Conducting Ground*	C-T Tai	1970
Parker, Jr., James C.	*Electromagnetic Scattering from Structures with Time-Varying Terminating Impedances*	C-T Tai	1970
Girardi, Philip G.	*A Study of Mutual Coupling Reduction in Phased Array Antennas by the Use of a Time Sharing Technique*	J. A. M. Lyon	1972

Stubenrauch, Carl F.	*Radiation from Sources in the Presence of a Moving Dielectric Column*	C-T Tai	1972
Tong, Tommy C-H	*Scattering of Electromagnetic Waves by a Periodic Surface with Arbitrary Profile*	T. B. A. Senior	1972
Smith, Dean L.	*The Trap-Loaded Cylindrical Antenna*	J. A. M. Lyon C-T Tai	1972
Mason, V. Bradford	*The Electromagnetic Radiation from Simple Sources in the Presence of a Homogeneous Dielectric Sphere*	C-T Tai	1972
Seydel, James A.	*Computerized Enhancement of Ultrasonic Non-destructive Testing Data*	J. R. Frederick T. B. A. Senior	1972
Foster, Harold E.	*Transient Radiation from Resistively Loaded Transmission Lines and Thin Biconical Antennas*	C-T Tai R. E. Hiatt	1973
Liu, Yu-Ping	*Excitation and Propagation of Waves Between Two Planar Surfaces*	C-T Tai C-M Chu	1973
Nagy, Louis L.	*The Short Pulsed Electromagnetic Radiation Phenomenon Pertaining to Vehicular Crash Sensors*	J. A. M. Lyon	1973

Pereira, Clovis S.	*Cylindrical Ground-Clutter Shield*	C-T Tai C-M Chu	1973
Desjardins, Gerard A.	*Scattering by a Thin Disk of Large Radius*	T. B. A. Senior	1974
Rozenfeld, Pawel	*The Electromagnetic Theory of Three-Dimensional Inhomogeneous Lenses and the Dyadic Green's Function for Cavities*	C-T Tai C-M Chu	1974
Hidayet, Mohamed A.	*VHF-UHF Phased Array Techniques Part II: Mutual Effects in Finite Array of Slots*	J. A. M. Lyon	1974
Raymond, William W.	*The Magneto-Optic Properties of Ultra-Thin Magnetic Films*	D. M. Grimes	1975
Mohammadian, Alireza H.	*Analysis of Transients on Transmission Lines*	C-T Tai	1980
Giles, Jr., Sammie	*Electromagnetic Fields Resulting from Simple Acceleration*	C-T Tai Y-P E. Yao	1981
LaHaie, Ivan J.	*Function-Theoretical Techniques for the Electromagnetic Scattering by a Resistive Wedge*	T. B. A. Senior	1981
Naor, Menahem	*Scattering by Resistive Plates*	T. B. A. Senior	1981
Jedrzejewski, Paul R.	*Backscatter from a Random Medium*	C-M Chu	1982

Martins-Camelo, Luis F.	*Wiener-Hopf Method Applied to a Dielectric Cylinder Asymmetrically Excited by a Circular Metallic Waveguide*	T. B. A. Senior D. L. Sengupta	1982
Mohassel, Jalil-Agha R.	*Meander Antennas*	C-T Tai	1982
Mason, John L.	*Finite Element Solution for Electromagnetic Scattering from Two-Dimensional Bodies*	W. J. Anderson T. B. A. Senior	1982
Pond, Jeffery M.	*The Application of Coupled Wiener-Hopf Integral Equations in Diffraction Problems*	T. B. A. Senior A. E. Heins	1982
Kimura, Hiroshige	*Study of Electromagnetic Scattering by Half Sheet with Cylindrical Tip*	C-T Tai V. V. Leipa	1983
Lan, Guey-Liou	*Investigation of a Class of Tunable Circular Patch Antennas*	D. L. Sengupta V. V. Leipa	1984
Ksienski, David	*Scattering by Distributions of Small Thin Particles*	T. B. A. Senior	1984
Radmanesh, Massoude	*Magnetostatic-Wave Propagation in a Finite YIG-Loaded Rectangular Waveguide*	G. I. Haddad C-M Chu	1984

Maa, Hsiao-fei	*An Asymptotic Solution for the Two Frequency Mutual Coherence Functions of a Random Slab*	C-M Chu V. V. Liepa	1985
Wang, Rose W.	*Reduction of the Edge Diffraction of a Circular Ground Plane by Using Resistive Edge Loading*	V. V. Liepa	1985
Burns, Joseph W.	*Scattering from Thin Wire Structures*	T. B. A. Senior	1987
Herman, Martin I.	*High Frequency Scattering from Canonical Impedance Structures*	J. L. Volakis	1987
Haupt, Randy L.	*Synthesis of Resistive Tapers to Control Scattering Patterns of Strips*	V. V. Liepa	1987
Willis III, Thomas M.	*Spectral Domain Analysis of Microstrip Patch Antenna Currents and Radiation*	D. L. Sengupta T. B. A. Senior	1987
Dunleavy, Lawrence P.	*Discontinuity Characterization in Shielded Microstrip: A Theoretical and Experimental Study*	L. P. B. Katehi	1988
Peters, Timothy J.	*Computation of the Scattering by Planar and Non-Planar Plates Using a Conjugate Gradient FFT Method*	J. L. Volakis	1988

Jin, Jianming	*Finite Element–Boundary Element Methods for Electromagnetic Scattering*	V. V. Liepa	1989
Sarabandi, Kamal	*Electromagnetic Scattering from Vegetation Canopies*	F. T. Ulaby T. B. A. Senior	1989
Ricoy, Mark A.	*Electromagnetic Scattering from Two-Dimensional Thick Material Junctions*	J. L. Volakis	1990
Harokopus, William P.	*High Frequency Characterization of Open Microstrip Discontinuities*	L. P. B. Katehi	1991
Pierce, Leland E.	*Optical and Infrared Scattering from Irregularly-Shaped Particles Small Compared to the Wavelength*	T. B. A. Senior H. Weil	1991
McDonald, Kyle C.	*Modeling Microwave Backscatter from Tree Canopies*	F. T. Ulaby	1991
Barkeshli, Kasra	*Applications of the Conjugate Gradient FFT Method in Scattering and Radiation Including Simulations with Impedance Boundary Conditions*	J. L. Volakis	1991

Zuerndorfer, Brian	*Spatial and Spectral Analyses of Remotely Sensed Images Using Scale-Space Techniques*	G. H. Wakefield A. W. England	1991
Livernois, Thomas G.	*Numerical and Experimental Analysis of Metal-Insulator-Semiconductor Microstrip Structures*	J. H. Bryant T. B. A. Senior	1991
Vandenberg, Norman L.	*Full-Wave Analysis of Microstrip-Fed Slot Antennas and Couplers*	L. P. B. Katehi	1991
Whitt, Michael W.	*Microwave Scattering from Periodic Row-Structured Vegetation*	F. T. Ulaby	1991
Tavakoli, Ahad	*Microwave Propagation Through Cultural Vegetation Canopies*	F. T. Ulaby K. Sarabandi	1991
Cheon, Changyul	*Design and Analysis of a Four-Wire Antenna for Anechoic Chamber Illumination*	V. V. Liepa E. N. Leith	1992
Van Deventer, Tahera E.	*Characterization of Two-Dimensional High Frequency Microstrip and Dielectric Interconnects*	L. P. B. Katehi	1992
Collins, Jeffery D.	*A Finite Element – Boundary Integral Method for Electromagnetic Scattering*	J. L. Volakis	1992

Syed, Hasnain H.	*Electromagnetic Scattering by Coated Convex Surfaces and Wedges Simulated by Approximate Boundary Conditions*	J. L. Volakis	1992
Dib, Nihad I.	*Theoretical Characterization of Coplanar Waveguide Transmission Lines and Discontinuities*	L. P. B. Katehi	1992
Eleftheriades, George V.	*Analysis and Design of Integrated-Circuit Horn Antennas for Millimeter and Submillimeter-Wave Applications*	G. M. Rebeiz	1993
Engel, Jr., Andrew G.	*Full-Wave Characterization of High-Frequency Nonplanar Interconnects*	L. P. B. Katehi	1993
Polatin, Paul F.	*Modeling and Inversion of the Radar Response of Vegetation Canopies*	K. Sarabandi F. T. Ulaby	1993
Ling, Curtis C-S	*An Integrated 94 GHz Monopulse Tracking Receiver*	G. M. Rebeiz	1993
Ali-Ahmad, Walid Y.	*Millimeter and Submillimeter-Wave Integrated Horn Antenna Schottky Recievers*	G. M. Rebeiz	1993
Oh, Yisok	*Microwave Polarimetric Backscattering from Natural Rough Surfaces*	K. Sarabandi F. T. Ulaby	1993

Kempel, Leo C.	*Scattering and Radiation from Cylindrically Conformal Antennas*	J. L. Volakis	1994
Gearhart, Steven S.	*Integrated Millimeter-Wave and Submillimeter-Wave Antennas and Schottky-Diode Recievers*	G. M. Rebeiz	1994
Natzke, John R.	*Edge Diffraction by Metallic and Resistive Sheets*	T. B. A. Senior	1994
Kormanyos, Brain K.	*A Subharmonic Mixing Antenna for Millimeter-Wave Receivers and Oscillating Antennas for Quasi-Optical Power Combining*	G. M. Rebeiz	1994
Chatterjee, Arindam	*Investigation of Finite Element—ABC Methods for Electromagnetic Field Simulation*	J. L. Volakis	1994
Austin, Richard T.	*Electromagnetic Wave Scattering by Power-Law Surfaces*	A. W. England F. T. Ulaby	1994
Sabetfakhri, Kazem	*Novel Efficient Integral-Based Techniques for Characterization of Planar Microwave Structures*	L. P. B. Katehi	1995

Landry, Joseph C.	*Far-Infrared Spectroscopy of CO_2 Clathrate Hydrate with Applications to the Martian Northern Polar Region*	A. W. England	1995
Cheng, Heng-Ju	*High Speed Signal Generation, Guidance and Detection in the Millimeter-Wave Regime by Ultrafast Optical Techniques*	L. P. B. Katehi J. F. Whitaker	1995
Budka, Thomas P.	*Microwave Circuit Electric Field Imaging Systems*	G. M. Rebeiz	1995
Kendra, John R.	*Microwave Remote Sensing of Snow: An Empirical/Theoretical Scattering Model for Dense Random Media*	K. Sarabandi F. T. Ulaby	1995
Chi, Chen-Yu	*Microwave and Millimeter-Wave Components Using Micromachining Technologies*	G. M. Rebeiz	1995
Weller, Thomas M.	*Micromachined High Frequency Transmission Lines on Thin Dielectric Membranes*	L. P. B. Katehi	1995
Nashashibi, Aolib Y.	*Microwave and Millimeter-Wave Propagation and Scattering in Dense Random Media: Modeling Experiments*	K. Sarabandi	1995

Filipovic, Daniel F.	*Analysis and Design of Dielectric-Lens Antennas and Planar Multiplier Circuits for Millimeter-Wave Applications*	G. M. Rebeiz	1995
Drayton, Rhonda F.	*The Development and Characterization of Self-Packages Using Micromachining Techniques for High Frequency Circuit Applications*	L. P. B. Katehi	1995
Galantowicz, John F.	*Microwave Radiometry of Snow-Covered Grasslands for the Estimation of Land-Atmosphere Energy and Moisture Fluxes*	A. W. England	1995
DeRoo, Roger D.	*Theory and Measurement of Bistatic Scattering of X-Band Microwaves from Rough Dielectric Surfaces*	F. T. Ulaby	1996
Ross, Daniel C.	*Hybrid Finite Element Modal Analysis for Jet Engine Inlet Scattering*	J. L. Volakis	1996
Stiles, James M.	*A Coherent, Polarimetric Microwave Scattering Model for Grassland Structures and Canopies*	K. Sarabandi F. T. Ulaby	1996

Gong, Jian	*Robust Development of Hybrid Finite Element Methods for Antennas and Microwave Circuits*	J. L. Volakis	1996
McCormack, Christopher J.	*Time-Frequency Analysis in Radar Backscatter Problems*	W. J. Williams V. V. Liepa	1996
Ohler, Shawn G.	*Space Electric Propulsion Plasma Characterization Using Microwave and Ion Acoustic Wave Propagation*	B. E. Gilchrist	1996
Siqueira, Paul R.	*Wave Propagation and Scattering in Dense Random Media*	K. Sarabandi	1996
Liou, Yuei-An	*Land Surface Process/ Radiobrightness Models for Northern Prairie*	A. W. England W. R. Kuhn	1996
Yook, Jong-Gwan	*Electromagnetic Modeling of High-Speed High Frequency Interconnects*	L. P. B. Katehi	1996
Ponchak, George E.	*Development of Passive Components for Millimeter-Wave Circuits*	L. P. B. Katehi	1997
Anastassiu, Hristos T.	*Electromagnetic Scattering from Jet Engine Inlets Using Analytical and Fast Integral Equation Methods*	J. L. Volakis	1997

Robertson, Stephen V.	*Micromachined W-band Circuits*	L. P. B. Katehi	1997
Bindiganavale, Sunil S.	*Fast Memory-Saving Hybrid Algorithms for Electromagnetic Scattering and Radiation*	J. L. Volakis	1997
Lin, Yi-Cheng	*A Fractal-Based Coherent Scattering and Propagation Model for Forest Canopies*	K. Sarabandi	1997
Bergen, Kathleen M.	*Classification Biomass Estimation, and Carbon Dynamics of a Northern Forest Using SIR-C/X-SAR Imagery*	C. E. Olsen, Jr.	1997
Özdemir, Tayfun	*Finite Element Analysis of Conformal Antennas*	J. L. Volakis	1998
Roman, Sanjay	*An Integrated Millimeter-Wave Monopulse Radar Receiver with Polarimetric Capabilities*	G. M. Rebeiz	1998
Chiu, Tsen-Chieh	*Electromagnetic Scattering from Rough Surfaces Covered with Short Branching Vegetation*	K. Sarabandi	1998
Cheng, Jui-Ching	*Theoretical Modeling of MMC's Using Wavelets, Parallel Computing and a Hybrid MOM/FEM Technique*	L. P. B. Katehi	1998

Tentzeris, Emmanouil M.	*Time-Domain Numerical Techniques for the Analysis and Design of Microwave Circuits*	L. P. B. Katehi	1998
Botros, Youssry Y.	*Optimal Phased Array Pattern Synthesis for Non-Invasive Cancer Ablation of Liver Tumors Using High Intensity Focused Ultrasound*	E. S. Ebbini J. L. Volakis	1998
Li, Eric S.-S.	*Millimeter-Wave Polarimetric Radar System as an Advanced Vehicle Control and Warning Sensor*	K. Sarabandi	1998
Bilen, Sven G.	*Pulse Propagation Along Conductors in Low-Density, Cold Plasmas as Applied to Electrodynamic Tethers in the Ionosphere*	B. E. Gilchrist	1998
Krause, Linda H.	*Relativistic Electron Bean-Atmosphere Interactions*	B. E. Gilchrist	1998
Goverdhanam, Karita	*Time Domain Characterization of Microwave Circuits*	L. P. B. Katehi	1999
Gauthier, Gildas	*Low-Noise Recievers, Micromachined Antennas and Low-Loss Transistors for Millimeter-Wave Applications*	G. M. Rebeiz	1999

Papapolymerou, Ioannis	*MMIC Passive and Active Structures*	L. P. B. Katehi	1999
Judge, Jasmeet	*Land Surface Process and Radiobrightness Modeling of the Great Plains*	A. W. England	1999
Kim, Edward J.	*Remote Sensing of Land Surface Conditions in Arctic Tundra Regions for Climatological Applications Using Microwave Radiometry*	A. W. England	1999
Henderson, Rashaunda M.	*Silicon-Based Micromachined Packaging Techniques for High-Frequency Applications*	L. P. B. Katehi	1999
Brown, Andrew R.	*High-Q Integrated Micromachined Components for a 28 GHz Front-End Transceiver*	G. M. Rebeiz	1999
DiDomenico, Leo D.	*Mobile Digital Communications Using Phase Conjugating Arrays*	G. M. Rebeiz	1999
Andersen, Lars S.	*Multi-Resolution Methods for Simulation and Design of Antennas*	J. L. Volakis	1999
Barker, Nicolas S.	*Distributed MEMS Transmission Lines*	G. M. Rebeiz	1999
Ellis, Thomas J.	*A Dual Polarized Planar Antenna for Radar and Communication Systems*	G. M. Rebeiz	1999

Shahine, Ghassan E.	*New Approaches to the Analysis of Morphological and Rhythmic Information of the Electrocardiogram*	B. A. Galler K. Sarabandi	2000
Herrick, Katherine J.	*W-band Three-Dimensional Integrated Circuits Utilizing Silicon Micromachining*	L. P. B. Katehi	2000
Chun, Donghoon	*Theoretical Modeling of Large-Scale Electromagnetic Problems Using a Hybrid MOM/FEM Method, Wavelets, and High-Performance Computing*	L. P. B. Katehi	2000
Brown, Arik D.	*Numerical Analysis and Application of Ferromagnetic Materials for Microstrip Antenna Applications*	J. L. Volakis	2000
El-Rouby, Alaa E.	*MMW Scattering by Tree Trunks and Surrounding Environment Modeling and Analysis*	F. T. Ulaby A. Y. Nashashibi	2000
Casciato, Mark D.	*Radio Wave Diffraction and Scattering Models for Wireless Channel Simulation*	K. Sarabandi	2001

Kouskoulas, Yanni A.	*The Application of Maximum Entropy Density Estimation to the Classification of Short Vegetation Using Multifrequency Polarimetric SAR*	F. T. Ulaby	2001
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