

A Brief History of the ElectroScience Laboratory
by Leon Peters, Jr.

The Antenna Laboratory had its inception in 1941 when Prof. W.L. Everitt (Dean Emeritus of the College of Engineering at the University of Illinois) invented a new model measurement technique for aircraft antennas. All model techniques, which are now general practice, were then in their infancy. When Everitt left Columbus for a wartime assignment in Washington, the primary responsibility for the fledgling project was assumed by Sinclair. The time was propitious because of war-time requirements for aircraft antennas and an increasing reliance on model measurements to predict the antenna performance before a full-scale prototype was built. Utilization of model techniques to evaluate the responses of radars to aircraft and to artillery shells further increased the growth potential of the group. The responsibility of deciding whether or not to allow and encourage growth belonged to Prof. Dreese as Department Chairman. Although Sinclair was only a graduate student, Prof. Dreese decided to support his efforts, and by 1946 the group had grown to approximately 50 employees and become known as the Antenna Laboratory.

When Dr. Sinclair left Ohio State after obtaining his Ph.D. degree in 1946, Mr. Robert B. Jacques took over the guidance of the Laboratory. After approximately a year, Mr. Jacques and some others from the laboratory staff formed their own company for the measurement of antenna patterns. This first spin-off, Antenna Research Laboratory, Inc., later was acquired by a larger company--as also happened with several later spin-offs.

Prof. Victor H. Rumsey became Supervisor of the Laboratory in 1948. A brilliant theoretician and inspiring teacher, he attracted a large number of excellent graduate students, mostly veterans of World War II. Five of these students, Tice, Levis, Kennaugh, Walter and Peters, ultimately became Lab Directors as did Fauty who was hired by Rumsey as Research Manager. Of this original group (1950-1954), eight of them have since become Fellows of the IEEE. This was approximately 1/3 of the technical staff (students). A major difference for the students of that period was most of them were fulltime employees and were permitted to take only one course per quarter. This made completing a degree a lengthy process. Today students are employed usually on a half-time basis.

Even during the early days of the Laboratory under Sinclair, the model technique had been extended to radar measurements. The theory and measurement of radar scattering now received new emphasis and became a major part of the activities of the Laboratory. Prof. Rumsey himself made and inspired important contributions in electromagnetic theory, traveling-wave antennas, and frequency-independent antennas. For the latter idea, conceived only shortly before he left for the University of Illinois and brought to fruition there, he received the 1962 Morris Liebman Award of the Institute of Radio Engineers.

Prof. Rumsey left Ohio State in 1954, and Dr. Thomas E. Tice became Supervisor. During the seven years of his administration the style of the Laboratory changed considerably. Under Prof. Rumsey, the structure had been that of one professor and a group of graduate students, and the line of endeavor had adhered closely to Prof. Rumsey's own interests of electromagnetic theory and antennas. Under Dr. Tice, and after 1961, Dr. Levis, the activities of the Laboratory grew in breadth. More faculty and increasingly more graduate students became involved, and the programs were more diversified technically. New areas into which the Laboratory ventured were highway automation, quantum detectors, satellite communications, and plasmas.

Radome research received increased emphasis. A series of annual (later biennial) Radome symposia at Ohio State brought together almost all research in this field, and a handbook, *Techniques for Airborne Radome Design*, was prepared under Tice's editorship. Considerable progress was also made in understanding the scattering of electromagnetic energy from rough surfaces, and much of this was collected in *Terrain Scattering Properties for Sensor System*

Design by R.L. Cosgriff, W.H. Peake, and R.C. Taylor. While all of these authors have left the Laboratory, this area is being led by Joel Johnson.

This Radome program evolved to the study of Frequency Selective Surfaces which was the subject of Prof. Munk's dissertation and ultimately led to the recent highly appraised Frequency Selective Surfaces, Theory and Design. Prof. Munk is just finishing a second related text entitled Finite Arrays and FSS.

Other work on arrays involves the use of optics for beam scanning purposes by Anderson and Collins and the design of arrays for a radio astronomy antenna by Ellingson for monitoring complete regions of space simultaneously.

In these early days, some of these students acted as Principle Investigators which would not be acceptable in later years. As some of these students graduated, they became faculty members, thus ending this practice. In still later years, a number of Ph.D. graduates became Research Scientists who, with faculty, assumed the role of Principle Investigator.

Lasers and non-linear optics became an important area of research and instruction. A symposium on "Lasers and Applications" was held in 1962, and the papers presented were published as a book under W.S.C. Chang's editorship. Optics involved atmospheric optical propagation, with emphasis on laser system effects, and the effects of turbulence on such systems, and the uses of coherent light in an ocean environment. Optics remains as a major topic at the ESL as used for beam steering of microwave arrays and fast switching networks for communications systems under Anderson and Collins.

The Satellite Communications research led to the design and implementation of a self-phased array of paraboloids for space communications, the demonstration of time division multiple access for satellite communication, and the detailed characterizations of several passive and active satellites. The name Antenna Laboratory was obviously inadequate to describe these activities, and it was changed to ElectroScience Laboratory (ESL) in 1967.

Various numerical techniques such as integral equations were now becoming important products of the ESL. Also, applications of the Geometrical Theory of Diffraction demonstrated that this novel tool was very practical. It was subsequently improved at the ESL under the title, The Uniform Theory of Diffraction (UTD). Computer codes for these and other numerical techniques are available from the ESL to this day. For his effort in developing the UTD, Prof. Kouyoumjian would later be elected to the National Academy of Engineers.

The radar scattering studies which were initiated in the early days of the Lab took full advantage of the newly evolved computational methods for many purposes such as antenna design, stealth, etc. These studies were the main reason that led to our leadership role in Compact Range design in more recent years. Ground Penetrating Radar studies also evolved from these scattering programs.

A recent industrial effort supported by Rostra Precision Controls, Inc., involves the design of bumper mounted radar which combines antenna and chip technology to detect obstacles in the path of the vehicle.

Short courses in 1965 and 1966 involved "Antenna and Scattering Theory -- Recent Advances," 1967 and 1968 focused on "Laser Propagation through the Atmosphere," and in 1969 "The Application of Optical Methods to Microwave Problems" was offered. This and a number of subsequent short courses incorporated UTD concepts in scattering and antenna analysis. In each case the purpose was to present the latest available material to a select group of workers in the particular area.

At that time the Laboratory staff of 120 included 22 faculty (mostly on a part-time bases) and approximately 65 graduate students, supported by a small permanent staff of full-time engineers, technicians, and clerical help.

There was a citation index given in the AP/S newsletter of February 1974. A former ESL student, Roger Harrington, was the author cited most often and was cited across all technical specialties. This was credited to his books which were widely used. Kouyoumjian was included in the top10 citations, Peters and Richmond were listed as 12th and 17th, respectively. In 1987, a 5-year citation index was made on the IEEE Trans. on Antennas and Propagation (only). Prof. Kouyoumjian was cited 135 times and Prof. Pathak 116 times for Uniform Theory of Diffraction references. Pathak was also a major contributor to the UTD concepts.

The ESL has always been and continues to be extremely fortunate in that they have been leaders in the area of computational techniques. Rumsey introduced us to variational computations and Equivalence currents. Richmond led us into Moment methods (MM). This MM expertise continues today under the guidance of Newman. Kouyoumjian and Pathak developed the UTD, whereas Rudduck, Ryan and Peters introduced Equivalent Currents to treat finite sized bodies. Marhefka incorporated these concepts into computer codes. Both the UTD and moment codes are available from this laboratory at a modest cost. In these later years, the expertise has grown to include various finite difference solutions with Rob Lee, Jin-Fa Lee and Fernando Teixeira.

Students and sponsors are extremely fortunate to have these capabilities at their disposal. While further development continues to be a goal at the ESL, existing computer programs are available for students interested in pursuing basic electromagnetic concepts. They, along with the available courses and experimental capabilities, are indeed very powerful tools available to these students and to all projects, as are the available electromagnetics courses.

Electromagnetics courses offered by the Electrical Engineering Department, with the exceptions of 711, 813 and 894J, were generated by research at the ESL. The Radiation from Antennas course (711) is taught from books by Kraus who is a colleague in the Electrical Engineering Department. The "Finite Elements for Electromagnetics" course (813) evolved from Robert Lee's graduate studies at the University of Arizona, but, of course, also contains new material from his own research at the ESL. The course "Electromagnetic Scattering from Random Media" (894J) is based mostly on Joel Johnson's Ph.D. work at MIT.

All the rest of the courses have been derived from the strong research program at the ESL. I have always maintained that I have never taught a graduate course from my own days as a student. Our current graduate electromagnetics courses include:

COURSE	TITLE	SUPERVISOR
613	Antennas & Propagation for Wireless Systems	R. Lee
614	Introduction to Electromagnetic Compatibility	Rojas
711	Radiation from Antennas	Rojas
713	Elements of Radio Wave Propagation	Johnson
614	Introduction to Electromagnetic Compatibility	Rojas
714	Radar Systems	Newman
716	Optics with Laser Light and Laboratory	Collins/Anderson
719	Electromagnetic Field Theory I	R. Lee
810	Electromagnetic Field Theory II	R. Lee
812	Applied High Frequency Methods in Electromagnetics	Pathak

813	Finite Elements for Electromagnetics	R. Lee
814	Method of Moments in Electromagnetics	Newman
817	Advanced Electromagnetic Theory I	Pathak
818	Advanced Electromagnetic Theory II	Pathak
819	Advanced Electromagnetic Theory III	Pathak
910	Periodic Surfaces in Electromagnetics	Munk (?)
917	Advanced Optical Concepts	Collins

These courses offer students a very wide choice so that selection can be made as needed for their current graduate research and for their future goals. Obviously, this is to the advantage of both the students and the project sponsors.

Awards, Fellowships, Etc.

George Sinclair in 1980 established the Sinclair Award, to be given to ESL staff members for outstanding service to the Lab. This award has been given to: Taylor (1980), Rumsey (1982), Fouty (1983), Richmond (1985), Burnside (1987), Jordan (1988), Kouyoumjian (1989), Peters (1991), Munk (1993), Poirier (1994), Young (1995), Pathak (1996) and Kennaugh (1997). The award winners are issued a check and a plaque. A duplicate of the plaque is kept on permanent display in the ESL lobby.

The highest honor achieved by an active ESL faculty or staff member is certainly Bob Kouyoumjian's election to the National Academy of Engineering (NAE) in 1994. I believe this is one of six such members on the OSU campus. This was accomplished through the efforts of Bob Hansen, a long term friend and supporter of the ESL. Two former members of the Antenna Laboratory have been elected to the NAE subsequent to their departure from the Laboratory. These are Vic Rumsey and Chen To Tai.

Two engineers, Prof. Kouyoumjian and Prof. Richmond, received centennial medals from the IEEE for technical contributions from the Antenna and Propagation Society. Of the eighteen medals or so awarded, five awardees were associated with the ElectroScience Laboratory in past years. Burnside, Peters and Sinclair have received the Distinguished Achievement Award from the Antenna Measurement Techniques Association.

More than 40 engineers associated with the Laboratory have become Fellows of the IRE/IEEE. Our founding fathers, George Sinclair (1954), Ed Jordan (1955) and Sidney Bertram (1967) were so honored. Buck Walter achieved Fellow status in 1971 and as ESL Director recognized that we needed to nominate other ESL staff members. This had been sadly neglected until then. Buck established a policy of nominating several individuals and requiring them to continue the effort needed to secure additional nominations. As a result of his initiative, the following staff and faculty members were elected as Fellows of the IEEE: Kouyoumjian (1976), Ksienski (1977), Richmond (1980), Peters (1981), Thiele (1982), Compton (1984), Burnside (1985), (Pathak was nominated by Andy Lee of the University of Illinois (1986)), Munk (1989), Rudduck (1990), Walton (1994), Marhefka (1995), Levis (1995), Young (1997), Gupta (2000) and Rojas (2001). The above policy is still being used.

There are a number of former ESL members such as Volakis at the Univ. of Michigan (1996) whose subsequent achievements are such that they should be nominated as Fellows of the IEEE. I have recommended that it should become a policy of this laboratory to pursue this goal. Brian Kent, who is at WADC, was elected Fellow in 2002, was nominated by Munk. Buck Walter and Gary Thiele were Presidents of the IEEE Antennas and Propagation Society in 1974 and 1982, respectively. Gary also served as IEEE Division IV Directory (1987-1988).

Ron Marhefka served as the Editor of the IEEE Transactions on Antennas and Propagation from 1992-1995 and the President of that distinguished society in 1988. Ron also received the Applied Computational Electromagnetics Society Distinguished Achievement Award in 1993. John Volakis, the new ESL Director and my graduate student, is the 2003 President-Elect of the IEEE APS Society. Walton, Rudduck and Gupta have served as Presidents of the Antenna Measurement Techniques Association in 1989, 1992 and 1997, respectively. A number of staff members have served as Associate Editors. Several faculty members served as National Distinguished Lecturers for IEEE APS, including: Kouyoumjian (1973-1975), Walter (1974-1975), Munk, (1982-1985), Burnside (1987-1989), and Pathak (1991-1993). Pathak is currently chairing this program for APS.

Various members received "best paper" awards. The list that follows is incomplete since no records were kept of these awards: Burnside, Marhefka and C.L. Yu received the IEEE APS R.W.P. King Award and the Best Application Paper award for two separate joint papers in 1975. Burnside also received the NASA (LARC) Group Award in 1984, the OSU Engineering Outstanding Faculty Member (Harrison Award) in 1983, the OSU EE Department Teacher of the Year Award in 1980, and the Distinguished Scholar Award from OSU in 1997. Ksienski received the Lord Brabazon Award from the Electronics and Radio Engineering in 1967 and 1976. Rojas received the R.W.P. King Prize Paper Award in 1988, and the Browder J. Thompson Memorial Prize Award in 1990. Gupta and Burnside received the H.A. Wheeler Application Prize Paper Award for 1991. Richmond received the IEEE APS best paper award posthumously in 1991. Rousseau and Pathak received the 1997 Schelkunoff Transaction Prize Paper Award. Jon Young received the IR-100 award for one of the 100 best new technological products in the USA in 1978 from the Industrial Research and Development Council. Before joining the Lab, Robert Lee won the 1990 URSI Prize Paper Contest and Johnson received the 1993 Geoscience and Remote Sensing Society Prize Paper Award and two of Volakis' students won best student paper awards in 2002 (IEEE APS Conference and ACES Conference).

There have also been numerous Engineering College (Lumley) Awards to laboratory faculty and staff members. There are often two or three such awards given to members of the Laboratory each year.

Where Did They Go?

This Laboratory supported students who obtained over 300 Ph.D. degrees and 500 M.Sc. degrees. Since we maintain that our first responsibility is that of graduate student education, a valid question should be: What did they do after graduation? Records over 51 years may be a little vague. However, an attempt is made herein to focus on this question.

First, in terms of their initial position after graduation, 42 students accepted university positions (presumably faculty) after receiving their Ph.D. degree. An additional 22 Ph.D. graduates assumed faculty positions at OSU. It is also known that at least 15 of our graduates became faculty members at some later time in their careers. Thus, approximately 25% of our Ph.D. graduates have at some time in their careers become university faculty members.

Several former laboratory members have also served as Department Chairpersons including: E. Jordan at the University of Illinois, J. Mentzer at Penn State, B. Cosgriff at the University of Kentucky, W.S.C. Chang at University of Washington, T. Tice at Arizona State, W. Peake at the Univ. of Maine, D. Hodge at VPI and OSU, and C. Pistorius at the University of Pretoria. The original faculty advisor who was the driving force that led to the founding of the Antenna Laboratory, Bill Everitt, became the Dean of Engineering at the University of Illinois at the end of World War II. One of our Post- Doctoral researchers, Roberto Tiberio, became a faculty member at the University of Florence (Italy) and subsequently became the first (and only) Dean and founder of the Engineering College at the University of Sienna. G. Thiele became an Associate Dean of Engineering at the University of Dayton.

Since most of our research is funded by the Federal government, the number of students who accept federal agency employment represents an added benefit to these sponsors. At least 16 of our Ph.D. graduates and 17 of our M.Sc. graduates have accepted such employment immediately after graduation. Most of them have remained in these positions. In addition to these cases, faculty have sometimes acted as advisors to students who came to OSU from one of these agencies to complete a graduate degree among others. I have supervised the graduate work of C.H. (Mike) Kruger from Wright Patterson Air Force Base and Constantine (Connie) Balanis then at NASA Langley and now a Professor at Arizona State University.

A number of companies have been established by former staff members. Sinclair both taught at the University of Toronto and established Sinclair Industries. Others include: Jacques- Antenna Research Laboratory, Inc.; Bulman- Ohio Semetronics; Chan- All Source Processing, Inc.; Huff-Spacecom Corporation; Barrick- Codar Ocean Systems, Ltd.; Swetnam- Lintek, Inc.; Dominek and Shamansky- Analytic Designs, Inc.; Compton- Compton Research, Inc.; Remcomb-Luebbers. Copeland formed and sold two companies.

Other former students have served as executives in their respective companies. These include: Chung- Pres. Satcom Electronics, Inc.; Ecker- Sr. Vice Pres. and Chief Technical Officer of Scientific Atlanta; Brackey- Vice Pres. Of Hughes; Hutchins- Vice Pres. Of Alliant Techsystems; Masters- President and Chairman of Antenna Research Associates; Mentzer- Vice Pres. of McDonnell Douglas Technologies, W.C.Y. Lee- Vice Pres. of Air Touch; T. Crowley- Executive Director of Safeguard Design Division at Bell Telephone Laboratories; E. Vaughn- Vice Pres. Of Research and Development of superior Electric.

There have been an increasing proportion of international graduate students working at the laboratory. Thus, it is important to examine where they were employed upon graduation. Students from Europe tended to return to their native lands while students from the Mideast and Asia tended to remain in the USA and represent a powerful component to our technology base. In 1996, Mid Eastern and Asiatic students seem interested in remaining in the USA provided technical positions were available.

In 1992, 27 students received M.Sc. degrees, four entered the Ph.D. program through the Lab, one entered a Ph.D. Geophysics program at OSU, two entered the Ph.D. programs at Colorado State and the Univ. of Michigan, three were employed by the Naval Research Labs and Wright Patterson Air Force Base and one by Lincoln Laboratory. Four returned to their native countries and the rest were employed by various U.S. industries including: Mission Research, Delco Electronics, Motorola, Texas Instruments, Mitre, Lincoln Laboratory, Loral and Dielectric Corporation. It is very clear that these are additional major contributions to the technology base of the United States in the form of highly trained engineers.

Former ESL students have written Electromagnetic Books including:

R.F. Harrington, Introduction to Electromagnetic Engineering, McGraw Hill, 1958.

R.F. Harrington, Time Harmonic Electromagnetic Fields, McGraw Hill, 1961.

R.F. Harrington, Field Computations by Moment Methods, 1992.

C.H. Walter, Traveling Wave Antennas, McGraw Hill, 1965.

R.A. Monzingo and T.W. Miller, Introduction to Adaptive Arrays, Wiley, 1980.

W.C.Y. Lee, Mobile Communications Engineering, McGraw-Hill, 1982.

W.C.Y. Lee, Mobile Cellular Telecommunications, McGraw Hill, 1995.

C.A Balanis, Antenna Theory: Analysis and Design, Harper and Row, 1982.

C.A Balanis, Advanced Engineering Electromagnetics, Wiley, 1989.

D.A. McNamara, C.W. Pistorius and J.A.C. Malkerbe, Introduction to the Uniform Theory of Diffraction, Artech House, 1990.

Edmund K. Miller, Louis Medgyesi-Mitschang and Edward H. Newman, Computational Electromagnetics (Frequency-Domain Method of Moments), IEEE Press, 1992.

Warren L. Stultzman and Gary A. Thiele, Antenna Theory and Design (2nd Ed.), Wiley, 1998.

D. Pozar, Microwave Engineering, 2nd Edition, Wiley, 1998.

D. Pozar, Antenna Design Using Personal Computers, Artech House, 1985.

D. Pozar and D. Schaubert, Microstrip Antennas: the Analysis and Design of Microstrip Antennas and Arrays, IEEE Press, 1995.

T.B.A. Senior and J.L. Volakis, Approximate Boundary Conditions in Electromagnetics, The Institution of Electrical Engineers, London, 1995. J.L. Volakis, A. Chatterjee and L.C. Kempel, Finite Element Methods for Electromagnetics, IEEE Press 1998.

J.J.H. Wang, Generalize Moment Methods in Electromagnetics, Wiley, 1991. K.S. Kunz and R.J. Luebbers, The Finite Time Domain Method for Electromagnetics, CRC Press 1993.

B. Munk, Frequency Selective Surfaces, Theory and Design, Wiley 2000. B. Munk, Finite Antenna Arrays and FSS's, submitted to Wiley. J.D. Kraus and R.J. Marhefka, Antennas for All Applications, 3rd Edition, McGraw-Hill 2002.

In addition to numerous journal papers, ESL members have authored many chapters for books devoted to special topics.

Funding Sources

The Antenna Laboratory was originally funded by the Department of Defense in support of World War II. While there were small industrial projects such as T.V. Antenna Studies supported by the Radio Corporation of America in the early 1950's, DoD funding was dominant. Further substantial government support came from NASA after 1960. There have subsequently been a number of industrial supported contracts, but most of these could be traced to government funds. Support from purely industrial support would be welcome and should be to the advantage of both the ESL and industry. An example of this is the research involving automobile antennas supported by Pittsburg Plate Glass Industries, AGC America and others initiated in the early 1990's and continuing to the present day.

There are three major criteria for pursuing research at the ESL. These are:

1. The advancement of science and technology
2. Provide support for graduate students including their theses and dissertations
3. Provide support for faculty and staff.

The third criteria is the least important!!

Of course, support for graduate students requires an adequate time frame to complete their theses and dissertations. The most important, however, is the advancement of science and technology. This almost always leads to a lengthy time frame. Another example is the study of Compact Range Technology studies initiated in the early 1990's, which continues even today with support of the Compact Range Consortium supported by various major industries.

The Future ElectroScience Laboratory

The personnel at the ESL look forward to future development with great enthusiasm. With a new Director, John Volakis, who is an ESL graduate that has worked in industry (Rockwell) and established his technical reputation in a 19 year period at the University of Michigan, we are well positioned to move into new areas of EM research in addition to a continued focus on the traditional areas.

As has already been stated, John is the 2003 President-Elect of the IEEE, has served as Associate Editor of the IEEE APS (1989-1993) and Radio Science (1994- 1997), and two of his students have won best paper awards. He has published over 180 Refereed Journal papers and has about 20 additional such papers in various states of preparation. For the past several years Volakis has directed a large group of research assistants. In the recent years, this group consisted of 3 research scientists and 12 graduate research assistants.

Principle Investigators at the ESL include Faculty and Research Scientists with a diverse background. The older faculty members, Newman, Pathak and Rojas, were trained at the ESL and are recognized as experts in their respective areas. Younger faculty members received degrees from a variety of institutions as indicated in parentheses. Anderson (U. of Vermont), Johnson (MIT), Khan (SUNY at Stony Brook), J. F. Lee (Carnegie Mellon University), R. Lee (U. of Arizona) and Teixeira (U. of Illinois), are equally well known in the scientific community. In addition there are our equally talented Senior Research Scientists, Gupta, Marhefka, Young, Research Scientists, Baertlein (U. of Arizona), Burkholder, Ellingson, T.-H. Lee, and Senior Research Associates, Chen, Hampson (Monash Univ., Australia, Paynter and Theuneissen (U. of Praetoria, S. Africa). There is also a group of retired researchers who remain actively involved in research. These include Burnside, Collins, Munk, Peters and Walton.

The variety and background of this talent in a leadership role will prove invaluable for tackling new research topics.

Acknowledgement

Part of the description of the first few years of this history was taken from an earlier version of the history by Professor Emeritus C.A. Levis.