A Tribute to Roger F. Harrington

by J. R. Mautz and E. Arvas

Roger F. Harrington was born in Buffalo, NY, USA, on December 24, 1925. He attended the public schools in that city and enrolled in the undergraduate program in Electrical Engineering at Syracuse University, Syracuse, NY in 1943. His education was interrupted from 1944 to 1946 for service in the U.S. Navy during World War II as an Electronics Technician and as an Instructor at the U.S. Naval Radio Materiel School, Dearborn, MI. He returned to Syracuse University after the war and earned the B.S. degree in 1948 and the M.S. in 1950, both in electrical engineering. From 1948 to 1950 he was employed as an Instructor and Research Assistant at Syracuse University. In 1950 he began his studies for the Ph.D. degree at The Ohio State University, Columbus, obtaining the degree in August 1952. The title of his dissertation is "Solution to some electromagnetic boundary value problems". Victor H. Rumsey was his dissertation advisor. The title page of Dr. Harrington's dissertation is shown in Figure 1. From 1952 to 1994, he held an appointment on the professorial staff at Syracuse University. Next, he was Visiting Professor at the University of Arizona in the Department of Electrical and Computer Engineering. At the time of this writing, he was living with a daughter, Judy, in Wheaton, IL.

Dr. Harrington's principal areas of research are electromagnetic theory and applied mathematics. During the period 1954 to 1958, Dr. Harrington undertook several different sponsored research projects. The first of these was on aperture antennas for the U.S. Army Signal Corps. Several basic formulas for radiation from aperture antennas in cylindrical bodies were derived and applied during this project. The second contract, done for the U.S. Air Force of Scientific Research, was an investigation of wave propagation in gyrotropic media. In this work an extended reciprocity principle was developed for such nonreciprocal media. The third contract, performed under a subcontract from the General Electric Company, was a study of the near-zone fields of antennas. This work resulted in the establishment of some fundamental limits to the performance of antennas.

Concurrent with the above work, Dr. Harrington wrote his first book, *Introduction to Electromagnetic Engineering*, which was published by McGraw-Hill in 1958 and reprinted by Dover in 2003. This book is somewhat unconventional in that it appeals to an electrical engineer's knowledge of circuit theory to establish the equations of electromagnetic theory. The book was used at a number of schools in the United States and abroad as a text for undergraduate and first-year graduate courses. At about the same time, Dr. Harrington wrote his second book, *Time-Harmonic Electromagnetic Fields*, published by McGraw-Hill in 1961 and reprinted in 2001 by Wiley-IEEE Press. "*Time-Harmonic-Electromagnetic Fields*", which is one of the most significant works in electromagnetic theory and applications, has been adopted extensively as a graduate-level text throughout the world. During the writing of

this second book, Dr. Harrington also worked on several research projects. Two of these were sponsored by the U.S. Rome Air Development Center. The first, on electromagnetic scattering by active reflectors, showed that instabilities could arise which make active reflectors impractical for long distance communication via satellites. The second project was on the reduction of antenna sidelobes by the use of nonuniform element spacing. About this time (1959), Dr. Harrington went to the University of Illinois as a Visiting Associate Professor. While there, he became interested in the use of electromagnetic fields to contain plasmas for thermonuclear research. This interest resulted in a project on electromagnetic forces in plasmas, sponsored by the U.S. Air Force of Scientific Research.

The research, which caused a change in Dr. Harrington's interest, was on matrix methods for field problems, sponsored initially by the Rome Air Development Center. The key to this work was the method of moments, a powerful technique for reducing functional equations to matrix equations, which can then be solved on a digital computer. To *publicize* this work his third book, *Field Computation by Moment Methods*, was published by MacMillan in 1968, kept in print for some time by Kreiger Publishing Company, and then reprinted in 1993 as a classic reissue in the IEEE Press Series on Electromagnetic Theory. The first author of this writing, J. R. Mautz, is one of his early Ph.D. students and a major contributor to the preparation of this book. The use of moment methods has changed the analysis of electromagnetic field problems in practice. Problems previously considered too difficult to handle are now routinely solved by the method of moments on computers. Dr. Harrington has given special courses at the University of California (at Berkeley in 1964), at the Technical University of Denmark in 1969, and at the East China Normal University in 1983 on this topic, as Visiting Professor. He has also given lectures and short courses on the topic at such places as the Universities of Mississippi, Southern California, Illinois, and Arizona in the U.S.A., and the Universities of Naples and Trondheim in Europe.

As a result of his work on the method of moments, a succession of further research projects was sponsored by Air Force Cambridge Laboratories and by the National Science Foundation. These projects involved the application of moment methods to a variety of problems, such as radiation and scattering by bodies of revolution, transmission of waves through apertures, analysis of antenna arrays, and so on. This work is used by the U.S. Air Force to analyze radar targets and antennas, on aircraft and missiles. Each phase of the work has been devoloped into a general purpose computer program, and these programs are used today throughout the world. Another project, on reactively loaded aperture antennas, was sponsored by the Office of Naval Research. This work established a novel principle for controlling directive antenna arrays by varying reactive loads at the element input terminals. The method shows promise of being of use in the design of electronically scanned antenna arrays.

More recently, Dr. Harrington has worked on the problem of electromagnetic radiation

from computers and electromagnetic penetration into bodies through apertures. The second author of this writing, E. Arvas, is one of his later Ph.D. students who worked on very small apertures.

For aperture problems, he has made extensive use of generalized network parameters, using admittance matrices to describe the behavior of apertures. He has also worked on the electromagnetic analysis of printed circuits. In particular, he has helped to develop a numerical analysis of multiconductor transmission lines in multilayered dielectric media. The analysis has been organized into several user-friendly PC computer programs marketed by Artech House. Dr. Harrington has lectured in several short courses on electromagnetic analysis of printed circuits and has served as a consultant to industry in this area.

As a result of his extensive and significant research efforts, Dr. Harrington has received a number of honors and awards [1]. He has received a half-dozen "best paper" awards, both locally and nationally. He received the IEEE Fellow Award in 1968, the Distinguished Alumni Award of the Ohio State University in 1970, and the Syracuse Sigma Xi Research Award in 1971. He was appointed as Fulbright Lecturer to the Technical University of Denmark in 1969, and as Visiting Scientist to the Yugoslavian Academies of Science in 1972. For the two years, 1973–1975, he served as Distinguished Lecturer for the IEEE Group on Antennas and Propagation, giving lectures throughout the United States on numerical methods. He was in demand for seminars at Universities here and abroad, and he served as a technical paper reviewer for many scientific journals. He has served on many national and international scientific and technical committees, workshops, and other activities. He has served as a consultant to a number of industries and government laboratories. In 1981 he won the IEEE Syracuse Section "Kurt Schlesinger" Award for the development of the method of moments in electromagnetics. He received the IEEE Centennial Medal in 1984, and the Syracuse University Chancellor's Citation in 1986. He was appointed Distinguished Professor of Electromagnetics at Syracuse University in 1988. He received the IEEE Antennas and Propagation Society Distinguished Achievment Award in 1989, the URSI Van der Pol Medal in 1996, the Jubilee Tesla Medal in 1998, the IEEE Electromagnetics Field Award in 2000, and an IEEE Third Millenium medal in 2000. His 1989 Distinguished Achievement Award was for his development of the method of moments, for his numerous advances in electromagnetic theory, and for his books and papers which have enabled so many students, researchers, and engineers to enhance their understanding of electromagnetic theory and its applications. His writing is reasonably complete for understanding and not overcomplicated. He unselfishly made all of his work available to the general public.

As you know, the process of prototype development has changed significantly during the last three decades. Today's engineers are under serious time-to-market pressure. They just cannot go through many iterations of "build, test, and rebuild". On the other hand, the design engineers in the RF/Microwave industry need to satisfy required specifications

using new materials that reduce cost and weight and have a smaller footprint to reduce size. All of these specifications are possible to meet because of widespread use of Numerical Electromagnetics Analysis tools. During the last four decades, these "commercial simulation software" matured to the point where "if measured results do not agree with the simulated ones, something must be wrong with the measured results". It is a pleasant coincidence that a recent (July 2013) issue of *Microwave Journal* [2] has its cover feature article on "RF/Microwave Design Software Review" where the state of software provided by industry's software vendors is studied.

No doubt, Harrington is one of the earliest and most significant pioneers in developing the fundamentals of *Computational Electromagnetics*. His book *Field Computation by Moment Methods* published in 1968 is a classic that is in the library of almost every engineer/researcher/scientist who has interest in computational electromagnetics. It is such a "complete" book in addressing vastly different possible problems that, so far, 46 years later, it still does not require a second edition. It was one of the most cited books in IEEE media. Harrington's students and colleagues have further applied the Method of Moments (MOM) to so many different problems that, today, MOM is practiced by thousands of engineers all over the world. As mentioned by M.N.O. Sadiku [3] in his book, "*the number of problems that can be treated by MOM is endless, . . . , The following problems represent typical EM-related applications areas:*

- *Electrostatic problems*
- *Wire Antennas and scatterers*
- *Scattering and radiation from bodies of arbitrary shape*
- *Transmission lines*
- *Aperture problems*
- *Biomagnetic problems"*

Many user-oriented software use MOM. One of the early ones is the famous *Numerical Electromagnetics Code* (NEC) developed at the Lawrence Livermore National Laboratory in 1981. NEC and its compact version MININEC are still being used effectively. Some of the commercial design software tools such as FEKO and Sonnet covered in the July 2013 issue of *Microwave Journal* are also MOM based.

In summary, MOM is a very important building block of Computational Electromagnetics, and Harrington is undoubtedly the most significant contributor/pioneer of MOM. A recent photograph of Dr. Harrington is attached.

References

[1] R. Harrington, "Origin and development of the method of moments for field computation," *IEEE Antennas and Propagation Magazine*, vol. 32, no. 3, pp. 31–35 (see "About the Author on pages 35 and 36), June 1990.

[2] D. Vye (Microwave Journal Editor), "RF/Microwave design software review," *Microwave Journal*, vol. 56, no. 7, pp. 22–42, July 2013.

[3] M. N. O. Sadiku, *Numerical Techniques in Electromagnetics, second edition*. New York: CRC Press, 2001.

SOLUTIONS TO SOME ELECTROMAGNETIC BOUNDARY VALUE PROBLEMS

DISSERTATION

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By

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Approved by:

Adviser

First published in 1961, Roger Harrington's book "Time Harmonic Electromagnetic Fields" is one of the most significant works in electromagnetic theory and applications. Professor Harrington is a Fellow of the IEEE. Prior to his retirement from active teaching he was a Distinguished Professor at Syracuse University.Among his many awards and honors, he was awarded IEEE Centennial Medal in 1984, the IEEE Antennas and Propagation Society Distinguished Achievement Award in 1989, the URSI Van der Pol Medal in 1996, the Jubilee Tesla Medal in 1998, the IEEE Electromagnetics Field Award in 2000, and an IEEE Third Millennium Medal in 2000.