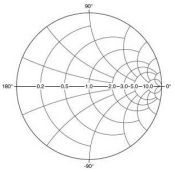
A. S. Inan, "Remembering Phillip H. Smith on his 100th Birthday," *2005 IEEE Antennas and Propagation Society International Symposium Digest*, Vol. 3B, pp. 129-132, Washington, D.C., July 3-8, 2005. (Note that this is the corrected version of the paper that was originally published in the *2005 IEEE AP-S International Symposium Digest*.)

Remembering Phillip H. Smith on his 100th Birthday

Aziz S. Inan
School of Engineering, University of Portland, Portland, OR 97203-5798
http://faculty.up.edu/ainan/

Introduction

Phillip H. Smith, inventor of the well-known Smith Chart, died in Berkeley Heights, New Jersey, on August 29, 1987, at the age of 82. Numerous biographical articles have already been published about Smith, his life, his chart, and his other achievements [1-15]. The goal of this biographical article is to help us remember Smith on his 100th birthday.



Smith's Early Life

Phillip Smith was born in Lexington, Massachusetts, on April 29, 1905, not far from MIT's Lincoln Laboratory. His parents, George and Rose Whitney Smith, were of Scottish and English ancestry. His mother was a descendant of Eli Whitney, the inventor of the cotton gin.

Smith spent his childhood in Lexington and attended Lexington public schools. In fifth grade, he had the same teacher that his dad had a generation earlier. While he attended Lexington High School in the early 1920s, he put together an amateur radio station using many homemade components. During this time, he also contributed a number of short articles to the radio section of the *Boston Traveler*. These radio-related activities left no doubt in Smith's mind that he wanted to pursue an electrical engineering career. However, they also had a negative impact on his studies in other areas such as history and French. As a result, he ended up spending an extra year studying these subjects in order to pass his college entrance exam.

In 1924, Smith entered Tufts College (now Tufts University) in Medford, Massachusetts, to study electrical communications. He maintained his radio amateur activities at college by owning and operating another amateur radio station. To commute between Lexington and Medford, he drove a reconstructed Model T Ford and later a four-cylinder Harley Davidson motorcycle. He also worked one summer as a Model T Ford garage mechanic, another summer as a draftsman, and another summer as a radio technician testing and troubleshooting deluxe Radiola brand radio receivers with price tags around $900—a small fortune in those days. In 1928, after graduating from Tufts College at the top of his class with a B.S. degree in E.E., he was offered and accepted a job at Bell Telephone Laboratories at a monthly salary of $120.

Working at Bell Telephone Laboratories and the Smith Chart

At Bell Laboratories, Smith's first assignment was in the Radio Research Department at the Deal Radio Laboratory on the coast of New Jersey. There he worked under J. C. Shelleng and E. J. Sterba, two well-known radio pioneers on directional shortwave antennas for trans-Atlantic and ship-to-shore radio telephones. His first task was to construct and test a 14-meter directional antenna array consisting of eight vertical dipoles to communicate across the Atlantic. In 1929, he was transferred to the new shortwave A.T.&T. Co. transmitting station in Lawrenceville, New

Jersey, where he struggled with antenna problems and electrical adjustments of system consisting a 1.5-mile-long line and some 20-odd directional antennas designed to communicate by short waves with Europe and South America. His task required countless measurements of standing waves which made him realize the important need for a quick method to compute the input impedance of transmission lines. In 1931, by modifying J. A. Fleming's 1911 "telephone" equation [16] in an effort to simplify the solution of the transmission line problem, Smith developed his first graphical solution in the form of a rectangular chart. Though the rectangular chart was very useful, Smith knew it had certain limitations on the amount of data that could be accommodated. He persistently continued to search for ways to improve his chart and never gave up refining it.

Smith's technical work was first published in 1932, as a footnote in an IRE Convention article written by his two colleagues at Bell Labs [17]. Smith also filed his first patent on the single-stub matching network on March 26, 1932 and the patent was issued on May 19, 1936 [18].

In 1934, Smith was transferred to the Radio Development Department at Whippany, New Jersey, to work on the development of commercial AM radio broadcasting equipment for the Western Electric Company. Later, while developing 500 kW coaxial line components for a radio station, he obtained a patent on the optimum conductor diameter ratio $\sqrt{e}$ for a coaxial transmission line, which results in maximum power handling capability for minimum diameter of the outer conductor [19, 20]. According to Smith, this was one of the simplest patents ever granted, the only claim being the single number 1.65.

In 1936, Smith constructed a new type of transmission line chart that eliminated most of the limitations in his first diagram. The new chart was a special polar-coordinate diagram which could show all values of impedances. Late in 1936, suspecting that a grid made up of a system of orthogonal circles might significantly enhance his chart, Smith approached two of his co-workers, E. B. Ferrell and J. W. McRae. They were familiar with the principles of conformal mapping, and early in 1937 helped Smith develop the transformation to a grid using orthogonal circles. This led to an improved chart which could accommodate all data from zero to infinity, essentially the same as "the Smith Chart" used today.

Smith approached a number of technical magazines for publication of his transmission line diagram; however the acceptance process was slow. Finally, after two years, Smith's article describing his chart was published in the January 1939 issue of *Electronics* magazine [21]. In a second article, published in the January 1944 issue of *Electronics*, Smith incorporated further improvements into his chart, including its usage alternatively as an impedance chart or an admittance chart [22, 23].

One of the first individuals who recognized the practical use of the Smith Chart in solving standing wave problems was Smith's former colleague from Bell Labs, A. G. Fox, who was involved in work on the new subject of waveguides. When the M.I.T. Radiation Laboratory was formed in 1940, their staff recognized the value of the Smith Chart and immediately put it into general use. Smith viewed M.I.T. people as his first customers. The first textbook which included coverage of the Smith Chart, written by the staff of the M.I.T. Radar School, was published in 1944 [24]. Around the same time, early coverage of the Smith Chart appeared in two other publications [25, 26]. Smith also constructed charts for L-type impedance transforming circuits which were published in *Electronics* magazine in 1942 [27, 28] and referenced in a wartime textbook published in 1942 [29].

In 1939, just before America entered the war, Smith was sent to Ft. Hancock to work with Signal Corps Laboratories on one of the most important "secret weapons" during World War II–radar. He spent about a year on Sandy Hook designing antennas and related components for the SCR-268 radar and later worked on the design of early submarine radar antennas under W. H. Doherty at Whippany, New Jersey.

After the war, Smith worked on the design of FM broadcasting antennas for Western Electric broadcasting equipment. During that time, he invented the "Cloverleaf" antenna [30]. Later, he became involved in military weapon system studies and supervised groups responsible for their high-frequency components.

After Retirement from Bell Labs

After a 42-year career at Bell Labs, Smith retired in 1970 and started a small company−Analog Instruments Company of New Providence, New Jersey−which initially sold a line of Smith Charts and related items. Later he added navigational instruments for light aircrafts. Around 1979-1980, Smith was diagnosed as having Parkinson's disease. He was still able to perform his normal activities until 1987 when he was hospitalized for a few days. He stayed in a nursing home for about two months before he died of pneumonia. When he died, it was reported that more than nine million copies of his chart had been sold.

Other Facts about Smith and His Achievements

For his contributions to the development of antennas and graphical analysis of transmission line characteristics, Smith was elected a Fellow of the IRE in 1952 [31]. Fifty years ago, at the age of 50, Smith served as the chairman of the IRE Antennas and Waveguides Technical Committee, between May 1, 1954 and April 30, 1955 [32]. He also received the 1974 Special Recognition Microwave Application Award from the IEEE-MTT Society for the application of microwave theory and techniques to the practical realization of the circular transmission line chart for analyzing microwave circuits, the Smith Chart [4, 5]. In 1990, the 50th anniversary of the Smith Chart was celebrated with a special session at the IEEE-MTT Society International Microwave Symposium in Dallas, Texas [10]. Smith also was elected to the New Jersey Inventors Hall of Fame in 1994.

Smith held 21 U. S. patents and published over 35 technical papers on antennas and transmission lines. He also wrote a book about the Smith Chart, published in 1969 [33].

A final note about Phillip Smith: One of his supervisors at Bell Labs described him as an intuitive, hardworking fellow, and perhaps more importantly, as one of those rare human beings with no enemies. He was liked and respected by his peers. Not being particularly versed in mathematics, he recognized when he needed help in solving a problem, and did not hesitate to seek it out. A quiet and humble man, he was always highly organized, persistent, super meticulous, upbeat and visionary in regards to technical matters. And it is the chart that he created 50 years before he died which still remains in use today, even with the high-tech computers and testing instruments, as the ultimate display which encompasses such a wide range of transmission line matching problems.

References:

[1] "Phillip H. Smith: Originator of the Smith Chart," *Microwave Journal*, vol. 1, no. 1, pp. 44-45, July/August 1958.

[2] G. S. Southworth, "More about Phil Smith…," *Microwave Journal*, vol. 1, no. 2, pp. 26-28, September/October 1958.

[3] F. A. Polkinghorn, "Philip Smith, Electrical Engineer," an oral history conducted in 1973, *IEEE History Center*, available at http://www.ieee.org/organizations/history_center/oral_histories/transcripts/smith3.html.

[4] J. H. Lepoff (Editor), "1974 Special Recognition Microwave Application Award to Phillip H. Smith," *1975 IEEE MTT-S International Microwave Symposium Digest*, pp. 6-7, Palo Alto, California, May 1975.

[5] J. B. Horton, "MTT Awards for 1974," *IEEE Trans. on Microwave Theory and Techniques*, vol. 23, no. 12, pp. 949-950, December 1975.

[6] J. Eyler (Editor), "Smith, Phillip H.," *McGraw-Hill's Leaders in Electronics*, McGraw-Hill, p. 470, 1979.
[7] J. Gregory (Editor), "Smith, Phillip H.," *Who's Who in Engineering*, 4th ed., American Association of Engineering Societies, p. 590, 1980.
[8] "Smith Chart Inventor," *IEEE, The Institute*, Obituary, p. 12, November 1987.
[9] L. Besser, "1987 IEEE MTT-S International Microwave Symposium Keynote Address," *IEEE Trans. on Microwave Theory and Techniques*, vol. 35, no. 12, pp. 1105-1106, December 1987.
[10] T. Saad, "Phillip Smith-A Brief Biography," *1990 IEEE MTT-S International Microwave Symposium Digest*, vol. II, Session T (Special Session): Smith Chart, pp. 837-838, Dallas, Texas, May 1990.
[11] J. E. Brittain, "The Smith Chart," *IEEE Spectrum*, vol. 29, no. 8, p. 65, August 1992.
[12] T. Saad, "Foreword," in L. M. Schwab, *Advanced Automated Smith Chart Software and User's Manual, Version 2.0*, pp. ix-xii, Artech House, 1995.
[13] R. Rhea, "Biography," in P. H. Smith, *Electronic Applications of the Smith Chart in Waveguide, Circuit, and Component Analysis*, 2nd ed., pp. xiii-xviii, Noble Publishing, 1995.
[14] "Phillip Smith," *IEEE Virtual Museum*, available at http://www.ieee-virtual-museum.org/collection/people.php?id=1234757&lid=1.
[15] "The Smith Chart," *IEEE Virtual Museum*, available at http://www.ieee-virtual-museum.org/collection/event.php?taid=&id=3456988&lid=1.
[16] J. A. Fleming, *The Propagation of Electric Currents in Telephone and Telegraph Conductors*, D. Van Nostrand, 1911.
[17] E. J. Sterba and C. B. Feldman, "Transmission Lines for Short-Wave Radio Systems," *Proc. I.R.E.*, vol. 20, no. 7, p. 1182, July 1932. (This paper was originally presented before the IRE Twentieth Anniversary Convention, Pittsburgh, PA, April 9, 1932.)
[18] P. H. Smith, "High Frequency Transmission System," *Official Gazette of the United States Patent Office*, vol. 466, no. 3, patent no. 2,041,378, p. 647, May 19, 1936.
[19] P. H. Smith, "Transmission Line," *Official Gazette of the United States Patent Office*, vol. 543, no. 2, patent no. 2,298,428, p. 264, October 13, 1942.
[20] P. H. Smith, "Optimum Coax Diameters," *Electronics*, vol. 23, no. 2, pp. 111-112 and p. 114, February 1950.
[21] P. H. Smith, "Transmission Line Calculator," *Electronics*, vol. 12, no. 1, pp. 29-31, January 1939.
[22] P. H. Smith, "An Improved Transmission Line Calculator," *Electronics*, vol. 17, no. 1, pp. 130-133, p. 318, p. 320, p. 322, and pp. 324-325, January 1944.
[23] J. Marcus and V. Zeluff (Editors), *Electronics for Engineers: Reference Articles, Charts, and Graphs from Electronics Magazine*, McGraw-Hill, pp. 326-331, 1945.
[24] *Principles of Radar Confidential*, The Staff of the M.I.T. Radar School, The Technology Press, pp. 8-66 to 8-69, 1944.
[25] W. Jackson and L. G. H. Huxley, "The Solution of Transmission-Line Problems by use of the Circle Diagram of Impedance," *J. I. E. E.*, pt. III, vol. 91, pp. 105-127, March 1944.
[26] W. Jackson, *High Frequency Transmission Lines*, Methuen's Monographs on Physical Subjects, John Wiley & Sons, Chapter VI, 1945.
[27] P. H. Smith, "L-Type Impedance Transforming Circuits," *Electronics*, vol. 15, no. 3, pp. 48-52, p. 54 and p. 125, March 1942.
[28] J. Marcus and V. Zeluff (Editors), *Electronics for Engineers: Reference Articles, Charts, and Graphs from Electronics Magazine*, McGraw-Hill, pp. 272-278, 1945.
[29] J. G. Brainerd (Editor), G. Koehler, H. J. Reich, and L. F. Woodruff, *Ultra-High-Frequency Techniques*, D. Van Nostrand, p. 546, 1942.
[30] P. H. Smith, "Cloverleaf Antenna for F.M. Broadcasting," *Proc. I.R.E.*, vol. 35, no. 12, pp. 1556-1563 and p. 1586, December 1947.
[31] "IRE Awards, 1952" *Proc. I.R.E.*, vol. 40, no. 5, p. 617, May 1952.
[32] "Institute Committees–1954," *Proc. I.R.E.*, vol. 42, no. 6, p. 1040, June 1954.
[33] P. H. Smith, *Electronic Applications of the Smith Chart in Waveguide, Circuit, and Component Analysis*, McGraw-Hill, 1969.