PHILIP H. SMITH

An Interview Conducted by

Frank A. Polkinghorn

IEEE History Center

January 19, 1973

Interview # 003

For the

IEEE History Center
The Institute of Electrical and Electronics Engineers, Inc.

and

Rutgers, The State University of New Jersey

It is recommended that this oral history be cited as follows:

Philip H. Smith, Electrical Engineer, an oral history conducted in 1973 by Frank A. Polkinghorn, IEEE History Center, Rutgers University, New Brunswick, NJ, USA.

Interview: Philip H. Smith
Interviewer: Frank A. Polkinghorn
Date: January 19, 1973

Polkinghorn: This is an interview with Philip H. Smith, former member of the technical staff of the Bell Telephone Laboratories, authority on antenna design, and originator of the Smith Chart for finding complex impedance. This interview was made on January 19, 1973, by Frank A. Polkinghorn, assisted by Ralph Lamar as recorder operator. Phil, I'd like to talk to you about your background and your career as a radio engineer. I think you were brought up in Lexington, Massachusetts? Will you tell us something about your family and education?

Smith: Yes, I was born and raised in Lexington, Massachusetts. When I was growing up, my family owned some twenty acres of farm land surrounding an old twenty-two room brick-ended farmhouse and barn. The house, which is now occupied by my sister, Mrs. Oliver Hooper, was built in 1799 and has been in the Smith family for six generations. I attended the Lexington public schools, and in the fifth grade I had the same teacher that my father had had a generation earlier, Miss Nellie Wright. My dad worked for twenty years for the brokerage firm of Paine, Webber and Company in Boston before he retired to go into the butterfly jewelry business and later a homemade candy business, both of which my mother had started to supplement family income.

In the early 1920s, while in Lexington High School, I put together an amateur radio station, 1ANB, with many homemade parts. The prefix W was not used in those days. During this period I contributed a number of short articles to the radio section of the Boston Traveler. Vacuum tubes were very expensive, and the so-called reflex circuits, in which a single vacuum tube performed several functions simultaneously, were of particular interest at the time. Also, Major Armstrong had just come out with a super-regenerated receiver. In this he periodically quenched an oscillating amplifier tube, which gave tremendous amplification, though difficult to control. I recall successfully building one of these curiosities and writing up my achievement in the Boston Traveler. My interest in radio left no doubt in my mind that I wanted an electrical engineering career. Unfortunately, it also detracted from my school grades, particularly in French and history. So I had to take an extra year studying those subjects to pass college entrance examination requirements.

After the equivalent of six years of French, I managed to pass the three-year intermediate French examination and an ancient history examination. I entered Tufts College in 1924 and majored in communications. I worked as a Model T Ford garage mechanic one summer, as a draftsman for another summer, and as a radio technician one summer for the Wireless Specialty Apparatus Company in Jamaica Plains, Massachusetts. My job was testing and troubleshooting Radiola receivers at the end of a long production line. The Radiola was the Cadillac of radio receivers at that time. They were in a console with a built-in power supply and loop antenna. The price tag was about $900. I graduated from Tufts College--now Tufts University--in 1928 with a degree of B.S. in E.E.

Polkinghorn: So you went to work for Bell Labs after that?

Smith: Yes. I was first interviewed by a General Electric Company representative, and I was made an offer of a job in their radio department in Schenectady, New York, at $24 a week. Before accepting this, and upon the advice of my Uncle Edward Dee, who was then assistant personnel director of the Western Electric Company, I applied for and was offered a job at Bell Telephone Laboratories, which I accepted. My first assignment was to the radio research department with the Deal Beach Radio Station in Deal, New Jersey. I started work on August 5, 1928. My salary was $30 a week. I was told I would receive a raise of $5 per week in six months if my work was satisfactory. We worked an eight-hour day, five and a half days a week. Deal was where the shortwave, transatlantic, ship-to-shore radio telephone research was being carried on. I had often listened in on my homemade receiver in Lexington to the radio telephone transmissions between Deal and the S.S. America at sea. Now I was working there. I was fortunate to have been assigned to work for two famous radio pioneers: Ernest J. Stillwell and John C. Shalley. Mr. Shalley had overall supervision of the Deal laboratory; and Stillwell, as we called him, was the antenna expert.

My first job was constructing and testing, with Art Cohen, another Bell Labs engineer, one or two years my senior, a fourteen-meter directional antenna array of eight vertical dipoles. This antenna was being the receiving site in the town of Rotten, England, which we jokingly called the "Rotten receiver." Shortwave radio was--and still is--vulnerable to magnetic storms caused by sunspots, and there was some hope that we could get across the Atlantic on a wavelength of fourteen meters during intervals when twenty- and thirty-meter wavelengths were knocked out by these storms.

Polkinghorn: What were the problems as you saw them at that time?

Smith: Well, prior to about 1927, telephone calls to Europe were via long-wave, very-low-frequency radio transmission, involving extensive and costly plant equipment which had very limited traffic capability. The demand for this service was far more than the system could supply. In 1927 Bell Laboratories had completed a huge experimental model, over a hundred feet long, that would improve the VLF transmitter, which was housed in a barn at Whippany, New Jersey. This was a single sideband transmitter that was capable of transmitting two telephone channels simultaneously with inverted speech, and was intended to supplement the existing long-wave facility at Houlton, Maine. However, this project was never completed because at about the same time, the far less expensive shortwave experimental installations, such as were being developed at Deal, were meeting with spectacular success in overseas voice communication. There were at least three major problems facing the early shortwave developments: One, a lack of understanding of the physics of shortwave radio propagation; two, the need for development of efficient, high-gain directional antennas; and, three, the need for development of large high-powered vacuum tubes. To illustrate the vacuum tube situation, the final stage of the shortwave transmitter, which I saw at Deal, initially consisted of a large bag of perhaps a hundred telephone repeater tubes, which in operation was a truly wondrous thing to behold. The Deal labs were actively pursuing work in all three of these areas. Personally, the work on antenna development held a particular fascination for me. I was able to contribute a number of basic inventions, including the transmission line matching stub and the conductor diameter ratio for the coaxial line, which is optimum for power transmission.

Polkinghorn: I suppose that this is when you got interested in finding complex impedances?

Smith: Yes. From the time I could operate a slide rule, I've been interested in graphical representations of mathematical relationships. In 1929 and 1930 I ran into an important need for a short method for computing input impedances of transmission lines. The shortwave development at Deal had reached the point where the Long Lines Department of AT&T had decided to go ahead with an ambitious project at Lawrenceville, New Jersey. This involved a mile-long array of curtain-type antennas supported on twenty-six steel towers, each 175 feet high, all beamed on England. And another half-mile-long similar array of antennas beamed on Argentina, South America. Having played a part in their design, I was given a major share of the responsibility for their proper electrical adjustment. This required countless measurements of standing waves to obtain the proper phasing and feed-line impedances. By taking advantage of the repetitive nature of the impedance variation along a transmission line and its relation to the standing-wave amplitude ratio and wave position, I devised a rectangular impedance chart in which standing-wave ratios were represented by circles. In January 1939 I had an article published in Electronics Magazine on a general-purpose circular slide rule with an impedance chart. Since then many articles by other authors have appeared in the literature dealing with specific uses.

Polkinghorn: I believe you wrote a book on the chart and how to use it.

Smith: Yes. I tried to write down the complete story of the development and uses of the so-called Smith Chart. This chart displays the behavior of all types of transmission lines and waveguides; consequently, it has found universal appeal. My book, published in1969, is entitled Electronic Applications of the Smith Chart in Waveguide, Circuit and Component Analysis.

Polkinghorn: Well, you finally left the Deal laboratory, didn't you?

Smith: Yes. In 1935 I left Deal on a six-month leave-of-absence, but I never returned. Bell Labs had decided not to go ahead with the long-wave transatlantic radio project called T-A-R, or "tar," and had established a laboratory for AM broadcast development under Bob Poole in the barn at Whippany, New Jersey. AM broadcasting was at the beginning of a period of renaissance due to the FCC's decision to permit power increases up to 50,000 watts of radiated power, provided it could be proven that this would not result in daytime interference with other AM broadcast stations. The key to obtaining FCC approval was the multi-tower directional antenna, which could control radiated power levels in chosen directions. Since increased power meant increased advertising revenue for the station, the Western Electric Company was flooded with requests for consultant services and new equipment. My new job involved both. I was kept busy for about three years calculating antenna array patterns, designing antenna branching and phasing circuits, and then getting involved with a mechanical design of a complete new line of Western Electric AM broadcast equipment. I subsequently served in the field engineering department of the laboratories under Stu Price, one of the charter members of the IRE, during which time I consulted on broadcast antenna installation problems and tuned and adjusted about twenty directional antenna installations throughout the eastern part of the country.

Polkinghorn: But then the war came along.

Smith: Yes. For some two years prior to U.S. involvement, the Signal Corps had started to work on a new secret weapon called radar, an acronym for Radio Detecting and Ranging. Radar, as we all know, proved to be one of the most important electrical developments of World War II. This first radar was known as the SCR-268, and operated on a frequency of about 215 MHz. In 1939 the Western Electric Company was asked to prepare manufacturing information based on the Signal Corps model, which would enable Western to eventually produce some 3,000 of these radars. Their function was primarily searchlight control, but there was some hope that they might prove to be sufficiently accurate for fire control--and they certainly served admirably in the Italian campaign.

As one of a team of specialists, I went to Fort Hancock in 1939 to work on the bedspring antennas used in this radar. These were small curtain arrays of dipole elements. There was a separate transmitting antenna and two separate receiving antennas, one of which load switched; that is, it tilted the beam back and forth rapidly in elevation and the other in azimuth. The antennas were manually steered in azimuth and in elevation by two separate operators who sat out in the open on hay-rake type seats, balancing pips on their respective A-scopes to keep the antennas on target. The field operator kept the target pip in the range gate on a third A-scope. The angles and range data were mechanically linked to an analog corner convertor and an M-4 gun director. The entire equipment was transportable on trailers. And the antennas, which could be rotated through 360^{o} in azimuth and 90^{o} in elevation, were some forty feet in overall length and ten feet high.

Polkinghorn: Then radars were developed operating on higher frequencies.

Smith: By the time the U.S. joined World War II, radars were being developed and operated on higher frequencies and consequently with smaller antennas. In 1940 a radar was developed at Whippany, under the direction of Bill Tynes, which operated on approximately 700 MHz, which gave splendid service, particularly in the Pacific. This was followed, with the British development of the magnetron, by a number of equipments operating around 3,000, and later 10,000, MHz. The antennas for these latter radars were based on optical principles using parabolic reflectors of various shapes and sizes and metal-plate lenses. Some scanned electronically and involved considerable ingenuity and design effort. Much help was provided by the Bell Laboratory's radio research group at the Holmdel, New Jersey, laboratory under Harold Friis. My contribution was the electrical design of submarine radar antennas for the BPS-1 and BPS-3 equipments. I was project engineer for the SE radar. Details of these antennas are too numerous and involved to go into very much at this point.

Polkinghorn: After the war, I believe you went back into broadcasting work.

Smith: After the war, FM broadcasting came into full blossom, and Western Electric started to design and provide a complete line of FM transmitters and antennas. At that time I designed a novel high-gain, stacked-array antenna whose elements resembled a cloverleaf--a four-leaf clover. Consequently, this was dubbed the "cloverleaf antenna." This was widely advertised by Western Electric, and several dozen installations around the country were made. But before the entire program got rolling, the competition from firms that had sprung up during the war and were now looking for new business, was so devastating that Western Electric decided to get out of the specialty products business. We abruptly terminated the FM development and sold various portions of our non-telephone business to several different companies. That ended my broadcast career.

Polkinghorn: You were at Murray Hill then for a while.

Smith: Yes. At Bill Dougherty's request, I went to work in the transmission research department at Murray Hill, New Jersey. Bill's problem was a surplus of fine scientists and a lack of sufficient engineering personnel. The project was to develop a new type of coaxial cable, which consisted of a large number of inner conductors embedded in a low-loss laminate. The theory predicted that this type of cable would have up to forty percent less attenuation than the simple tube conductor cable for the same amount of conductor dimension. This cable, known as Cloggston cable, was invented by A.M. Cloggston at Bell Laboratories. It was company confidential at the time. If it could have been successfully developed and produced at a reasonable cost, it would obviously have been of immense value to the Bell System. After nine months' effort, it became clear to me that tolerance requirements and the thickness and spacing of the conducting layers were beyond any practical possibility to achieve. I felt that I was knocking my head against a stone wall. The project was subsequently put on a back burner.

Polkinghorn: So you went back to Whippany in military projects.

Smith: Yes. I returned to supervise a group working on the radar design for the Distant Early Warning DAR line, which was to be extended across the Arctic reaches of North America. We also worked on the Sage System antennas for tracking all airplanes of known or unknown origin flying above the continental United States. The radar provided coverage in areas shadowed by mountainous terrain. And there was the Nike Zeus, the Nike X projects, Nike II projects, as well as the low-altitude missile radar known as HAWK, later developed by Raytheon.

Polkinghorn: The Nike Zeus had a huge antenna, as I recall.

Smith: Yes. This antenna, built on an army project at White Sands Missile Range, certainly was a novel and unique design in many respects. It used a solid sphere that was lightweight, artificial dielectric, eighty feet in diameter. I originally proposed this design as an alternative to the larger rotatable arrangement of parabolic reflector-type antennas. The huge sphere served as a common focusing element for a large number of feed horns mounted on its surface, which produced a multitude of individual pencil beams. The entire assembly rotated at ten revolutions per minute on what was then the world's largest ball bearing, some thirteen feet in diameter. It provided hemispheric coverage at a data rate of three-second intervals. A subsequent design, which I had proposed, and which was installed at Kwajalein in the Nike II installation, used a half sphere dielectric over an extended, flat, conducting ground plane. The ground plane provided a mirror image of the half sphere, thereby creating the effect of a full sphere. In this antenna the large lens was stationary, and only the feed horn assemblies rotated. The dielectric lens in the Kwajalein antenna was composed of expanded-beam polystyrene, molded into two-foot cubes. The foam was loaded with millions of 3/8-inch-long aluminum slivers randomly oriented. The dielectric constant of the box was varied from mere unity at the surface of the lens to 1.4 at its center, by varying the concentration of the slivers. The basic principles of the variable dielectric spherical lens are credited to Professor Lunenberg of Brown University, which he derived from ray optics.

Polkinghorn: How did that Lunenberg antenna work out?

Smith: Well, these antennas performed fully as predicted. However, as in any rapidly developing field, specific models at various stages of development cannot keep pace with newer concepts, such as, in this case, the electronically steered phased arrays used in later defense systems. The Nike Zeus antenna at White Sands and the Nike II at Kwajalein provided much insight into the target-acquisition and tracking problem. The Nike Zeus antenna was finally junked, but not without some criticism that it might have been of considerable value to radio astronomers. The Nike II at Kwajalein was also junked, and some of the polyform can still be seen in the construction of native huts and paddleboats. The most important commercial spin-off from this antenna development was the extensive use shortly thereafter of molded expanded-beam polystyrene. And also in domestic articles such as hot cups, cold cups, insulation, packing forms, even surfboards, and so forth.

Polkinghorn: You also worked on the antennas for the Safeguard System, did you not?

Smith: Yes. My group was given responsibility for the electrical design of the phased-array antennas in the Safeguard System. I coordinated this design effort in the Bell Laboratories with Wheeler Labs on Long Island, who worked with us on the subcontract. Wheeler Labs assigned between fifteen and twenty engineers to this project, extending over a period of about four years. It was my job to keep them busy and productive.

Polkinghorn: What do you consider the most important work that you did?

Smith: Well, I guess it would have to be the development of my transmission-line impedance chart, of which over eight and one-half million copies have been sold. The most enjoyable work was in AM broadcasting.

Polkinghorn: You've been quite active in professional societies, particularly in the IRE and its succession to the IEEE, have you not?

Smith: Yes, I have. I'm presently a member of Commission Six of Union Radio Scientific International, or URSI, and a member of six committees in the IEEE. Over the years I've served on many more. I was chairman of the GAP Committee for the IEEE's fiftieth anniversary issue of Proceedings. Although much of my work has been associated with standards, I've also served on section and group awards committees and membership and on some of the committees.

Polkinghorn: I believe you're a Fellow of the Institute.

Smith: Yes, I was elected a Fellow in 1952, "for contributions to the development of antennas and graphical analysis of transmission line characteristics."

Polkinghorn: You've written quite a few articles also, have you not?

Smith: Yes. I have written something over thirty articles for publication in my own name, as well as contributed to many proposals and documents that went out over the company's name.

Polkinghorn: I believe it would also be interesting to know that you hold a pilot's license for airplanes.

Smith: Well, I first learned to fly and obtained my pilot's license in 1950. I've since owned two airplanes, which I've flown over most of the United States, Mexico, Cuba, and the Bahamas. In all, I've accumulated 1500 hours of flying time. Flying has given me one of my greatest pleasures.