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Probing the Sky

Probing the Sky with Radio Waves: From Wireless Technology to the Development of Atmospheric Science. By Chen-Pang Yeang. Chicago, IL: University of Chicago Press, 2013, 384 pages.

Probing the Sky with Radio Waves: From Wireless Technology to the Development of Atmospheric Science, by Chen-Pang Yeang, reads like a suspense novel. Yet it represents a masterpiece of philosophical and historical significance, displaying intimate knowledge of the technical and scientific subject matter. *Probing the Sky with Radio Waves* leads us from Heinrich Hertz's discovery of the propagation of centimeter length waves in 1888 and Guglielmo Marconi's transatlantic high frequency radio transmissions in 1901, to the discovery of Earth's ionosphere and the remote exploration of the ionosphere with radio waves in the 20th century. The explosive expansion of "wireless" communication from these early days to our time warrants this intimate look at the initially slow development of wireless radio, the engineers and inventors and the radio amateurs advancing the technology, and the physicists and mathematicians on all continents who developed the theories of radio wave propagation in an atmosphere that is partially "ionized" by solar ultraviolet and X-ray radiation: the ionosphere. Engineers, especially, and students in the frontier technology and research of space weather exploration will greatly value finding the origins of their research tools and methods in this excellent history. Application of the Humboldtian approach: "comprehensive and extensive fieldwork, careful preparation for expeditions, meticulous collection of data" turned natural history into modern field theory. Yeang reports on the often diverging efforts of individuals and teams of scientists, mainly in Europe and the United States, who tried to explain how radio waves can propagate over large distances in a then widely unknown medium, the atmosphere/ionosphere, in the presence of a conductive boundary, the earth's surface.

The book is divided into three major parts. The early studies from about 1901 to 1919 are portrayed in Part I (chapters 2–4). Eminent scientists at the time led the endeavors to explain how radio waves can propagate to large distances along the earth's curvature: the Briton, Hector Macdonald in Cambridge, the French mathematician Henri Poincaré in Paris, and the theoretical physicist Arnold Sommerfeld in Munich and electrical engineer Jonathan Zenneck in Braunschweig, Germany. They all developed models for the surface diffraction of radio waves around the curvature of a large perfectly conducting sphere, although Zenneck's team also considered the effects of limited conductivity. The problem was, as Yeang discloses, that these surface diffraction theories explained the long-distance propagation in principle, but there were no numerical experimental data against which to test the theories. The situation changed after 1910 when the U.S. Naval Wireless Laboratory in Washington began conducting large-scale propagation studies that produced the Austin-Cohen formula for the specification of the electric field strength as a function of distance and wave length λ. It soon became apparent that none of the surface diffraction theories had an exponential decay factor proportional to $\lambda^{-1/2}$ that the empirical Austin-Cohen formula predicted. The mathematical physicists in Germany, France, and England tried applying more refined mathematical tools to improve the model predictions, while the "radio physicists" and "radio engineers" in the U.S., U.K., and the Netherlands increasingly turned their attention to the possibility of "atmospheric reflection" of radio waves.

Part II (chapters 5–8) of the book tells the story of the" discovery" of the ionosphere. As early as 1902, Oliver Heaviside in England and Arthur Kennelly in the United States had independently postulated the existence of a "conducting layer" in the upper atmosphere, subsequently referred to as the Kennelly-Heaviside layer. But it took another decade before questions about the physical nature of this layer were asked. The English engineering scientist William Eccles was the first in the 1910s to describe the layer as "a body of electrons and positive ions that emerged as sunlight decomposed air." The commercial and military

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applications of wireless technology in the early decades favored long radio waves with wavelengths above 200 meters, and U.S. government regulations limited the use of the radio spectrum by radio amateurs to frequencies above 1.5 MHz, i.e., λ < 200 m, which was considered a "useless" band at the time. The radio amateurs found that short-wave radio can successfully communicate over larger distances at least at certain times of the day, and in World War I the military on both sides discovered the advantages of short-wave radio: smaller antennas and larger bandwidth. Radio amateurs will appreciate the great coverage Yeang gives in chapter 5 to the contributions made by enthusiastic amateurs around the world to the development of short-wave radio technology and propagation characteristics. In the U.S., the hobbyist society of radio amateurs, the American Radio Relay League (ARRL), cooperated closely with the National Bureau of Standards (NBS) in national and transatlantic "fading" experiments, and John Dellinger and his team at NBS analyzed the large database that was collected (it is interesting to note here that the Union Radio-Scientifique Internationale (URSI), which was founded in 1919, presents the "Dellinger Gold Medal" every 3 years to an outstanding radio scientist/engineer). In chapter 6, Yeang delineates how wave propagation studies began evolving into atmospheric physics research in the 1920s. To explain the observations made with the studies and to make reliable propagation predictions it became necessary to explore the physics of the "reflecting atmospheric layer" that had earlier been conjectured by Kennelly, Heaviside, Eccles, and others. In this process, short-wave radio became a powerful tool for remote sensing of the upper atmosphere, initially in the U.S. and the U.K. Edward Appleton at the Cavendish Laboratory used a "frequency changing" technique that provided the long sought-after "direct" evidence for the existence of the Kennelly-Heaviside layer. This layer is today called the E layer after Appleton's experiments established the existence of a second layer that he called the F layer in the upper atmosphere, or as we say today, the ionosphere. Sir Edward Appleton also was the first to recognize and describe the effect of the earth's magnetic field on radio wave propagation in the ionosphere. He received the Nobel Prize in Physics in 1946, and now every three years URSI awards the "Appleton Prize" for outstanding ionospheric physics research. In the U.S., Gregory Breit and Merle Tuve at the Carnegie Institute of Washington conducted pulse-echo experiments for the exploration of the ionosphere. Their pulse sounding technique in advanced digital form is still widely used today for monitoring and exploring the ionosphere, for example in the worldwide ionosonde network of the Digisonde Global Ionosphere Observatory (GIRO) that simultaneously measures ionospheric vertical electron density profiles in real time at nearly 100 stations.

Part 3 (chapters 9–11) portrays and reviews the development of the general magneto-ionic theory evolving in the U.K., the U.S., Germany, and France. The author cites the monograph of John Ratcliffe "The Magnetic-Ionic Theory" (1959) as providing a good synopsis of the major developments of radio-wave propagation theory in the 1920s. The microphysics treatment of the ionosphere engaged many scientists in the late 1920s and the 1930s, and the debate – as the author shows – continues today. Ratcliffe's monograph takes a pragmatic approach in describing the interaction of radio waves with the ionosphere by adopting the so-called "Appleton-Hartree" equation for the index of refraction that was derived with the microphysics approach. The discussion about whether the "Lorentz correction," which considers the interactive forces between charged particles should be included in the Appleton-Hartree equation, is fascinating. Yeang concludes that the Lorentz term should be removed from the equation, as was already done by Radcliffe.

I thoroughly enjoyed reading Yeang's book, and my only regret is that it was not around when I entered the field of ionospheric radio physics. Much of my frustration reading the literature and textbooks would have been alleviated had I realized at the time that so many of the "facts" presented were based on hypotheses or assumptions. Prof. Yeang provides this insight with his book. One reference that I was missing was the first book ever published with the title *Die Ionosphäre* by Karl Rawer in 1952 (translated into English in 1956, *The Ionosphere*). But this complaint may be too personal, and merely triggered by the fact that I have been Rawer's student.

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