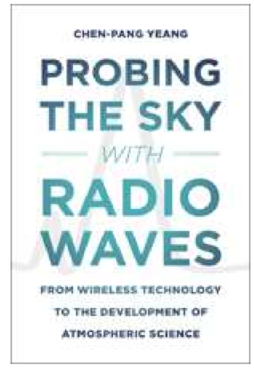

Title: ***Probing the Sky with Radio Waves ~ From Wireless Technology to the Development of Atmospheric Science***
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Reviewer: Whitham D. Reeve

Every person interested in radio propagation who is alive today knows the Earth's upper atmosphere is ionized by solar radiation, but such knowledge did not always exist. How and when was it discovered? ***Probing the Sky with Radio Waves*** provides answers by starting at the beginning of radio in the late 1800s and progressing through the arduous and time consuming experiments, guesswork, arguments, analyses and measurements and more measurements through the early 1930s. This book likely will become a classic on the discovery of how terrestrial radio waves propagate.

The Sun controls Earth's ionosphere. Earth's ionosphere, in turn, greatly affects radio communications and radio astronomy and even precision navigation using global satellite navigation systems. All radio astronomers – amateur and professionals alike – can benefit by reading ***Probing the Sky with Radio Waves***. Readers learn the history of science and technology associated with ionospheric radio transmission and reception from the time of Marconi's claim of overseas communications in 1901 through the 1930s. By that time the development of ionospheric science had moved from theory development to routine measurement. Those measurements, which continue today, have helped us learn many technical details of ionospheric propagation. Nevertheless, our knowledge is far from complete.

This is not a book on the mathematics of radio propagation. Rather, it is a narrative that is not afraid to mention and attempt to explain the relevant principles of radio and ionospheric physics. This book's scope is much narrower than the broad subject of the ionosphere and ionospheric radio propagation. It is focused on how the ionosphere was probed with radio waves to learn and measure its properties. The main interest is ionospheric sounding, which is a radar technique that involves transmitting a range of frequencies into the ionosphere and measuring the returned signals to determine the altitudes of reflection. Early investigations of radio propagation used single frequencies or frequencies within a narrow range and it was not until a wider range was employed that the ionosphere began to be revealed.

From my perspective, there is too little discussion of the radio technology used to accomplish the early probing. However, there are detailed discussions of the people involved, including physicists, engineers and amateur radio operators, and how they collaborated, argued, competed and experimented to explain why and how their radio transmissions were or were not received.

Probing the Sky with Radio Waves is not as well illustrated as it should be – it is nothing like Ken Davies' ***Ionospheric Radio Propagation*** in that regard. Also, many illustrations are taken from original scientific papers but, unfortunately, they are poorly or incompletely explained by the author. Many charts have unlabeled axes or the axes labels are not defined anywhere. For me this considerably slowed my reading of the book as I struggled to determine exactly what a given chart actually showed and why it was relevant. Perhaps the author understood the chart but I did not, and I suspect other technical readers will have similar problems.

This book is for readers who already have a working knowledge of Earth's ionosphere and how it affects radio propagation. It is a bonus if you also are interested in radio history. Many things associated with propagation will be recognizable, including the so-called *Heaviside layer* and *Appleton formula*, *Appleton-Hartree formula*, *Lorentz correction* and so on. Two scientists, Oliver Heaviside and Arthur Kennelly, separately proposed in 1902 a huge conducting concentric shell in the upper atmosphere to explain how radio waves reached long distances beyond the horizon. In this theory radio waves were reflected back and forth between the conductive Earth and the conductive reflection layer. This became known as the Kennelly-Heaviside layer or just Heaviside layer, a name sometimes used today (particularly in Britain) to explain low and medium frequency transmissions propagated below the E-region of Earth's ionosphere.

Prior to the theoretical proposal for the Heaviside layer, other explanations were published to explain how long wavelengths (hundreds of meters) could reach beyond the horizon. At that time, state-of-the-art radio technology used wavelengths in the range of 400 m corresponding to a frequency of 750 kHz. At first, the principles of diffraction were borrowed from optics to explain beyond horizon propagation along Earth's surface. This seemed adequate for wavelengths longer than 200 m. However, as equipment capable of transmitting and receiving higher frequencies became available, it soon became clear that diffraction theory could not explain everything that was happening, including the so-called skip zone where radio waves could not be received at certain intermediate distances.

In 1912 a physicist named William Eccles proposed a theory of atmospheric ionization from solar radiation, which caught the eyes of other scientists and led to additional research and measurements. Theories abounded, some mutually exclusive. Most were ultimately wrong or incomplete. Many theories were advanced that fit only specific equipment configurations and frequencies and, thus, were repeatable only with identical setups. However, each new theory or set of measurements was a stepping stone that provided an incremental contribution. At the same time investigators improved their apparatus and made additional measurements to help prove or disprove each new theory. ***Probing the Sky with Radio Waves*** discusses each step, the people involved and when they performed experiments and published their results.

By the early 1920s radio amateurs had advanced their own state-of-the-art in radio electronics and started to make their own measurements. Many of those amateurs had been associated with military radio in World War I and had accumulated considerable knowledge of radios and antennas at shorter wavelengths (frequencies of a few megahertz). They became heavily involved in transatlantic radio experiments and provided specific measurements for use in theory development while at the same time fighting with commercial radio broadcasters for spectrum. At this time the American government was not as strict as European governments, the latter readily granting monopoly status to giant corporations at the expense of their radio amateurs. In spite of this, American radio amateurs along with amateur radio enthusiasts in Britain and France made considerable contributions to our knowledge of ionospheric radio propagation.

Eventually, some scientists became convinced that refraction in Earth's upper atmosphere played an important role. Refraction is the bending of an electromagnetic wave path caused by varying velocities of propagation in the ionospheric regions. Refraction theories were initially developed for ionized media without taking into account the geomagnetic field. However, solutions to radio propagation equations were eventually developed that included magnetic effects. The most important and longest lasting equation was given the name Appleton-Hartree formula, although others also derived the same formula about the same time (for interested readers, this formula is derived in the Davies book previously mentioned). Solutions showed that a linear polarized radio wave in the ionosphere and magnetic field splits into two oppositely rotating elliptically polarized components called the ordinary and extraordinary waves. These have different phase velocities within the ionized media and interact with it in different ways. The angular relationships between the propagating wave and Earth's magnetic field can take on infinite variations, to say nothing of the ionosphere's variations with frequency. These are the magneto-ionic effects that are still being studied today.

The first attempt to explain the skip zone – an area between the transmitting and receiving stations that cannot receive sky waves – was by radio amateur John Reinartz in 1925. His theory was based on the Heaviside layer and had other shortcomings, but it was a start. Eventually, Albert Taylor and E.O. Hulburt of the US Naval Research Laboratory (NRL) came up with a good explanation that they published in early 1926. It is somewhat surprising that NRL collaborated with radio amateurs on many experiments and measurements during this timeframe. The US Navy is like navies all over the world – they are not known for collaborating, even within their own ranks.

Toward the end of the ***Probing the Sky with Radio Waves***, the author provides interesting descriptions of experiments done to measure home-made laboratory plasmas in glass tubes with electrodes, oscillators and inductive tuning. These plasmas were made to simulate the ionosphere and thus learn the ionosphere's characteristics under tightly controlled conditions. However, problems arose in that the resulting measurements did not agree with the theory. Many scientists were convinced the theory was correct and, thus, the measurements must be wrong (sound familiar?). Several different parties repeated the experiments with either the same or slightly different setups but always obtained the same results. Stuck in the trench of supposedly faulty measurements, someone would describe what was wrong with each experimental setup and efforts would then be made in the next experiment to correct the problem. However, after several iterations of the same measurements with the same results, it finally dawned on the more open-minded investigators that the theory was wrong. So, it was back to the chalkboard to develop new theories.

The book as a whole follows a chronological path but individual sections and chapters often do not because of the necessities of presentation. I occasionally found this temporarily confusing. However, all-in-all, this is an interesting book that describes the paths followed from there to here in radio propagation science. It always amazes me how much was learned a long time ago using very unsophisticated equipment by our current standards. It also amazes me how little science and scientists have changed over the last 100 years.

Reviewer - Whitham Reeve presently is a contributing editor for the SARA journal, *Radio Astronomy*. He worked as an engineer and engineering firm owner/operator in the airline and telecommunications industries for more than 40 years and has lived in Anchorage, Alaska his entire life.