Microwave Spectral Line Model Development: A Retrospective in Honor of Dr. Hans J. Liebe

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The quantum mechanical basis for microwave spectral line models of oxygen and water vapor absorption as used in radio astronomy, Earth and planetary remote sensing, and telecommunications can be traced to the work of J.H. Van Vleck in 1934, and extended by Van Vleck and V.F. Weisskopf (1945), G. Herzberg (1950), then more fully studied by C.H. Townes and A.L. Schawlow (1955), M.W.P Strandberg (1954), and others. The extensive impact of spectral line models in radiowave propagation is ubiquitous, and seen in the design of virtually all microwave radar, radiometer, navigation, and communication, systems, as well as in many devices such as lasers, masers, fiber amplifiers, and atomic clocks used for precision timekeeping. However, the early spectral line models required a more complete empirical characterization of the absorptive and refractive line parameters for water vapor and oxygen than available using approximate solutions to the problem of interacting fields and distributions of gas molecules.

Beginning in the late 1960s, the phenomenological characterization of atmospheric spectral line parameters was undertaken by Dr. Hans J. Liebe at the National Telecommunications and Information Agency (NTIA) in Boulder. Using closed-path resonators, Dr. Liebe performed extremely careful laboratory measurements of the absorption and refraction of oxygen and water vapor. Owing to the wide range of opacities exhibited by water vapor and oxygen, along with the nascent state of millimeter-wave technology, such measurements were difficult to make with the precision needed to improve existing theoretically-based models. Dr. Liebe's careful attention to detail in the development of his equipment and in his data analysis resulted in the Millimeter-wave Propagation Model (MPM, 1977), later refined in 1985. The MPM remains to date perhaps the most reliable and oft-cited means of accurately predicting terrestrial atmospheric refractivity at frequencies from ~1 up to ~300 GHz, including the effects of Zeeman splitting of the spin-rotational O_2 band, the water vapor continuum spectrum, and the absorption by liquid water and aerosols. The development of this valuable legacy model, some of its many contemporary applications in passive remote sensing, and a discussion of Dr. Liebe's experimental methods will be presented.