From November 2009 *High Frequency Electronics*

The Amazing Mr. Maxwell

Over the past few years, much attention has been given to the life and work of James Clerk Maxwell, whose famous set of equations define the behavior of electromagnetic fields. In the RF/microwave community, much of this attention has been the result of lectures and articles by Dr. James Rautio of Sonnet Software.

Another recent article [1] highlights a number of Maxwell's achievements other than his field equations and sheds light on his methods for approaching scientific problems. These notes highlight the two sides of Maxwell's work: great admiration for his work on EM field theory, and the lack of recognition of much of his other work, as well as his place in history.

Maxwell's "Other" Achievements

Maxwell often completed or clarified the work of predecessors and contemporaries. For example, building on techniques begun by Newton, Helmholtz and others, he developed the definitions and techniques of combining colors, settling on the Red-Green-Blue method that would later become the basis for color television. Under Maxwell's direction, a distinguished photographer of the day created the first-ever color photograph. He also confirmed that the receptors in the human eye responded to three colors, explained the cause of color blindness, and developed a means of evaluating macular degeneration!

Maxwell also determined the behavior of Saturn's rings, which led to further work on the kinetic theory of gases. His work on Saturn's rings would not be confirmed by observations for another 38 years, but his work with Boltzmann on gases led to the first ever application of statistical mathematics in science—the distribution probability of gases as a function of temperature. It is widely accepted that this work led directly to the use of statistical probabilities in quantum mechanics.

Among his other achievements are the method for analysis of physical stresses using polarized light and the reconciliation of different methods and theories for determining the speed of light.

Creating Mathematical Descriptions

Maxwell's greatest talent was developing the mathematical outline of physical laws. His famous equations are often considered as completing the mathematics of work by Faraday, Gauss, Ampere and others. His first paper (at age 14) was an analysis of plane curves, which led to further geometric analysis of optics. He contributed to different researchers' work on optical theory, and especially optical instruments, by providing mathematical descriptions of optical paths and the means for maintaining accuracy throughout the optical path.

His Method of Mechanical Visualization

To understand how Maxwell approached his science, we need to know that he arrived at many of his conclusions through an intuitive process, based on mechanical analogy. For example, he approached the work of Faraday by comparing the laws of electricity to the behavior of an incompressible fluid.

Much has been said about his electromagnetic field theory being based on an aether, a medium that is acted upon by electromagnetic forces. Although Maxwell personally believed in the existence of an aether, his theory did not require it. He understood that it was an artificial construct which helped build a mathematical model. After all, he had already shown that factors developed by analogy may "drop out of the equation" in the final mathematical descriptions. Today, the use of such fictional structures is a common mathematical technique.

Maxwell even defined an experiment that would confirm or deny the existence of the aether. Some years later, the experiment was famously performed by Mickelson and verified that an aether did not exist.

Difficulties in Being Properly Recognized

History has had mixed responses to Maxwell's work, and he has often been overlooked in references to the world's greatest scientists. Part of this lack of recognition is due to hard-to-describe intuitive concepts included in some of his work. He was also continually criticized for having incomplete mathematical descriptions—although recognized as ground-breaking at the time, his famous equations required "clean up" by Heaviside, Hertz, Poynting, Fitzgerald and others in order to make them useful for experimentation.

Maxwell was not an egotist; he did not promote himself like many of his contemporary scientists. He was well-respected and deeply involved in the discourse concerning his specialties, but he may not have been so well known in the larger scientific community.

Similarly, he did not insist on having every answer. He was apparently comfortable with open-ended problems. For example, when working on the dynamics of gases, he found that the system as a whole could be described, but did not remain valid down to the molecular level. Instead of trying to force the creation of an uncertain theory, he simply said something like, "we don't yet understand the behavior of molecular encounters." He was right—the answers would show up later in quantum theory.

Maxwell's equations have this open-ended characteristic. Perhaps this is his greatest achievement—his work is a framework that has been built upon by later discoveries, not replaced by them.

Reference

1. T. Sarkarm, M. Salazar-Palma, D. Sengupta, "Who Was James Clerk Maxwell and What Was and Is His Electromagnetic Theory," *IEEE Antennas & Propagation Magazine*, Vol. 51, No. 4, August 2009.