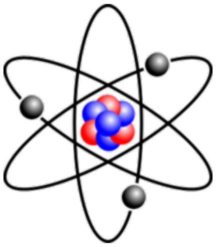

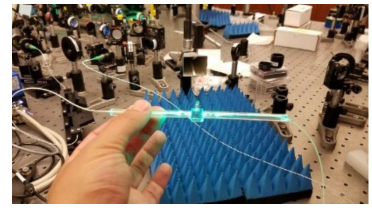

Rydberg Atom-Based Sensors:
Transforming Measurements and Detection of Radio-Frequency Fields and Communication Signals

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Fundamental to all electromagnetic/communication measurements is having accurately calibrated probes, antennas, and power meters in order to measure either electric (E) fields or power. One of the keys to developing new science and technologies is to have sound metrology tools (i.e., measurement tools) and techniques. A stated goal of international metrology organizations, including the National Institute of Standards and Technology (NIST), is to make all measurements traceable to the International System of Units (SI). The world of measurement science is changing rapidly with the SI redefinition that occurred in 2018. As a result of the shift towards fundamental physical constants, the role of primary standards and measurements must change. Atom-based measurements allow for direct SI-traceable measurements, and as a result, measurement standards have evolved towards atom-based measurements over the last few decades; most notably length (m), frequency (Hz), and time (s) standards. Recently, there has been a great interest in extending this to magnetic and electric (E) field sensors. In the past 10 years, we have made great progress in the development of a fundamentally new direct SI-traceable approach based on Rydberg atoms (traceable through Planck's constant, which is now an SI defined constant). In these Rydberg atom-based sensors, a conventional antenna (which relies on currents flowing on metal surfaces) is replaced with atomic-vapor placed inside glass cells. The Rydberg atom-based sensors now have the capability of measuring amplitude, polarization, and phase of the RF field. As such, various applications are beginning to emerge. These include SI-traceable E-field probes, power-sensors, voltage standards, receivers for communication signals (AM/FM modulated and digital phase modulation signals), and even streaming video and playing video games over the air with no lag time. In fact, this new atom-based technology has allowed for interesting and unforeseen applications. These new Rydberg atom-based sensors will be beneficial for 5G and beyond in that they will allow for the calibrations of both field strength and power for frequencies above 100 GHz. Most of the work on Rydberg atom-based sensors has been done at room temperature (the atomic vapor in contained in a glass cell, something called "hot vapor" or "warm vapor"). However, there is other work being done in cold-atom Rydberg sensor systems. These cold-atom systems allow of the detection of blackbody radiation, which can lead to fundamentally new ways for thermometry (the measurement of temperature) and lead to improvements in the uncertainties in optical-clock for time standards. In this talk, we will present a historical journey of the development of this technology, and in the process, we will summarize this work and discuss various applications.

Bio: Dr. Christopher Holloway is a NIST Technical Fellow and a Fellow of the IEEE and has been at NIST for over 25 years. He is also on the Graduate Faculty at the University of Colorado at Boulder. He received his B.S.E degree from the University of Tennessee, and his Master and PhD degrees from the University of Colorado at Boulder. His is an expert in electromagnetic theory and metrology, quantum-optics, Rydberg-atom systems, and atom-based sensors. He has a publication h-index of 63 with over 300 technical publications (including 152 refereed journal papers and 133 conference papers) and has over 15,000 citations of his papers. He also has 10 patents in various fields in engineering and physics. He is the Project Leader for the Rydberg-Atom-Sensor Project and is the Group Leader for the Electromagnetic Fields Group.