Rydberg atom-based sensors: Transforming measurements and detection of radio-frequency fields and time-varying signals

Dr. Christopher L. Holloway

National Institute of Standards and Technology, Boulder, CO 80305, USA,
christopher.holloway@nist.gov

The unique properties of Rydberg atoms allow for radio-frequency (RF) spectroscopy, which has resulted in intriguing applications. For example, Rydberg atom receivers allow for the detection and receiving of time-varying fields and communication signals without an antenna and front-end electronics. The idea in these Rydberg atom-based sensors is to replace conventional antennas (which rely on conduction electrons bound by the antenna geometry) with atom-sensors (glass cells filled with atomic vapor: atomic-bound electrons).

One of the keys to developing new science and technologies is to have sound metrology tools and techniques. Atom-based measurements allow for unprecedented accuracy in measurement systems, 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 (H), electric (E), and other physical quantities. These Atom-based measurements allow for direct International System of Units (SI) traceable measurements. The development of Rydberg atom-based sensors has allowed for SI-traceable measurements for E-fields and RF power. With the great progress in the development of Rydberg atom-based sensors, interesting and unforeseen applications are emerging. These applications include, (1) SI-traceable measurements for electric field and power, (2) amplitude and phase detection of time-varying signals, (3) angle-of-arrival, (4) waveforms and spectrum analyzers, (5) plasma sensors, (6) near-field and sub-wavelength imaging, (7) blackbody detection and thermometry, (8) DC/AC voltage measurements, and even streaming video over the air. As well as many other applications.

One of the more intriguing applications for Rydberg atom-based sensors is in the detection of time-varying signals. These atom-based receivers allow for the detection of amplitude-, frequency-, and phase-modulated signals. In fact, in receiver applications, these Rydberg-atom sensors act like an antenna (to detect the signal) and they perform the demodulation and down conversion automatically. That is, these Rydberg receivers can eliminate a lot of the front-end devices and electronics when compared to conventional receivers. The atom-based sensors have sizes on the order of 10 mm as compared to conventional antennas with sizes on the order of a wavelength of the field being detected. Atom-based sensors are in effect, truly electrically small antennas. The Rydberg atom sensors are broadband, detecting fields from a few kHz to THz (and even down to DC), with large dynamic range (a few micro V/m to kV/m fields). Furthermore, these new Rydberg atom-based sensors will be beneficial for 6G and beyond in that they will allow for the calibrations of both field strength and power for frequencies above 100 GHz.

In this talk, I will present a historical journey of the development of this technology, and in the process, I will summarize this work and discuss various applications.