The Uncertainties Associated with Rydberg Atom Based Electric Field Measurements

Christopher L. Holloway*[1], Joshua A. Gordon[1], Haoquan Fan[2], Santosh Kumar[2], James P. Shaffer[2]
[1]National Institute of Standards and Technology, Boulder CO, USA
[2]University of Oklahoma, Department of Physics, Norman OK, USA
holloway@boulder.nist.gov, 303-497-6184

In recent work we have demonstrated a fundamentally new approach for electric (E) field measurements (Holloway et al., *IEEE Trans on AP* 12, 6169-6182, 2014; Sedlacek et al., *Nature Phys*, 8, 819, 2012). The new approach is based on the interaction of RF-fields with Rydberg atoms, where alkali atoms are excited optically to Rydberg states and the applied RF-field alters the resonant state of the atoms. For this technique, the Rydberg atoms are placed in a glass vapor cell. This vapor cell acts like an RF-to-optical transducer, converting an RF E-field to an optical frequency response. The approach utilizes the concept of electromagnetically induced transparency (EIT), where the RF transition in the four-level atomic system causes a split of the transition spectrum for the probe laser. This splitting is easily measured and is directly proportional to the applied RF field amplitude (through Planks constant and the dipole moment of the atom). Therefore, by measuring this splitting we get a direct measurement of the RF E-field strength. The significant dipole response of Rydberg atoms over the GHz regime indicates that this technique can be used for traceable measurements over a large frequency band including 1 GHz to 500 GHz (Holloway et al., *IEEE Trans on AP* 12, 6169-6182, 2014). The new approach has several benefits over existing techniques, including, 1) a direct SI units linked *E*-field measurement, 2) a self-calibrating measurement due to atomic resonances, 3) a technique that is independent of current approaches, 4) a very small spatial resolution: optical fiber and chip-scale, and 5) a technique with vastly improved sensitivity and dynamic range over current E-field methods.

It is important to understand the measurement uncertainties of the new technique in order for it to be viable. In general, the uncertainties can be grouped into two different categories: (a) quantum based uncertainties (i.e., parameters and issues related to the atomic physics aspect of the technique), and (b) RF based uncertainties (i.e., parameters and issues related to the RF aspect of the technique). In this presentation we discuss these various types of uncertainties and discuss how the uncertainties can be controlled and reduced. We illustrate that the uncertainties of the new measurement technique can be smaller than existing measurement approaches, as such, enabling the benefits discussed above to come to fruition.