Uncertainties in RF Electric Field Metrology Based on Rydberg Atom Spectroscopy

Matt T. Simons[1], Marcus D. Kautz[1], Joshua A. Gordon[1], David A. Anderson[2], Georg Raithel[2,3], and Christopher L. Holloway[1]

[1] National Institute of Standards and Technology, Boulder, CO 80305
[2] Rydberg Technologies, Ann Arbor, MI 48104
[3] University of Michigan, Ann Arbor, MI 48109

Currently, RF Electric field probes require calibration, have long SI-traceability paths, are large relative to the field under test, and interfere with the field being measured. In order to calibrate a probe, it must be placed in a known field, however the field can only be 'known' by measuring it with a calibrated probe. This chicken-and-egg problem limits the absolute accuracy of the calibration to 5% at best. Recently, Rydberg states of alkali atoms (both cesium and rubidium) have been used to measure the field strength of frequencies between $\sim$ 100s of MHz up to $\sim$THz. This Rydberg atom-based method is independent of previous field probe techniques, and provides direct SI-traceability.

The Rydberg atom-based approach uses electromagnetically-induced transparency (EIT), a phenomenon where an atom vapor that would normally absorb a laser is made transparent for a narrow optical frequency by the presence of a second laser. An external RF field alters the frequency range by creating two windows of transparency. The optical frequency difference Δf between the two is directly related to the strength of the applied RF E-field $|E_{RF}|$, such that

$$|E_{RF}| = 2\pi \frac{\hbar}{\wp} \Delta f$$

where $\hbar$ is Planck's constant (which will be an SI-defined constant in 2018), and $\wp$ is the dipole moment of the atomic transition, which can be calculated to a very high accuracy. This converts an amplitude measurement to an optical frequency measurement, which can be done more accurately, and is directly SI-traceable. This method also has other advantages over traditional probes: it uses a dielectric vapor cell rather than a metal antenna, it is not limited in size by the wavelength of the RF field being measured, and it can measure a very large range of frequencies with one probe.

In this work we examine several aspects of the technique relating to RF measurement accuracy. First, we explore the effect of band-limited white noise on the EIT spectra. Noise affects atom-based RF E-field measurements through different mechanisms than in traditional probes. Second, we attempt to quantify the major sources of uncertainty in the system, including uncertainties in the atomic response ('quantum' uncertainties) and in the field measurements ('RF' uncertainties). These are instrumental steps toward validating the Rydberg atom-based E-field technique as a standard metrology tool.