A Rydberg Atom-Based Mixer for Phase and Weak Signal Detection

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Electromagnetically-induced transparency (EIT) with Rydberg atoms has been studied as a method for radio frequency (RF) electric (E) field and polarization measurements. Atom-based measurements have many advantages over current techniques, as they can work over a large range of frequencies (MHz $\sim$ THz), have low field perturbations, and are directly SI-traceable to Planck's constant. We demonstrate a method for using Rydberg atoms to measure the phase of an RF field, beyond previously demonstrated field amplitude and polarization measurements, completing a full characterization of an RF field. This method also allows for the detection of weak signals.

In this approach we use the Rydberg atoms as a mixer in a heterodyne scheme to detect RF phase. A second RF field is used as a local oscillator (LO), detuned from the RF signal of interest. The Rydberg atoms act as a mixer naturally, demodulating the RF and LO, and the frequency difference between the LO and RF signal (the intermediate frequency, or IF) is detected by probing the atoms with a laser. The phase of the IF is directly related to the phase difference between the LO and RF ($\Delta\phi$). We vary the phase of the RF by translating the source (a horn antenna) by fractions of the RF wavelength, and compare the measured phase change vs. distance to the theoretical propagation constant (Fig 1), and find agreement to within 0.1 %.

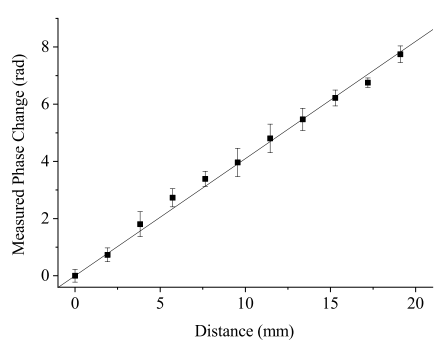

Figure 1: Measured phase shift vs. RF horn position. Data points are average of 5 trials, with error bars representing the standard deviation. The line is the theoretical propagation constant, $\Delta\phi/\Delta d = 409.7$ rad/m.

This technique can also be used to measure weak RF fields normally not detectable with EIT/AT-splitting. The effect of a weak RF field on the probe laser tansmission is enhanced by the presence of an LO field. This research extends the abilities of atom-based RF field metrology, making it more competitive with existing coherent RF detection technology.