Simultaneous multi-band radio-frequency detection using high-orbital-angular-momentum states in a Rydberg-atom receiver: Supplement

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DETERMINING TRANSITION FREQUENCIES USING EIT IN LADDER SYSTEMS

Method

In our ladder excitation scheme, the addition of an RF field resonant with an adjacent level modifies the spectrum in one of two ways. For even numbers of levels, a strong RF field causes an Autler-Townes (AT) splitting in the lineshape, resulting in two distinct peaks appearing in the spectrum. On resonance, the amplitude of these peaks are equal, which can be used as criteria for determining the exact transition frequency. For small detuning about resonance, the change in amplitude of the features is linear [1], and the transition frequency can be extracted from the intersection of two straight-line fits. For an odd number of levels, there is transparency at line centre causing a single feature to be present. The separation of this feature from the two AT peaks of the previous field can be used to determine the transition frequency. Both methods assume no perturbing effects in the lineshape.

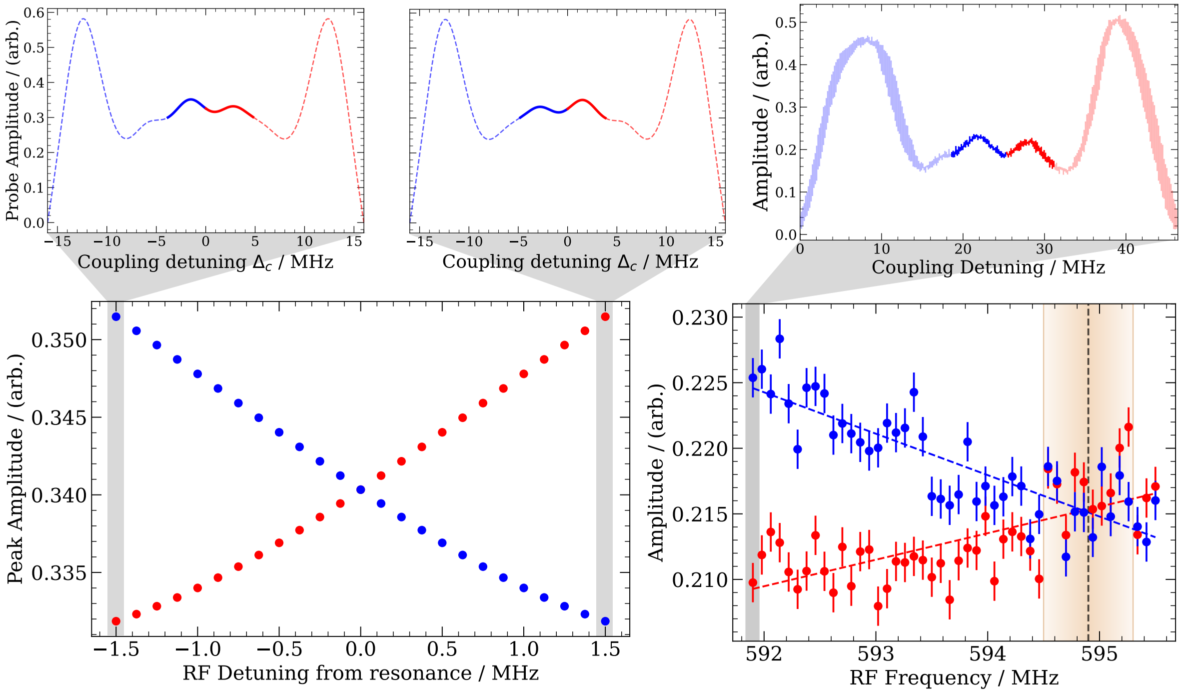

FIG. 1. Demonstration of method for determining transition frequencies using EIT in ladder systems. **Left:** Modelled peak amplitudes (using [2]) against RF detuning, extracted from AT splittings of the 18I → 18K transition. The two insets show modeled spectra when the field is detuned 1.5MHz either side of the 18I → 18K resonance, corresponding to the first and last pairs of data points. **Right:** Measured peak amplitude data of the 18I → 18K transition as the RF is detuned. The straight dashed line fit determines where the AT splittings have the same amplitude - assumed to be on resonance when neglecting perturbing effects. The blacked dashed line shows the extracted transition frequency, 594.9(4) MHz, and the error as the shaded beige band, calculated from statistics of the fit. The inset shows the measured spectrum used to extract the first pair of data points when the RF field is 592 MHz.

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Systematic Uncertainties

Here we will discuss some sources of uncertainty associated with the above method for transition frequency measurement.

The main source of error from statistical fits is derived from the laser amplitude noise which causes a change in probe transmission. This could be further reduced in experiment via use of laser amplitude stabilisers and by the increase of coupling power to increase the SNR.

Any detuning from resonance of the previous fields in the ladder scheme will cause an asymmetry in the lineshape. This compounds into a change in the measured resonant frequency of subsequent fields by shifting the AT peak amplitudes. We minimised this uncertainty by first measuring transition frequencies of previous resonant fields before those of subsequent fields. The uncertainty in these measurements can then be taken as the uncertainty in the RF detuning of the following field.

The DC stark effect results in a shift of the transition frequency due to stray electric fields in the cell, introducing a further uncertainty. It has been recently highlighted that the polarizability scales significantly with high ℓ states and as such would present a significant uncertainty on the higher ℓ transitions measured [3]. Whilst we cannot currently reliably measure the magnitude of any stray DC electric fields in the cell, we can place bounds on the expected shift using the polarizability of the state of interest. For example, the polarisability of the $n = 17$I ($\ell = 6$) state is 119 MHz cm^{-2} / V^2 [4]. From this, we can calculate that a DC electric field uncertainty of order 0.1 V/cm results in a 0.6 MHz error in the measured transition frequency. At higher principal quantum number, this effect presents a significant uncertainty due to the already present n^7 scaling. The 40I state has an expected polarisability of (56.8×10^3) MHz cm^{-2} / V^2.

The AC Stark effect may become significant as the number of fields increase during higher ℓ measurements. Again, this can be minimised by first taking a measurement at low power of the dressing field to minimise this shift. Numerical models, such as `ARC`, could be used to estimate the AC Stark shift for a given electric field strength which could be estimated from the Rabi frequency of said field. Further investigation should be done in how the AC Stark effect shifts the line shape and hence determination of resonant frequencies. The shift in the resonance of subsequent fields could be investigated against the field strength of previous fields and the resonant frequency could be taken in the limit of zero field strength.

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[2] L. Downes, Simple python tools for modelling few-level atom-light interactions, Journal of Physics B: Atomic, Molecular and Optical Physics (2023).

[3] A. Duspayev, R. Cardman, D. A. Anderson, and G. Raithel, High-angular-momentum rydberg states in a room-temperature vapor cell for dc electric-field sensing, arXiv preprint arXiv:2310.10542 (2023).

[4] N. Šibalić, J. D. Pritchard, C. S. Adams, and K. J. Weatherill, Arc: An open-source library for calculating properties of alkali rydberg atoms, Computer Physics Communications **220**, 319 (2017).