Fourier mode decomposition approach to Floquet-Liouville problem for unclosed atomic loop transitions

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Multi-level atoms, e.g. excited to Rydberg states, present many unique opportunities, but present several challenges for numerical treatment of their interaction with multiple laser fields. In hot-atom systems this is further aggravated by the necessity to include Doppler broadening. Further challenges arise if the system is time-dependent, as the system then doesn't have a strict steady-state solution. Our study presents a numerically efficient approach to solving the Floquet-Liouville problem, focusing on unclosed atomic loops, as exemplified by Rydberg-atom microwave sensing protocols. By manipulating terms within the master equation and applying Fourier decomposition of Floquet-Lindblad modes, we uncover new insights into the control and coherence of atomic states under periodic driving, resulting from uncloseness. The results are particularly relevant for superheterodyne Rydberg sensors [1], where the main question is the efficient transfer of modulation from a weak microwave signal field to light. These findings enhance our understanding of quantum dynamics in Floquet systems and offer potential applications in modelling quantum communication, sensing and transduction protocols [2].

[1] M. Jing et al., Atomic superheterodyne receiver based on microwave-dressed Rydberg spectroscopy, Nature Physics **16**, 911-915 (2020).
[2] S. Borówka et al., Continuous wideband microwave-to-optical converter based on room-temperature Rydberg atoms, Nature Photonics **18**, 32-38 (2024).