Quantum Spectral Analysis by Landau-Zener Transitions

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Quantum spectrum analyzers promise enhanced sensitivity, resolution and noise decoupling, compared to time-domain sensing, by measuring directly in the frequency domain. To date, such analyzers have been filter banks with quantum sensors sampling fixed frequencies, arrayed in time \cite{1} or space \cite{2}. We present a swept-sine quantum spectrum analyzer implemented on a single preparation of an ultracold atomic ensemble qubit. Sweeping a single sensor across a band generates Landau-Zener (LZ) transitions as the sensing frequency crosses resonance with an external oscillatory field. Continuous Faraday measurement of the transverse spin \cite{3} yields a rich time-series of characteristic LZ evolution. Retrieving the amplitude, frequency and phase of an external signal from this time-series proved to be a formidable inverse problem. Through Hilbert demodulation we perform quantum process tomography that can be represented as a Bloch sphere trajectory (Fig. 1). We then estimate signal parameters by regressing the solution of the time-dependent Schrödinger equation to the evolution of the state. Fig 1 shows successful retrieval of an LZ transition driven by a $B_s = 3.4(9) \, \text{nT}$ signal at $f_s = 10.000(1) \, \text{kHz}$, with the $\langle \hat{F}_z \rangle$ fit in black retrieving parameters of $B_s = 3.26(2) \, \text{nT}$ and $f_s = 10.0076(3) \, \text{kHz}$, while phase has proven more difficult. Further developments of the protocol and analysis techniques will enable expansion to multi-frequency spectra.

![Bloch sphere representation](image1.png)

Figure 1: Bloch sphere representation, both processed data (L) and fit reconstruction (R), with projection traces for $\hat{F}_z$ and equatorial angle $\phi_{xy}$ in a demodulated frame of reference.

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